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Summary

The way in which climate policy and climate risks are currently accounted for in financial and real investment decisions is inadequate. The paper demonstrates weaknesses in methods presently used and proposes an alternative that aims to bridge the duration gap between climate policy modeling and mitigation capital. The core tool is real options analysis combined with an Integrated Assessment Framework designed to capture the complex set of issues linking climate change, climate policy and the economy. The tools are meant for use in both capex decisions by corporations and portfolio decisions by investors. The tools will be a hedge against the risk of mitigation short squeeze occurring because investment is deferred beyond the 5 year or less timeframe of finance.

Keywords: Climate alpha, option value, abatement short squeeze, green transition

JELClassification: G11, G17, G18, Q54

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Climate alpha and the global capital market[1]

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Abstract

The way in which climate policy and climate risks are currently accounted for in financial and real investment decisions is inadequate. The paper demonstrates weaknesses in methods presently used and proposes an alternative that aims to bridge the duration gap between climate policy modeling and mitigation capital. The core tool is real options analysis combined with an Integrated Assessment Framework designed to capture the complex set of issues linking climate change, climate policy and the economy. The tools are meant for use in both capex decisions by corporations and portfolio decisions by investors. The tools will be a hedge against the risk of mitigation short squeeze occurring because investment is deferred beyond the 5 year or less timeframe of finance.

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Introduction

Climate policy actions currently cover about 22% of the global GHG emissions. According to the World Bank, as of 2021, 137 nations and jurisdictions priced carbon in the form of a carbon tax or introduced emissions trading[2]. The carbon price varies from \$1/tCO_2 (Kazakhstan ETS) to about \$140 in Sweden. Decarbonization of the global economy is lagging relative to the stated goal of stabilization of well below the 2^0C goal by the end of this century. Despite additional NDC commitments and the return USA to the Paris agreement, the emissions gap continues to increase[3]. The world may end up short of about 700 Gt of CO2 reductions relative to those required for the 2ºC goal[4]. Carbon pricing will play an important role in the net-zero transition but on its own will not be sufficient to reach the net-zero emissions target. Transition to the net-zero economies will require unprecedented efforts to rebalance the global capital market and fundamental changes in corporate investment strategies. Investments in decarbonization across the economy must ramp up to US\$5-6 trillion by 2030. It constitutes about 25-30% of the global investment pool. From a marginal ESG/SRI type of investment analysis, the climate investment will become part of the mainstream profit-driven investment activity.

In our view, the transition to the net-zero emissions trajectory will not be a smooth transformation of the global and national economies. Accumulated gaps between stated goals and the actual transition will be resolved in the sequential adjustment of climate and environmental policy, followed by multiple shocks to the global and regional economies. Over-accumulation of carbon-intensive capital turns into stranded assets.[5] while lagging investment in low carbon transition results in an abatement short squeeze[6]. One-time loss of resource rent and carbon-intensive

[2] The World Bank "Carbon Pricing Watch 2021".
[3] https://www.unep.org/resources/emissions-gap-report-2021
[4] Estimated based on IEA Nat zero report as a difference between emissions under the net-zero scenario and low international cooperation scenario (https://www.iea.org/reports/net-zero-by-2050)
[5] See: World Bank 2021 and Peszko, G., Van Der Mensbrugghe, D., Golub, A., Ward, J., Marijs, C., Schopp, A., Rogers, J. and Midgley, A., (2020).
[6] A short squeeze occurs when many investors bet on the stock price to go down, but the stock's price shoots up instead. Abatement short squeeze occurs when, in response to a significant correction of climate policy,

capital stock translates into a few percent of GDP losses in carbon-dependent countries.

The magnitude of loss from these trends at the level of individual corporations is much greater than on the country level. The destruction of the carbon-intensive capital stock creates new investment opportunities for capital formation in sectors with high returns on investment, increased labor productivity, etc. But climate policy uncertainties obscure the future value of low carbon and green assets and discourage investment in low carbon and green transition.

These uncertainties create deferral options for new investments aligned with the global decarbonization goals. Therefore understanding deferral behavior is critical to spotting new investment opportunities. But on the flip side, a corporation that starts investing in low carbon and green capital ahead of competitors secures a comparative advantage in the future not only to successively cope with climate policy shocks but to harvest the excessive return on investment in the aftershock environment and expand its market share soon after the climate policy shock. It does so by benefiting from the experience gained in pre-climate policy shock period.

Understanding the option value of the early mover corporations requires a proper valuation of: a) an option to harvest immediate revenues in the aftershock period and b) an option to expand operation and gain market share in a new climate policy environment. Pricing these options is critical to understanding the true value of low carbon and green investment and estimating the first mover's risk premium. Calculating an option value of low carbon and green assets enables an "apple to apple" valuation when "climate value" is expressed in monetary terms. In contrast to non-market ESG indicators, it puts climate in risk-return metrics, clearly expressing the climate value in terms familiar to the entire investment community, not only to climate and environment enthusiasts. It does so by showing how a contribution to the decarbonization of the global economy is essential but not sufficient to reprogram

corporations are forced to reduce emissions in a short period of time competing for a limited supply of carbon allowances, carbon free equipment etc. (for more details see: Golub, et al (2018) and Golub, Lubowski, and Piris-Cabezas,(2020).

from one-third to one half of capital investment into green transition. We call this hidden value of corporations well positioned to benefit from emerging climate policy, climate alpha.

The climate alpha is analog to a well-known indicator to investors of return on active investment strategy applied to securities traded on the stock market.[7] Alpha is a measure of the additional return on an active investment (investment portfolio) relative to the return on an appropriate benchmark passive investment portfolio, market index, etc. Climate alpha investing is an investment in real assets.

Traditional alpha investing consists of digging into the historical data in the hope of detecting market anomalies to find a candidate for alpha investing. However, the climate alpha is about understanding the future. Although there is fast-growing literature on the impact of climate change and climate change policy of corporations, the historical data does not capture the magnitude of the future climate shocks and shocks of climate policy. Therefore, climate alpha is fundamentally a mark to model valuation methodology. This realization poses the question: what models should be applied to detect climate alpha? This paper introduces a new forward-looking valuation methodology and explains the modeling framework needed to conduct the monetary estimates of climate alpha. International banks and corporations have limited expertise in assessing investment based on the future value of low carbon capital using a mark to model valuation approach and real options analysis. Until now, the major investment banks and corporations have treated climate investment primarily as a part of ESG and SRI. Effective emissions weighted price of carbon is about \$5/tCO2, which creates some economic incentives but is insufficient to ramp up global investment. Climate alpha methodology provides state-of-the-art investment decision support and equity valuation. Investment banks could use this new quantitative instrument as well as wealth management companies, corporations, and public investment and development institutions.

