Does Climate Risk Have the Same Impact on Corporate Bond Yields across Credit Ratings?

Jiemin Huang

Abstract— This paper studies the impact of climate risk on the yields of corporate bonds with different credit ratings. We find the impact of climate risk on AAA rated corporate bonds. When climate risk increases, the yield of AAA rated corporate bonds increases. But it explains only a tiny fraction of corporate bond yields. The model is more significant after taking the logarithm of climate risk. After maturity is added to the model, both the impact from climate risk and from maturity on the yield of AAA rated corporate bonds is significant. But the impact of climate risk on AA+ corporate bond yields is not significant and the impact of selling back on the yield of AA+ corporate bonds is significant and negative. When the selling back increases, the yield of AA+ corporate bonds decrease. The impact from the issuance on the yield of AA+ corporate bonds is significant and positive. When the issuance increases, the yield of AA+ corporate bonds increase. For AA rated corporate bonds, the impact from the independent variables on the yield of AA rated corporate bonds is not significant. Model does not hold.

***Index Terms*—climate risk, corporate bonds, yield, putback, duration**

I. Introduction

SCHOLARS at home and abroad have conducted much research on this issue.

Marcus Painter (2020) examines the impact from climate change on municipal bonds. He finds that counties affected by climate change have to pay more underwriting fees and initial yields when they issue long-term municipal bonds. But climate change only influences underwriting fees and initial yields of long-term municipal bonds. The impact disappears when we compare the underwriting fees and initial yields of short-term municipal bonds. Higher issuance costs of the bonds issued by counties affected by climate-risk are driven by lower credit ratings. When 2006 Climate Change Critical Review was published, the difference in the cost of issuing bonds increased between counties influenced and not influenced by climate-risk.

Some scholars research on how long-term climate risk changes are priced in financial markets. Hong et al. (2019) analyzes climate change-induced droughts and find that the market does not react to this risk. However, Bansal et al. (2016) study climate change. He uses temperature rise as a proxy variable and find that the impact from temperature rise on asset values is negative, which suggest that markets price climate change. In the real estate market, Bernstein et al. (2019) find that houses facing the risk of sea level rise are sold at a discount compared to houses not facing the risk.

There are four kinds of consequences from climate change including production risk, reputational risk, regulatory risk and litigation risk. Hong et al. (2019) demonstrates that the impact from production risks induced by prolonged droughts on stock returns of food industry companies is negative. Dell et al. (2012) find that high temperatures reduce agricultural and industrial output. Chava (2014) demonstrates that capital costs of firms excluded from environmental screening are higher. These companies face two kinds of risk including reputational risk of being labelled as climate change indicators and regulatory risk because the impact from future regulation-related climate change on current output is negative. Bernstein et al. (2019) demonstrate that the impact from physical risks arising from sea level rise on the prices of exposed houses is negative. They then find that if the liquidity of house market is excellent the impact is very small.

Hallegatte et al. (2013) first calculate exposed population by an altitude-based geographic information system. With the estimated capital of each resident exposed populations are converted into exposed assets. For the existing defense levels of coastal cities, the approach of Linham, Green, and Nichollas is used.

Credit ratings affect municipal bond prices because investors rely on them to assess credit risk (Cornaggia et al., 2017). In addition, the impact from credit rating on the local economy is significant.

Adelino et al. (2017) find that bond credit rating correlates with local government spending and employment positively.

To sum up, scholars have studied the yields and prices of corporate bonds and municipal bonds, and find that credit risk, downside risk, liquidity and climate change are important influencing factors. This paper intends to analyze climate risks basis on the impact on corporate bond yield spreads.

II. Data

This paper collects Shanghai corporate and municipal bond yield data from the Cathay Pacific database. Treasury bonds, policy bank bonds, central bank bills, financial bonds, government-backed institutional bonds, ultra-short-term financing bonds, medium-term notes, short-term financing bills, Perpetual medium-term notes, SME collective notes,

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convertible bonds, etc. are excluded. Then corporate bonds and municipal bonds with the maturity of 2-15 years are retained. Short-term, ultra-short-term bonds and special bonds are excluded because they do not have the characteristics of ordinary bonds, which may easily lead to unobjective results.

We select data of corporate and government bonds issued from 2005 to 2019, and those bonds are classified into three credit ratings including AA, AA+ and AAA.

III. Variables Settings

The variables selected in this paper are corporate bond yield (yield), climate risk (climate risk), bond issuance (issue size), maturity date (maturity), bond credit rating (rating), put (put), callable (crdeem), selling back (crtsell), whether to trade across markets (market).

The climate risk in this paper is based on the calculation method in the paper of Hallegatte (2013), and the ratio between the possible losses from sea level rise and the local GDP.

