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The Economic Value of Climate Information in Adaptation Decisions: Learning in the Sea-level Rise and Coastal Infrastructure Context

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ABSTRACT

Traditional methods of investment appraisal have been criticized in the context of climate change adaptation. Economic assessment of adaptation options needs to explicitly incorporate the uncertainty of future climate conditions and should recognise that uncertainties may diminish over time as a result of improved understanding and learning. Real options analysis (ROA) is an appraisal tool developed to incorporate concepts of flexibility and learning that relies on probabilistic data to characterise uncertainties. It is also a relatively resource-intensive decision support tool. We test whether, and to what extent, learning can result from the use of successive generations of real life climate scenarios, and how non-probabilistic uncertainties can be handled through adapting the principles of ROA in coastal economic adaptation decisions. Using a relatively simple form of ROA on a vulnerable piece of coastal rail infrastructure in the United Kingdom, and two successive UK climate assessments, we estimate the values associated with utilising up-dated information on sea-level rise. The value of learning can be compared to the capital cost of adaptation investment, and may be used to illustrate the potential scale of the value of learning in coastal protection, and other adaptation contexts.

1. Introduction

Global sea levels have risen ~0.20 m in the last century (Church et al., 2013), and there is widespread agreement that sea levels will continue to rise during the 21st century (Jenkins et al., 2009; IPCC, 2014). Along with this increasing hazard, the growth of coastal populations world-wide (Nicholls, 1995) is leading to increased exposure to coastal flooding, particularly for coastal infrastructure that facilitates economic growth in these regions (Hall et al., 2006; Brown et al., 2011). These pressures are likely to require consideration of substantial future infrastructure investment (European Environment Agency, 2014), though the costs of such investments would involve making trade-offs with competing scarce economic resources (Hunt, 2008; Chambwera et al., 2014). In this context, the economic appraisal of adaptation investments for coastal infrastructure becomes an important part of the decision-making process, though public acceptability and technical feasibility remain binding constraints on such an investment decision. This paper investigates practical aspects of such appraisals, particularly relating to the treatment of uncertainties, the role of learning, and the user-friendliness of the methods used to make such appraisals.

For several decades now, determining the accurate magnitude of future sea-level rise (SLR) has been a priority in global/national climate change assessments (IPCC, 1990, 2001, 2013). The complexity and scale of the physical processes involved in estimating future SLR (i.e. glacial, atmospheric, ocean, land), however, means there remains uncertainty surrounding future magnitudes (Horton et al., 2014). Despite the early acknowledgement of the usefulness of probabilistic or stochastic information, the majority of national sea-level projections remain largely deterministic (e.g. Katsman et al., 2011; Lowe et al., 2009; Howard et al., 2014). More recently, though, efforts have been made towards quantification of uncertainties (e.g. Kopp et al., 2014; Grinsted et al., 2014; Jackson and Jevrejeva, 2016), and it is therefore reasonable to ask what effect improved stochastic estimates of sea-level rise

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Abbreviations: AC, adaptation costs; CBA, cost benefit analysis; C_C, capital costs; C_{CM}, coastal maintenance cost; C_{IM}, inland maintenance costs; DC, damage costs; d, lateness (delay) time; DMC, do minimum costs; EBCR, expected benefit cost ratio; ENPV, expected net present value; I_{pass}, direct economic impact of passenger disruption; IPCC, Intergovernmental Panel on Climate Change; L, lateness time; vt, lateness value; n_{pass}, number of passengers; NPV, net present value; PVB, present value benefits; PVC, present value costs; ROA, Real Options Analysis; SES, socio-economic scenario; SLR, sea-level rise; UKCP, United Kingdom Climate Programme; UKCIP, United Kingdom Climate Impact Programme; VTT, value of travel time

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might have on investment decisions related to vulnerable coastal infrastructures.

Traditional economic appraisal techniques such as Cost Benefit Analysis (CBA) are somewhat limited in their effectiveness in handling the type of non-probabilistic uncertainties associated with projections of future climate change (Turner et al., 2007; Watkiss et al., 2015). Furthermore, adaptation decisions such as those associated with infrastructure may not always need to be "all-or-nothing" investments, and as long as some flexibility in construction design exists they can be characterised as choices along defined continua of costs, risks and benefits that change over time. Thus, decision analysis is likely to be improved if it can explicitly incorporate the uncertainty of future conditions in estimating the economic value of adaptation investments. It is also important to recognise that these uncertainties may diminish over time as a result of improvements in forecasting techniques and availability of observational data. In this case, a more dynamic form of decision-making may be beneficial (Mun, 2002).