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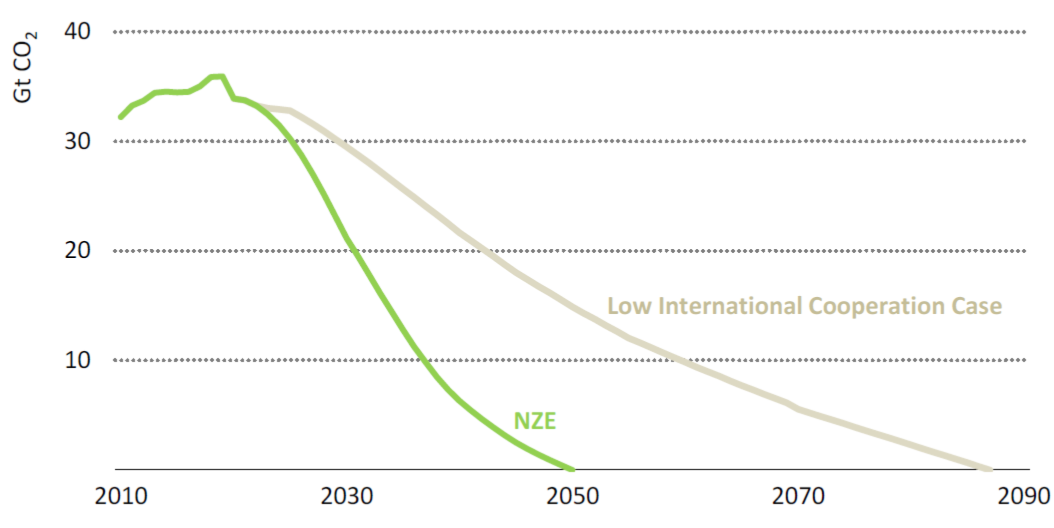
[7] For example, pair trading is one type of alpha investing strategy.

In the next section, we discuss the transformations of the economy and society that create climate alpha. Section 2 outlines the valuation methodology. Section 3 presents a scatch of the modeling framework. Section 4 – discussion and section five – conclusions.

Shifts and shocks

Transition to the net-zero economy and green transition, in general, constitutes an environment that creates climate alpha. Although most of the discussion in this paper is about decarbonization, adaptation is also a necessary process that creates climate alpha. A preemptive strategy to build an economy and society resilient to climate change (or even better anti-fragile) is a vital development priority and, at the same time, promising business. Sometimes decarbonization and adaptation are complementary (energy-efficient and climate-protected buildings). Sometimes, they are not. Keeping in mind that adaptation is another source of climate alpha, we continue focusing on decarbonization.

Figure 1. Global energy-related CO2 emissions in the Net-Zero Emissions (NZE) pathway and the Low International Cooperation Case pathway



Source: IEA 2021[8]

[8] https://www.iea.org/reports/net-zero-by-2050

The NZE curve in Figure 1 above represents the net-zero emissions pathway consistent with limiting the global temperature rise to 1.5 °C. The NZE pathway estimates that the cumulative emissions from the energy sector would amount to 460 GtCO2 and also assumes, alongside corresponding GHG emissions reductions in other sectors.

Unfortunately, the global economy is not on the NZE pathway yet, and the total cumulative emissions are likely to exceed 500 Gt CO2. Considering revised NDCs and national climate policies, the actual emissions and projected emissions trajectory are nowhere near meeting the net zero by 2050. The emissions gap continues to increase[9]. At the same time growing concern about climate change creates building up pressure on politicians to drastically improve climate policy. Any major climatic event may trigger adjustments.

Transition to a net-zero carbon emission economy is neither a linear nor a deterministic process. Right now, there is a significant gap between current emissions and the net-zero trajectory, known in the literature as the emission gap. However, radical policy adjustments in the foreseeable future are inevitable under the pressure of public demand for stricter environmental policy on the one hand and disruptive technological innovations on the other hand. The dynamics are characterized by positive feedback, tipping points, phase transition, and bifurcation. Combination of such processes constitute a major transition event known in the literature as dragon king. In contrast to the black swan, some predictability is possible. However, it requires applications of new instruments for financial analysis.

In our view, such a transition results in an abatement of shorts squeeze (Golub, et al (2018) and Golub, Lubowski, and Piris-Cabezas,(2020)), multiple shocks on the global and regional economies, stranded assets[10]. But as we said before, this destruction of the capital stock creates new investment opportunities for capital

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[9] See UNEP Emissions gap report 2021: https://www.unep.org/resources/emissions-gap-report-2021

[10] World Bank. The Changing Wealth of Nations 2021: Managing Assets for the Future.
Peszko, G., Van Der Mensbrugghe, D., Golub, A., Ward, J., Marijs, C., Schopp, A., Rogers, J. and Midgley, A., 2020. *Diversification and cooperation in a decarbonizing world: climate strategies for fossil fuel-dependent countries*. World Bank Publications.

formation in sectors with a high return on investment, increased labor productivity, etc.

For corporations it is not clear when climate policy may be modified, how radical the strengthening of climate policy would be and how many adjustments will be made over the coming decades during a lifetime of a new investment. Business has to make important investment decisions that would determine committed carbon emissions for the lifetime of deployed capital in context of climate policy uncertainty.

In response to climate policy uncertainty business is likely to exercise a "tween deferral strategy" (see: Golub, Lubowski, and Piris-Cabezas, (2020)), that combines two components:

- Deferring investment into carbon intensive assets (new construction or major modernization of existing ones);
- Delay investment into low carbon and energy efficient technology unless these investment yields an immediate return competitive with other investment opportunities;

The first strategic response to climate policy uncertainty reflects stranded assets. Business does not discount the possibility of climate policy in the nearest future that may significantly reduce return on carbon intensive capital. Fossil fuel-based technologies are mature and there is not much headroom for some efficiency improvements to compensate for the losses associated with cost of carbon. Many corporations who are participants of the Carbon Disclosure Project (CDP) use an internal carbon pricing. It helps them to avoid some risky investment into carbon intensive technologies.

The second strategic response is driven by concern that long delay in climate policy implementation may reduce the return on low carbon technologies below a "comfortable level" and reduce equity value of a corporation beyond an acceptable level. These corporations are inclined wait until at least some climate policy uncertainty is resolved and so they exercise a deferral option on low carbon technologies. Even participants of CDP that use an internal carbon price to justify rejection of a carbon intensive project do not use the carbon price to decide on accepting a low carbon project.

In both cases corporations preserve as much flexibility as it possible and waiting for a new information that may reduce a deferral value on either option.

All corporations are exposed to climate policy uncertainty in a more or less similar way. Therefore, most of them are building up short positions on carbon abatement. Even partial resolution of climate policy uncertainty may spark a synchronized surge of demand on carbon allowances or carbon abatement technologies. Since most of corporations are short on abatement, there is no way to quickly close the gap.

Some corporations have plans on how to deploy low carbon technology and reduce exposure to climate policy when policy is introduced. R&D creates a call option on new technology. However, deployment of new technologies requires time and in any case, corporations would be exposed to some transition cost.

Introduction of even a relatively modest price on carbon ($20-50/tCO2) will trigger a massive capital adjustment across the global economy in all sectors directly or indirectly exposed to the new climate policy environment.

Valuation: the curse of terminal value

The climate change risks and risks related to emerging climate policy have come to the attention of corporations and investors only in the last decade.[11]. Cevik and Miryugin (2022)[12] conduct an extensive literature review and original econometric analysis providing solid evidence that climate change and extreme weather events have significant negative macroeconomic consequences. Extending this analysis to a corporate level, the authors show that exposure and vulnerability to climate change is strongly associated with a higher cost of capital (cost of borrowing) and lower levels

[11] Faccini, R., Matin, R. and Skiadopoulos, G., 2021. *Are climate change risks priced in the us stock market?* (No. 169). Danmarks Nationalbank Working Papers. See also: Pástor, L., Stambaugh, R.F. and Taylor, L.A., 2021. Sustainable investing in equilibrium. *Journal of Financial Economics*, *142*(2), pp.550-571.

