S&P Global
Market Intelligence

Climate-Linked Credit Analytics for Public Firms

A Global Tool Assessing the Credit Risk of Climate-Related Carbon Policy Scenarios

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Overview

In recent years, the activity of central banks and regulators has intensified worldwide, with their goal being to estimate and/or manage future economic losses linked to climate change that may be experienced by Insurers and Banks.[1]

In particular, central banks are converging towards the integration of monitoring climate-related financial risks in day-to-day work and setting expectations that financial firms are adequately addressing relevant risks. Financial firms would do this by reporting their financial exposure to climate change risks and by conducting the appropriate scenario analysis to assess strategic resilience to climate change policy.[2]

Indeed, further to the 2015 Paris Agreement,[3] more than 185 countries have committed to curbing greenhouse gas (GHG) emissions by introducing a variety of policies over the next decades to limit global warming, including a carbon tax that penalizes company-specific CO_2 emissions. The introduction of a carbon tax may increase costs for companies operating in high CO_2-intensive sectors, but may also generate revenue opportunities for those that manage to adopt greener technology. This may enable them to reduce costs associated with emissions, or seize market-share from their competitors.

At S&P Global Market Intelligence, we have developed two scenario tools that enable asset managers and risk managers at Banks and Non-financial Corporations to estimate the impact of an introduction or increase of a carbon tax on the credit risk score[4] of firms, globally:

- For upstream Oil & Gas firms: This tool was developed in consultation with Oliver Wyman[5] and conditions full financial statements of public and private upstream Oil & Gas companies on future carbon tax scenarios, across the next three years.[6] Estimated company financials can then be input into S&P Global Market Intelligence Credit Analytics' fundamentals-driven statistical models (e.g., CreditModel™) or judgmental-driven Scorecards to determine the change of a credit risk score. Further work is planned to cover other high CO_2-emitting sectors (such as Coal Mining, Real Estate, Transportation, Power Utilities, Shipping, and Agriculture).
- For public firms: This leverages Trucost's database of CO_2 emissions at a company level and projects future market capitalization of public companies, globally, based

[1] "Central Banking – Focus Report – Climate Change" Published by Infopro (Airqualitynews, May 2019) – available at https://airqualitynews.com/2019/05/08/scientists-developing-green-fuels-from-industrial-co2/
[2] The Bank of England has announced it will introduce a climate-related scenario in the 2021 Banks' annual stress testing exercise. See, for example, "New economy, new finance, new Bank – the Bank of England's response to the van Steenis review of the Future of Finance", Bank of England (June 2019).
[3] "Chapter XXVII – Environment – 7.d Paris Agreement", United Nations (12 December 2015).
[4] S&P Global Ratings does not contribute to or participate in the creation of credit scores generated by S&P Global Market Intelligence. Lowercase nomenclature is used to differentiate S&P Global Market Intelligence credit model scores from the credit ratings issued by S&P Global Ratings.
[5] Oliver Wyman is a third-party consulting firm and is not affiliated with S&P Global or any of its divisions.
[6] "Extending Our Horizons: Assessing Credit Risk and Opportunity in a Changing Climate", Oliver Wyman (April 2018).

on pre- or user-defined scenarios. Future market capitalization is then used within S&P Global Market Intelligence's Probability of Default Model Market Signals (PDMS), a market-driven probability of default (PD) model, to determine the change in creditworthiness of those companies.

These tools can also be employed to support the Task Force on Climate-related Financial Disclosures' (TCFD)[7] recommendations (some of which will become mandatory in 2020 for signatories of the Principles for Responsible Investment) on forward-looking scenario analysis of potential paths to a low-carbon economy, and on disclosure of related transition risks.

In the remaining part of this document, we discuss the Climate-Linked Credit Analytics Tool for Public Firms. A separate paper discusses the tool for the upstream Oil & Gas sector.[8]

Entity Coverage and Model Features

The Climate-Linked Credit Analytics Tool for Public Firms adopts a top-down, market-driven view, providing a granular, company-specific assessment for 34,000+ public (financial and non-financial) companies, globally.[9]

Global Coverage

The coverage includes both developed and developing countries. For details please refer to Appendix A.

Company-Specific CO_2 Emissions

Lack of robust data on businesses' GHGs by country hinders the quantification of any impact analysis. This is expected to improve over the next few years, as disclosure standards will be enhanced and companies should be more transparent. In the meantime, it requires leveraging the most up-to date and extensive databases available, as well as devising reasonable proxy mechanisms when information is missing.

Trucost's database currently stores the history of reported and estimated Scope 1 (direct),[10] Scope 2 (indirect),[11] and Scope 3 (supply-chain related)[12] carbon emissions for more than 12,600 companies globally, since 2005.[13] Estimates are based on a proxy mechanism that leverages the intensity of carbon emissions (tons of CO_2 emissions per dollar of total revenues)[14] and firms' total revenues. For large companies operating in many countries, Trucost's database calculates the geographical distribution of carbon emissions. The database is updated and expands monthly as more companies are added.

The tool currently calculates the costs incurred by companies under a carbon-tax scenario based on Scope 1 and 2 emissions, but users can opt to restrict the calculation to Scope 1 emissions only, or add Scope 3 emissions.

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[7] TCFD was established by the Financial Stability Board between December 2015 and March 2016. See, for example, "About the Task Force", Task Force on Climate-related Financial Disclosures, available at https://www.fsb-tcfd.org/about/ (April 2019).
[8] "Climate-Linked Credit Analytics for Upstream Oil & Gas Companies", L. Vidovic, G. Baldassarri, S&P Global Market Intelligence (February 2020).
[9] Source: S&P Capital IQ Platform; as of September 1, 2019.
[10] E.g., emissions from fuel combustion, company vehicles, and fugitive emissions.
[11] E.g., emissions from used electricity, heat, and steam.
[12] E.g., upstream emissions from purchased goods and services, as well as downstream emissions. Currently, Trucost database estimates only upstream emissions.
[13] This is equivalent to 80% of global emissions. See, for example, "TCFD Scenario Analysis: Integrating future carbon price risk into portfolio analysis", Trucost (2019).
[14] Based on actual emissions of companies in the same region and industry sector.

Carbon Price Risk Premium Scenarios

Scenario analysis is a common approach employed by risk managers and analysts to assess the potential impact of future events, under uncertainty. However, there are several challenges that need to be tackled that may compound the long-term nature of the risks and the characteristics of this nascent field:

- Countless potential scenarios: As of February 2019, carbon pricing (in the form of a carbon tax or carbon emission trading scheme) already exists in 28 countries,[15] ranging from <0.1$/t$CO_2$e (Poland) up to circa 130$/t$CO_2$e (Sweden), and covering approximately 6% of the annual global GHGs.[16] To limit global warming to two degrees Celsius above pre-industrial levels, it is estimated that a seven-fold increase in the current average price of carbon in Organization for Economic Co-operation and Development (OECD) countries will be necessary by 2030.[17] However, carbon pricing policy may follow a different path in each national jurisdiction, both in terms of the final level and overall timeframe over which it will be introduced.
- Longer time horizons: The 2015 Paris Agreement requires a multi-year concerted effort among all nations, with the goal to limit global warming to approximately 2.7 degrees Celsius by 2100. This timeframe is much longer than the typical time horizon used in current stress testing exercises run by Banks,[18] and introduces uncertainties.

