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# Is real options analysis fit for purpose in supporting climate adaptation planning and decision-making?

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## Abstract

Even though real options analysis (ROA) is often thought as the best tool available for evaluating flexible strategies, there are profound problems with the assumptions underpinning ROA rendering it unsuitable for use in supporting planning and decision-making on climate adaptation. In the face of dynamic and deep uncertainty about the future, flexible strategies which can be adapted in response to how the uncertainty is resolving are attractive. Traditional cost-benefit analysis cannot account for the value created through optionality. ROA sets out to amend this. There are however several profound problems with how ROA tries to do this. It is typically not clear what is the baseline plan, without options, against which value is to be estimated. Different baselines significantly change option value. Even if option value can unequivocally be established for a given scenario, ROA relies on expected values over a set of scenarios. First, this requires assigning weights, or probabilities, to scenarios. Given the long-time horizon involved in climate adaptation, these probabilities are meaningless. Second, the expected value over a set of scenarios need not obtain in any single scenario and is thus not a meaningful summary of option value.

This article is categorized under:

Climate Economics > Iterative Risk-Management Policy Portfolios

## KEYWORDS

bioinformatics, docking, lead optimization, machine learning, virtual screening

## 1 | INTRODUCTION

Within the broader literature on climate adaptation planning and decision-making, one strand of research has a strong analytical focus on designing effective climate adaptation strategies in the presence of a wide variety of presently irresolvable uncertainties (Dessai & Hulme, 2007; Dessai, Hulme, Lempert, & Pielke jr, 2009; Lempert, Popper, & Bankes, 2003; Maru & Stafford Smith, 2014; Wise et al., 2014). Uncertain changes in the climate, technological, socioeconomic, and political system, and the dynamic interaction among these changing systems pose a challenge to planners and

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decision makers. There is a substantial risk of making inappropriate decision. That is, decisions which are too late or too soon, too little or not enough.

Because of the presence of unavoidable uncertainty, decision makers are advised to look for robust decisions that have satisfactory performance across a large range of plausible futures. One of the key design principles for such robust decisions is to make plans that are flexible and can be adapted over time in response to how the world actually unfolds (Haasnoot, Middelkoop, Offermans, van Beek, & van Deursen, 2012; Hallegatte, 2009; Kwakkel, Walker, & Marchau, 2012; Walker, Haasnoot, & Kwakkel, 2013).

Existing economic evaluation approaches are ill equipped to evaluate flexible strategies under uncertainty (Dittrich, Wreford, & Moran, 2016; Lempert, Schlesinger, & Bankes, 1996; Yzer, Walker, Marchau, & Kwakkel, 2014). A general approach to the economic evaluation of candidate plans is to use cost-benefit analysis (CBA). The main question a CBA helps to answer is whether to invest or not. In adaptive plans and strategies, however, the choice is not between whether to invest or not, but whether to invest now, later, not at all, or to invest a little right now and to maintain the possibility of making the bigger investment in the future. To answer this type of question, we need to know the value of all these options. It has been claimed that real options analysis (ROA) can be used to answer these questions (Hallegatte, Shah, Lempert, Brown, & Gill, 2012).

In this opinion, I will present a number of reasons why ROA is not suitable for supporting the economic evaluation of flexible climate adaptation strategies. Since ROA is an extension of CBA, many of the arguments that can be leveled against CBA, also apply to ROA. Both are very sensitive to the discount rate that is being used (Hallegatte et al., 2012), and the choice of the appropriate discount rate in the context of climate change is a contested topic (Dennig, 2018). Planning and decision-making on climate adaptation typically involves a wide variety of stakeholders with diverging interests and values. Moreover, these actors are distributed in space and time. Any aggregation over the interests of the various actors runs afoul of Arrow's paradox (Arrow, 1950; Kasprzyk, Reed, & Hadka, 2016; Sen, 2017), raises ethical concerns, as well as being another source of contestation. The ex ante assessment of costs and benefits produced by CBA often deviate substantially from the ex post costs and benefits, particularly in the case of large infrastructure projects. This is amongst others due to many perverse incentives and biases in the decision-making process within which CBA is being used, resulting in the survival of the unfittest (Flyvbjerg, 2009; Flyvbjerg, Bruzelius, & Rothengatter, 2003). These three lines of critique of CBA, and ROA by extension, already raise questions about the suitability of ROA. In this opinion piece, however, I would like to focus on several issues that are more specific to ROA, and which, taken together, raise substantial doubts about the claim that ROA can be used to estimate the value of options in climate adaptation.

