Climate Risk

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1 Introduction

We used the Merton framework with historical data to evaluate equity volatility and asset volatility. Then we use public data from Exxon Mobil to assess the increased transition risk from net-zero aligned pathways.

2 Parameters setup

The risk-free rate is to be r = 0.05 and we will focus on 1 year PD(T=1).

3 Estimate model parameters

3.1 Estimate equity volatility

Since we are focusing on 1 year PD, we decided to use annualized $ln(\frac{S_k}{S_{k-1}})$ volatility as the σ_E. As a result, we can get the summary of volatility in different years:

	log return volatility (daily)	log return volatility (year)
2022	0.022829792	0.362411706
2021	0.01861881	0.295564451
2020	0.033204085	0.527098514
2019	0.011494361	0.182467318
2018	0.013840392	0.219709404
2017	0.007094654	0.112624138
2016	0.011990882	0.190349345
2015	0.014139187	0.224452631
2014	0.010376326	0.164719064
2013	0.008101785	0.128611849
2012	0.009418702	0.149517264

Figure 1: Summary for log return volatility in different years

3.2 Estimate Asset and its Volatility

For the calculation of market capitalization, we took the average closing price over the time step of one year.

We used the fsolve function with the assumption that finding A from A = E+D, the starting point, then arrived at the following estimated assets and their volatility by years as below:

Year	sigma	A(billion)
2012	0.14544909	266.310869
2013	0.12031396	283.90384
2014	0.15280557	306.418171
2015	0.20188003	271.755298
2016	0.17264208	289.400972
2017	0.10155711	291.754954
2018	0.20015251	294.225325
2019	0.16227597	290.181813
2020	0.42035055	206.868588
2021	0.26711527	256.902699

Figure 2: Summary for log return volatility in different years

The PD values plotted by year are shown below:

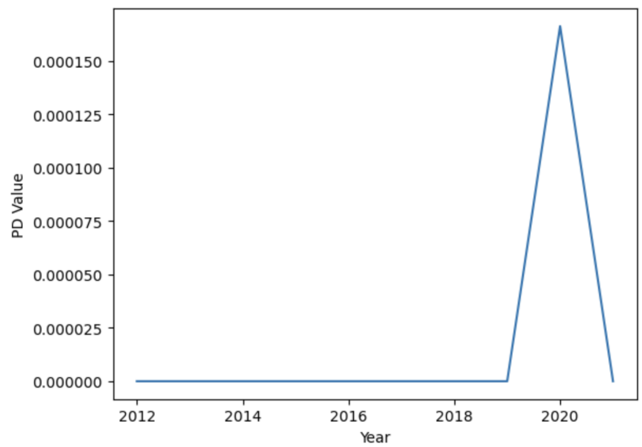

Figure 3: PD time-series

During the year 2020, we observed a gigantic peak in the probability of default. Such a phenomenon is unprecedented given that the chances of default were almost negligible in normal scenarios. Notice that our client Exxon is a multinational oil and gas company, it suffered from the global energy crisis and a tightened energy market in the year 2020, as commodity prices reached record highs. Such event introduced noise to the company's fundamental financial condition. This, together with the surging outstanding debt, drove up the volatility of equities and assets. By virtue of the Merton model, the probability of default arrives at its maximum in 2020.

4 Emission Pricing

In this section, we adjust the Merton model to account for the carbon prices as a penalty to the asset value calculation. Overall, we adapt three scopes of emissions per year.

Essentially, scope 1 and 2 are those emissions that are owned or controlled by a company, whereas scope 3 emissions are a consequence of the activities of the company but occur from sources not owned or controlled by the reporting organization. Scope 3 emissions include all sources not within an organization's scope 1 and 2 boundaries.

A recent estimate of Exxon's scope 1 and 2 emissions is given as 112 million tonnes of CO2 per year and their scope 3 emissions are estimated to be at least 650 million tonnes of CO2 per year.

4.1 Constant Pricing

Setting E, D, σ_e, and σ_a fixed to the average of the history data, we can first calculate the corresponding Asset value, which is around 275.77 billion. Then it is easy to figure out the probability of default adjusted for the carbon prices in three scenarios:

