Climate Risks and the Practice of Corporate Valuation

(For consideration: the *Handbook of Finance and Sustainability*)

Roberto Bianchini

Bocconi University
Department of Finance
Via Rontgen 1
20136 Milan, Italy
Roberto.bianchini@unibocconi.it

Gianfranco Gianfrate[1]

(corresponding author)

Harvard University
79 JFK Street
02138 Cambridge (MA), USA
Tel.: +1 617 495 1314
Gianfranco_gianfrate@hks.harvard.edu

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Abstract

Global investors and asset owners are no longer treating climate change as a peripheral issue. From the perspective of seeking superior investment returns and of reducing risks, investors are exploring new ways to capitalize on the opportunities emerging from the transition to a low carbon economy. The practice of finance, and in particular of corporate valuation, is acknowledging this new context by looking into approaches that could accurately reflect the impact of climate risks on equity value. The development of carbon-related financial products and the growing availability – across industries and jurisdictions - of environmental footprint data are valuable "ingredients" for valuations. We assess to what extent carbon risks can be factored in the most common valuation techniques (ie Discounted Cash Flow models) as well as in more sophisticate approaches such as scenario-based valuations, Monte Carlo simulations, decisional trees, and real options.

Keywords: climate change risks, carbon footprint, carbon pricing, Discounted Cash Flow, equity valuation, cost of capital, scenario analysis, Monte Carlo simulations, decision tree, real options.

1. INTRODUCTION

As climate change and global warming are addressed by tougher regulation, new emerging technologies, and shifts in consumer behaviours, their materiality on the valuation of many industries and companies appear severe. In some sectors, the shocks are going to be profound. According to some estimates,[2] the impact of high carbon price on the cash flow of utilities, industrial companies, and airlines will be substantial and pose serious risks to companies and investors.

As a first step in our analysis, it is necessary to provide a definition of climate risk(s). Climate risks principally encompass policy and legal, technology, market and economic factors as well as reputational risks. Those various risks, which have climate change as a common element, may translate to asset risk to financial intermediaries and investors.[3] It is worth recalling that the definition of risk in finance is related to the variability of an expected outcome, and that the direction of such variability does not actually matter.

Climate risks do exist not only for companies whose performance is negatively affected by an increase of carbon price but also for companies that are positively affected in scenarios with carbon becoming more and more costly (see Exhibit 1). As a consequence, there are valuation implications of carbon risks for companies that have direct or indirect exposure to GHG (GreenHouse Gas) emission constraints, such as those in the fossil fuel industry or that are heavily reliant on fossil fuels. But there is a valuation impact also on "low-carbon" companies such as renewable energy—which are usually referred to as a potential "hedge" against carbon assets—because, in many ways, policy and market risks for low-carbon assets are negatively correlated with those of high-carbon assets. In fact, carbon pricing is on the whole positive for wind energy and negative for oil and gas. It is worth noting that low-carbon assets also face

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[2] See for example, "How Climate Change Could Affect Corporate Valuations," *McKinsey Quarterly,* n. 29 (Autumn 2008).

[3] Carbon risks differ from the so-called physical climate risks, which are risks associated with "physical impacts from climate change that could impact carbon assets and operating companies. These impacts may include physical damage and/or capital expenditures necessary in response to variations in weather patterns (such as severe storms, floods, and drought) and "slow onset" impacts such as sea level rise, desertification, etc." (UNEF). Of course, whereas physical climate risks generally affect negatively operations (e.g., an asset cannot operate due to physical impacts), nonphysical carbon risk factors influence the overall risk profile of companies.

many of the same types of risk as carbon assets (e.g., policy and market/economic risks) but the nature and direction of these risks is different and often symmetrical from those facing carbon assets (e.g., the risk that industrial or innovation policies supporting renewable energy are discontinued or not enacted).

Exhibit 1: An overview of the main climate risks relevant for companies [Table in Text]

Type of Risk	Definition	Nature of Impact	Examples
Policy and Legal	Policies or regulations that could impact the operational and financial viability of carbon assets	Impacts physical carbon assets and companies that own/operate assets	Fuel-efficiency standards for personal vehicles; emissions trading systems; US.EPA regulations targeting air pollution, and GHGs from power plants
Technology	Developments in the commercial availability and cost of alternative and low-carbon technologies	Impacts technology choices, deployment, and costs and demand profiles	Energy storage technologies; advances in renewable energy technologies, carbon capture and storage; alternative fuels
Market and Economic	Changes in market or economic conditions that would negatively impact carbon assets	Impacts physical carbon assets and companies that own/operate assets	Changes in fossil fuel prices; changes in consumer preferences

Source: UNEF

Academic research[4] examining the valuation implications of a firm's environmental performance has followed several approaches, with some analyzing financial performance and cost of capital, and others focusing directly on market value itself. Studies that examine the relationship between environmental and financial performance include Jaggi and Freedman (1992), Hart and Ahuja (1996), and Clarkson et al. (2011). For example, using Toxic Release Inventory (TRI) data reported to the U.S. EPA to measure environmental performance, Clarkson et al. (2011) show

[4] Practitioner publications about the integration of sustainability in the corporate valuation process are gaining momentum as well. For example, KPMG (2014) notes that historically, externalities have had little or no impact on the cash flows or risk profiles of most companies: they have not been fully rewarded for their positive externalities and have also not being penalized for the damage they cause through negative externalities such as carbon emissions. The report presents a framework to identify such externalities, to recognize what is driving their internalization, and to understand the potential effects on corporate value. It is assumed that companies equipped with this understanding will be in a stronger position to develop effective response strategies that protect and create value, both for shareholders and for society. Reports that tackle the relationship between sustainability and corporate value have been published by McKinsey (2012), IRRC (2009), and Morgan Stanley (2014).

that firms with marked improvement in environmental performance experience significant improvement in financial performance in subsequent periods, a finding consistent with the argument that improved environmental performance leads to future competitive advantages. Alternatively, others have focused on the relationship between environmental performance and the cost of equity capital. These studies include Sharfman and Fernando (2007), Connors and Silva-Gao (2009), and Schneider (2011), all of which find, using TRI data, that firms exhibiting better environmental performance benefit from a lower cost of capital. Kruger (2015) shows that climate change transparency does affect corporate value.