## 2 | WHAT IS ROA ANYWAY?

A first problem is that even though many people discuss ROA in the context of climate adaptation, it is not obvious whether there is a shared univocal understanding of what ROA actually is. If we look at some of the most cited papers returned by a simple search in Scopus on "climate adaptation" AND "real options," we see various answers to what real options are. Jeuland and Whittington (2014) restrict real options to the option to defer a capital investment and do not discuss the idea of trying to assign value to this option. Woodward, Goulby, Kapelan, Khu, and Townend (2011) characterize ROA as the economic valuation of flexibility, for which the value of flexibility is the difference between the expected performance with flexibility and the performance when the option is implemented deterministically. This position is similar to Watkiss, Hunt, Blyth, and Dyszynski (2015), according to whom ROA is an economic analysis method for assigning value to waiting for future information. Dittrich et al. (2016) see real options as flexibility conditional on how uncertainty resolves over time, without an explicit consideration of the problem of assigning value to this flexibility. Hence, for Dittrich et al. (2016), ROA is quite similar to pathway approaches (Haasnoot, Kwakkel, Walker, & ter Maat, 2013; Wise et al., 2014).

The history of real options can be traced back to Myers (1977). He introduced the idea of viewing corporate assets as future growth opportunities, and drew an analogy with call options. The idea is that the total value of a firm includes the potential future growth. This potential of future growth is dependent on the current assets and the choices that are open due to these assets. A central challenge then becomes to assign value to these choices such that they can be included in the assessment of the total value of the firm.

There now exists a varied academic literature of ROA applied to natural resources management, corporate strategy, manufacturing, supply chain management, inventory management, real estate, research and development, and labor force management (Lander & Pinches, 1998). Over the last decade, there has also been a growing interest in the use of real options in the context of engineering design (de Neufville, 2003; de Neufville & Scholtes, 2011).

In the context of climate adaptation, I understand a real option as the right, but not the obligation, to implement an action for a cost over a (possibly unbounded) time frame (De Neufville & Smet, 2019). What makes these actions real is that they involve the building of infrastructure for example, flood protection such as the heightening or strengthening of embankments, or developing new side channels or other forms of building with nature. Typically, there is not only a cost associated with implementing an action. There is also often a cost to acquire the option to implement an action at some future date. For example, by building a wider embankment today, one creates or buys the option of cheaper future heightening. ROA then is the estimation of the value of a real option. That is, does the value created by the real option outweigh the costs of acquiring the option. This understanding of ROA is consistent with Woodward et al. (2011) and Watkiss et al. (2015).

### 3 | VALUING OPTIONS

The key challenge in ROA is establishing the value of various options. Three families of methods can be found in the literature. These are (1) continuous time models, (2) tree- and lattice-based approaches, and (3) Monte Carlo simulation-based analyses (Chow & Regan, 2011; Lander & Pinches, 1998; Trigeorgis, 1996).

The continuous time models are closest to the option valuation approaches as developed in finance. The iconic model is the Black-Scholes equation. As argued extensively by de Neufville and Scholtes (2011), the assumption underlying these models do not hold for many or even most real options, rendering this family inapplicable to the valuation of real options. In contrast with financial options, there is no clear replicating portfolio, typically there is no market for trading real options (McGrath, 1997), real options are often very context specific so there is limited data available on past performance of the assets, the context in which the assets are valued might be undergoing systematic change, and many real options are open ended in the sense that they can be utilized in a variety of ways and lack a clear termination date. Similar arguments are raised by Lander and Pinches (1998), who wonder whether one can specify the stochastic process that determines the value of a real option, or whether there even is such a well-defined process. Moreover, they point out that financial option pricing techniques, like Black-Scholes, assume that the asset price is perfectly observable, there is perfect arbitrage, and perfect liquidity. None of these assumptions holds for real options.