[12] Cevik, Serhan and Miryugin, Fedor, Rogue Waves: Climate Change and Firm Performance (May 2022). IMF Working Paper No. 2022/102, Available at SSRN: https://ssrn.com/abstract=4129567.

of productivity and return on investment. Fernando, Liu, and McKibbin (2021) examined sensitivity of stock indices to the global macroeconomic consequences of chronic climate change and extreme climate shocks as well as the economic effects of transition risk of exposure to climate policies. The authors confirmed the results of other studies regarding the economic costs of climate change and the transition risk of climate policy. However, most of the studies were focused on historical data, and only some took into account future transitions. Forward-looking analysis usually focuses on stranded assets and the future risk if climate change itself on the present market value of global financial assets Dietz, Bowen, Dixon, and Gradwell (2016). The forward-looking analysis of the positive effect of climate policy and asset diversification on long-term economic growth was established in a World Bank Group study[13] (). But this study focused on countrywide positive effects and not on corporations. Climate shocks and climate policy shocks have long-term consequences for the economy and for individual corporations. Over time countries and corporations adapt to climate shocks and shocks of climate policy, but the transition period may take time. During a significant period, some countries and corporations will be winners and some losers.

In a deterministic case, the value of an asset could be obtained by calculating cash flows attributed to the underlying asset and its time distribution and discounting this cash flow with an appropriate rate for cost of capital rate (Copeland et al. 2007; Massari et al. 2016 p.5) or the weighted average cost of capital. Asset valuation plays a vital role in finance for investment analysis of a corporation, IPO, merger, and acquisition, to support the decision to buy or sell a particular stock, etc. There are two dominating approaches for asset valuation:

- Discounted cash flow (DCF) and
- Multiples valuation method;

[13] Peszko, G., Van Der Mensbrugghe, D., Golub, A., Ward, J., Marijs, C., Schopp, A., Rogers, J. and Midgley, A., 2020, op. cit.

Application of discounted cash flow requires forecasting of future revenues and cost. At the same time, the multiples valuation method relies on currently observed indicators like the enterprise value per earnings, the price per earnings ratio, the price per book value, etc. The multiples valuation method derives the value of the underlying asset from the value of similar assets. This method is popular in quantitative finance since it allows the application of well-established technical instruments like regression analysis (Taylor 2011), factor models (Chincarini 2006), etc. However, the multiples valuation relies on two critical assumptions: (i) The company's value is proportional to selected indicators; and (ii) The growth rate of cash flow and the risk level is constant.

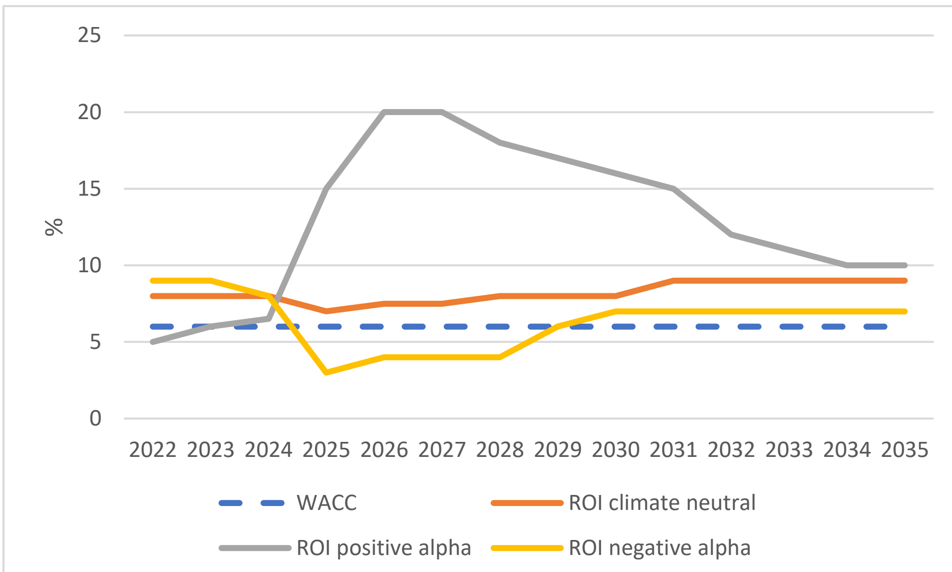
These assumptions are excessively restrictive when we account for structural transformations of the global and national economies that may significantly change the value of underlying assets.

On the contrary, DCF focuses on future cash flows and the opportunity cost of capital. According to Massari et al. (2016), "…financial valuation methods produce reliable estimates if and only if the specific in-depth business analysis is performed" (p.228). The major problem for company valuation is a relatively short time horizon of a business plan. A standard plan horizon is usually 2-5 years. Valuations based on this horizon "…only explain a small portion of total firm's value. In fact, the bulk of the value is a function of the longer-term results obtained beyond the standard plan horizon" (Massari et al. 2016 p.228). Copeland et al. (2000) also underscore the importance of a longer-term planning horizon for proper assets valuation. Stress-testing a company's future value requires consideration of several external and internal factors that would determine net cash flow during the lifetime of corresponding assets. For example, in preparing IPO or assessing M&A, an investment bank would use several quantitative tools to predict future returns and quantify risks.

Commonly used Wall Street valuation techniques are based on stationarity assumptions. The so-called multiples method or price per earnings extrapolates current revenues to perpetuity. The price-to-earnings-growth valuation method extrapolates the observed trend and could be even more misleading than a method based on the capitalization of current revenues. When dealing with nonstationary process, the most valuable information is hidden in the terminal value. Figure 2 illustrates the change in the valuation of carbon-dependent assets. A naive interpretation of the terminal value may seriously mislead the valuation.

Figure 2 illustrates how the application of these methods may mislead valuation.

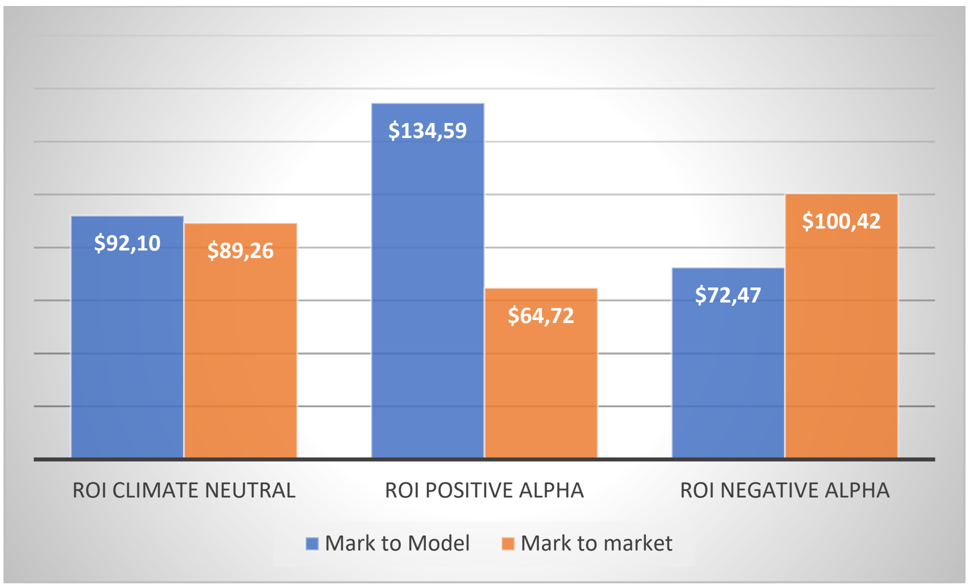
Figure 2: Return on investment differently affected by emerging climate policy



Consider three divergent investment options: first take an asset with relatively low current return on investment but positively exposed to future climate policy—any tightening of the climate policy results in a significant ROI increase. In figure 2, its current and future returns are presented with "ROI positive alpha" (gray line). The current return is even below WACC, marked with a dashed line. Without considering the future changes in ROI, this investment option will be rejected. On the contrary, carbon-intensive investments yield a current return (orange line in figure 1 called "ROI negative alpha") above WACC and above the return on investment not exposed to climate policy (red line called "ROI climate neutral).