IV. Analysis of Empirical Results

A. Analysis of the impact of climate risk on the yield of AAA-rated corporate bonds

Yield analysis of AAA corporate bonds

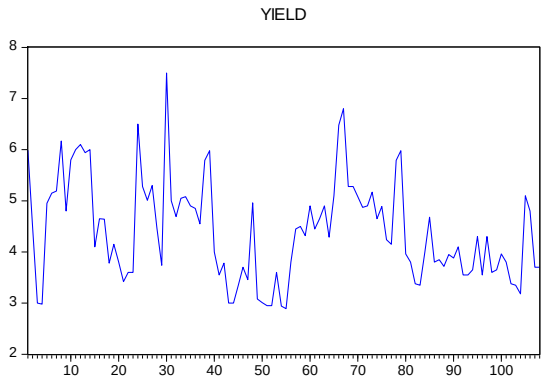

Figure. 1. Yields of AAA-rated corporate bonds

As it is shown in figure 1, the vertical axis represents the yield in % and the horizontal axis represents the serial number of the corporate bond. There are 108 AAA-rated corporate bonds. The yield of AAA-rated corporate bonds fluctuates greatly. The minimum is less than 3% and the maximum is 7.5%.

Descriptive statistical analysis

Table 1 Descriptive statistical analysis

	YIELD	RISK	DEEM	SELL	SIZE	MAT	PUT	mar
Mean	4.41	0.04	0.03	0.72	14.56	4.65	0.69	0.13
Median	4.30	0.02	0.00	1.00	10.00	5.00	1.00	0.00
Max	7.50	0.21	1.00	1.00	50.0	10.0	1.00	1.00
Mini	2.89	0.00	0.00	0.00	3.00	2.00	0.00	0.00
Std. D	0.99	0.04	0.17	0.45	10.02	1.20	0.46	0.34
Skewness	0.59	2.13	5.75	-0.99	1.37	1.22	-0.84	2.21
Kurtosis	2.88	7.73	34.03	1.98	4.83	8.82	1.71	5.86
JB	6.26	182	4927	22.4	48.9	179	20.29	124
P	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00

From table 1 we find that the mean value of the yield is 4.41, the median value is 4.30, the maximum value is 7.50, the minimum value is 2.89, the standard deviation is 0.99, the skewness is 0.5868, the kurtosis is 2.88, the JB value is 6.26, and the probability is 0.04. The corporate bond yield is significant at the 5% confidence level.

The mean value of the climate risk is 0.04, the median value is 0.02, the maximum value is 0.21, the minimum value is 0.00, the standard deviation is 0.04, the skewness is 2.13, the kurtosis is 7.73, the Jarque-Bera value is 182.14, and the probability value is 0.00. The climate risk is significant at 1% confidence level.

The mean value of deem is 0.03, the median value is 0.00, the max value is 1.00, the mean value is 0.00, the standard deviation is 0.17, the skewness is 5.75, the kurtosis is 34.03 and the Jarque-Bera value is 4927. The deem is significant at the 1% confidence level.

The mean value of selling back is 0.72, the median value is 1.00, the maximum value is 1.00, the minimum value is 0.00, the standard deviation value is 0.45, the skewness value is -0.99, the kurtosis is 1.98, the Jarque-Bera value is 22.36, the probability is 0.00. The selling back is significant at the 1% confidence level.

The mean value of issuance size is 14.56, the median value is 10.00, the maximum value is 50.00, the minimum value is 3.00, the standard deviation value is 10.02, the skewness value is 1.37, the kurtosis value is 4.83, the Jarque-Bera value is 48.85, and the probability value is 0.00. The issuance size is significant at the 1% confidence level.

The mean value of maturity is 4.65, the median value is 5.00, the maximum value is 10.00, the minimum value is 2.00, the standard deviation value is 1.20, the skewness value is 1.22, the kurtosis value is 8.82, the Jarque-Bera value is 179.45, the probability is 0.00. The maturity is significant at the 1% confidence level.

The mean value of put is 0.69, the median value is 1.00, the maximum value is 1.00, the minimum value is 0.00, the standard deviation value is 0.46, the skewness value is -0.84, the kurtosis value is 1.71, the Jarque-Bera value is 20.29, the probability value is 0.00. Put is significant at the 1% confidence level.

The mean value of market is 0.13. The median value is 0.00. The maximum value is 1.00. The minimum value is 0.00. The standard deviation is 0.34. The skewness value is 2.21. The kurtosis value is 5.86. The Jarque-Bera value is 124.4 and the probability value is 0.00. The market is significant at the 1% confidence level.