Tree- or lattice-based approaches to the valuation of real options are rooted in the work of Cox, Ross, and Rubinstein (1979). More recent developments of this approach can be found in Copeland and Antikarov (2001), Copeland and Antikarov (2003), and Brandao and Dyer (2005). These approaches rely on discrete time-based evaluation, although it is often possible to achieve the required precision by making the discrete time steps arbitrarily small. One of the key assumptions of tree- and lattice-based approaches to option valuation is the Market Asset Disclaimer, according to which the present value of the project without options is the best unbiased estimator of the market value of the project. Because there is no market for many assets, this assumption cannot be properly tested; moreover, it is not always clear what a project without options exactly entails. As a result, the present value assigned to the project without options can heavily influence the resulting real option valuation (Brandao & Dyer, 2005). Another fundamental issue with these approaches is that they typically can only deal with a single source of uncertainty describable by a random walk. If there are multiple interacting sources of uncertainty, these have to be combined first into a scenario tree. ROA results are sensitive to the exact way in which this tree is constructed (Erfani, Pachos, & Harou, 2018). Alternatively, it is possible to combine more than one stochastic variable as demonstrated by Tee, Scarpa, Marsh, and Guthrie (2014). I do not know of any example, however, where they moved beyond two sources of uncertainty. A last problem, particularly relevant in the context of adaptation to uncertain changing conditions, is that tree- or lattice-based approaches are difficult to apply in case of interactions or path-dependencies between options (Gersonius, Ashley, Pathirana, & Zevenbergen, 2013; Wang & Neufville, 2005).

The third family of approaches to real options valuation is to use Monte Carlo simulation. One of the most elaborate developments of this type of approach is offered by de Neufville and Scholtes (2011). In this approach, one aims at identifying the distribution of the net present value under many realizations of the various uncertain factors. By comparing the distribution of the net present value for projects with and without options, an assessment of the value of an option can be made. This approach relies critically on the a priori specification of the conditions under which an option is exercised, which can be done based either on expert-based decision rules or through optimization (Wang & Neufville, 2005). Just like tree- and lattice-based approaches, simulation-based approaches rely on the Market Asset Disclaimer. They thus suffer from the same problem that it is often not obvious what the baseline plan is against which the value of an option has to be established. To take a simple example, imagine a plan with two options. What is the baseline against which to evaluate option value? Is it the plan with both options utilized? Is it for option A, the plan with option

B implemented at the start (and vice versa for option B)? What if there are interaction effects between both options that either improve their joint value, or instead reduce their joint value? There is no obvious right answer to these questions, and hence any estimated option value is critically dependent on this choice. Another problem is that calculating option value requires the ex ante specification of both all relevant scenarios (see Derbyshire, 2017b for further elucidation), as well as all possible ways in which the option might be used. For example, a spatial reservation where land is set aside for future flood plain expansion might, due to changing technology, insights, and so on be used in quite a different way than envisioned in the analysis today. Since one can close neither the event range of the scenario space, nor the set of possible ways in which an option can be used, how can one claim to accurately estimate option value?