Mark to market valuation using multiples assigned the highest value to the carbon-intensive investment (say \$100 billion in figure 3)[14]. Investments with positive exposure to climate policy have the lowest value at \$65 billion. It is below the return on investment that yields WACC. Buying high-quality corporate bond with a 6% coupon (i.g. WACC), the investor gets higher or about the same value as the asset. Or at least it is what the mark to market approach says: a valuation based on observed information that reflects the current state of the market and historical data.

Figure 3: mark to market vs. mark to model valuation



A forward-looking valuation with a short-term horizon (say three years) would not make much difference. The impact of climate policy on ROI is hidden in terminal value, in the revenues beyond a short-term planning horizon. Proper accounting of the future changes in return on investment flips a choice in favor of assets with positive exposure to climate policy.

Accounting for low carbon transition is an extension of the well-known discounted cash flow calculation methodology illustrated in figure 3. DCF, or discounted cash flow, is a foundational metric in capital market transactions. It sets enterprise value as the present value of future free cash flows discounted at a risk-adjusted weighted

[14] Calculated as the NPV of return with a discount rate equal to WACC.

average cost of capital. DCF requires access to reasonable medium-term financial projections and a degree of corporate finance acumen - both common among capital markets agents.

Both valuation methods produce about the same value of climate-neutral investment ($89-92 billion). Considering these as a benchmark, the climate alpha is about $43 billion according to the mark to model valuation. The deterministic framework is good as an illustration for the methodology. In real life (assuming we convinced an investor to use the mark-to-model valuation methodology), we need to explicitly account for uncertainty.

A typical criticism of the forward-looking approach is an appeal to a limited ability to predict the future. Scenario analysis partially solves this problem. The WBG 2020 and WBG 2021 provide examples of how to use scenario analysis to valuate fossil fuel reserves and carbon-dependent assets. Scenario analysis represents the view of the decision-maker on the future. This view could be based on a solid analysis of the de-carbonization transition, intuitions, interpretations etc. The bottom line – forward-looking analysis allows formalize any available knowledge and apply a formal valuation method. In that interpretation, the forward-looking valuation is a just technique to organize knowledge about the future in a manageable way. Models help to organize that knowledge, and put together in integrated frameworks all assumptions and anticipations. The model is essential to revile direct and indirect connections among different parameters that determine future value. It is a mistake to think that mark-to-market valuation of simple extrapolation based on historical data has more foundation than the forward-looking analysis that may involve speculative assumptions.

The mark to market and simple extrapolation is also a model with embedded assumptions about the future—just the simplest one. The model assumes the market is near equilibrium and /or on a stationary growth trajectory. Needless to say, a green transition is a nonstationary process that includes both shocks and shifts. The stationarity hypothesis doesn't hold. And a conventional warning: past performance is not a good predictor of the future – all investors are familiar with this disclosure –

is more relevant than ever. Why do portfolio managers still prefer this method? In our view – to avoid the risk of being blamed for a wrong investment decision. If a manager follows the common practice, it is more difficult to blame than in case an investor uses a proprietary forward-looking model.

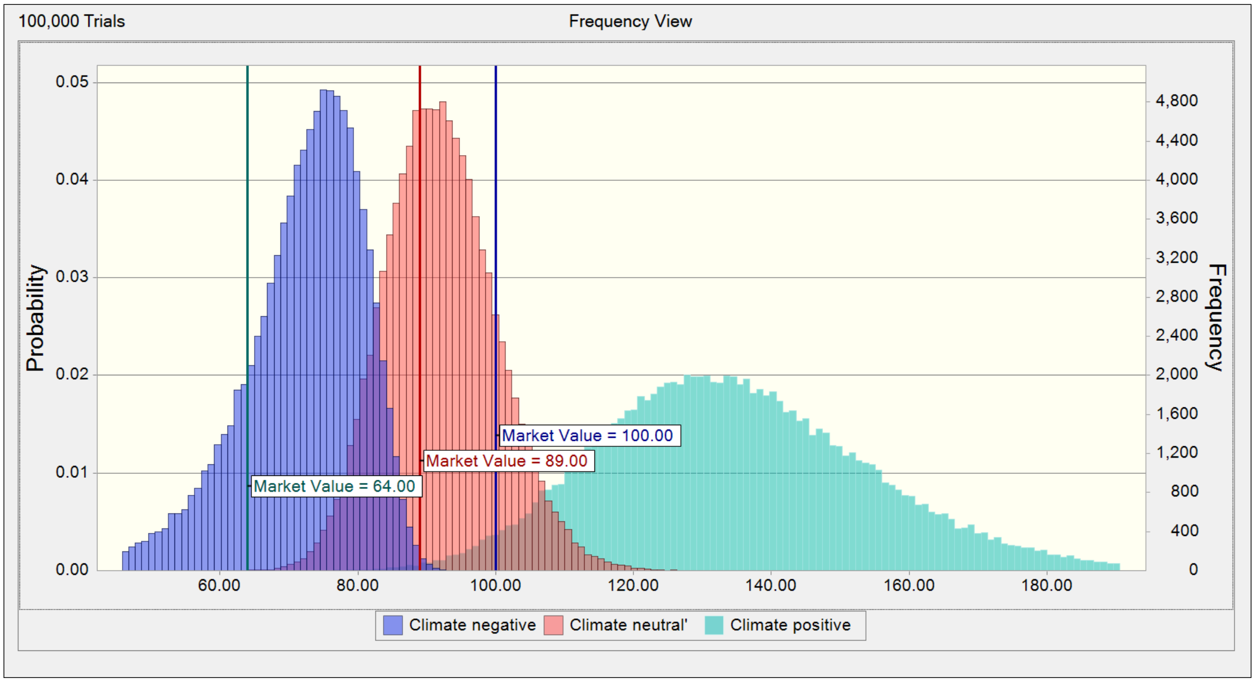
Theory of alpha investing

Climate alpha is a future abnormal return on capital invested in real assets. In contrast, the traditional interpretation of alpha is an abnormal return in equity. In both cases, an investor is chasing the future abnormal return. The difference is in the time horizon. Investing in the stock market, an investor usually plans for a relatively short period of holding. Investing in climate alpha may require sticking to the investment for a decade. That makes climate alpha investing resemble value investing. Since the Climate alpha is a value of uncertain opportunities by its nature, it is an option value.

Permanent changes of the global economy are taking place as a transition to a new equilibrium takes place under a new modeling paradigm and set of instruments. The goal is modeling capital rebalancing, which requires explicit representation of vintage capital.

Given the uncertain nature of return on investment, a probabilistic analysis should be conducted. Figure 4 illustrates output of the probabilistic model. The vertical lines show the current market value of assets. PDFs present its future value computed using the probabilistic mark to model analysis.

Figure 4: Forward-looking probabilistic analysis of return on investment



The climate alpha is calculated as a value of the call option on the asset with changes in the future and uncertain return. In this example, at the money call option value of assets positively exposed to climate alpha is about $70B, and the climate-neutral asset's option value is $4.7B. In contrast, negative climate assets have an option value of around zero. The option value is calculated using the current market value of assets computed as the mark to market value as a strike price. Instead of using historical volatility, we use computed the distribution of the future return.