The tool for public firms enables users to select between: i) a user-defined scenario applying a global carbon price risk premium, where the severity of the overall tax increase from current levels is assumed to be independent of the industry sector, the geography, and the time horizon, and ii) a slow, moderate, or fast scenario developed by Trucost and spanning a period of 30 years, from 2020 to 2050.[19]

- The slow path is based on the full implementation of the existing Nationally Determined Contributions (NDCs),[20] and is envisaged to limit global warming to between 2.7 and 3.0 degrees Celsius above pre-industrial levels.
- The moderate path assumes a delayed action in the short term, followed by a rapid uptick in prices later on to achieve a maximum global warming of two degrees Celsius.
- The fast path assumes a seven-fold increase in the current average price of carbon, to achieve approximately \$120/tCO_2 by 2030 in OECD countries.

These three scenarios form the basis of Trucost's database of country/sector-level annual carbon price risk premia up to 2050, covering 44 major economies. The tool applies an averaging mechanism for the remaining countries.

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[15] As of November 2018.
[16] Carbon Pricing Dashboard, The World Bank (available at https://carbonpricingdashboard.worldbank.org/map_data).
[17] "Talking Points: Internal carbon pricing stress testing for climate risk", Trucost (July 2017) - available at https://www.trucost.com/publication/talking-points-internal-carbon-pricing-stress-testing-business-for-climate-change-risk/.
[18] Typically two to three years.
[19] "TCFD Scenario Analysis: Integrating future carbon price risk into portfolio analysis", Trucost (2019).
[20] NDCs is a term used to refer to reductions in GHGs of countries that ratified the Paris Agreement. Intended NDCs (INDCs) identify the post-2020 voluntary national climate targets, including mitigation and adaptation, which countries committed to at the United Nations Climate Change Conference held in Warsaw in 2013.

Model Primary Outputs

The model's primary outputs include the future market capitalization of each public company in the chosen sector, scenario, and year, as well as the change in credit score (expressed in notches).

The credit score change can be used on a standalone basis, or applied as an overlay to the current credit risk assessment provided by S&P Global Ratings or generated with other quantitative models.

A Top-Down Framework for Climate-Related Transition Risk Assessment

There is currently no recognized industry standard to assess the impact of climate change transition risks on the creditworthiness of Banks' exposures. In addition, transition to a low-carbon economy poses risks, but also offers opportunities for companies that may be able to embrace greener technology and potentially seize market share from their competitors. It is important to consider both aspects when gauging the financial materiality of climate-related scenarios in order to assess the potential impact on a firm's creditworthiness.

Company Creditworthiness

Assessing the creditworthiness of public companies can be done in a variety of ways. This includes: i) a statistical regression model that leverages a firm's financial ratios and links them to the firm's default likelihood (fundamentals view), or ii) a structural approach that leverages public companies' market capitalization information and then estimates a market-implied measure of a distance to default (DD). Our tool leverages this latter approach, as it easily applies to all public companies. It also leverages Trucost's emission data to perform an empirical analysis in an automated and unified framework. This eliminates the need to develop multiple statistical models that condition company financials on carbon pricing policies, based on the specific characteristics of how each industry sector operates.[21]

PDMS

PDMS assesses the PD of more than 34,000+ public companies globally, on a daily basis, using firms' market equity and total liabilities. [22]

The model represents a commercial evolution of the original Merton model,[23] with several enhancements to address some of the key shortcomings of market-driven models.[24]

- Country and industry factors act both as model output stabilizers, reducing model volatility, and risk discriminators for companies operating in different geographies and sectors.
- A robust volatility treatment is employed to further reduce spurious signals due to isolated and sudden market movements and outliers.
- A country-specific credit default swap (CDS) market-derived score is included to account for early-warning signals arising from systematic changes of credit risk at a country level.

[21] In a separate paper, we adopt the fundamentals view and show how it can be applied to upstream Oil & Gas companies. See, for example, "Extending Our Horizons: Assessing Credit Risk and Opportunity in a Changing Climate", Oliver Wyman (April 2018).
[22] Source: S&P Capital IQ Platform; as of September 1, 2019.
[23] "On the Pricing of Corporate Debt: the Risk Structure of Interest Rates", Robert C. Merton, Journal of Finance Vol. 29, pp. 449–470 (1974).
[24] "PD Model Market Signals: an enhanced structural probability of default model", G. Baldassarri, A. Chen (S&P Global Market Intelligence, 2016).

- A company-level revenue (or asset) size adjustment is included to account for the existence of smaller companies and better align with empirically observed default rates.

The current version (v1.1) of the model was recalibrated in 2015 and has since shown consistently strong[25] performance during the regular annual backtesting exercises.[26]

PDMS generates a company's PD over a one-year time horizon, its term-structure, and the implied credit score.[27] We leverage the implied credit score to support the empirical analysis.

The tool for public firms adopts a numerical approximation to quickly estimate the final output of PDMS for each company, based on each firm's new market capitalization. Further details on the numerical approximation and its validity can be found in Appendix B.

Linking Climate Change and Credit Risk

To assess the impact of a given carbon price risk premium on the creditworthiness of public companies, and capture both the risks and opportunities related to a transition, the tool includes the following steps and assumptions:

- **Additional (Carbon Tax) Cost:** For a given scenario, we estimate the additional annual cost that company i will incur in future year y, taking into account the geographical distribution of its Scope 1 and 2 emissions and the future carbon price risk premium in different countries/sectors:

$$Additional\ Cost_{i,y} = \sum_{e=1}^{2}\sum_{c=1}^{n} carbon\ emissions_{i,e,c} \cdot carbon\ price\ risk\ premium_{e,c,y,s}$$

  where:

  e is the type of carbon emissions (Scope 1 or 2 emissions)

  c is the country where emissions are produced

  n is the total number of countries

  y is the year of future carbon prices

  s is the industry sector in which the company operates.

  Despite the expectation that governments will only tax Scope 1 emissions (to avoid the risk of double taxation on Scope 2 and 3 emissions), our formula includes indirect Scope 2 emission costs that companies will incur from raising bills on purchased electricity, heat, and steam. Ultimately, Scope 2 emissions are also driven by downstream customers' behavior/usage of electricity and heat. However, users can mute the impact of Scope 2 emissions, if they so require.

- **Proxy Mechanism:** For companies outside Trucost's database, we apply a proxy mechanism based on the following waterfall:

[25] Average Receiver Operating Characteristic of 88%.
[26] PDMS v1.1 will be replaced by v2.0 in 2020. V2.0 will feature further enhancements, such as a recalibrated and further optimized performance, a company-specific CDS score (for companies with CDS), and a weighted moving average at the PD level to further dampen short-term market-driven noise. The choice of the model version used in our empirical analysis does not materially impact the overall results, since we adopt a similar model calibration in both versions and look at changes in credit scores.
[27] The implied credit score is expressed in lowercase letters to distinguish it from the S&P Global Ratings issuer credit rating.