## 4 | THE PROBLEMS WITH ASSIGNING PROBABILITIES TO STATES OF THE WORLD

Option value is the expected value over the set of uncertain futures. Thus, irrespective of which evaluation technique is being used, all rely on the assignment of probabilities to the different scenarios. In the context of climate adaptation this is fraught with difficulties (Shortridge & Smith Camp, 2019). First, climate adaptation planning typically uses a long time horizon of 30 years or more. For such a time horizon, the only certainty is that the world will look substantially different from today. Technology will be profoundly different. Land use and socioeconomic circumstances will be quite different. And the exact way in which climate will be changing at the local or regional scale is also profoundly uncertain. True, model-based analysis and expert opinion might be used to bound this uncertainty. But for many socioeconomic and climate parameters relevant in adaptation planning, we have no basis to do much more than bounding the uncertainty, if even that. The level of detail in for example, climate information required in most planning problems often required downscaling with the associated cascade of uncertainty (Wilby & Dessai, 2010). Relying on subjective beliefs of expert does not fundamentally resolve this problem for what basis do these experts have for their beliefs? If the recent past can teach us anything, then at least it should have taught us that experts are often profoundly wrong and overconfident.

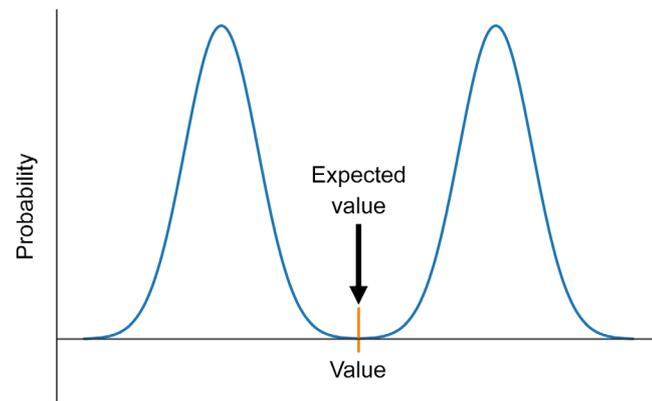
Many of the uncertainties that will shape the future will coevolve with the decision made over time. For example, a choice to invest in stronger and higher embankments will profoundly affect the resulting land use in the area protected by these embankments (see for example, Barendrecht, Viglione, & Blöschl, 2017 for more flood risk examples). The clear separation between choices and states of nature required by Savage's axioms for subjective expected utility thus do not hold.

Since climate adaptation planning typically brings together a variety of stakeholders, these stakeholders might also have fundamentally different beliefs about what the future might hold and which dimensions of the future are relevant to consider. Trying to assign probabilities to uncertain futures can then easily become a source of contestation.

In short, climate adaptation planning is characterized by both deep and dynamic uncertainty. Rather than rely on evaluation techniques to support planning that simply assume this away by insisting on the need for probabilities, we should be developing techniques that fit with the reality that we do not have informative probabilities about the future, and might not even be able to bound the uncertainty with high confidence (Weaver et al., 2013).

## 5 | A SPECIFIC PROBLEM WITH EXPECTED VALUES

Even if we disregard the problems surrounding the assignment of probabilities, there is another fundamental problem with ROA: the idea of expected values. Consider the situation shown in Figure 1. Let us assume that we have an option with a bimodal symmetrical distribution of option value over the ensemble of scenarios. A situation like this can easily arise in case of nonlinear dynamical systems with two attractors. Depending on how the uncertainty unfolds, the system is attracted to either attractor which will determine option value resulting in bimodal distribution. The expected value over the ensemble however does not obtain in any scenario. Thus, the expected value over the ensemble tells virtually nothing about what value to expect out of the option in whatever real future we end up in. Geltner and de Neufville (2018) call this the flaw of averages. Shackle already made this point in the 1950s, right around the time that Savage was developing subjective expected utility theory (Derbyshire, 2017a, 2017b). More recently, Gintis (2009), although strongly advocating the use of subjective expected utility as the unifying basis for the behavioral sciences, cautions against its use in single-shot, nonrepeatable, unique choice situations—which is exactly what one faces in many climate adaptation planning and decision-making contexts.