Now consider three corporations: one corporation holds carbon-intensive assets, the second holds climate-neutral assets, and the third holds assets with positive exposure to climate alpha. Each corporation has one billion outstanding shares. The current share price is $100, $89, and $65, respectively. According to our numerical example, a portfolio with one share of each corporation has an option value of $46. The option value of this portfolio is the sum of call options values for climate-positive and climate-neutral corporations minus the value of the put option, about $29 per share of a corporation negatively exposed to climate alpha. The acquisition cost is $283 (purchase price for three shares and put option on negative climate corporation[15]) while forward value computed based on mark to model valuation is $329.

This example of portfolio valuation demonstrates the differences between the two valuation methodologies. Further, it shows how the real options methodology is applied in a mark to model valuation. Ignoring the option value of the portfolio will result in over-investment in carbon-dependent assets. Eventually, such a portfolio loses a significant fraction of its value. On the other hand, clear communication of an option value of a portfolio containing low carbon assets helps an investor cope with below-market ROI for the period before the climate policy triggers appreciation of the carbon-free assets. So why hold carbon-intensive assets at all? Carbon-intensive holdings generate current returns reducing the opportunity cost of holding carbon-free assets that currently underperform relative to the market. With unclear timing for tightening climate policy, the carbon-intensive assets recreate a hedging function.

Modeling framework

The proposed methodology explicitly considers uncertainty and addresses it using probabilistic models along with a real option valuation methodology to detect climate alpha. Computing the probability distribution of DCF taking into account climate alpha (we call it DCF-c-α) requires the computation of different parameters, including probability distribution function (PDF) of the carbon price, cost of capital specific for the corporation in question, shifts in market share, and prices of other goods and services affected by carbon price, etc. The Carbon-Alpha model is a sophisticated distributed cost of carbon modeling framework. It is an integration of climate, CGE, bottom-up PE, and DCF models makes this framework superior to any existing modeling approaches.

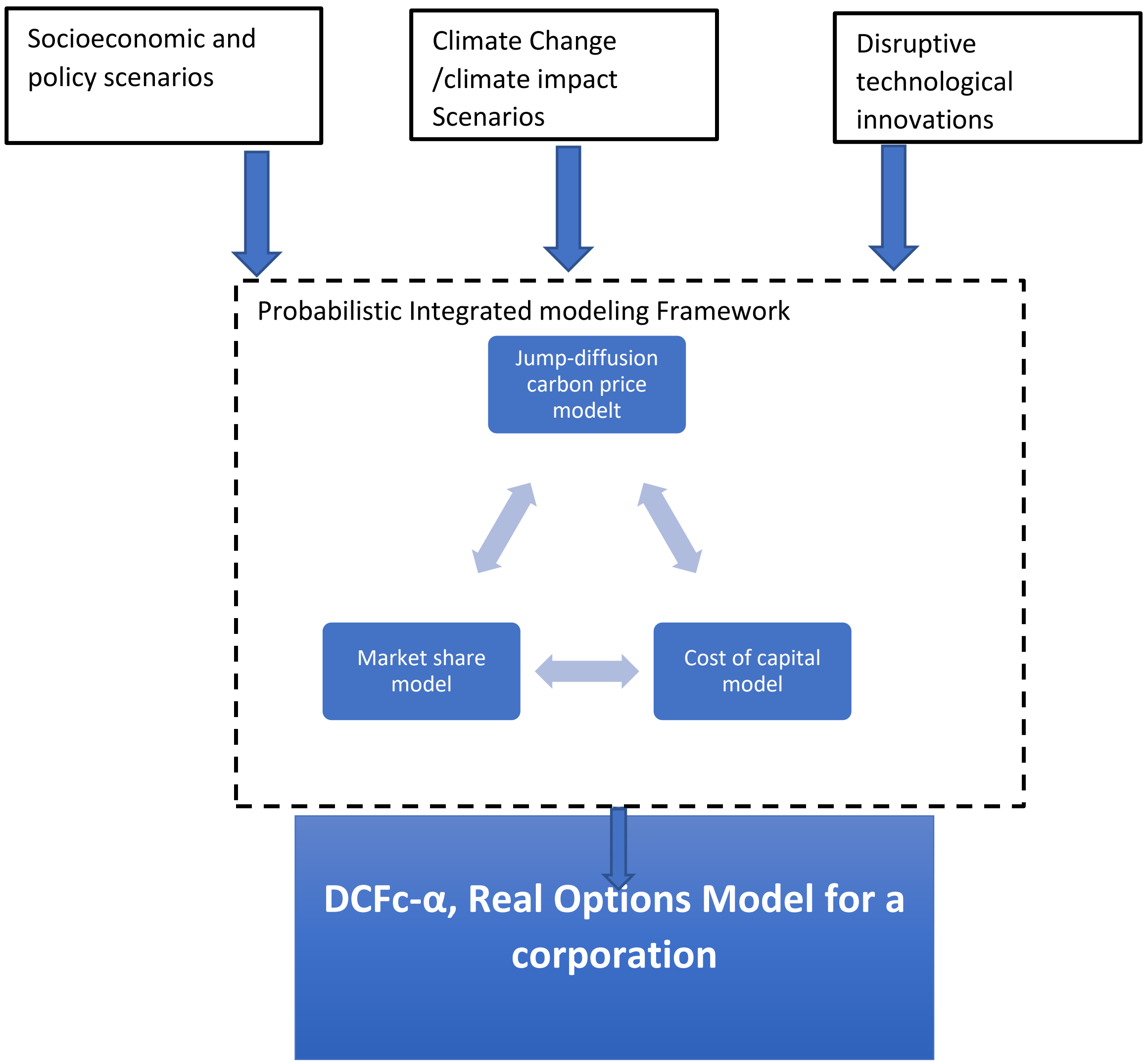
[15] The actual market price of the put option could be lower if the option is priced based on historical volatility and beta.

Figure 5 illustrates the architecture of such a modelling framework. The socioeconomic environment, climate change, and disruptive technological innovations constitute inputs for an integrated assessment modeling framework. Uncertainty is an inherent characteristic of external factors mentioned above; thus, the integrated assessment framework is designed as a probabilistic model. This model computes probability distributions of critical parameters needed to calculate an option value of environment-improving investments.

The global and regional climate policy module connects impacts of external shocks and "translates" it into the probability distribution of the shadow carbon price. The climate policy module generates carbon prices by taking into account different environmental policy scenarios, including national climate policies, border adjustment taxes, and other essential parameters that constitute climate policy based on cutting-edge climate science and profound policy analysis. It also generates the cost of capital specific for each region (country) and shifts in the share of different sectors in countries' output. The modeling methodology extends the methodology described in WBG 2020 and WBG 2021, extending it from exploratory scenarios to full-scale probabilistic analysis.

The global dynamic CGE translates carbon prices into final prices of all goods and services represented in the global CGE and changes in demand and supply over the short (1-5 years), medium (5-15 years), and long (15-50 years) terms. The dynamic CGE model features sophisticated consumer demands and inter-sectoral factor mobility, incorporates advanced treatment of investment behavior, and accounts for relations to keep track of foreign ownership of capital. In addition, it captures the complex adjustment of the global economy to emerging climate policies all around the Globe.

Figure 5: Framework-climate alpha



This modeling framework not only enables analysis to detect carbon alpha in the value of corporations it also produces all necessary output to conduct a probabilistic cost-benefit analysis of large investment programs and projects. Thus this modeling framework could be used for public policy analysis and for BCA of public finance as well as investment choices for private corpoerations.