Climate risks do appear to be of growing concern for global companies and investors. With such risks becoming more and more material, the open question for the practice of finance is how and to what extent such risks should be incorporated in securities valuation.

2. FROM CLIMATE RISKS TO CARBON PRICING

In order to determine the impact of climate risks on the value of corporate assets we need tool to quantify such risk in a "language" that is consistent with companies and with the "ingredients" of the valuation process. The price of carbon is such a tool: it is not the only one but currently in the scientific and policy debate it is possibly the best way to measure climate risks in economic terms.

Carbon prices translates in corporate costs for companies whose operations produce carbon emissions. If carbon price increases and companies are not able to translate (quickly and/or effectively) such increase to price to customers, then—all else being equal from an operations and financial point of view—there is a reduction of the cash flows which, in turn, is reflected in a lower corporate value. The opposite can be true for those companies that benefit from carbon prices increases.

Therefore, it should be a surprise that the phrase "put a price on carbon" has become increasingly popular as the debate about how to address climate change quickly moves from theory to action.

2.1 Carbon Pricing Practices

From a practical point of view, there are several possible ways to price carbon, and they all tend to lead to the same result. The various possible approaches try to quantify and capture the *external costs* of carbon emissions—costs that society pays in other forms, such as droughts, heat waves, damage to cultivations, health care—and tie them to their sources just through a price on carbon.

The objective of carbon pricing is to shift the social costs of damage back to those who are responsible for them, and who can actually curb them. In this way, polluters are ultimately left with the decision on whether to discontinue their polluting operations, to reduce emissions (e.g., by adopting cleaner technologies), or to continue to pollute and pay for it. Therefore, the price of carbon provides an economic signal to polluters who can decide for themselves how to respond. In this way, the global and local environmental goals are expected to be achieved in a flexible and efficient way. The pricing of carbon also has the advantage of stimulating technology and operational innovation, fostering the economy transition toward a low-carbon configuration.

There are two main approaches for pricing carbon: carbon taxes and emission trading systems (ETS). The former consists of defining a tax rate on greenhouse gas emissions or—more frequently—on the carbon content of fossil fuels. Following this approach, the overall emission reduction associated with the carbon tax is not predefined (but it can be estimated), while the carbon price is.

With the latter approach (also known as cap-and-trade system), the objective is to cap the total level of greenhouse gas emissions. The firms who perform better than expected in reducing the emissions can sell their surplus allowances to the larger emitters. In this way, the firms that are more effective in reducing the emissions get rewarded, while the least-effective ones get penalized. This is a market mechanism where the interplay between supply and demand for emissions allowances is reflected in a market price for greenhouse gas emissions. The caps ensure that the required emissions reductions will progressively take place by keeping all the emitters within the boundaries of the pre-allocated carbon budget.

The choice between carbon taxes and ETS systems (or the coexistence of the two) depends on national policymakers and economic circumstances. According to the World Bank, 40 countries have a carbon pricing system in place, and that number is expected to increase significantly over next few years following the climate change agreement (COP21) reached in Paris in 2015.

2.2 External versus Internal Carbon Prices

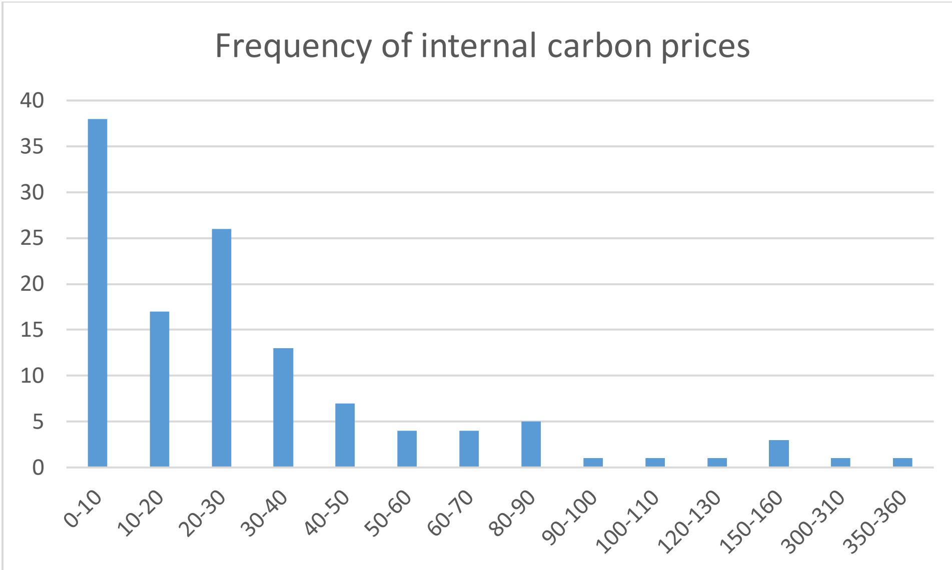
Many companies around the world are using an *internal carbon price*, which is different from, but in relation with, carbon expressed in terms of taxes or ETS prices. Internal carbon price can be a powerful tool in ongoing business strategies. For instance, carbon pricing can be embedded and drive business planning. In fact, many companies acknowledge the process of ongoing climate change—including extreme and unpredictable weather events—as a key relevant business factor for which they wish to be prepared.