- We use the average carbon emission intensities for companies in the same country/industry,[28] or (if not available)
- In the same country, or (if not available)
- In the same industry.

- **Emissions Reduction:** The tool for public firms includes an option to take into account future global emission reductions. If the user selects this option, future company-specific emissions are reduced in line with the global emission reduction projections reported in the Climate Action Tracker,[29] in line with the specified transition path. In this case, the tool will adjust the additional cost (carbon tax) to take into account savings arising from the reduction of current taxed emissions, based on current carbon tax values reported by the World Bank in each country.[30]
- **Abatement Costs:** Abatement costs represent additional costs to cover actions that companies will need to take to reduce carbon emissions by adopting new technology and, thus, reducing the risk of stranded assets. McKinsey & Company carried out an extensive analysis to estimate the abatement costs that companies in various industry sectors and geographic regions will incur in order to fully leverage available green technologies or adopt innovative technologies that offer a high degree of certainty about their implementation potential by 2030.[31] We extrapolate the values estimated by McKinsey to 2050 and multiply the relevant value ($/tCO2e) for a given industry and year by the overall emission reduction over the chosen path versus the business as usual (BAU) scenario. These estimated abatement costs (net of taxes, subsidies, or carbon tax considerations, plus reflecting a capital cost similar to long-term government bond rates) are added to the carbon tax costs for each individual company.[32] If users decide to disregard abatement costs, a new option gets activated within the tool, enabling users to choose whether or not to take into account revenue loss (see below).
- **Oil Prices and Interest Rates:** An increase in oil prices or a decrease in interest rates is expected to decrease the overall abatement costs.[33] Users can edit the initial values used to estimate abatement costs within the tool and check the impact on the final results.
- **Company Revenues:** The estimation of the future change to company revenues includes three drivers: i) business growth, ii) costs pass-through, and iii) transition opportunity:

  i) *Business Growth:* For consistency purposes, we assume it scales linearly with the projected global carbon emission growth, if companies keep operating as per current policy.[34] Users can also change the growth percentage in the tool.

  ii) *Cost Pass-Through:* The additional carbon tax and abatement cost represents an expense that the company will incur. We assume companies will try to pass this additional cost on to customers (when positive) by increasing the price of goods/services. Due to price elasticity of demand,

[28] We use 4-digit Primary Industry Classification Standard (PICS), S&P Global Market Intelligence's extension of GICS, to define the industry.
[29] "2100 Warming Projections", Climate Action Tracker (accessed 1 May 2019), https://climateactiontracker.org/global/temperatures/.
[30] Carbon Pricing Dashboard, The World Bank (available at https://carbonpricingdashboard.worldbank.org/map_data).
[31] "Pathways to a Low-Carbon Economy – Version 2 of the global greenhouse gas – abatement cost curve", McKinsey (2009).
[32] In some instances, annual abatement costs may be negative, reflecting a net economic benefit arising from lower energy spending in future years due to investments in more/newer carbon-efficient infrastructure.
[33] "Pathways to a Low-Carbon Economy – Version 2 of the global greenhouse gas – abatement cost curve", McKinsey (2009).
[34] "2100 Warming Projections", Climate Action Tracker (accessed 1 May 2019), https://climateactiontracker.org/global/temperatures/.

only a fraction of the price increase can be successfully passed on and, thus, generate actual revenues.[35] We assume that industry sectors belong to one of four broad groups characterized by a different degree of elasticity. The table below summarizes these groupings.[36]

Table 1: Price elasticity of demand assumptions

Price Elasticity	Industry Sector
Highly Inelastic	Food and Staples Retailing Food, Beverage, and Tobacco Household and Personal Products Health Care Equipment and Services Pharmaceuticals, Biotechnology, and Life Sciences Banks Diversified Financials Insurance Software and Services Telecommunication Services Utilities
Inelastic	Energy Capital Goods Retailing
Elastic	Commercial and Professional Services Transportation Consumer Durables and Apparel Media and Entertainment Real Estate
Highly Elastic	Materials Automobiles and Components Consumer Services Technology Hardware and Equipment Semiconductors and Semiconductor Equipment

Source: Trucost (as of April 1, 2019).

iii) *Transition Opportunity:* The fraction of costs that companies successfully transfer to their customers represents a (demand-adjusted) revenue opportunity. We assume that public companies within the same industry sector compete for this revenue pot. We expect geographic intra-sectorial demand shifts will balance out over the long timeframes considered here. The demand-adjusted revenue pot within each industry is reallocated among companies operating in that industry in proportion to their current market share (comparing their current revenues versus total industry

[35] The price elasticity of demand for electricity, heat, and steam related to Scope 2 emissions is assumed to be highly inelastic.
[36] The numerical values corresponding to each grouping are proprietary to S&P Global Market Intelligence, but can be edited by the user.

revenues) and their ability to adopt greener technology (assumed to be reflected by their current capital expenditure),[37] and inversely proportional to their overall Scope 1 and 2 emissions, normalized by company revenues. This last component enables the model to implicitly account for the possibility of substitution of goods/services within the same industry, as customers may give preference to companies that emit less CO_2 and, thus, pass on fewer costs. Users can switch this option on/off.

- **Stranded Assets and Revenue Loss:** Many environmental and climate change studies refer to the concept of "stranded assets" as assets that will suffer from unanticipated write-downs, devaluations, or conversion to liabilities, perhaps due to a sudden change in legislation policy that limits their use.[38] Estimating stranded assets and lost revenues over future scenarios is a complex exercise, since demand for these assets (e.g., unburnable oil reserves) is not expected to decrease in the short-term. In addition, several new technologies are expected to help, converting potential stranded assets back into usable assets in the longer term.[39] The tool enables users to estimate future revenue loss should companies not have time to adopt (or choose not to convert to) greener technology, but are forced by governments to reduce GHG emissions from current levels. Since carbon emissions and revenues are directly proportional, the tool uses the percentage reduction of CO_2 emissions under a given scenario as an estimate of the percentage of future revenue loss at a company level. This option can be switched on/off by the user.
- **Net Earnings Change:** Given the change in revenues and costs associated with the chosen scenario, we calculate the net change in earnings (EBITDA) for each company.
- **Future Market Capitalization:** We then apply common valuation techniques to estimate the future market capitalization of each company. A median multiple[40] for each industry is applied to each company in that industry[41] to calculate the future change in market capitalization from the current value.
- **Credit Score Change:** Finally, we use the future market capitalization within PDMS to calculate the new PD, new associated credit score, and change in credit score for each public company.
- **Technical Default:** Companies whose future market capitalization falls to zero or below are treated as "technical" defaults (and assigned a credit score equal to 'd').