Correlation analysis

Table 2 Correlation analysis

	yield	risk	Deem	Sell	size	Mat	Put	Mar
yield	1.00	0.18	-0.07	-0.10	-0.29	0.22	-0.07	-0.05
risk	0.18	1.00	-0.04	0.07	0.22	0.16	0.08	0.24
Deem	-0.07	-0.04	1.00	0.10	0.01	0.05	-0.25	-0.07
Sell	-0.10	0.07	0.10	1.00	0.00	0.46	0.93	-0.01
size	-0.29	0.22	0.01	0.00	1.00	-0.01	0.00	0.08
Mat	0.22	0.16	0.05	0.46	-0.01	1.00	0.43	0.34
Put	-0.07	0.08	-0.25	0.93	0.00	0.43	1.00	0.02
Mar	-0.05	0.24	-0.07	-0.01	0.08	0.34	0.02	1.00

According to the correlation analysis results in table 2, whether the Put is bearish or not is highly correlated with the selling back and the correlation coefficient is 0.9349; the selling back correlates with the maturity date and the correlation coefficient is 0.4569; the maturity date correlates with put bearishness and the correlation coefficient is 0.4265;

maturity expiration date correlates with whether the market trades across markets, and the correlation coefficient is 0.3439.

According to the correlation analysis results, we find the strong correlation with some variables, so we make the stepwise regression analysis.

Regression Analysis of Corporate Bond Yield and Climate Risk

TABLE 3 REGRESSION ANALYSIS OF CORPORATE BOND YIELD AND CLIMATE RISK

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.5615	0.1235	36.9425	0.0000
CLIMATE_RISK	4.1416	2.2522	1.8388	0.0687
R-squared	0.0309	Mean dependent var		4.4142
Adjusted R-squared	0.0218	S.D. dependent var		0.9871
S.E. of regression	0.9763	Akaike info criterion		2.8082
Sum squared resid	101.0250	Schwarz criterion		2.8578
Log likelihood	-149.6402	Hannan-Quinn criter.		2.8283
F-statistic	3.3815	Durbin-Watson stat		0.8894
Prob(F-statistic)	0.0687			

From above regression analysis we find that the climate risk is significant at the 10% confidence level. The constant term is also significant but R^2 is small, which indicates the impact from climate risk AAA-rated bonds, but it can only slightly explain the increase in corporate bond yields.

Regression analysis after adding deem redeemability

TABLE 4 REGRESSION ANALYSIS AFTER ADDING DEEM CALLABILITY

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.5778	0.1252	36.5727	0.0000
CLIMATE_RISK2	4.2247	2.2576	1.8713	0.0641
CRDEEM	-0.4800	0.5730	-0.8377	0.4041
R-squared	0.0373	Mean dependent var		4.4142
Adjusted R-squared	0.0190	S.D. dependent var		0.9871
S.E. of regression	0.9776	Akaike info criterion		2.8200
Sum squared resid	100.3544	Schwarz criterion		2.8945
Log likelihood	-149.2805	Hannan-Quinn criter.		2.8502
F-statistic	2.0368	Durbin-Watson stat		0.8897
Prob(F-statistic)	0.1356			

It can be seen from table 4 that after the callable factor is added to the model, the constant term is significant at the 1% confidence level, the climate risk is significant at the 10% confidence level, but the callable factor is not. The callable variable is excluded.

Analysis after adding sell-back factors

From table 5 we find that when the sell-backable variable is added the constant term is significant at the 1% confidence level, the climate risk is significant at the 10% confidence level, and the sell-backable variable is not significant. The variable of sell-backable is excluded.

TABLE 5 IS ANALYZED AFTER ADDING SELL-BACK FACTORS

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.6917	0.1917	24.4793	0.0000
CLIMATE_RISK	4.0043	2.2597	1.7720	0.0793
SELL	-0.1871	0.2104	-0.8889	0.3761
R-squared	0.0382	Mean dependent var		4.4142
Adjusted R-squared	0.0198	S.D. dependent var		0.9871
S.E. of regression	0.9772	Akaike info criterion		2.8192
Sum squared resid	100.2705	Schwarz criterion		2.8937
Log likelihood	-149.2353	Hannan-Quinn criter.		2.8494
F-statistic	2.0825	Durbin-Watson stat		0.9200
Prob(F-statistic)	0.1297			

Regression analysis after adding Put bearish factor

TABLE 6 ANALYSIS AFTER ADDING BEARISH FACTORS

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.6382	0.1839	25.2201	0.0000
CLIMATE_RISK2	4.0365	2.2672	1.7804	0.0779
PUT	-0.1158	0.2053	-0.5643	0.5738
R-squared	0.0338	Mean dependent var		4.4142
Adjusted R-squared	0.0154	S.D. dependent var		0.9871
S.E. of regression	0.9794	Akaike info criterion		2.8236
Sum squared resid	100.7196	Schwarz criterion		2.8981
Log likelihood	-149.4767	Hannan-Quinn criter.		2.8539
F-statistic	1.8391	Durbin-Watson stat		0.9084
Prob(F-statistic)	0.1640			

From above table we find that when the variable of put is added, the constant term is significant at the 1% confidence level, the climate risk is significant at the 10% confidence level, and the put-back variable is not significant. Put-back is excluded.