Time	Scenario	Cost E12	Reduced Asset E12	PD E12
2025	Nationally Determined Contributions (NDCs)	2.87E+09	2.73E+11	6.56E-34
2030	Nationally Determined Contributions (NDCs)	8.59E+09	2.67E+11	2.45E-33
2035	Nationally Determined Contributions (NDCs)	9.73E+09	2.66E+11	3.20E-33
2040	Nationally Determined Contributions (NDCs)	9.95E+09	2.66E+11	3.36E-33
2045	Nationally Determined Contributions (NDCs)	1.02E+10	2.66E+11	3.53E-33
2050	Nationally Determined Contributions (NDCs)	1.04E+10	2.65E+11	3.71E-33
2025	Delayed transition	0.00E+00	2.76E+11	3.40E-34
2030	Delayed transition	0.00E+00	2.76E+11	3.40E-34
2035	Delayed transition	3.85E+10	2.37E+11	3.19E-30
2040	Delayed transition	6.53E+10	2.10E+11	3.11E-27
2045	Delayed transition	6.63E+10	2.10E+11	3.97E-27
2050	Delayed transition	9.97E+10	1.76E+11	4.26E-23
2025	Net Zero 2050	2.23E+10	2.53E+11	6.26E-32
2030	Net Zero 2050	2.68E+10	2.49E+11	1.84E-31
2035	Net Zero 2050	3.58E+10	2.40E+11	1.66E-30
2040	Net Zero 2050	5.47E+10	2.21E+11	1.92E-28
2045	Net Zero 2050	5.79E+10	2.18E+11	4.44E-28
2050	Net Zero 2050	6.75E+10	2.08E+11	5.48E-27

Across the three scenarios, when we reduce the asset value based on the cost from scope 1 and 2 emissions, the calculated probabilities of default generally agree, implying a small likelihood of default (close to 0).

We argue that adjusting for the scope 1 and 2 emissions is reasonable, particularly for an oil company, By nature, both scope 1-direct emissions and scope 2- emissions originate from the company's owned and controlled sources. This indicates that the penalty for emission does not impact the overall credit behavior of the firms. Since increased emission costs come from controllable sources that the oil company can control, then it becomes an additional operational cost to the company and increases the probability by a small percentage. The oil companies can price back the additional emission costs to the product price.
In order to defend such a claim, we need to test the assumptions in constant emission settings. New information surrounding the company's internal ESG initiative goals, the external government policies on carbon emission, and product profitability with increased operational costs are necessary.

Time	Scenario	Reduced Asset E123	PD E123
2025	Nationally Determined Contributions (NDCs)	2.56E+11	3.21E-32
2030	Nationally Determined Contributions (NDCs)	2.17E+11	5.13E-28
2035	Nationally Determined Contributions (NDCs)	2.10E+11	3.93E-27
2040	Nationally Determined Contributions (NDCs)	2.08E+11	5.78E-27
2045	Nationally Determined Contributions (NDCs)	2.07E+11	8.52E-27
2050	Nationally Determined Contributions (NDCs)	2.05E+11	1.26E-26
2025	Delayed transition	2.76E+11	3.40E-34
2030	Delayed transition	2.76E+11	3.40E-34
2035	Delayed transition	1.40E+10	9.99E-01
2040	Delayed transition	-1.69E+11	1.00E+00
2045	Delayed transition	-1.75E+11	1.00E+00
2050	Delayed transition	-4.03E+11	1.00E+00
2025	Net Zero 2050	1.24E+11	5.47E-16
2030	Net Zero 2050	9.32E+10	2.70E-11
2035	Net Zero 2050	3.19E+10	1.49E-01
2040	Net Zero 2050	-9.62E+10	1.00E+00
2045	Net Zero 2050	-1.18E+11	1.00E+00
2050	Net Zero 2050	-1.83E+11	1.00E+00

When we introduce scope 3 emission, we observe that when delayed transition kicks in starting in the year 2035, the reduced asset value quickly falls below 0, leading to an absolute certainty of default.

Additionally, under the Net Zero 2050 policy, holding scope 3 emission yields negative reduced asset value starting from 2040.

This calculation makes economic sense to include scope 3 emissions in the calculation depending on the government policy's severity on emissions. If the overall emission hits a critical point such that it is necessary to end the companies that are not hitting the emission target, it makes sense to better off the economy and includes scope 3 emission.

4.2 Emission Pathway

Exxon has the plan to reduce scope 1 and 2 emissions to zero by 2050, we assume the emission pathway is linear from today and reduce to 0 by 2050.