The tool ignores any further change in company revenues due to systematic changes (e.g., the business cycle) or idiosyncratic drivers (e.g., company specific), as well as any change in company liabilities. This is equivalent to assessing how a company can withstand a future carbon price increase based on what we know today. However, future forecasts on any of

[37] In the absence of good coverage of actual research and development expenses reported by companies, we use capital expenditures as a proxy.
[38] "Stranded Assets", Carbon Tracker (August 2017) - available at https://www.carbontracker.org/terms/stranded-assets/.
[39] Examples of new technologies include the employment of recently discovered bacteria in the Pacific ocean that are able to absorb CO_2 and turn themselves into a food source for other sea creatures, or the use of several electrochemical and photo-electrochemical devices powered by wind and solar energy that draw in polluted air from factories and power plants and convert factory-generated CO_2 emissions into sustainable chemicals and fuels without any wasteful byproducts. See, for example, "Bacteria that absorbs CO2 has been discovered at the bottom of the Pacific ocean", Hannah Osborne, (Newsweek, November 2018) – available at https://www.newsweek.com/bacteria-absorbs-co2-has-been-discovered-bottom-pacific-ocean-1225993 or "Scientists developing green fuels from industrial CO2", Thomas Barrett, (Airqualitynews, May 2019) – available at https://airqualitynews.com/2019/05/08/scientists-developing-green-fuels-from-industrial-co2/.
[40] We chose market capitalization/EBITDA, as this is one of the most common multipliers used in the industry.
[41] If the industry-specific median valuation multiple turns out to be negative, we replace it with the average of all industry-specific median valuation multiples. In our case, however, this does not happen.

these components can be easily implemented by the user, leveraging the Capital IQ Excel® Plugin.[42]

A detailed list of all inputs and outputs of the model is reported in Appendix B, along with the typical “response types” that companies and governments may adopt in tackling the energy transition, and the implied assumptions linked to each choice.

Case Study

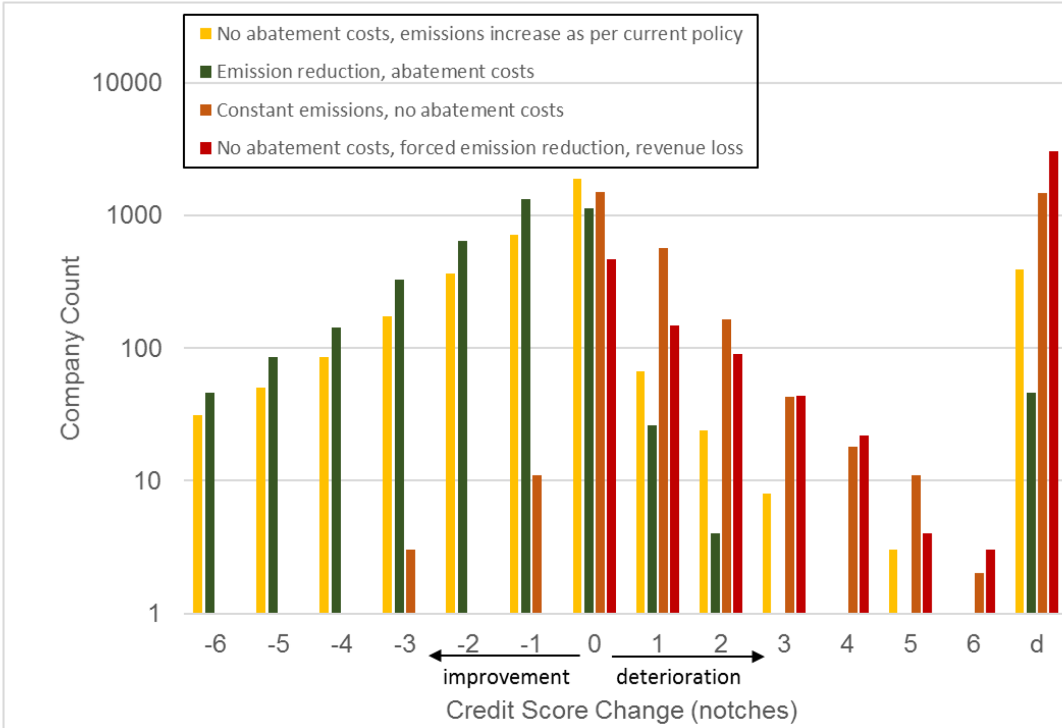
The tool can be employed to perform risk and opportunity analysis over a given transition scenario at an individual company level or for multiple public companies. It can also be used to perform stress testing analysis or to accommodate the case of “sudden shocks” (e.g., where emissions remain fixed at current levels or regulatory pressure suddenly increases and forces companies to decrease their current emissions, without the ability to adapt and, therefore, losing revenues).

Below, we show the distribution of credit score changes by 2050 for public companies within the Materials sector, one of the highest CO_2-emitting sectors, over a fast (i.e., two degrees Celsius) transition scenario, where the carbon tax rapidly increases and companies react in various ways:

- Yellow bars: Companies keep increasing carbon emissions and do not invest in new/greener technology, but pay a carbon tax on increased emissions.
- Green bars: Companies manage to meet CO_2 emission reduction targets in 2050 by investing in greener technology and, thus, sustaining abatement costs in addition to carbon tax costs. Revenues include both a growth component and a cost-related component.
- Amber bars: Companies maintain current (2019) levels of CO_2 emissions saving on abatement costs, but sustaining carbon tax costs. Revenues grow only in proportion to the fraction of total costs passed on to their consumers.
- Red bars: Companies do not invest in new/greener technology and pay a high carbon tax, and governments impose additional policies that forcefully reduce carbon emissions (e.g., by progressively banning use of certain materials), thus leading to revenue losses on affected companies.

[42] Due to the forward-looking, long-term, and uncertain nature of climate-related transition risks and opportunities, backtesting the outputs of the public firms tool is out of scope.

Fig. 1: Distribution of credit score change by 2050 for public companies in the Materials sector, over a fast transition. Please, note the semi-logarithmic scale used to zoom in on the y-axis.



Source: S&P Global Market Intelligence. As of September 1, 2019. For illustrative purposes only.

Despite some of these scenarios being extreme (as in the amber case) or highly unlikely (as in the red case), they are still useful to obtain a sense of the potential impact of company inaction or abrupt government policies in comparison to alternative, more rational choices.

A few comments:

1. In all cases, a significant fraction of companies (up to 44%) remains with the same credit score under the fast transition. The remainder change their credit score in either direction, confirming the importance of managing risks, but also seizing opportunities over the long-term.
2. In the yellow case, the distribution of score changes is skewed towards the left due to the expected revenue growth, but a significant number of companies may also be affected negatively, and up to 10% of firms in this sector may end in a technical default ('d') when their projected market capitalization falls to zero or to a negative value by 2050. This type of scenario essentially shows the cost of inaction by companies that simply bear carbon tax costs on increasingly higher carbon emissions. It is worth noting that the technical defaults reported here are a cumulative rate over the next 30 years. For comparison purposes, the long-term average cumulative (30 years) default rate of BBB-rated companies by S&P Global Ratings is higher than 10%.[43]

[43] Source: S&P Global Market Intelligence's CreditPro™ database (as of September, 1 2019). The CreditPro database stores the historical S&P Global Ratings' issuer credit ratings, as well as the corresponding default experience.