**FIGURE 1** A simple problem with expected values

Under the label of ergodicity economics, the critique of using expected values over an ensemble of scenarios is being developed more formally. Ergodicity economics aims at a revision of core economic assumptions, many of which made over 300 years ago, drawing on much more recent developments from mathematics in the form of ergodic theory, in an attempt to resolve a variety of economic paradoxes and anomalies (Peters, 2019). Following Peters and Gell-Mann (2016), we can say that an expected value over an ensemble of scenarios is meaningful only if the expected value is independent of time, and the average over time in any scenario converges to this expected value. Clearly this does not hold for real options. In different futures, the value of the option changes. For example, in case of high-end sea level rise, an option for raising levees will gain value, while in a future with low-end sea level rise the option loses value. Put differently, the expected value over an ensemble of scenarios is not necessarily the same as the expected value within a scenario over time. But then, following Peters and Gell-Mann (2016), expected values based on ensembles are not meaningful. What is decision relevant is the performance of an option over time. Looking at the average (weighted) performance over a set of scenarios provides no information on this. Expected values over an ensemble are not the numbers you are looking for.

## 6 | CONCLUSION

Given the implausibility of assigning meaningful probabilities to future scenarios, the questionable value of calculating the expected value over a set of scenarios, as well as the more specific problems with the available valuation techniques, what are the implications for ROA? The values calculated through either tree- and lattice-based techniques, or through Monte Carlo simulation, are meaningful only in ‘model land’. To use these numbers uncritically as if they have any bearing on reality is to be oblivious to the set of heroic assumptions and gross simplifications necessary to produce these numbers in the first place (Thompson & Smith, 2019). Moreover, using these numbers in real world decision-making processes can easily frustrate rather than aid the process. Therefore, I contend that ROA is not fit for purpose in aiding real-world climate adaptation decision-making and planning processes.

Yet, at the same time, real option thinking rightly emphasizes the importance of optionality and flexibility as key considerations for planners and decision makers involved in climate adaptation, given that the uncertainties involved are both dynamic and deep. Guthrie (2019) points out that other approaches that emphasize optionality and flexibility, like dynamic adaptive policy pathways (Haasnoot et al., 2013), have ignored the question of assessing the value offered by flexibility. More generally, trying to understand the value created through optionality has largely been ignored in the broader family of robust decision-making approaches. Instead, this family of approaches emphasizes decision aiding, adaptive planning, and exploratory scenario thinking (Kwakkel & Haasnoot, 2019). Optionality and flexibility are instrumental in enhancing the robustness of plans. Meaningful options are determined through stress testing a candidate strategy over a large set of scenarios and establishing conditions under which policies fail (Bryant & Lempert, 2010; Lempert, Groves, Popper, & Bankes, 2006). The question of option value never really occurred within this literature. However, understanding the value created by options over the set of scenarios is evidently decision relevant (as is its converse, the cost of lock-in (Haasnoot et al., 2019)).

It is an open research question how to understand and assess option value within robust decision-making approaches. This is a nontrivial problem. What is the correct baseline against which to compare a plan with two or

more options? What of interaction effects amongst options? How may we use distributional information on option value over a set of scenarios in supporting decision-making? Can option value be understood as improvement in robustness as Mahnovski (2006) seems to do? What about reframing the assessment of option value within a scenario discovery approach (Bryant & Lempert, 2010) where one would try to understand the conditions under which option value is positive or negative?

Making progress on assessing the value of options within robust decision-making approaches will also require a fundamental discussion of how analysis contributes to decision-making. Should analysis be understood in a normative sense to indicate the optimal choice, given axioms or rationality, or is analysis meant to foster multistakeholder deliberation in pursuit of shared understanding of the problem situation and means for addressing this (Tsoukiàs, 2008)? Whether an option is worth its costs is in the end a judgment call. Analysis and quantification can help support decision makers in coming to this judgment, but they should not become fig leaves for them to hide behind (Pilkey & Pilkey-Jarvis, 2007). Trying to express option value in a single number, which is what ROA sets out to do, runs counter to this understanding of how decision analysis techniques can be useful in aiding multistakeholder decision-making.

## CONFLICT OF INTEREST

The author has declared no conflicts of interest for this article.

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