Preparedness includes use of an internal carbon price, based on the business assumption that addressing climate change will be both a business cost and possible business opportunity, regardless of the regulatory environment.

The companies that adopt internal carbon prices are the ones that expect an eventual regulatory approach in some form to address climate change. Therefore, companies cite use of a carbon price as a planning tool to help identify revenue opportunities and risks, and as an incentive to drive maximum energy efficiencies to reduce costs and guide capital investment decisions. Those companies deem it prudent and useful to use the concept of a carbon price as part of their planning for achieving reductions in greenhouse gas (GHG) emissions.

By analysing the data gathered by the Carbon Disclosure Project (CDP) issued in 2015 (see Exhibit 17.2), prices used range from US\$0.95 to \$360 per metric ton of CO_2, and companies use varying terminology, such as *internal carbon price; shadow price; internal carbon fee; carbon adder;* or *carbon cost*. Companies that have international operations are especially sophisticated in pricing carbon as a response to the regulatory environments in which they operate. This is particularly true for European and Australian companies that operate in jurisdictions where GHG emissions reductions are compulsory and covered by mandatory cap-and-trade programs or carbon taxes.

Exhibit 2 Frequency distribution of internal carbon prices (in $) per ton of CO_2



Source: Bento and Gianfrate (2016)

CDP shows that companies have also set internal targets for GHG emissions reductions, either in terms of absolute tons or carbon intensity, and use an internal carbon price or gauge to evaluate return on related investments, or to incentivize employees to meet established corporate targets. With this background, utility and energy companies are the most likely to employ internal carbon prices for strategic operational decision-making, as they make long-term plans to meet energy and electricity needs, load factors, and amortization of plant investments and costs.

It is worth noting that even the highest value in the range used to internally price carbon by US companies appears significantly lower than most estimates produced by climate change specialists. For example, in 2015 the United States Environmental Protection Agency (US EPA) released some estimates[5] of the social costs of carbon (SCC), which include scenarios with costs very far from the ones currently used by US companies. The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is

[5] Those estimates are intended to allow US government agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that impact cumulative global emissions. Therefore, they represent a useful and reliable guideline of the current administration's range of carbon valuations. The future policies adopted by the government are likely to assume such range of valuations and to price the carbon accordingly for US companies.

intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change (see Exhibit 3).

Exhibit 3 Estimates of the Social Cost of CO2, 2015–2050[6]

	Discount Rate and Statistic			
Year	**5% Average**	**3% Average**	**2.5% Average**	**3% 95th percentile**
2015	$11	$36	$56	$105
2020	$12	$42	$62	$123
2025	$14	$46	$68	$138
2030	$16	$50	$73	$152
2035	$18	$55	$78	$168
2040	$21	$60	$84	$183
2045	$23	$64	$89	$197
2050	$26	$69	$95	$212

Source: United States Environmental Protection Agency, 2015

3. INCORPORATING CARBON RISKS IN CORPORATE VALUATION

What are the strategies to incorporate carbon risks in corporate valuation? Throughout the book we have discussed the possible ways we can adjust the value of companies for their risk. Technically, the riskiness of the equity (or of the corporate assets) is encapsulated in a single number: either higher discount rate or lower cash flow (Damodaran, 2012).[7]

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[6] Exhibit 17.3 shows the social carbon costs (SCC) according four different discount values to be used in regulatory analyses. Three values are based on the average SCC at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

[7] A third possible approach is the application of a discount factor as in the cases of discounts for lack of liquidity/marketability.

There are more informative ways to treat the relevant risks incorporated in corporate assets such as carbon risks. We can, as discussed in the first four chapters of this book, quantify the value of companies in a certain number of scenarios, rather than synthesizing the different outcomes in a single expected value.

Depending on the level of uncertainty, on the information available, and the time and effort investable in the valuation, it is possible to choose one of three DCF approaches:

1. Standard DCF, to be preferred when uncertainty is limited and there is a clear dominant likely scenario.
2. Scenario-based DCF to be used when there is significant amount of uncertainty and there is one or more scenario(s) that alternative to the most likely one and that could have extreme—either positive or negative—consequences for company's value. Usually two extreme scenarios are worked out: one optimistic and one pessimistic.
3. Stochastic simulation DCF to be used when detailed data are available (or assumed) regarding the probability distributions of key variables affecting future cash flows. This approach, as discussed, is mathematically complex but it can be handled by software packages easily available.

The increasing relevance of carbon risks for companies will require more and more often nonstandard valuation processes. Given the great uncertainty of future carbon prices a scenario-based DCF or a stochastic simulation are the two approaches to be preferred especially for companies whose operations are particularly exposed to carbon risks. We discuss in detail each of these approaches in the next sections, but we will focus first on the relationship between climate risks and cost of capital for companies.

4. CLIMATE RISKS AND THE COST OF CAPITAL

In general, climate risks can be classified as non-diversifiable risks. For diversifiable risks is possible to calculate the cost of insuring as the discount rate of expected future damages as function of distribution function of occurrence of damages and the level of interest rate. But when we analyze the possible future consequences of environmental risks no one can credibly promise of providing insurance to catastrophic climate disaster (yet). Hence this class of risks are mostly non-diversifiable and the main driver of pricing becomes the societal risk aversion. The economics of pricing environmental risks are very similar to those of pricing other valuable nonrenewable resources: how much people must pay to utilize scares resources?

Primary evidence we have about how society prices non diversifiable risk is the equity risk premium. The exposure of single company or project to this non diversifiable risks depends on the covariance between its returns and the returns of the market: the beta. Theoretical asset pricing models like the capital asset pricing model (CAPM) are typically applied to derive the risk-adjusted equity cost of capital (e.g. Litzenberger et al., 1980). The CAPM postulates that the market excess return is the only relevant risk factor for the return of single stocks. CAPM is an asset pricing model that aims to explain why one risky asset provides a different expected return than another.