Discussion

"Beat the market"! – that is the goal of each ambitious investor. This motivation is in the root of each active investing strategy. But is it possible to beat the market consistently? Several anecdotal evidences suggest yes, but the market efficiency theory says no. The financial markets already incorporate all available information, so all securities are priced based on this information, and there are no opportunities to earn an excess return. Therefore, the active investment must be a zero-sum game [16]. This is true unless markets are moving from one equilibrium to another. In this case investment aligned with a new economic structure could consistently outperform an investment in capital that new technologies will replace, i.e outperform investment not aligned with green transition. It happen if the knowledge provided by our approach is not adopted by all agents and that some are making decisions using less effective tools. In the medium to long term the advantage of the first mover will disappear in an efficient market. However, it will also mean that the entire economy is closer to a new equilibrium where returne on investment is higher than in the old equilibrium.

Decarbonization of the global economy and green transition, in general, is a transition of the global economy to a new steady-state with significantly higher productivity owing to the complementarity of green energy, AI, highly educated work force, deployment of robots and 3-D printers etc. In the foreseeable future, a green transition of the global economy will become the mainstream of economic development and, therefore, will be the main profit-driven activity. Decarbonization alone will be accountable for one-third of the global investment. The climate alpha project aims to equip the business community with analytical instruments to calculate the future value of investment consistent with the green transition and decarbonization of the global economy and navigate the long-term process of wealth creation, building a cleaner and safer future. The climate alpha is an economic

[16] Fama, E.F. and French, K.R., 2010. Luck versus skill in the cross-section of mutual fund returns. *The journal of finance*, *65*(5), pp.1915-1947.

indicator that best represents the future value of capital assets and predicts long-term return on investments attributed to permanent shifts in capital value. In other words, the climate alpha represents a positive “fixed effect” of the green transition and decarbonization of the global economy.

The capital stock adjustment will take the form of debt accumulation (corporate bonds, commercial loans, etc.), merger and acquisition, number of IPOs, etc. In theory, the decarbonization of the global economy could be an attractive outlet for global capital. Investment into low carbon technologies and renewable energy should be ramped up. Investment banks will face a spike of that kind of investment demand and may be short on relevant expertise. Eventually, almost all energy investment will be associated with the decarbonization of the global economy. The global economy will experience an investment short squeeze mainly due to the limitation of existing investment channels and lack of expertise in the valuation of "carbon equities".

Penetration of the new technologies primarily focused on fighting climate change has a spillover effect on the entire economy. The secondary climate alpha could be found in any sector of the economy. For example, the transition to wind and solar energy creates unique opportunities to deploy robots and 3-D printers or water decomposing by electrolysis technologies to produce hydrogen and other electricity-intensive technologies with flexible demand.

Annex 1. Cost-benefit analysis under uncertainty and assets valuation

The application of quantitative tools for economic analysis like IAMs, CGE, and "bottom-up" energy models provide decision-makers with essential information about anticipated benefits and costs of climate policy, the value of the investment, cost of capital, etc. Calculated economic indicators create a foundation for the application of Cost-Benefit Analysis (CBA) for public policy, development programs, large investment projects, etc.

Cost-benefit analysis is a powerful tool to support the decision-making process. It allows choosing between a wide range of well-specified alternatives (development goals, investment strategies, etc.), providing a common denominator to assess and rank them in a consistent way. In our case, alternatives are specified as different strategies for capital formation on the national level in order to build "an assets portfolio" less vulnerable to the future global and regional climate policy. According to AR5 WG3, CBA is extremely useful when dealing with well-defined problems like the benefits and costs of building levees to reduce the likelihood and consequences of flooding given the projected sea-level rise attributed to climate change. Another example mentioned in AR5: CBA can provide a framework for defining a range of global long-term abetment targets across countries to facilitate negotiations (see also Stern, 2007).

"The main advantage of CBA in the context of climate change is that it is internally coherent and based on the axioms of expected utility theory. As the prices used to aggregate costs and benefits are the outcomes of market activity, CBA is, at least in principle, a tool reflecting people's preferences…this line of reasoning can also be the basis for recommending that this approach not be employed for making choices if market prices are unavailable. Indeed, many impacts associated with climate change are not valued in any market and are therefore hard to measure in monetary terms. Omitting these impacts distorts the cost-benefit relationship" (AR5, WG3, Chapter 2 p.28).

Acknowledging the important role of CBA for decision making, AR5 also stresses major challenges when defining the optimal level of mitigation actions:

(1) The need to determine and aggregate individual welfare,

(2) The presence of distributional and intertemporal issues, and

(3) The difficulty in assigning probabilities to uncertain climate change impacts."[17]

[17] http://opim.wharton.upenn.edu/risk/library/IPCC-AR5-WG3-Ch02_Mitigation-of-Climate-Change_Assessment-of-Response-Policies.pdf p.27.

“A strong and recurrent argument against CBA (Azar and Lindgren, 2003; Tol, 2003; Weitzman, 2009, 2011) relates to its failure in dealing with infinite (negative) expected utilities arising from low probability, catastrophic events often referred to as ‘fat tails’.” (AR 5, WG 3, Chapter 2 p.28).

Indeed, costs and benefits of each alternatives depend upon the value of critical economic parameters (elasticities, autonomous technological progress including AEEI, available technologies and energy resources, etc.) as well as on continuous climate policy events and actions by other countries or corporations (evolution of a shadow price of carbon, in explicit or implicit form, border adjustment actions that targets carbon imbedded in tradable goods and commodities, voluntary actions taken by investors of corporations regarding direct and indirect carbon emissions, etc.).

As noted above, uncertainties create some challenges for CBA applications. Although some uncertainties are difficult to quantify, the "infinite (negative) expected utilities" argument is not relevant since, in case of assets valuation, a finite economic value should indeed exist. In the worst-case scenario, the losses should not exceed the sunk cost. A potential upside is also limited as long as an investment could be scaled up or replicated (knowledge is not rival and could not be made permanently exclusive) or substituted (in case of exhaustible resources). Therefore, an application of CBA should not be ruled out on the grounds d of the arguments mentioned above.

When conducting CBA under uncertainty, some assumptions regarding distribution of critical exogenous parameters should be made. There are several examples in the literature when authors explore plausible hypothesis regarding uncertain parameters and assign subjective probability distributions (for example, Gillingham et al (2015), Ortiz et al (2011), Nordhaus (2008), Bosetti et al (2008), Anda et al (2009) in integrated assessment analysis of climate policy, WGSCC (2009, 2013) for calculation of social cost of carbon, Webster et al. (2008) in running numerical experiments with the EPPA model, Golub, Keohane (2013) in modeling carbon market and carbon allowances strategic reserve, IEA (2007) in energy modeling). As a result, the return on assets and its NPV is computed as a probability distribution.

Pringles et al. (2015) apply ROA for power transmission network transformation in the context of power market uncertainty.

Some uncertainties may not be presented as distributions, for example, policy choices by other players. In this case, it would be productive to construct a plausible set of alternatives and keep it separate from quantifiable uncertainties. Then policy analysis and assets valuation could be conducted for each alternative separately. For instance, for high and low see level rise, climate policy implemented by trading partners with and without border adjustment, etc. Quantifiable and non-quantifiable[18] Uncertainties could be sorted out while building an event tree.

If there are relatively few underlying uncertain parameters presented as intervals, an event tree is relatively simple. Therefore, benefits and cost of policy interventions or the value of assets in question could also be presented as intervals. For example, Mercer (2015) considers four uncertain exogenous parameters, including climate change, and reports estimated changes in an asset return as an interval (see figure 1 in Mercer (2015)). The information about a plausible interval for asset returns (summarized in figure 1, Mercer (2015)) is helpful for an investor who is building an equity portfolio being conscious of climate change. For example, investment in infrastructure looks attractive: positive central value, relatively high upside, while the downside is limited. On the contrary, according to Mercer (2015), investment in private equity and small cap equity appears not attractive due to the mostly negative impact of climate change and climate policy on its return. Although these metrics may be useful to understand the potential exposure of various assets to climate change and climate policy, it is not conclusive on the fair value of assets exposed to climate change and climate policy.