Analysis after joining the market whether there are cross-market factors

TABLE 7 REGRESSION ANALYSIS AFTER ADDING MARKET TO CROSS-MARKET FACTORS

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.5633	0.1253	36.4319	0.0000
CLIMATE_RISK	4.0817	2.3334	1.7493	0.0832
WHCRSMAK	-0.0305	0.2897	-0.1051	0.9165
R-squared	0.0310	Mean dependent var		4.4142
Adjusted R-squared	0.0126	S.D. dependent var		0.9871
S.E. of regression	0.9808	Akaike info criterion		2.8266
Sum squared resid	101.0144	Schwarz criterion		2.9011
Log likelihood	-149.6345	Hannan-Quinn criter.		2.8568
F-statistic	1.6805	Durbin-Watson stat		0.8910
Prob(F-statistic)	0.1913			

When market factor is added to the model, not only the model is not significant but also the market factor is not significant, so this variable of market is excluded.

Regression analysis after taking the logarithm of climate risk

TABLE 8 REGRESSION ANALYSIS AFTER TAKING THE LOGARITHM OF CLIMATE RISK

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.6060	0.3125	11.5390	0.0000
LN_CLIMATE_RISK	0.2033	0.0751	2.7069	0.0079
R-squared	0.0647	Mean dependent var		4.4142
Adjusted R-squared	0.0558	S.D. dependent var		0.9871
S.E. of regression	0.9591	Akaike info criterion		2.7727
Sum squared resid	97.5078	Schwarz criterion		2.8224
Log likelihood	-147.7266	Hannan-Quinn criter.		2.7929
F-statistic	7.3271	Durbin-Watson stat		0.8828
Prob(F-statistic)	0.0079			

From table 8, we find that if we take the logarithm of climate risk, the model, the constant term and the logarithmic climate risk factor are significant at the 1% confidence level. Compared with the climate risk model not taking logarithm, this model is more significant.

Regression analysis after taking the logarithm of the maturity variable

TABLE 9 REGRESSION ANALYSIS AFTER TAKING THE LOGARITHM OF THE MATURITY VARIABLE

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.9715	0.611991	8.123541	0.0000
LN_CLIMATE_RISK	0.1991	0.073219	2.719752	0.0076
LN_MATURITY	0.8969	0.348642	2.572424	0.0115
R-squared	0.1201	Mean dependent var		4.4142
Adjusted R-squared	0.1033	S.D. dependent var		0.9871
S.E. of regression	0.9347	Akaike info criterion		2.7301
Sum squared resid	91.7269	Schwarz criterion		2.8046
Log likelihood	-144.4263	Hannan-Quinn criter.		2.7603
F-statistic	7.1664	Durbin-Watson stat		0.9287
Prob(F-statistic)	0.0012			

From table 9 we find that when the logarithm of the maturity is taken the model and the constant term is significant at the 1% confidence level. The climate risk is significant at the 1% confidence level and coefficient is 0.1991, indicating that if other factors do not change when the climate risk changes by 1 unit, the corporate bond yield changes by 0.1991 units. After taking the logarithm of the maturity date, it is significant at the 5% confidence level and the coefficient is 0.8969 indicating that when the maturity date changes by one unit, the yield changes by 0.8969 units.

B. Analysis of the impact of climate risk on the yield of AA+ corporate bonds

Yield analysis of AA+ corporate bonds

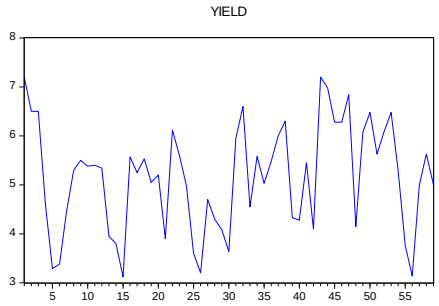

Figure. 2. Yield chart of AA+ grade corporate bonds

As it is shown in above Figure 2, the vertical axis represents the yield in % and the horizontal axis represents the serial number of the corporate bond. There are 59 corporate bonds with the credit rating of AA+. The yields of AA+ corporate bonds fluctuate greatly. The lowest is 3.2% and the highest is 7.5%. Compared with the corporate bond yields below AAA in figure 1, yields of corporate bond above AAA+ are more volatile and riskier.