4.1 Is there a Carbon Beta?

Moving from a single-factor model to a multifactor approach, environmental risks can be estimated as exposure of companies to that specific class of risks. The estimation of environmental beta is derived by the identification of market price/return related to these class of risks.

One of the most important financial product that represent a proxy of environmental risks is carbon price. Carbon markets have been developed in some countries (most notably in Europe) and are under implementation or consideration in others (eg China). The pricing of carbon influences company business strategies, on the one hand, and investor decisions, on the other hand. Companies involved in industries under ETS scheme (electricity generation and energy intensive industries such as steel, glass) are exposed to carbon price volatility and the stringent obligations set by regulation on carbon quota can increase the dependence of company results with respect to carbon market. For these companies the beta might not truly reflect the exposure of the company to the amount of risk that cannot be diversified away. Underestimating carbon risks can be even more costly for non- (or not-enough-) diversified investors. In those situations, it can be advisable to compute the cost of capital with the inclusion of an ad hoc estimation of carbon risks.

Therefore, a multifactor model, which explicitly estimates a carbon risk premium and the company's sensitivity to that premium, should deliver a more precise estimate of the stock's return, thus allowing for a more accurate measure of the cost of capital. The cost of equity capital for any company exposed to carbon risk can be derived as follows:

$$\mu_i = r_f + \beta_{iM}(\mu_M - r_f) + \beta_{iCO2}(\mu_{CO2} - r_f) \qquad (1)$$

According to (1), the expected return on stock i μ_i is equal to the risk-free interest rate r_f plus the risk premiums for market risk and carbon risk. The latter is based on a stock's sensitivities to carbon factor as expressed by β_{iCO2}, which show expected returns μ_{CO2}.

A multifactor asset-pricing model that includes a carbon beta can be an effective tool to assess carbon risk materiality in terms of corporate value. This approach could be potentially extended to other environmental-related sources of risk, such as other pollutants or water.

4.2 Empirical Evidences on Carbon Beta

Koch and Bassen (2013) have proposed an interesting approach to this estimation: they carried out an empirical analysis of European utilities. Koch and Bassen research hypothesis pertain the link between carbon price and cost of equity for European utilities corporations: if carbon prices are a systematic risk factor for European utility corporations, investors should require a carbon price risk premium; and, from a valuation perspective, the additional carbon premium should raise the equity cost of capital for utilities. Moreover, the two researchers assume that carbon-related risks of individual companies are asymmetrically distributed. While the majority of average-emitting utilities might be unaffected by carbon price fluctuations because the increase in power prices covers much of the compliance costs for their balanced plant portfolios, carbon risks should be concentrated on utilities with an extremely high- emitting fuel mix. More specifically, Koch and Bassen argue that a company's carbon risk exposure is determined by the dependence on and intensity of carbon-based power generation. A similar line of thought can be read in Busch and Hoffmann (2007).

The analysis of Koch and Bassen also accounts for previous work of Boyer and Filion (2007), Oberndorfer (2009b) and Sadorsky (2001), which shows that energy prices constitute significant sources of risk for energy stocks, and include excess returns of energy prices. Consequently, the cost of equity capital expressed as the expected return of a utility stock is derived by Koch and Bassen as follows:

$$\mu_i = r_f + \beta_{iM}(\mu_M - r_f) + \beta_{iCO2}(\mu_{CO2} - r_f) + \beta_{ienergy}(\mu_{energy} - r_f) \quad (2)$$

Koch and Bassen assume that expected return on company is determined by specific parameter that capture behavior of energy markets given the different carbon intensity of power generation technologies (coal, oil and natural gas). The two authors analyze 20 European utility stocks between 2005 and 2010 with more than 2000 MW as power generation capacity, excluding companies with carbon free power generation. Based on monthly stock return, future price of carbon traded on ICE ECX and future prices of coal (API2), gas (ICE) and oil (ICIS) the find that 20 European utility stocks show a highly significant impact of market returns on utility returns, as captured by positive market beta coefficients. Moreover they find that 4 of the 20 utility companies exhibit a significant sensitivity to the carbon price factor. This finding documents, on the one hand, that company specific carbon-related risks are strongly asymmetrically distributed to a few utility firms but, on the other hand, that for the great majority of European utilities carbon price fluctuations are not a relevant additional risk factor.

Gianfrate (2016) performs a similar analysis with more comprehensive time horizon: 2005-2011, covering the entire EU-ETS Phase II scheme. Gianfrate finds that the average β_{iCO2} for the entire sample is equal to 0.03, and such coefficient is statistically significant. At more granular level, grouping the sample on the basis of the carbon emission intensity of their operations (measured as CO2 Kg/MWh), he notices that the β_{iCO2} is above 0.03 (statistically significant) for utilities with the highest carbon-intense operations. Whereas the carbon shrinks to 0.02 for average emitters (and loses statistical significance) and it is above 0.06 and regains statistical significance for utilities with the relatively lowest carbon intensity. These results are consistent with the view that carbon price risks have a symmetrical impact on the utilities that are the best and the worst in terms of carbon intensity. For the former, there is a carbon price risk associated with their role as sellers of allowances, thus a risk affecting potential revenues; for the latter, there is a risk as buyers of allowances, therefore a risk that could affect their costs. Carbon risks do exist and are relevant for both of those categories.

4.3 Limitations of Carbon Beta

The carbon beta approach relies on the existence of a liquid market for carbon allowances as well as on the assumption that stock markets are not pricing correctly the information about carbon and, more generally, climate change risks. Both elements are highly debatable in theory and practice. Still, the idea of adjusting the cost of capital directly using the price of carbon expressed by trading platforms has its merits. The more markets are established to trade carbon permits, the more room there will be for techniques to disentangle the sources or risks for companies and for stockholders.