Mercer (2015) considered four uncertain parameters. Therefore the interpretation of results is relatively easy. For example, the highest losses in return on assets in the coal industry is a result of a combination of the highest price of carbon, the highest

[18] "Non-quantifiable" requires more explanations. For example, before some initial learning, there is not enough information to come up with a trustworthy initial assignment of subjective probabilities, the decision-maker is not willing to assign a probability to an uncertain factor in question and is inclined to consider marginal outcomes like maximum and minimum value for oil price or annual economic growth rate.

rate of technological innovations in alternative energy, etc. When the number of uncertain factors increases, the number of possible combinations increases exponentially. It creates some computational challenges and also makes interpretation of results less obvious[19].

Robust decision-making (RDM) framework offers a way out. Application of RDM detects the most "problematic situations" (like borders of intervals depicted in figures 1 and 2 in the Mercer (2015) executive summary) and then retrieves a particular combination of uncertain parameters that result in these "corner outcomes" (scenario recovery process). Highlighting "the worst-case scenarios" and then applying mini-max optimization criteria, RDM identifies a precautionary policy from a set of available interventions. AR5 makes a direct connection between RDM and the precautionary principle (PP). According to IPCC AR5, "…RDM is a particular set of methods developed over the last decade to address the PP in a systematic manner. RDM uses ranges or, more formally, sets of plausible probability distributions to describe deep uncertainty and to evaluate how well different policies perform with respect to different outcomes arising from these probability distributions. RDM provides decision-makers with tradeoff curves that allow them to debate how much expected performance they are willing to sacrifice in order to improve outcomes in worst-case scenarios. RDM thus captures the spirit of the precautionary principle in a way that illuminates the risks and benefits of different policies". (AR5, WG3, Chapter 2 p.p. 30, 31).

Application of RDM imposes very general conditions on the input data that fit any kind of experts' judgments: "There is no requirement to determine the precise probability of each future climate scenario but there must be sufficient reason to believe each scenario is plausible. Consequently, a binary assessment of likelihood (plausible or implausible) is necessary. How to ascribe this form of likelihood to different scenarios is non-trivial." (Daron 2014 pp 467,468). I.e., all uncertain

[19] A formal algorithm (usually Latin-Hyper Cube (LHC) or Monte-Carlo simulations (MC)) is applied to compute combined uncertainties. LHC helps to avoid computational complications, while MC provides an opportunity to account for correlation and covariance a priory, excluding some unrealistic states of the world.

parameters could be presented in the form of binary (or multinomial) scenarios without prior consideration of the relative plausibility of different realizations of an uncertain parameter in question. Therefore, the results of computations bear no information about the relative plausibility of computed outcomes. RDM just seeks to find a decision that performs well across possible future scenarios but does not provide a decision-maker with benefits estimation. "Neither info-gap[20] nor RDM provide a strict ranking of alternative decisions. Rather, both provide decision support, summarizing trade-offs for decision makers to help inform their judgments about the robustness of alternative decision options."(Hall et al. p. 1658). "Robust Decision Making is a decision-support method premised on robustness rather than economic optimality (see Watkiss et al. (2014)).

"Cost-benefit analysis under uncertainty applied to adaptation uses subjective probabilities for different climate futures … Risk aversion can be taken into account through (nonlinear) welfare functions or the explicit introduction of a risk premium. When conducting cost-benefit analyses under uncertainty, an important question is the timing of action, that is, the possibility of delaying a decision... Real option techniques are an extension of cost-benefit analysis to capture this possibility and balance the costs and benefits of delaying a decision" (AR5 WG2 p. 956).

AR5 WG2 reviews different tools for decision making under uncertainty that apply in a different context and with a different degree of quantification of available information: from a loose specification of a plausible interval to fitting specific probability distributions. Watkiss et al (2014) provide a taxonomy and discuss the strengths and weaknesses of each method (see diagram adopted from Watkiss et al. (2014).

[20] Info-gap is another formal method to handle deep uncertainty.

CBA and hedonic pricing of risk

"Cost-benefit analysis used to be one of the World Bank's signature issues. It helped establish the World Bank's reputation as a knowledge bank and served to demonstrate its commitment to measuring results and ensuring accountability to taxpayers… Current Bank policy states that cost-benefit analysis should be done for all projects at appraisal—the single exception is for projects for which benefits cannot be measured in monetary terms, in which case a cost-effectiveness analysis should be performed."(WB 2010 p. ix). However, recognizing the legitimate difficulties in quantifying WB 2010 concludes, this policy should be revisited and "…the Bank needs to ensure that cost-benefit analysis is done with quality, rigor, and objectivity: poor data and analysis misinform, and do not improve, results" (WB 2010 p. ix).

Stranded assets valuation: CBA frontier and complementarity between ROA and RDM

Identification of assets that could be potentially stranded is the major focus of our study. Mark to market valuation can hardly help to compare investment into different assets with respect to a risk of being stranded since this risk has not been priced yet. We apply a hedonic model to capture this risk. By definition, a hedonic model identifies a price of an underlying asset according to the premise that the price is determined both by internal characteristics and external factors affecting it[21]. Internal characteristics determine return and asset value in status quo, while future possible realizations of a climate policy constitute external factors.

Application of ROA allows calculation of the hedonic price of risk. Therefore, according to the economic theory of investment under uncertainty, there is an additional value to the investment option from waiting before making an irreversible investment until some uncertainty about future output of investments in question is resolved. At the same time, delay means lost opportunities from operation of carbon intensive sectors and productive use of fossil fuel assets. The application of ROA

[21] http://www.investopedia.com/terms/h/hedonicpricing.asp#ixzz3rsLVwmfX

balances the benefits of delaying investments and opportunity cost of the lost production. Greater uncertainty results in a higher value to delay investments into carbon-intensive assets. However, relatively high productivity of carbon intensive production may "overweight" option value to delay investment. The economic value of waiting is called a value of a deferral option. Higher degree of uncertainty results in a higher value of a deferral option. Premature investment into assets with an uncertain return results in losses of value of the deferral option.

Thus investment into assets with an uncertain return, i.e., risky investment, has a lower value relative to a risk-free or low-risk investment. Usually, investment risk is diversifiable, and risky investments could be hedged. A shadow value of risk could be interpreted as a hedging cost of an underlying position. If in the status quo, the value of the asset is V_0 (calculated as the expected NPV of the future return on investment), then the cost of hedging strategy δ equals to the cost of a put option with a strike price V_0. If the risk is diversifiable, i.e. the country has several options to invest in other assets with an uncorrelated return, then the fair forward value of the asset is $V_0 - \delta$. If the risk is not diversifiable, the hedging cost could be up to the full value of the maximum loses. Then mini-max criterion is a more appropriate valuation approach. For that reason, AR5 WG2 recommends the mini-max approach in case of adaptation.

Method selection: CBA or precautionary principle (PP)

Not all methods for risk analysis are comparable with the CBA framework. Ability to specify a subjective probability is critical to selecting an appropriate analytical tool. Figure A-1. summarizes this selection.