AA+ corporate bonds face climate risk analysis

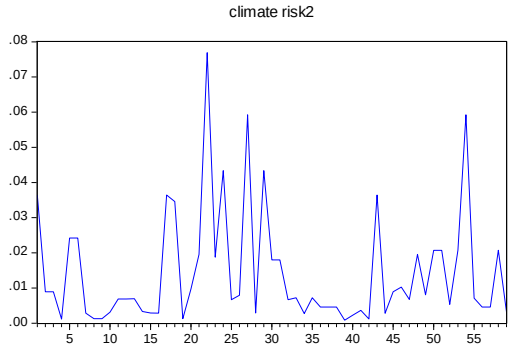

Figure.3. AA+ rated corporate bonds face climate risk map

As it is shown in figure 3, the vertical axis represents the climate risk in % and the horizontal axis represents the serial number of the corporate bond. The total number of the corporate bonds is 59. From above figure we find that the climate risk is highly volatile. The highest is about 0.08% and the lowest is close to zero.

Descriptive statistical analysis of AA+ corporate bond yields

TABLE 10 DESCRIPTIVE STATISTICAL ANALYSIS OF AA+ CORPORATE BOND YIELDS

	Yield	risk	Deem	Sell	size	Mat	Put	Mar
Mean	5.16	0.01	0.10	0.63	11.78	4.97	0.53	0.14
Median	5.30	0.01	0.00	1.00	8.90	5.00	1.00	0.00
Max	7.20	0.08	1.00	1.00	60.0	8.00	1.00	1.00
Min	3.12	0.00	0.00	0.00	1.00	2.00	0.00	0.00
S. D.	1.10	0.02	0.30	0.49	11.56	1.44	0.50	0.35
Skew	-0.13	1.88	2.64	-0.53	2.71	-0.01	-0.10	2.13
Kurt	2.13	6.30	7.95	1.28	11.31	2.26	1.01	5.53
JB	2.04	61.45	128	10.02	241.9	1.35	9.83	60.3
P	0.36	0.00	0.00	0.01	0.00	0.51	0.01	0.00

From above table we find that the mean value of the yield is 5.1593, the median value is 5.3000, the maximum

value is 7.2000, the minimum value is 3.1200, the standard deviation is 1.1012, the skewness is -0.1339, the kurtosis is 2.1303, the JB value is 2.0356 and the probability value is 0.3614. The corporate bond yield is not significant.

The mean value of climate risk is 0.0143, the median value is 0.0071, the maximum value is 0.0769, the minimum value is 0.0008, the standard deviation is 0.0164, the skewness is 1.8770, the kurtosis is 6.3020, the Jarque-Bera value is 61.4468 and the probability value is 0.0000. The climate risk is significant at the 1% confidence level.

The mean value of deem is 0.1017, the median value is 0.0000, the max 1.0000, the min value is 0.0000, the standard deviation value is 0.0164, the skewness value is 2.6356, the kurtosis value is 7.9465 and the Jarque-Bera value is 128.4588. It is significant at the 1% confidence level.

The mean value of selling back is 0.6271, the median value is 1.0000, the maximum value is 1.0000, the minimum value is 0.0000, the standard deviation value is 0.4877, the skewness value is -0.5258, the kurtosis value is 1.2764, the Jarque-Bera value is 10.0212 and the probability value is 0.0067. It is significant at the 1% confidence level.

The mean value of issuance size is 11.7831, the median value is 8.9000, the maximum value is 60.0000, the minimum value is 1.0000, the standard deviation value is 11.5602, the skewness value is 2.7119, the kurtosis value is 11.3062, the Jarque-Bera value is 241.9225, and the probability is 0.0000. Selling back is significant at the 1% confidence level.

The mean value of maturity is 4.9661, the median value is 5.0000, the maximum value is 8.0000, the minimum value is 2.0000, the standard deviation value is 1.4380, the skewness value is -0.0105, the kurtosis value is 2.2598, the Jarque-Bera value is 1.3479 and the probability value is 0.5097. The maturity is not significant.

The mean value of put bearish is 0.5254, the median value is 1.0000, the maximum value is 1.0000, the minimum value is 0.0000, the standard deviation value is 0.5036, the skewness value is -0.1018, the kurtosis value is 1.0104, the Jarque-Bera value is 9.8336, the probability value is 0.0073. The bearish is significant at the 1% confidence level.

The mean value of cross-market is 0.1356, the median value is 0.0000, the maximum value is 1.0000, the minimum value is 0.0000, the standard deviation value is 0.3453, the skewness value is 2.1288, the kurtosis value is 5.5319, the Jarque-Bera value is 60.3220 and the probability value is 0.0000. Market is significant at the 1% confidence level.