5. SCENARIO-BASED VALUATION

Scenario-based valuation require at least two scenarios, but very often consists of three: a best case, a most likely case, and a worse case. To gauge the effect of risk on value, expected cash flows are estimated under all scenarios. The valuation outcomes can be treated in two ways. They can be considered as a measure of the “value at risk” providing information on how the corporate value would be affected in case certain exogenous factors do happen. For example, assuming that there are three scenarios and that the company value is $100 million under the most likely scenario, $120 million under the optimistic scenario, and $70 million under the pessimistic scenario, we can conclude that with regards to the value under the most likely scenario, there is a 20 percent upside risk and a 30 percent downside risk. Alternatively, we can synthesize the scenarios results by weighting the probabilities attached to each scenario. In this case, assuming that the most likely scenarios has 50 percent probability and the other two scenarios have 25 percent probability each, we can conclude that the expected value for the company is $100 million × 0.5 + $120 million × 0.25 + $70 million × 0.25 = $97.5 million.

Scenario analysis particularly fits corporate valuation sensitivity to carbon risk, as climate change experts usually do use scenarios to forecast the consequences of certain climate policies (or lack thereof). Scholars, academic journals, think tanks, and governmental agencies produce abundant wealth of data, often encapsulated in scenarios frameworks, about carbon prices. The estimates of the social costs of carbon released by the US EPA presented in Exhibit 17.2 are just one among many available.

Provided that there are reliable estimates about the cost of carbon, in order to build a scenario-based valuation for a company, it is necessary to identify other relevant factors (if any) around which comprehensive scenarios could be built. For example, for energy and utilities, usually there is a strong correlation between revenues growth and national economic growth. However, depending on the specific circumstances, other factors such as geographical expansion or the adoption of a new technology could be considered.

The second step is usually to determine the number of scenarios to be worked out. Two is the minimum number, and some corporates prepare and work on 20 different scenarios. The choice about the number should actually be a function of how different the scenarios are, how accurately they can be forecasted by analysts, and the amount of time and resources that can be invested in preparing them.

Once the number and the drivers of the scenarios are set, the cash flow should be estimated under each scenario and, if appropriate, probabilities should be attached to each of the scenarios.

To illustrate how scenarios-based valuation should be used when scenarios are built around carbon (and maybe other factors), we assume that we want to value an electricity utility. The valuation is in real terms, which is equivalent to a case with the expected inflation equal to zero, and we assume a cost of capital insensitive of the various scenarios equal to 5 percent.

The company currently sells 1 million MWh at a price of $100 per MWh. The costs for the company (excluding carbon costs) are equal to $30 per MWh, while the carbon costs are the factor scenarios are going to be built around. For sake of simplicity, we assume that EBITDA is an accurate estimate of the cash flows to firm, being the amount of investments exactly equal to the yearly depreciation (the input is presented in Exhibit 4).

The company is unable to pass any increase of costs to its customers. As a consequence, given also the absence of inflation, the price per MWh is expected to remain $100 in future.

Out of the possible factors around which it would be informative to build scenarios, in this case two are picked. One is the carbon cost/price, the other the expected growth (in real terms) for the company.

Exhibit 4. Cash Flow Estimate

Current Cash Flow		
Revenues per MWh ($)		100
MWh sold	1,000,000	
Total revenues ($)	100,000,000	
Costs per MWh ex. carbon ($)		30
Costs except carbon ($)	30,000,000	
Carbon costs per MWh ($)		34
Carbon costs ($)		34000000
Cash flow ($)	36,000,000.00	

As for the carbon cost (per MWh), $34 is assumed as the most likely (moderate) scenario two other scenarios are deemed worthy of consideration:

- An optimistic scenario with carbon price at $15;

- A pessimistic scenario with carbon price at $60.

For the real economic growth, while the historical average rate of 3% per year is assumed as the most likely, two alternative scenarios are considered as well:

- An optimistic scenario with a growth of 4.5% per year;
- A pessimistic scenario with a growth of 1.5% per year.

By using the assumptions discussed before and the input in Exhibit 17.4, we obtain nine cash flow estimates (shown in Exhibit 17.5) depending on the possible combinations of the three GDP growth rates and of the three Carbon prices.

Exhibit 5: Cash Flow Estimates Under Scenarios

	Low Carbon price (15$)	**Moderate Carbon price (34$)**	**High Carbon price (60$)**
High (real) economy growth (4.5%)	$57.48 million	$37.62 million	$10.45 million
Average (real) economy growth (3%)	$56.65 million	$37.08 million	$10.30 million
Low (real) economy growth (1.5%)	$55.83 million	$36.54 million	$36.54 million

The value of the company can be computed under each scenario by discounting the estimated cash flows.

The further step consists of estimating the probability associated with each scenario, as shown in Exhibit 6.

Exhibit 6: Probability of each Scenario

	Low Carbon price (15$)	**Moderate Carbon price (34$)**	**High Carbon price (60$)**	***Sum***
High (real) economy growth (4.5%)	5%	5%	10%	***20%***
Average (real) economy growth (3%)	10%	35%	10%	***55%***
Low (real) economy growth (1.5%)	5%	10%	10%	***25%***
Sum	***20%***	***50%***	***30%***	***100%***

Each cell of the table in Exhibit 6 reports the joint probability of a certain combination of the carbon price and economy growth scenarios. For example, the probability of having a carbon price equal to 60$ and a high growth rate of the economy is equal to 10%.

The last step of the valuation scenarios-based is the multiplication of the valuation of the company under each cash flow scenario times the probability associated to that specific cash flow estimate. By computing the sum of all the products of cash flows by their probability, we finally obtain the expected value which is the scenarios-based company valuation.