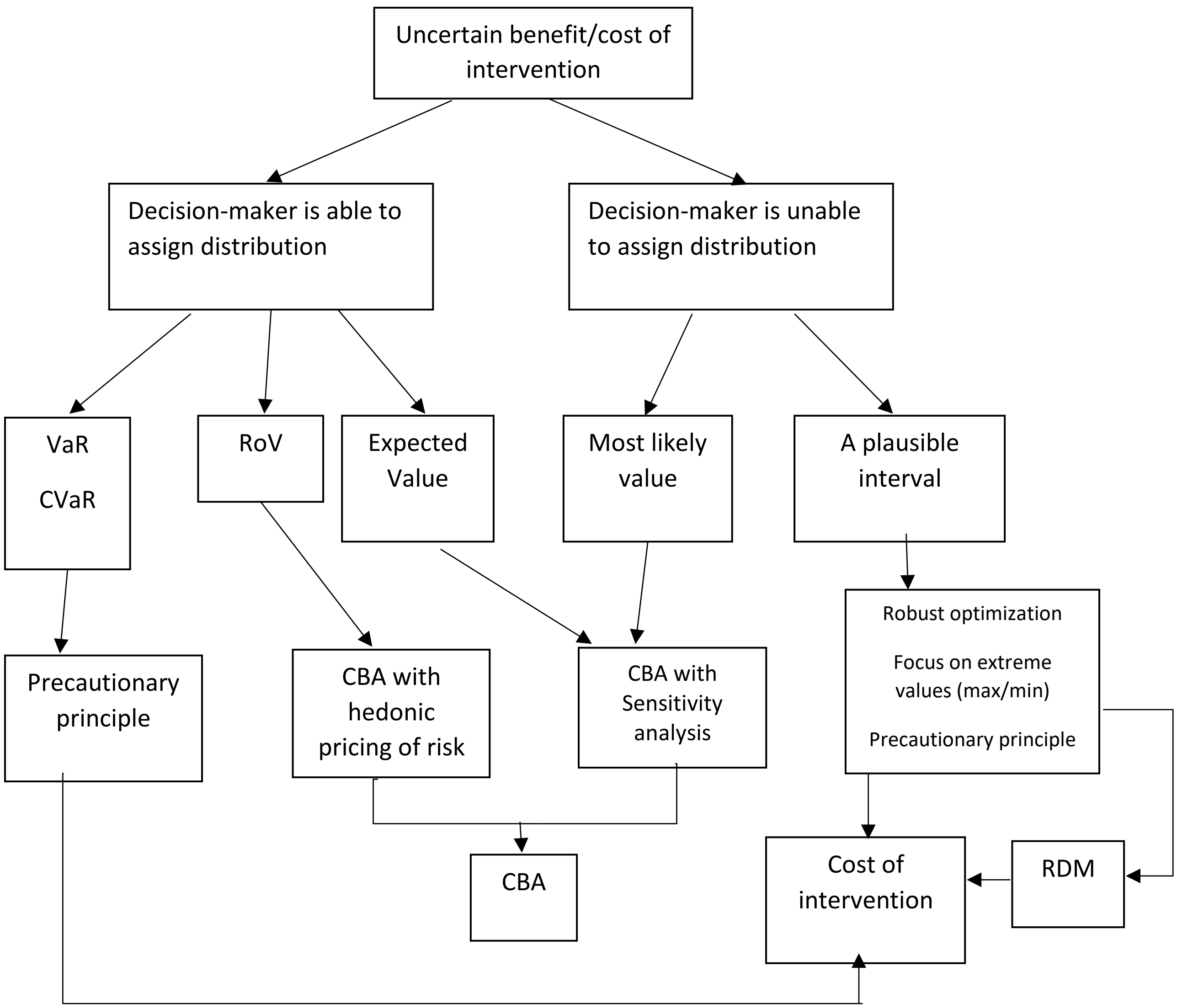


Figure A-1. CBA and PP in session under uncertainty

CBA allows ranking of alternatives and CBA with ROV of risk provides a balanced metrics for benefits and cost of climate policy (see Anda et al 2009). Investing in any assets can produce two possible outcomes: a positive return or a loss of capital. Investing in carbon intensive assets is associated with an increased probability of a loss of capital in the future as a result of changing exogenous conditions and policy actions by other countries.

Putting aside an issue of quantification of environmental goods and services, and assuming we are dealing with quantifiable in monetary terms indicators, the major issue is an ability to assign subjective probabilities to the underlying uncertain parameters. This ability or inability may determine a choice of an analytical tool illustrated in Figure 1. Inability to represent an uncertain parameter with a distribution is a reason to favor robust optimization and RDM. However, if a decision-maker inclines to choose a single value to represent an uncertain parameter (i.e. just ignoring risk), CBA could be conducted in a "deterministic" form.

Ability or inability to assign probabilities to exogenous uncertain parameters is one important factor to choose between RDM and ROA. It is also important to consider ability of a country to cope with losses in the worst case scenario. If potential losses are prohibitively high, then decision should be governed by a precautionary principle. Then RDM or robust optimization would be a leading analytical tool. For example, suppose there is a scenario when a country may lose 50% of budget revenue due to significant losses of resource rent. In that case, this scenario should be mitigated regardless of the probability of this worst-case scenario, i.e., the decision procedure relies on RDM. If in the worst-case scenario losses appear manageable (and risk diversifiable), then decisions should be governed by CBA.

Application of Hart-Foster risk metrics (see: Foster & Hart (2009)) helps to understand the selection of CBA and RDM. Foster and Hart propose a measure of the riskiness of holding a risky asset that depends on the critical wealth level, below which it becomes "risky" to invest in the asset. Applying this methodology to the valuation of carbon-intensive assets, we may establish a relation between a wealth of a country and maximum tolerable losses. For example, in Figure A-2. maximum tolerable losses (in % of GDP) are represented as a function of GDP per capita.

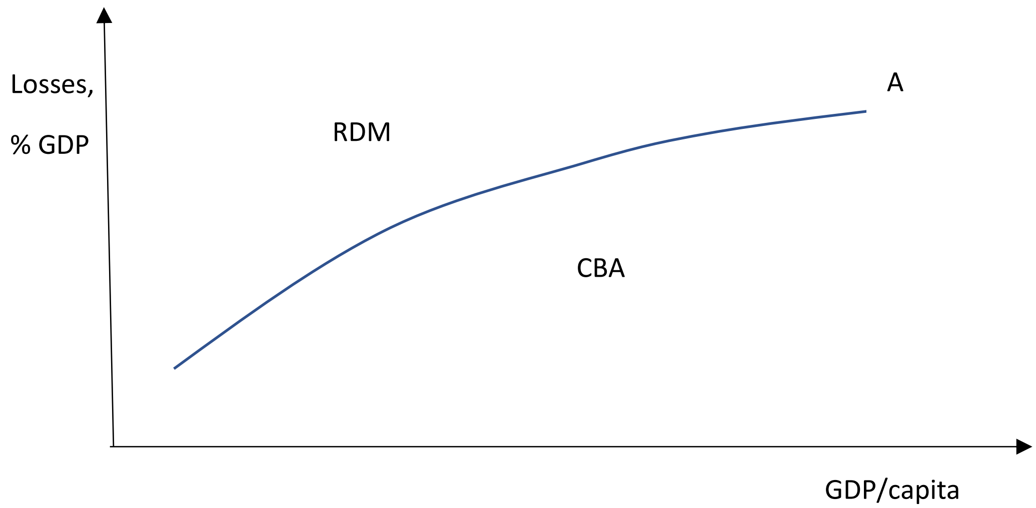


Figure A-2: A frontier of RDM/CBA application

If the economic potential of some countries is higher, then this country could tolerate higher losses. A concave curve A establishes a frontier between CBA and RDM. If potential maximum losses are below curve A, then a decision process could be governed by CBA. Otherwise, RDM should be a governing instrument for decision-making on investment in risky assets.

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