Correlation analysis

TABLE 11 CORRELATION ANALYSIS

	Yield	risk	Deem	Sell	size	Mat	Put	Mar
Yield	1.00	0.12	-0.17	-0.23	-0.22	0.11	-0.12	0.35
risk	0.12	1.00	-0.18	-0.06	0.42	0.10	0.05	0.00
Deem	-0.17	-0.18	1.00	0.26	-0.14	0.24	-0.35	-0.13
Sell	-0.23	-0.06	0.26	1.00	0.03	0.15	0.81	-0.31
size	-0.22	0.42	-0.14	0.03	1.00	0.17	0.11	0.07
Mat	0.11	0.10	0.24	0.15	0.17	1.00	0.00	0.50
Put	-0.12	0.05	-0.35	0.81	0.11	0.00	1.00	-0.22
Mar	0.35	0.00	-0.13	-0.31	0.07	0.50	-0.22	1.00

From Table 11 we can find that the yield rate correlates with whether there is a cross-market transaction and the correlation coefficient is 0.3476. The climate risk correlates with issuance size and the coefficient is 0.4201. Deem correlates with put and the coefficient is -0.3540. The correlation between selling back and put is strong and the coefficient is 0.8114. The selling back correlates with whether there is a cross-market transaction and the coefficient is -0.3089. The maturity date correlates with whether the market trades across markets, and the coefficient is 0.4956.

Empirical analysis of factors affecting the yield of AA+ corporate bonds

1) Analysis of the impact of climate risk on the yield of AA+ corporate bonds

TABLE 12 ANALYSIS OF THE IMPACT OF CLIMATE RISK ON THE YIELD OF AA+ CORPORATE BONDS

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.0458	0.1911	26.407	0.0000
CLIMATE_RISK	7.9314	8.8055	0.9007	0.3715
R-squared	0.0140	Mean dependent var		5.1593
Adjusted R-squared	-0.0033	S.D. dependent var		1.1012
S.E. of regression	1.1030	Akaike info criterion		3.0672
Sum squared resid	69.346	Schwarz criterion		3.1377
Log likelihood	-88.484	Hannan-Quinn criter.		3.0947
F-statistic	0.8113	Durbin-Watson stat		1.0739
Prob(F-statistic)	0.3715			

From Table 12 we find that the impact from climate risk on the yield of AA+ corporate bonds is not significant. We perform regression analysis after taking the logarithm of climate risk.

TABLE 13. REGRESSION ANALYSIS OF CLIMATE RISK AFTER LOGARITHM

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.8816	0.636687	9.237857	0.0000
LN_CLIMATE_RISK	0.1495	0.128375	1.164178	0.2492
R-squared	0.0232	Mean dependent var		5.1593
Adjusted R-squared	0.0061	S.D. dependent var		1.1012
S.E. of regression	1.0978	Akaike info criterion		3.0579
Sum squared resid	68.6999	Schwarz criterion		3.1283
Log likelihood	-88.2076	Hannan-Quinn criter.		3.0854
F-statistic	1.3553	Durbin-Watson stat		1.0926
Prob(F-statistic)	0.2492			

From Table 13 we find that the constant term is significant at the 1% confidence level, and the climate risk after taking the logarithm is still not significant, so this variable is excluded.

2) Stepwise regression analysis on other variables

TABLE 14 ANALYSIS OF THE IMPACT OF PUTBACK ON THE YIELD OF AA+ CORPORATE BONDS

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.4868	0.2304	23.8137	0.0000
SELL	-0.5222	0.2910	-1.7949	0.0780
R-squared	0.0535	Mean dependent var		5.1593
Adjusted R-squared	0.0369	S.D. dependent var		1.1012
S.E. of regression	1.080698	Akaike info criterion		3.0264
Sum squared resid	66.5708	Schwarz criterion		3.0968
Log likelihood	-87.2789	Hannan-Quinn criter.		3.0539
F-statistic	3.2216	Durbin-Watson stat		1.1087
Prob(F-statistic)	0.0780			

From Table 14 we find that the constant term is significant at the 1% confidence level. The selling back is significant at the 10% confidence level and coefficient is -0.5222 which indicates that when the selling back changes by one unit, the yield of AA+ corporate bonds changes by -0.5222 units. R^2 is 0.0535 and this indicates that sell-back can explain 5% of the AA+ corporate bond yield.

TABLE 15 ANALYSIS OF THE IMPACT OF ISSUANCE ON THE YIELD OF AA+ CORPORATE BONDS

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.4050	0.2024	26.7081	0.0000
ISSUE_SIZE	-0.0209	0.0123	-1.6937	0.0958
R-squared	0.0479	Mean dependent var		5.1593
Adjusted R-squared	0.0312	S.D. dependent var		1.1012
S.E. of regression	1.0839	Akaike info criterion		3.0323
Sum squared resid	66.9632	Schwarz criterion		3.1027
Log likelihood	-87.4523	Hannan-Quinn criter.		3.0598
F-statistic	2.8687	Durbin-Watson stat		1.1692
Prob(F-statistic)	0.0958			

From Table 15 we find that the constant term is significant at the 1% confidence level, the circulation is significant at the 10% confidence level and the coefficient between is -0.0209. This means that if other factors don't change, when the issuance volume changes by one unit, the AA+ corporate bond yield changes by -0.0209 units. The R^2 is 0.0479, indicating that the issuance volume can explain 4.79% of the AA+ corporate bond yield.