6. STOCHASTIC SIMULATIONS-BASED VALUATION

The estimation of company/asset valuation through deterministic DFC model assumes highly predictable cash flows and a discount rate which incorporate idiosyncratic and systemic risks. As described in the previous section, multifactor CAPM can be applied to incorporate environmental risks whenever such risks are priced throughout financial products. But multifactor CAPM has several drawbacks: many environmental risks are not traded through financial products (i.e. water scarcity, warming trend), markets of environmental financial products such as carbon futures are illiquid, highly influenced by evolution of regulation and characterized by relative short time series. Moreover, the impact of environmental risks at company level are typically company specific. For instance, the consequence of variation of carbon price on company results is directly linked to the energy intensity of industrial processes, to the specific technologies applied in the consumption/production of energy. In a framework of high environmental risks, the conventional risk-adjusted cash flow approach has some relevant limitations and that it is not able to realistically reproduce the uncertainty of the real world that it tries to describe.

Given the high degree of uncertainty related to the impact of environmental risks at company and environment level, company valuation with a standard deterministic DCF model can determine biased results. If key variables in the DCF model such as discount rate, free cash flow components, growth rate cannot be represented as deterministic inputs, the Monte Carlo method is a valid support to overcome these difficulties, as it is an informative way to present and assess a firm's uncertain and risky environment. The approach indeed can be applied effectively to the modeling of stochastic processes and to the simulation of future uncertain scenarios on the basis of a given statistical distribution.

6.1 The Monte Carlo Approach to Equity Valuation

In very broad terms a Monte Carlo technique is a simulation of designing a model of system and then conducting numerical experiments to obtain a statistical understanding of the system behavior. This requires that certain variables in the model be assign random values associated with certain probability distributions. This sampling from various probability distributions requires the use of random numbers to create a stochastic simulation of the system behavior. The stochastic simulation of system behavior is called a Monte Carlo simulation.

Monte Carlo simulations are used to construct theories for observed behavior of complicated systems, predict future behavior of a system, and study effects on final results based upon input and parameter changes within a system. The stochastic simulation is a way of experimenting with a system to find ways to improve or better understand the system behavior.

Monte Carlo methods use the computer together with the generation of random numbers and mathematical models to generate statistical results that can be used to simulate and experiment with the behavior of various business, engineering and scientific systems. Some examples of application areas where Monte Carlo modeling and testing have been used are: the simulation and study of specific business management practices, modeling economic conditions, war games, wind tunnel testing of aircraft, operations research, information processing, advertising.

Monte Carlo simulations usually employ the application of random numbers which are distributed over the interval [0,1]. These distributed random numbers are used for the generation of stochastic variables from various probability distributions. These stochastic variables can then be used to approximate the behavior of important system variables. In this way one can generate sampling experiments associated with the modeling of system behavior.

Monte Carlo simulation can be utilized to build a probability distribution function of company value; several steps need to be sequentially applied to properly build a valuation model enhanced via a Monte Carlo simulation.

In *Step 1,* a conventional DCF model (or another fundamental valuation model that might be preferred on the basis of the investment valued) is set up. In this phase, precise mathematical relations are designed to link the value drivers of a firm (the inputs of the model) to the value measure (the output of the model).

In *Step 2,* the risk variables, which are all those value drivers that have a much deeper influence on the outcome of the valuation model (i.e., a higher impact on value), need to be identified. The identification of the most relevant value drivers is crucial to increase the clearness of the model. As a matter of fact, we will substitute the single point estimator with more complex probability distributions only for these selected value drivers, and not for all of them. The selection of the most critical value drivers is carried out through both a qualitative and a quantitative evaluation. Qualitatively, we will look at certain features of the variables under consideration, such as their past patterns and their future expected variability; quantitatively, we will use specific tools to estimate the impact of a change in each variable on the final valuation output of the model.

In *Step 3,* the probability distributions of the selected risk variables are investigated and defined. In this critical step, therefore, a full range of the possible values potentially taken by each of the risk variables is defined and probability weights are allocated to this range of values. The probability distribution of a risk variable is typically derived considering the frequency distribution of the available historical data. Nevertheless, an obvious prerequisite to apply this methodology is the existence and availability of past data on the identified value driver and the assumption that future behavior of value driver will follow the historical pattern. Based on the characteristics of value driver two possible approaches can be followed: the straight identification of a theoretically known statistical distribution of value driver, the identification of specific pattern of value driver and the simulation of the realization of this pattern through a Monte Carlo simulation. In the first case statistical analysis of past data helps to identify to theoretical distribution that better fit the available data and the parameters that describe the distribution (for instance mean and standard deviation for Gaussian distribution). In the second case the analysis of historical data, and in particular the analysis of time series allows to build a specific pattern of the variable. In fact for same variables (prices, but also demand) we cannot assume independence of the value driver realizations along time horizon. Typically prices and interest rates show specific pattern (e.g. mean reversion, volatility clustering) along observed time horizon and the simulation of these patterns through simple correlations can bias the result of the valuation.

6.2 Price pattern generation

Environmental risks are frequently related to the behavior of energy markets: many researches find relation between carbon price, gas and coal and electricity prices. To evaluate the impact of environmental risks through a stochastic model, the inclusion of a standard statistical distribution of stochastic variable could be insufficient to capture the possible future behavior of environmental risks in which company could incur. A more sophisticated way to utilize a Monte Carlo simulation to build a stochastic valuation model is to draw a model to simulate the spot price pattern of our stochastic variable. We focus on spot price model due to the characteristics of energy industry and environmental risks: the limited numbers of financial, products, both spot and forward, related to environmental risks and the limited liquidity of forward curves far deliveries limit the possibility to utilize forward data as non-biased expectation of future spot price.

Environmental risks are frequently related to energy industry. Energy and commodity prices are somewhat different than other prices set in financial markets. Due to short term supply and demand imbalances, prices for short-term delivery of the commodity - or spot prices tend to exhibit significantly different behavior than prices for delivery of the commodity in the future, or forward prices.