3. The green case shows the advantage of investing in new/greener technology, thus reducing carbon emissions and paying lower carbon tax (whilst incurring higher operating costs on new technology). In this case, the vast majority of companies (71%) experience an improvement in credit score by 1 or more notches, while 26% will remain with the same score, and only 1% will incur a technical (cumulative) default over the next 30 years.
4. The amber case assumes companies maintain current emission levels without converting to new technology. Companies will pay a carbon tax (over the fast transition scenario) on their emissions and increase their revenues only in proportion to the fraction of costs passed on to their customers. This leads to a significant distribution skew towards the right-hand side, with 38% of companies at risk of technical default.
5. The red case corresponds to an extreme situation, where companies do not convert to new technology, but have to pay an increased carbon tax, while governments enforce restrictive laws to curb carbon emissions (e.g., by banning use of obsolete technology or imposing carbon emission caps) and induce revenue losses among companies in proportion to the carbon emissions reduction. In this case, the technical (cumulative) default rate over the next 30 years increases to almost 79%, with potentially severe consequences for this sector and the overall economy as a whole.

This analysis shows the flexibility of the tool in accommodating various transition scenarios and firms' behaviors (or response types), as well as the importance of striking a balance between carbon pricing policies and the actions that companies will need to take in order to adopt new technology and reduce carbon emissions.

Conclusion

To date, 185 countries have ratified the 2015 Paris Agreement, committing to combat climate change and intensify the actions and investments needed for a sustainable low-carbon future. One of the primary policy tools contemplated by governments is the introduction (or increase where already available) of a carbon tax penalizing firms' GHG emissions, thus directly impacting their financial performance and potentially affecting their creditworthiness. Meanwhile, financial regulators in several jurisdictions are planning to include climate-linked scenarios in the annual bank stress testing exercise. S&P Global Market Intelligence's Climate-Linked Credit Analytics Tool for Public Firms leverages company-specific CO_2 emissions from Trucost and employs a quantitative top-down approach to estimate how climate transition risk may change the market capitalization and creditworthiness of public companies globally within the next 30 years, based on Credit Analytics' PDMS. The tool is automated and runs on more than 34,000 companies. Users can perform scenario analysis based on pre- or user-defined scenarios, include future emission reductions, and account for transition opportunities arising from companies adopting new technology and/or seizing market share from their competitors. All assumptions are reported in a transparent way and can be edited by the user, as needed.

The tool can be used by corporate sustainability teams to support TCFD recommendations/disclosures, as well as by financial regulators and credit risk managers to perform scenario analysis that address both risks and opportunities, or stress testing exercises focusing on down-side risks at the entity level.

APPENDIX A

Global Coverage (as of September 2019).

Country	Country ISO Code
Afghanistan	AFG
Åland Islands	ALA
Albania	ALB
Algeria	DZA
Andorra	AND
Angola	AGO
Anguilla	AIA
Antarctica (British Antarctic Territory)	ATA
Antigua and Barbuda	ATG
Argentina	ARG
Armenia	ARM
Aruba	ABW
Australia	AUS
Austria	AUT
Azerbaijan	AZE
Bahamas	BHS
Bahrain	BHR
Bangladesh	BGD
Barbados	BRB
Belarus	BLR
Belgium	BEL
Belize	BLZ
Benin	BEN
Bermuda	BMU
Bhutan	BTN
Bolivia	BOL
Bonaire, Sint Eustatius & Saba	BES
Bosnia & Herzegovina	BIH
Botswana	BWA
Brazil	BRA
British Indian Ocean Territory	IOT
British Virgin Islands	VGB
Brunei Darussalam	BRN
Bulgaria	BGR
Burkina Faso	BFA
Burundi	BDI

Country	Country ISO Code
Cambodia	KHM
Cameroon	CMR
Canada	CAN
Cape Verde	CPV
Cayman Islands	CYM
Central African Republic	CAF
Chad	TCD
Chile	CHL
China	CHN
Christmas Island	CXR
Cocos (Keeling) Islands	CCK
Colombia	COL
Comoros	COM
Congo Brazzaville	COG
Cook Islands	COK
Costa Rica	CRI
Côte d´Ivoire	CIV
Croatia	HRV
Cuba	CUB
Curaçao	CUW
Cyprus	CYP
Czech Republic	CZE
Democratic Republic of Congo	COD
Denmark	DNK
Djibouti	DJI
Dominica	DMA
Dominican Republic	DOM
Ecuador	ECU
Egypt	EGY
El Salvador	SLV
Equatorial Guinea	GNQ
Eritrea	ERI
Estonia	EST
Ethiopia	ETH
Falkland Islands (Malvinas)	FLK
Faroe Islands	FRO
Fiji	FJI
Finland	FIN
France	FRA
French Guiana	GUF
French Polynesia	PYF
Gabon	GAB

Country	Country ISO Code
Gambia	GMB
Georgia	GEO
Germany	DEU
Ghana	GHA
Gibraltar	GIB
Greece	GRC
Greenland	GRL
Grenada	GRD
Guadeloupe	GLP
Guatemala	GTM
Guernsey	GGY
Guinea	GIN
Guinea-Bissau	GNB
Guyana	GUY
Haiti	HTI
Heard Island & Mc Donald Islands	HMD
Honduras	HND
Hong Kong	HKG
Hungary	HUN
Iceland	ISL
India	IND
Indonesia	IDN
Iran	IRN
Iraq	IRQ
Ireland	IRL
Isle of Man	IMN
Israel	ISR
Italy	ITA
Jamaica	JAM
Japan	JPN
Jersey	JEY
Jordan	JOR
Kazakhstan	KAZ
Kenya	KEN
Kiribati	KIR
Kuwait	KWT
Kyrgyzstan	KGZ
Laos	LAO
Latvia	LVA
Lebanon	LBN
Lesotho	LSO
Liberia	LBR

Country	Country ISO Code
Libya	LBY
Liechtenstein	LIE
Lithuania	LTU
Luxembourg	LUX
Macau	MAC
Macedonia	MKD
Madagascar	MDG
Malawi	MWI
Malaysia	MYS
Maldives	MDV
Mali	MLI
Malta	MLT
Marshall Islands	MHL
Martinique	MTQ
Mauritania	MRT
Mauritius	MUS
Mayotte	MYT
Mexico	MEX
Moldova	MDA
Monaco	MCO
Mongolia	MNG
Montenegro	MNE
Montserrat	MSR
Morocco	MAR
Mozambique	MOZ
Myanmar	MMR
Namibia	NAM
Nauru	NRU
Nepal	NPL
Netherlands	NLD
New Caledonia	NCL
New Zealand	NZL
Nicaragua	NIC
Niger	NER
Nigeria	NGA
Niue	NIU
Norfolk Island	NFK
North Korea	PRK
Norway	NOR
Occupied Palestinian Territory	PSE
Oman	OMN
Pakistan	PAK