TABLE 16 REGRESSION ANALYSIS OF WHETHER THERE IS A CROSS-MARKET TRANSACTION FACTOR

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.0090	0.1458	34.3442	0.0000
Market	1.1085	0.3961	2.7986	0.0070
R-squared	0.1208	Mean dependent var		5.1593
Adjusted R-squared	0.1054	S.D. dependent var		1.1012
S.E. of regression	1.0416	Akaike info criterion		2.9526
Sum squared resid	61.8364	Schwarz criterion		3.0231
Log likelihood	-85.1025	Hannan-Quinn criter.		2.9801
F-statistic	7.8324	Durbin-Watson stat		1.2793
Prob(F-statistic)	0.0070			

From Table 16 we find that the constant term is significant at the 1% confidence level, whether the cross-market factor is significant at the 1% confidence level and the coefficient is 1.1085. If the cross-market transaction factor changes by one unit, and other factors remain unchanged, AA+ company bond yields change by 1.1085 units. R^2 is 0.1208, indicates that cross-market factors can explain 12.08% of AA+ corporate bond yields.

C. Analysis of the impact of climate risk on the yield of AA-rated corporate bonds

Yield chart of AA-rated bonds

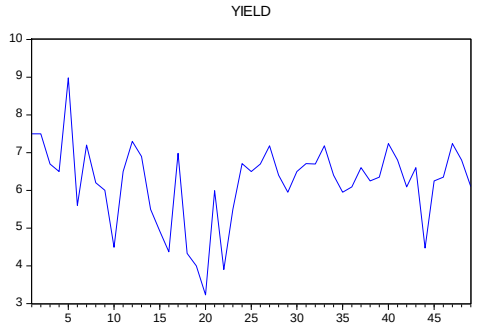

Figure. 4. Yield chart of AA-rated bonds

As it is shown in Figure 4, the vertical axis represents the climate risk in % and the horizontal axis represents the serial number of the corporate bond. There are 49 AA-rated corporate bonds. The yield of AA-rated corporate bonds fluctuates greatly with a minimum of 3.2% and a maximum of 9%. Compared with the AAA-rated corporate bond yields in Figure 1 and the AA+-rated corporate bond yields in Figure 2, AA-rated corporate bond yields are more volatile and riskier.

AA-rated corporate bonds face climate risks

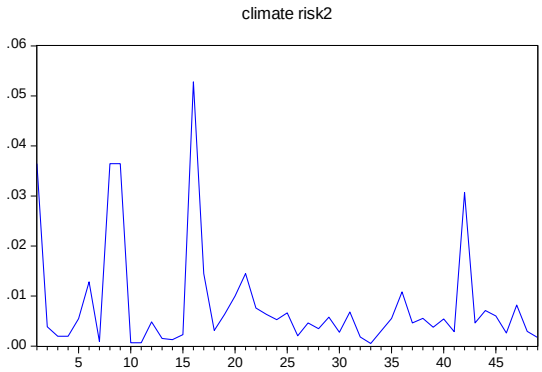

Figure .5. Graph of AA-rated corporate bonds facing climate risks

As it is shown in Figure 5, the vertical axis represents the climate risk in % and the horizontal axis represents the serial number of the corporate bond. From above figure we find that the highest climate risk is close to 0.055%, and the lowest is close to zero. Climate risk is highly volatile.

Descriptive statistical analysis

TABLE 17 DESCRIPTIVE STATISTICAL ANALYSIS

	YIELD	RISK	DEEM	SELL	SIZE	MAT	PUT	MAR
Mean	6.208	0.008	0.061	0.755	9.129	5.674	0.490	0.490
Median	6.400	0.005	0.000	1.000	8.000	6.000	0.000	0.000
Max	8.980	0.053	1.000	11.00	27.00	8.000	1.000	1.000
Min	3.230	0.001	0.000	0.000	1.000	3.000	0.000	0.000
S. D.	1.082	0.011	0.242	1.575	4.920	1.180	0.505	0.505
Skew	-0.694	2.489	3.660	5.745	1.402	-0.499	0.04	0.041
Kurt	3.846	8.576	14.399	38.101	5.537	3.0543	1.002	1.002
JB	5.392	114.05	374.69	2785	29.183	2.038	8.167	8.167
P	0.068	0.000	0.000	0.000	0.000	0.361	0.017	0.017

Table 17 illustrate the mean, median, maximum, minimum, standard deviation, skewness and kurtosis of each series. Only the maturity series pays a normal distribution, and other

series are peak thick tail.