There are several important properties associated with the volatility of spot energy prices, principal among them being:

- Seasonal Effects. Weather and climate changes determines recurrent variations in supply and demand with direct impact on energy prices pattern characterized by strong seasonal patterns.
- Mean-Reversion. Prices tend to fluctuate around and drift over time to values determined by the cost of production and the level of demand.
- Occasional Price Spikes. Large changes in price attributed to major shocks (e.g. generation/transmission outages, unanticipated political events ...).

Each of the processes presents set of advantages and disadvantages. The more simple ones may provide a simplistic view of reality, but allow us to characterize the multiple sources of risk in a very limited number of parameters, and therefore are easier to interpret and calibrate from market prices. The more complex processes provide the ability to incorporate more information about the possible price changes, but at the cost of having to estimate many more parameters and increasing the probability of model errors.

7. DECISION TREE ANALYSIS AND REAL OPTIONS

One of the major criticism to DCF approach to valuation is that the outcome of the model is unaffected by future decision of the management, ignoring the value of flexibility. Typically, management reacts to deviations from expected scenario generated by internal or external factors. Management flexibility allow to maximize the returns/minimize the losses based on the most updated set of information. The flexibility can be seen as a potential incremental value and can only be determined applying a (real) option pricing or a decision tree approach. In the context of climate risks, the impact of variation of environmental costs/revenues for companies, the impact of extreme risks due to climate change can be evaluated drawing scenario where management reacts to the evolution of the external context or through a model able to price these factors.

7.1 Valuing with decision tree analysis

Decision tree analysis (DTA) is extensively used in the decision analysis science and, thanks to its flexibility, is considered effective tools in valuation of assets and companies that involve contingent decisions. A decision tree shows strategic road map, and through this map it is possible to monitor each company decision, variation of market conditions, changing in regulatory framework and modelling them as a specific decision node. DTA is also called decision flow network and decision diagram because, typically, asset/company to have value has to pass through a series of "tests", with failure at any point potentially translating into a complete loss of value.

In DTA, for each decision point (or node), is possible to determine outcomes (for instance success or failure), the probability and the payoff of the outcomes. Decision trees enable the practitioners to "recognize the interdependencies of decisions made at different stages" of the project investment (Trigeorgis, 1996). It reflects synergies that NPV misses. What's more, decision trees calculate the "maximum expected NPV rather than just the expected NPV" based on a serial of optimum circumstances (Galli &Armstrong, 1999).

In decision tree analysis the discount rate, probabilities, and the expected value of each alternative are determined based on practitioners' knowledge of the investment. Decision trees enable the practitioners to "recognize the interdependencies of decisions made at different stages" of the project investment (Trigeorgis, 1996).

DTA analysis can be divided in several fundamental steps:

- Step 1. Dividing the analysis into risk phases. The key to developing a decision tree is defining the phases of risks that company/project will be exposed to in the future. Typically, companies face market and regulatory risks;
- Step 2. Estimation of the probabilities of the outcome: once the outcomes at each phase

are defined, the probabilities of the outcomes have to be computed. In addition to the requirement that the probabilities across outcomes have to sum up to one, the analyst will also have to consider whether the probabilities of outcomes in one phase can be affected by outcomes in earlier phases. In DTA the probabilities are typically defined based on analyst experience and knowledge of the industry;

- Step 3. Definition of decision points: embedded in the decision tree will be decision points where you will get to determine, based upon observing the outcomes at earlier stages, and expectations of what will occur in the future, what your best course of action will be;
- Step 4: cash flows/value at end nodes computation: estimating what the final cash flow and value outcomes will be at each end node;
- Step 5: Folding back the tree: the last step in a decision tree analysis is termed "folding back' the tree, where the expected values are computed, working backwards through the tree. If the node is a chance node, the expected value is computed as the probability weighted average of all of the possible outcomes. If it is a decision node, the expected value is computed for each branch, and the highest value is chosen (as the optimal decision). The process culminates in an expected value for the asset or investment today.

In spite of its superior features over NPV and real option pricing, decision trees have their fundamental discrepancies that are hard to be fixed. First, "for complex investments, the more the steps are added to the decision tree, the more difficult it is to apply decision trees in real asset investments" (Baker & Pound, 1964). Decision tree analysis can easily become unmanageable, as the number of different alternatives through the tree to be evaluated expands geometrically with the number of decisions, outcome variables, or states considered for each variable (Trigeorgis, 1996). Second, the payoff of variables in decision trees are hard to estimate. Further, "market demand does not have just 'high' or 'low' values; there are quite a few intermediate values." (Trigeorgis, 1996). At last, "discount rate in decision tree is a big problem, since, among several reasons, it cannot be constant across the tree." (Trigeorgis, 1996). The optimization that occurs at decision nodes changes the expected future cash flows, altering the risk profile of the project then the risk adjusted return for the project without any flexibility cannot be utilized to discount cash flaws under flexible environment. To simplify, some decision trees apply risk free rate according to risk neutral approach in financial models. However, this approach is flawed as pointed out by Trigeorgis (1996). “It is inconsistent to build the tree forward using the actual probabilities and expected rate of return but ... move backward discounting at the risk-free rate (without using certainty-equivalent or risk-neutral probabilities).”