In a similar fashion to **Section 4.1 constant pricing**, we first study the 3 scenarios using the Merton framework including only the scope 1 and 2 emissions. The calculated probabilities of default are as follow:

Time	Scenario	E12 Emission	Cost E12	Reduced Asset E12	PD E12
2025	Nationally Determined Contributions (NDCs)	100000000	2.57E+09	2.73207E+11	6.11E-34
2030	Nationally Determined Contributions (NDCs)	80000000	6.14E+09	2.69634E+11	1.39E-33
2035	Nationally Determined Contributions (NDCs)	60000000	5.21E+09	2.70558E+11	1.12E-33
2040	Nationally Determined Contributions (NDCs)	40000000	3.55E+09	2.7222E+11	7.66E-34
2045	Nationally Determined Contributions (NDCs)	20000000	1.81E+09	2.73958E+11	5.15E-34
2050	Nationally Determined Contributions (NDCs)	0	0.00E+00	2.75772E+11	3.40E-34
2025	Delayed transition	100000000	0.00E+00	2.75772E+11	3.40E-34
2030	Delayed transition	80000000	0.00E+00	2.75772E+11	3.40E-34
2035	Delayed transition	60000000	2.06E+10	2.55159E+11	4.14E-32
2040	Delayed transition	40000000	2.33E+10	2.52439E+11	7.93E-32
2045	Delayed transition	20000000	1.18E+10	2.63942E+11	5.21E-33
2050	Delayed transition	0	0.00E+00	2.75772E+11	3.40E-34
2025	Net Zero 2050	100000000	1.99E+10	2.55824E+11	3.53E-32
2030	Net Zero 2050	80000000	1.92E+10	2.56609E+11	2.93E-32
2035	Net Zero 2050	60000000	1.92E+10	2.56569E+11	2.96E-32
2040	Net Zero 2050	40000000	1.95E+10	2.56245E+11	3.20E-32
2045	Net Zero 2050	20000000	1.03E+10	2.6543E+11	3.68E-33
2050	Net Zero 2050	0	0.00E+00	2.75772E+11	3.40E-34

Aligning with our methodology, we see that the scope 1 and 2 emissions decline in a linear manner, with carbon costs decreasing monotonically, trending towards zero. The carbon cost is relatively small compared to the asset value, therefore the terminal effect on the probability of default is negligible.

Time	Scenario	E12 Emission	Cost E12	Cost E3	Reduced Asset E123	PD E123
2025	Nationally Determined Contributions (NDCs)	100000000	2.57E+09	1.67E+10	2.57E+11	2.99E-32
2030	Nationally Determined Contributions (NDCs)	80000000	6.14E+09	4.99E+10	2.20E+11	2.71E-28
2035	Nationally Determined Contributions (NDCs)	60000000	5.21E+09	5.65E+10	2.14E+11	1.19E-27
2040	Nationally Determined Contributions (NDCs)	40000000	3.55E+09	5.77E+10	2.14E+11	1.07E-27
2045	Nationally Determined Contributions (NDCs)	20000000	1.81E+09	5.90E+10	2.15E+11	9.36E-28
2050	Nationally Determined Contributions (NDCs)	0	0.00E+00	6.02E+10	2.16E+11	8.05E-28
2025	Delayed transition	100000000	0.00E+00	0.00E+00	2.76E+11	3.40E-34
2030	Delayed transition	80000000	0.00E+00	0.00E+00	2.76E+11	3.40E-34
2035	Delayed transition	60000000	2.06E+10	2.23E+11	3.18E+10	1.50E-01
2040	Delayed transition	40000000	2.33E+10	3.79E+11	-1.27E+11	1.00E+00
2045	Delayed transition	20000000	1.18E+10	3.85E+11	-1.21E+11	1.00E+00
2050	Delayed transition	0	0.00E+00	5.79E+11	-3.03E+11	1.00E+00
2025	Net Zero 2050	100000000	1.99E+10	1.30E+11	1.26E+11	2.44E-16
2030	Net Zero 2050	80000000	1.92E+10	1.56E+11	1.01E+11	1.63E-12
2035	Net Zero 2050	60000000	1.92E+10	2.08E+11	4.85E+10	6.84E-04
2040	Net Zero 2050	40000000	1.95E+10	3.17E+11	-6.11E+10	1.00E+00
2045	Net Zero 2050	20000000	1.03E+10	3.36E+11	-7.07E+10	1.00E+00
2050	Net Zero 2050	0	0.00E+00	3.92E+11	-1.16E+11	1.00E+00

Lastly, introducing scope 3 emission yields a greater impact on the carbon cost, evident from the material reduction in asset value over the years. This is consequential when we hold the scope 3 emissions constant. Inheriting from the logic in **Section 4.1 Constant Pricing**, the reduced asset value drops below zero, yielding an absolute default.

Note that here we assume the pathway only applies to scope 1 and 2, with scope 3 fixed. To assess how scope 3 emissions evolve under each scenario, we need to address the indirect impact of which the company's value chain. This is under the assumption that the company is able to assess the emission from sources that are not under their control. In a nutshell, the company needs to make predictions about its future activities that result in indirect carbon emissions. It would be helpful to also investigate the industrial outlook and how peer companies manage their emission initiatives.