D. Regression analysis

TABLE 18 REGRESSION ANALYSIS

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	7.472044	1.153091	6.480012	0.0000
CLIMATE_RISK	3.067254	14.59115	0.210213	0.8345
CRDEEM	0.154525	0.830080	0.186157	0.8532
CRTSELL	-0.176702	0.106456	-1.659852	0.1046
ISSUE_SIZE	-0.011803	0.035197	-0.335341	0.7391
MATURITY	-0.167132	0.216393	-0.772353	0.4443
PUT	-0.533222	0.461626	-1.155096	0.2547
WHCRSMAK	0.413960	0.556872	0.743367	0.4615
R-squared	0.308897	Mean dependent var		6.208163
Adjusted R-squared	0.190903	S.D. dependent var		1.082369
S.E. of regression	0.973589	Akaike info criterion		2.932628
Sum squared resid	38.86291	Schwarz criterion		3.241496
Log likelihood	-63.84938	Hannan-Quinn criter.		3.049812
F-statistic	2.617917	Durbin-Watson stat		1.772918
Prob(F-statistic)	0.024867			

As it is shown in table 18, for AA-rated corporate bonds, the impact from the independent variables on the yield of AA-rated corporate bonds is not significant. Model does not hold. Compared to AAA-rated corporate bonds and AA+-rated corporate bonds, their yields are affected by climate risk and some other independent variables.

V. CONCLUSION

This paper explores the impact from climate anomalies caused by global warming on yields of different credit rating corporate bond.

The study finds the impact from climate risk on AAA-rated corporate bonds. If climate risk increases, the yield of AAA-rated corporate bonds will increase. But it only explains a tiny fraction of corporate bond yields. The model is more significant after taking the logarithm of climate risk. If the factor of maturity is added to the model, the impact from climate risk and maturity on the yield of AAA-rated corporate bonds is significant. If maturity decreases, corporate bond yields will decrease.

The impact of climate risk on AA+ corporate bond yields is not significant. The impact of the selling back and issuance on the yield of AA+ corporate bonds is significant. If the selling back increases, the yield of AA+ corporate bonds will decrease. If the issuance increases, the yield of AA+ corporate bonds will increase.

For AA-rated corporate bonds, the impact from the independent variables on the yield of AA-rated corporate bonds is not significant. Model does not hold. Compared to AAA-rated corporate bonds and AA+ corporate bonds, their yields are affected by climate risk and some other independent variables.

REFERENCES

[1] Marcus P., 2020. An inconvenient cost: The effects of climate change on municipal bonds. *Journal of Financial Economics* 135 (2020) 468–482.

[2] Hong, H.G., Li, F.W., Xu, J., 2019. Climate risks and market efficiency. *J. Econom* 208 (1), 265–281.

[3] Bansal, R., Kiku, D., Ochoa, M., 2016. Price of Long-Run Temperature Shifts in Capital Markets. National Bureau of Economic Research Working Paper 22529. *Unpublished Working Paper*.

[4] Bernstein, A., Gustafson, M., Lewis, R., 2019. Disaster on the horizon: the price effect of sea level rise. *J. Financ. Econ.*

[5] Dell, M., Jones, B.F., Olken, B.A., 2012. Temperature shocks and economic growth: evidence from the last half century. *Am. Econ. J. Macroecon*. 4 (3), 66–95.

[6] Chava, S., 2014. Environmental externalities and cost of capital. Manag. Sci. 60 (9), 2223–2247.

[7] Hallegatte, S., Green, C., Nicholls, R.J., Corfee-Morlot, J., 2013. Future flood losses in major coastal cities. *Nat. Clim. Change* 3 (9), 802–806.

[8] Cornaggia, J., Cornaggia, K.J., Israelsen, R.D., 2017. Credit ratings and the cost of municipal financing. *Rev. Financ. Stud*. 31 (6), 2038–2079.

[9] Adelino, M., Cunha, I., Ferreira, M.A., 2017. The economic effects of public financing: evidence from municipal bond ratings recalibration. Rev. *Financ. Stud*. 30 (9), 3223–3268.

[10] Aripin, Hanny Haryanto, and Wisnu Agastya, "Synthesis of Compound Facial Expressions Based on Indonesian Sentences Using Multinomial Naive Bayes Model and Dominance Threshold Equations," Engineering Letters, vol. 30, no.1, pp50-59, 2022.

[11] Ahmad Fitri Jamali, Aida Mustapha, and Salama A. Mostafa, "Prediction of Sea Level Oscillations: Comparison of Regression-based Approach," Engineering Letters, vol. 29, no.3, pp990-995, 2021.

[12] Xue Deng, Yingxian Lin, and Huidan Zhuang, "Uncertain Portfolio with Fuzzy Investment Proportion Based on Possibilistic Theory," Engineering Letters, vol. 29, no.2, pp803-812, 2021.