7.2 Application of decision tree analysis to climate risks

DTA can be utilized to evaluate the impact of climate changes on asset and company valuation. One of the possible application is related to the impact climate change on investment performances. Variation of climate conditions (temperature, rainfalls, level of water reservoir) can dramatically impact on companies’ results in sectors such as energy production, agriculture, transports. DTA can be utilized to model possible evolution over times of the climate conditions. For instance, is possible to draw subsequent evolution of rainfalls over years assuming a binomial tree: in each node we can assume increasing or reduction of rainfalls with respect to previous years. Corresponding to a specific levels of rainfalls is then possible to compute the cash flow generated by the target company or asset (for instance hydroelectric power plant production, agricultural production) incorporating the possibility to dismantle the asset or production activity in the case of adverse scenarios. Through a decision tree model is possible to draw different rainfall scenarios based on the assumption of impact of climate change evolution and policies on the uncertain variable. One of the key assumption in a DTA approach is the definition of probability associate at each branch, different approach can be utilized:

- Analysis of the historical probability of occurrence. The rainfall variation over year can be determined analyzing the evolution of the variable in the last 20-50 years determining the probability of subsequent increasing or decreasing;
- Definition of the probability based on practitioner’s expertise. For instance the probability of a certain policy scenario is a variable under a huge cone of uncertainty and the probability of occurrence can be drawn only based on personal expertise and experience;
- Third alternative is related to probability based of specific pattern of the uncertain variable. For instance, in a binominal trees where the uncertain variable moves according to a Geometric Brownian motion is possible to define the probability only based on the volatility of the uncertain variable and the discount rate.

7.3 The real option valuation framework

Real option modeling is a multi-disciplinary subject. It has been applied in almost every industry during past decade. Mitchell and Hamilton first proposed technology real options in 1988: "the firm purchases an R&D option by investing on new technology research and development." Real option valuation, compared with NPV, enabled the firms to incorporate market flexibilities. With the real asset investments being divided into phases the risk of the whole project is limited to the investments incurred. Firms accumulate market and technology knowledge through the process of investments at each stage and benefit from modifying their investments and technology strategy with learning. Many researchers suggested integration of Real Options and NPV for project valuation. Trigeorgis (1993c) even quantified this approach by:

NPV of the real asset investment=NPV of estimated cash flows + option values.

Calculation of real option value of assets or company basically starts with the computation of the underlying asset value by a traditional DCF method using a risk adjusted discount rate. Then, it adds the investment cost (strike price) and the value created by the uncertainty of the asset value and flexibility due to contingent decision.

Types of real option can almost be endless as the flexibility for managers to make different decisions in the process of their investment project is numerous. Real option can be classified as simple standalone option for example an option to renew equipment in a factory. or compound option where many different decisions need to be made over the life of the project or many projects which depend on each other where the payoff of one option is another option. Most common real option are:

- Option to defer: enables a company to defer its investment decision for some period of time or until more information about the project is available
- Option to expand: enables a company to make changes or expand their current production
- Option to contract: enables a company to reduce the scale of its production if market conditions turn out to be unfavorable
- Option to abandon: if a project turns out to be unsuccessful it can have value for a

company to have the option to abandon it and in some cases sell it for its salvage value instead of keeping it going and experiencing substantial loss

- Option to switch: in uncertain markets where product and material prices fluctuate frequently the option to switch between either input materials or output products can be very valuable.

Real option solutions are based on models developed for pricing financial options. Several methods are available to calculate option value and within each method there are many computational techniques (eg partial differential equations, Monte Carlo simulations). Valuation models based on real options model uncertainty by assuming an analytically tractable stochastic process. Yet, traditional real options solution approaches typically rely on models that are highly stylized closed-form formulations based on the assumption that the value of the real asset over time can be modeled as a stochastic process (e.g. McDonald and Siegel, 1986; Paddock et al. 1988; Capozza and Li, 1994) or they are based on the use of a discrete dynamic programming approximation of a stochastic process (e.g. Trigeorgis, 1991; Trigeorgis, 1993; Kogut and Kulatilaka, 1994). Neither of these approaches can generally handle complex projects that include rework, learning curves or other stochastic processes embedded within nonlinear feedback structures characterized by delays (Forrester, 1961; Forrester, 1975). Application of real option valuation method to practical problems have been limited by the mathematical complexity of the approach and by the restrictive assumptions required. Although real options have advantage over NPV in modeling real asset investment flexibilities, real option modeling assumptions are problematic in calculation, since real options have been valued with the framework of financial option modeling following the complete market assumption and Geometric Brownian Motion distribution of the underlying assets. Real option models must fail once the conditions are violated and especially for specific assets is extremely difficult to justify the assumption of complete market or a price behavior in accordance with GBM.

8. CONCLUSION

Climate risks, along with the impact of carbon pricing, carries direct and indirect exposure for companies. Over the medium- or long-term, such risks can materialize and damage both profitability and asset valuations in unexpected ways. Companies and investors that fail to take account of these risks may suffer significant stress and have little flexibility to manage their exposure. The practice of corporate valuation is recognizing this situation by expanding its toolkit to include techniques and approaches better suited to capture the nature and potential severity of climate risks.

Within the DCF framework, a possible approach to factor climate risks consists of adopting a multifactor cost of capital pricing model that explicitly includes a carbon premium and a carbon beta. Such approach is heavily dependent on the availability of data and should be used especially by non- (optimally) diversified investors.

As most predictions and analysis about climate change are in the form of scenarios, a scenario-based DCF valuation has the advantage of using consistent and easily available data. This way we estimate not only an expected value but we also get a sense of the range of possible outcomes for corporate value, across optimistic and pessimistic scenarios.

Simulation-based DCF valuations provide the most complete assessment of risks since they are based upon probability distributions for the critical input (ie carbon price). The probability distribution for climate risks may be difficult to estimate, but the growing data about climate risks are progressively easing such constraint.

Decision trees offer the possibility of modelling expected business behaviors in a sequential way and are helpful in structuring corporate valuations when subsequent events (eg increase in carbon price) can trigger corporate responses (eg switch to a cleaner technology). Similarly, real options valuations allow to model and quantify the bundle of possible strategies a company can pursue as a consequence of climate risks, however the parameters for such valuations are usually difficult to estimate.

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