Country	Country ISO Code
Palau	PLW
Panama	PAN
Papua New Guinea	PNG
Paraguay	PRY
Peru	PER
Philippines	PHL
Pitcairn Islands	PCN
Poland	POL
Portugal	PRT
Qatar	QAT
Réunion	REU
Romania	ROU
Russia	RUS
Rwanda	RWA
Saint Barthélemy	BLM
Saint Helena, Ascension & Tristan da Cunha	SHN
Saint Kitts and Nevis	KNA
Saint Lucia	LCA
Saint Martin	MAF
Saint Pierre & Miquelon	SPM
Saint Vincent and the Grenadines	VCT
Samoa	WSM
San Marino	SMR
Sao Tome and Principe	STP
Saudi Arabia	SAU
Senegal	SEN
Serbia	SRB
Seychelles	SYC
Sierra Leone	SLE
Singapore	SGP
Sint Maarten	SXM
Slovakia	SVK
Slovenia	SVN
Solomon Islands	SLB
Somalia	SOM
South Africa	ZAF
South Georgia & the South Sandwich Islands	SGS
South Korea	KOR
South Sudan	SSD
Spain	ESP
Sri Lanka	LKA
Sudan	SDN

Country	Country ISO Code
Suriname	SUR
Svalbard & Jan Mayen	SJM
Swaziland	SWZ
Sweden	SWE
Switzerland	CHE
Syria	SYR
Taiwan	TWN
Tajikistan	TJK
Tanzania	TZA
Thailand	THA
Timor-Leste	TLS
Togo	TGO
Tokelau	TKL
Tonga	TON
Trinidad and Tobago	TTO
Tunisia	TUN
Turkey	TUR
Turkmenistan	TKM
Turks & Caicos Islands	TCA
Tuvalu	TUV
Uganda	UGA
Ukraine	UKR
United Arab Emirates	ARE
United Kingdom	GBR
Uruguay	URY
Uzbekistan	UZB
Vanuatu	VUT
Vatican City	VAT
Venezuela	VEN
Vietnam	VNM
Wallis & Futuna	WLF
Western Sahara	ESH
Yemen	YEM
Zambia	ZMB
Zimbabwe	ZWE

APPENDIX B

We briefly discuss the major inputs and outputs of the Climate-Linked Credit Analytics Tool for Public Firms:

Summary of Inputs

Input	Comment
Current date	**Pre-populated.** Used to calculate the current PD and the credit score for each public company.
Industry sector	**User-defined.** Choose among 21 industry sectors or select "all" to estimate the impact of a climate-related transition scenario on the credit score of companies in a specified industry sector or of all public companies, respectively.
Scenario	**User-defined.** "Global": Assumes a carbon tax increase applied globally. "Slow": Assumes a carbon tax increase that follows Trucost's slow transition scenario over the next 30 years. "Moderate": Assumes a carbon tax increase that follows Trucost's moderate transition scenario over the next 30 years. "Fast": Assumes a carbon tax increase that follows Trucost's fast transition scenario over the next 30 years.
Carbon tax increase ($/tCO$_2$)	**User-defined** (gets activated only when scenario is set to "Global"). Specify global carbon tax increase; this will be applied to all countries and industry sectors.
Year	**User-defined.**

Input	Comment
	Specify a future year for Trucost's selected scenario or for the user-defined global scenario.
Projected global emission growth (current policy)	**Pre-populated** (based on estimated CO_2 emissions growth projected for specified year – see above) or user-defined via user-override.
Targeted emission reduction from current level (%)	**Pre-populated** (based on estimated CO_2 emission reduction) or user-defined via user-override.
Abatement costs	**Pre-populated** (based on Response Type field – see further down) or user-defined via user-override. When "Yes" is selected, companies within the same industry sector reduce CO_2 emissions by the fraction specified in "Emission Reduction (%)" field – see above – by incurring further abatement yearly costs versus future projected emissions under the current policy.
Revenue loss	**Pre-populated** (based on Response Type field – see further down) or user-defined via user-override. This option activates only when abatement costs are set to "No". When "Yes" is selected, companies within the same industry sector lose future revenues in proportion to "Emission Reduction (%)" field. This is useful to simulate an action imposed by governments.
Transition opportunity	**Pre-populated** (based on Response Type field – see further down) or user-defined via user-override. When "Yes" is selected, companies within the same industry sector compete for market share of the revenues opportunity arising from passing on a fraction of their additional carbon tax costs to other companies.
Interest rate	**Pre-populated or user-defined via user-override.**

Input	Comment
	It affects the abatement costs (higher long-term interest rate increases abatement costs).
Oil ($/barrel)	**Pre-populated or user-defined via user-override.** It affects the abatement costs (higher oil price reduces abatement costs).
Response type	**User-defined**, based on four options (described in detail in the next table). **Adaptation, Business as usual (BAU), Forced action, Conservative.**

Source: S&P Global Market Intelligence. As of July, 1st 2019. For illustrative purposes only.

Summary of "Response types":

Comment	Abatement Costs	Revenue Loss	Transition Opportunity	Projected Global Emissions Growth	Targeted Emission Reduction (%)
Response Type: Adaptation Companies face yearly costs to adopt new/greener technology and decrease emissions in line with targeted emission reduction (by specified year). They also face carbon tax costs on (reduced) emissions, in line with specified scenario. On the revenue side, companies benefit from: i). revenue growth (in line with global projected emission growth), and ii.) carbon tax costs passed on to their customers. Companies directly compete only for revenue pot arising from carbon tax costs passed on to their customers.	Yes	No	Yes	pre-calculated	pre-calculated
Response Type: Business as Usual In this case, the targeted emission reduction is user-overridden and	No	No	Yes	pre-calculated	-Absolute (Projected Global Emission Growth)

Comment	Abatement Costs	Revenue Loss	Transition Opportunity	Projected Global Emissions Growth	Targeted Emission Reduction (%)
equalized to a negative value. This corresponds to the situation where companies do not invest in new technology, but keep increasing their emissions in line with the projected global emissions growth, as per current policy. In essence companies will pay a carbon tax on increased emissions, and will try to pass their costs on to consumers (competing for it). In addition, companies will also benefit from increased revenue growth (again, in line with the projected global emissions growth).					
Response Type: Forced Action This scenario corresponds to a potentially extreme situation, whereby companies do not invest in new technology and governments increase carbon tax and further impose highly restrictive policies, to force firms to curb their carbon emissions. In this case, it is assumed companies lose revenues in proportion to the emission reduction.	No	Yes	Yes	pre-calculated	pre-calculated
Response Type: Conservative This scenario corresponds to a situation where companies manage to reduce carbon emissions from current levels, and their abatement costs are perfectly offset by future revenue growth. Companies compete for the revenue pot, including carbon tax	No	No	Yes	0%	pre-calculated

Comment	Abatement Costs	Revenue Loss	Transition Opportunity	Projected Global Emissions Growth	Targeted Emission Reduction (%)
costs passed to customers.					

Source: S&P Global Market Intelligence. As of September, 1 2019. For illustrative purposes only.

Summary of Outputs

Output	Comment
Current carbon tax costs on current emissions	Calculated as product of current carbon tax (if any) times carbon emissions.
Scope 1 additional carbon tax costs ($)	Calculated as product of Scope 1 carbon emissions times carbon tax for Scope 1.
Scope 2 additional carbon tax costs ($)	Calculated as product of Scope 2 carbon emissions times carbon tax for Scope 2.
Additional carbon tax costs on current emissions level (million $)	Calculated as sum of previous two fields.
Abatement costs to reduce emissions (from current levels, or from BAU growth (million $)	Calculated as product of emission reduction (from current levels or from BAU growth, if the business growth option is activated) times the relevant abatement costs.
Additional total costs after reduction of emissions (if any)	Calculated as additional carbon tax costs on current emission level, reduced by relevant reduction factor minus savings on current carbon tax (arising from reduction of current emissions) plus abatement costs (if any).
Absolute weight	Intermediate field used in the calculation of the opportunity share (directly proportional to company revenues and capital expenditures and inversely proportional to reduced emissions).
Opportunity share	Overall opportunity share, obtained by normalizing absolute weights to 100%.
Revenue opportunity and growth/loss	Sum of carbon emission costs passed to customers (taking into account competition for revenue share), and of revenue growth based on emission increase projected under current policy (if abatement costs are active) or

Output	Comment
	revenue loss in proportion to targeted emission reduction (if “Revenue Loss” option is activated).
Change in EBITDA	Change in EBITDA = Revenue Opportunity - Additional Total Costs on targeted reduced emissions, and abatement costs versus projected emissions.
Valuation multiple	Company-specific current market capitalization (average over past 90 days)/last twelve months EBITDA.
Median multiple by industry	Median value of valuation multiple for companies in the same industry. If valuation multiple is negative, it is replaced with the average of the positive median multiples across all other industries. If this is not available, it is replaced by a predefined positive value (6.4), updated on a yearly basis.
Change in market capitalization	Estimated change in market capitalization due to selected carbon tax scenario. Calculated as Median Multiple times EBITDA change.
Future market capitalization	Future market capitalization due to specified carbon tax scenario = current market capitalization plus change in market capitalization.
Old DD	Current DD, generated by PDMS.
New DD	Future DD, based on selected carbon tax scenario (see Appendix C)
Old implied PD	Current PD, generated by PDMS.
New implied PD	Future PD, based on selected carbon tax scenario (see Appendix C).
Credit score change	Change in credit score due to carbon tax scenario (if market capitalization falls to zero or below, this is considered a technical default). The improvement is capped at no more than 13 notches, based on the observed historical behaviour of S&P Global Ratings, over a 30 year time horizon (see Appendix C).

Source: S&P Global Market Intelligence. As of September, 1 2019. For illustrative purposes only.

APPENDIX C

Below, we briefly discuss a numerical approximation applied in the tool to estimate the change in credit risk score for all public companies under a given carbon tax transition scenario. This numerical approximation speeds up the calculation of the new DD for each public company, based on the chosen carbon tax scenario. With a typical i7 core laptop, it takes around 30 minutes to generate the model output for all public companies (approximately 34,000), for one scenario. Of course, less time is needed should the user select one industry sector.

Within PDMS, the calculation of a company credit score for a given day requires 80 days of past market capitalization values. These market values, as well as the short-term interest rate and the firm's total liabilities, are used to calculate a DD value by employing an iterative approach with two unknowns in two equations.[44] This "raw" DD value is, in turn, shifted by an industry-specific adjustment and mapped to a PD.

In order to calculate the future DD for a given scenario, one needs to employ the iterative approach by estimating the future market capitalization for 80 future days (assuming the interest rate and total liabilities remain the same). However, this approach can be quite time consuming.

In order to save time, the tool employs a numerical approximation, such that:

DD_scenario = **F** (*DD_current*, *m*)

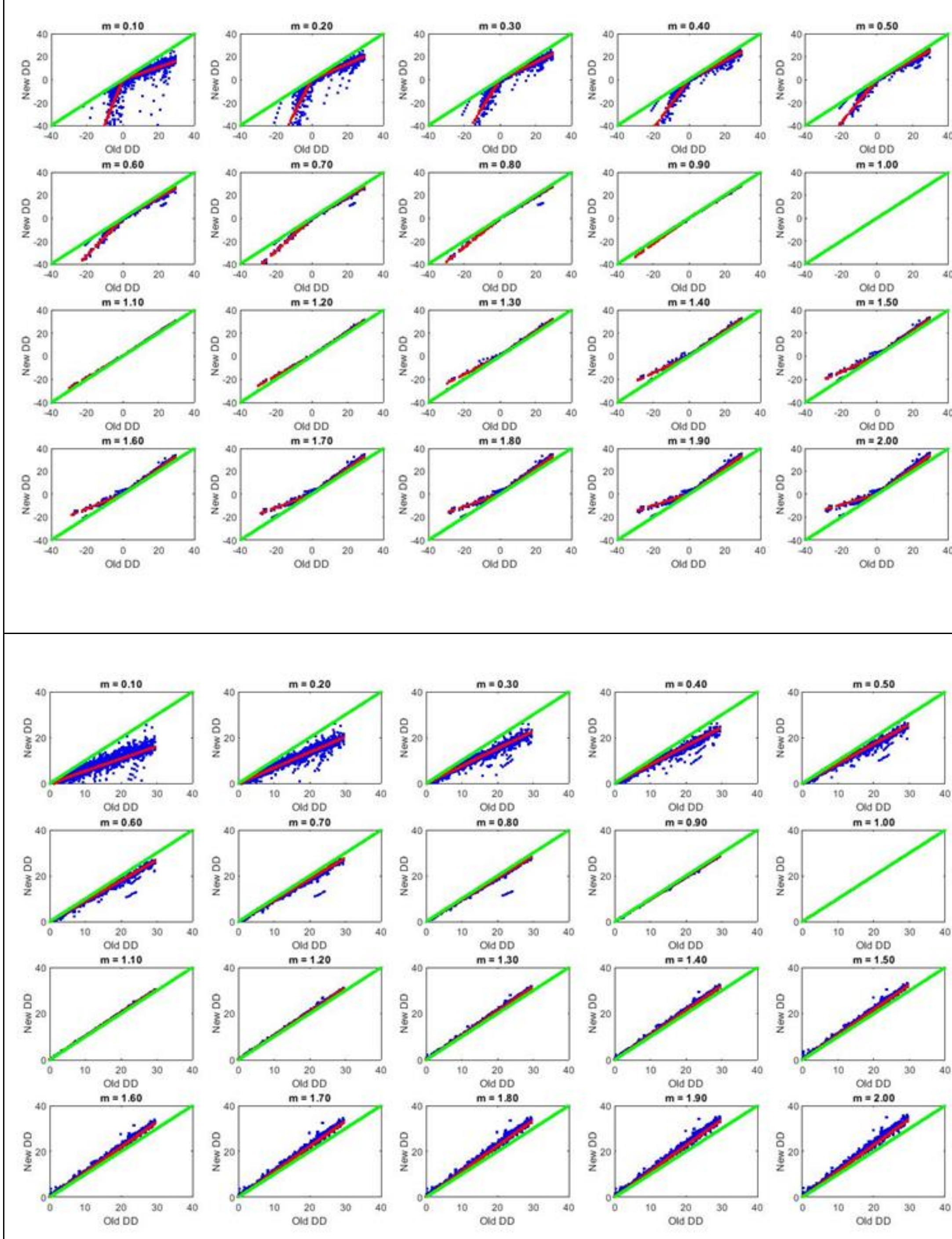
where:

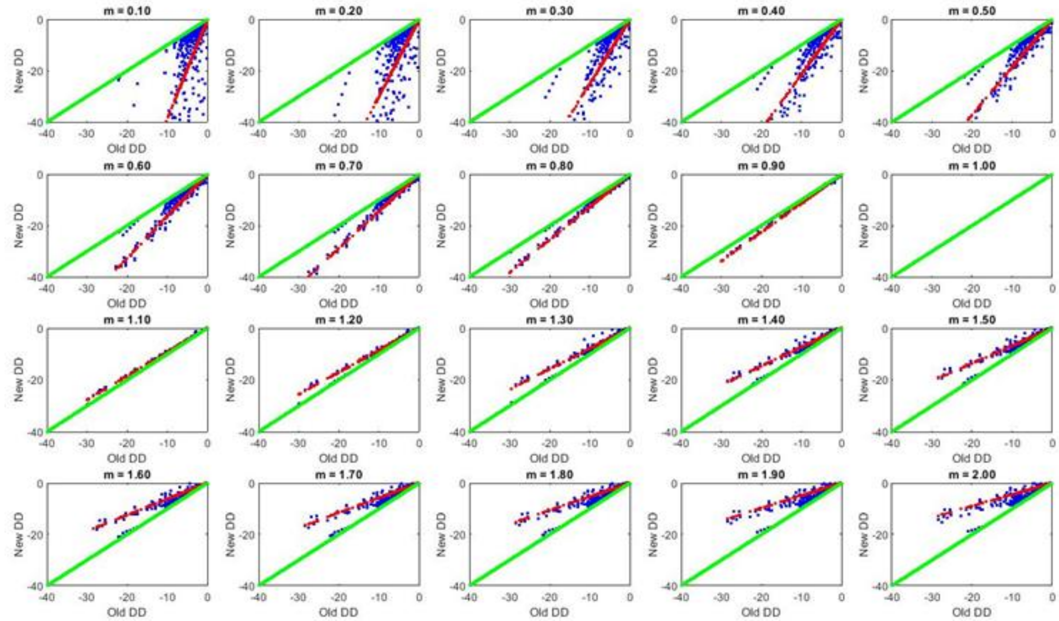
- *DD_scenario* is the new DD of a company, based on the chosen carbon tax scenario.
- *DD_current* is the current DD, as of the specified date, prior to the application of the chosen scenario.
- *m* is the scaling factor by which the current market capitalization of a company needs to be adjusted to obtain the future market capitalization under the given carbon tax scenario.
- **F** is a proprietary parametric expression whose parameters are adjusted to best fit the actual data obtained with the exact approach.

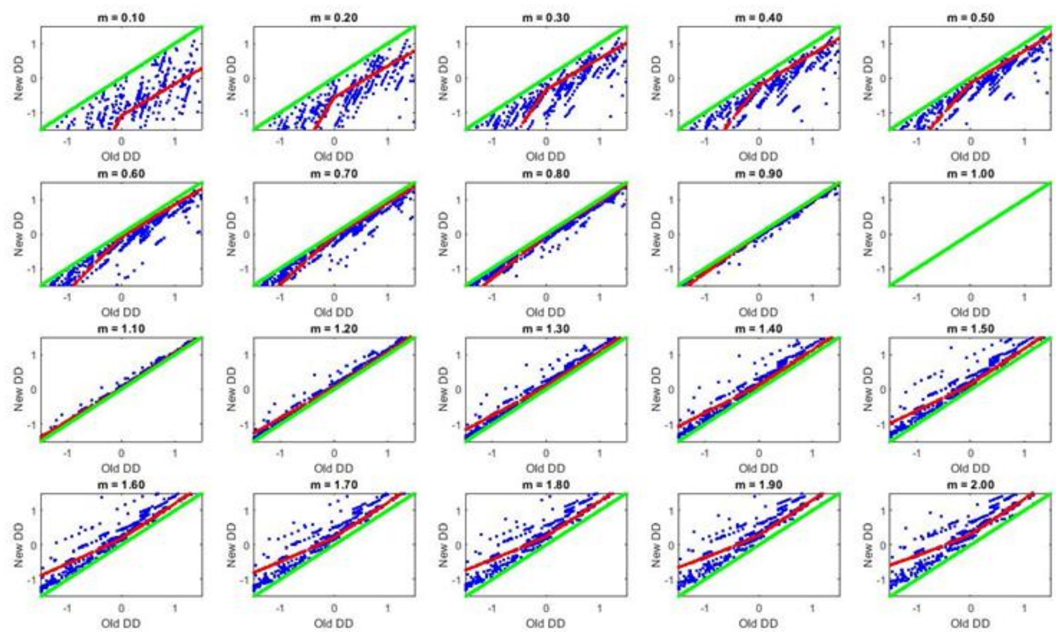
Below are several plots showing the goodness of fit of our empirical approach, for various combinations of DD_current and MC_Multiplier values. The red curve is obtained with the optimized functional form F, while the green line represents the "*DD_scenario = DD_current*" curve and is shown purely for reference purpose.

[44] "PD Model Market Signals: an enhanced structural probability of default model", G. Baldassarri, A. Chen (S&P Global Market Intelligence, 2016).

Figure 2: Goodness of fit for DD approximation.







Source: S&P Global Market Intelligence. For illustrative purposes only. As of date needed.

Once the DD is calculated, it is adjusted to account for industry-specific default rates (as extracted from S&P Global Ratings historical database), and mapped to a one-year PD via a logistic function calibrated to the global historical default rates, before all adjustments mentioned in the PDMS section of this document.

We also performed a similar analysis to account for the potential scenario where both total liabilities and total market capitalization change. In essence, we found that the numerical approximation still holds if one calculates:

$$m = m_1 / m_2, \text{ where}$$

m_1 = future market capitalization/current market capitalization,

m_2 = future total liabilities/current total liabilities.

Finally, the change in credit score is calculated by inverting the relationship established between the credit score and associated observed default rate for the one-year time horizon.[45]

About S&P Global Market Intelligence

At S&P Global Market Intelligence, we know that not all information is important—some of it is vital. Accurate, deep, and insightful. We integrate financial and industry data, research, and news into tools that help track performance, generate alpha, identify investment ideas, understand competitive and industry dynamics, perform valuation, and assess credit risk. Investment professionals, government agencies, corporations, and universities globally can gain the intelligence essential to making business and financial decisions with conviction.

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[45] "Probability of Default term structure: calculating the probability of default of credit risk issuers for short- and long-term horizons", G. Baldassarri, H.Ma (S&P Global Market Intelligence, 2017).