A variety of methods to better handle uncertainties in adaptation responses to climate change risks has been proposed, including, for example, Real Options Analysis (ROA), Portfolio Analysis (PA) and Robust Decision Making (RDM) (Watkiss et al., 2015; Dittrich et al., 2016). Indeed, there is a recognition in a number of user communities that these methods may have some merit; an often-cited example is the UK guidance on economic appraisal of adaptation published in order to stimulate uptake of such methods (HM Treasury, 2009). Of the potential alternatives to traditional appraisal methods such as CBA, ROA is promoted on the basis that it incorporates the concept of flexibility in responding to changing patterns of uncertainty and learning over time (Dittrich et al., 2016). ROA gives two types of results (or value) that set it apart from conventional economic analysis (Watkiss et al., 2015). Firstly, through the identification of deferred benefits of waiting for new information, rather than investing immediately, it can promote the delaying of adaptation responses. This is possible if the benefits of the new information outweigh the costs of waiting. Alternatively, in projects which fail conventional CBA it can promote initial action or the potential for future investment by providing an economic tool to incorporate the value of flexibility, e.g. to expand, contract or stop adaptation measures.

Evolving from financial options valuation (e.g. Black and Scholes, 1973; Merton, 1973), ROA allows investment decisions to account for future uncertainty by delaying action until more evidence (e.g. data or learning) becomes available, thereby allowing a more informed decision. It allows the decision maker to value the current investment risk with uncertain future outcomes. ROA is therefore likely to be most relevant for long life-time projects where uncertainties may be more significant in the estimation of economic efficiency (Kontogianni et al., 2014; de Neufville et al., 2009). Consequently, it is thought to be particularly useful for infrastructure-based investment decisions that need to account for climate change risks (Glanemann, 2014). Possible improvements in computer processing capabilities, combined with developments in climate science and improved knowledge of the extent and timing of climate change risks as a result of improvements in climate data, are recognised as offering potential means through which learning can occur (Ingham et al., 2007; Hulme and Dessai, 2008; Glanemann, 2014).

Current practice has been slow to adopt these decision methods in adaptation appraisal; anecdotal evidence suggests that their relative complexity and resource-intensiveness may be responsible for the low level of take-up (Herder et al., 2011). Furthermore, the validity of ROA in informing real-world decisions depends in part on the degree to which learning is actually possible. Previous studies (see Woodward et al., 2013; Kontogianni et al., 2014, and; Linquiti and Vonortas, 2012) undertake simulation exercises in the coastal adaptation context that impose hypothetical assumptions regarding rates of learning and decision time-frames in order to demonstrate the principles of ROA. Consequently, it is relatively straightforward to show that the inclusion of a time-dynamic dimension in the economic analysis is likely to be beneficial. In this paper, we test the validity of these assumptions by using national climate data in the context of the analysis of a section of iconic coastal rail infrastructure that is potentially vulnerable to sea-level rise in South-West England (Dawson et al., 2016). Specifically, we utilise two sequential sets of climate projections, endorsed and published by the UK Climate Impacts Programme (UKCIP), that were produced eight years apart from each other but that represent the most recent sets of information to guide adaptation decisions. Thus, our ex post analysis investigates the value of new data sets used in adaptation planning and allows us to identify the option value that can result from learning between successive generations of climate scenario projections that were created precisely for informing real-life decisions. It should be noted, however, that even when new information becomes available and learning is consequently possible, the existence of option value is contingent on there being the opportunity to delay a decision that could be informed by the learning.

The operationalisation of conventional ROA also depends on being able to attach objective probabilities to the alternative scenarios of benefits/costs. As highlighted by Lowe et al. (2009), however, alternative climate scenarios are not currently characterised in terms of their objective probability of occurrence, due to a limited number of historical analogues on which to base such projections. Honest economic analysis is then forced to embrace alternative analytical methods. We therefore explore and demonstrate the extent to which the ROA method can maintain tractability by allowing the application of alternative decision rules – including maximin, maximax and the Laplace criterion (Pearce and Nash, 1981) – to be simulated by the use of subjective, analyst-determined, probabilities. We show that these can be imposed in such a way as to facilitate measures of economic efficiency under alternative assumptions regarding risk attitude preferences, where objective probabilities do not exist (see Section 2).

Finally, we respond to the perception in the potential user community that ROA is too complex to adopt in decision analysis, by identifying the simplest form with which the method can derive results that robustly inform an investment decision. In this way, we look to highlight the extent to which the method can be made accessible and so encourage its take-up in real-world decisions. In the following Section (2), we outline the method of the study, including a description of data used. We then present the results of our ex post analysis in Section 3 and follow with a discussion of their implications for the research area and some concluding remarks in Section 4.

2. Methods and Materials

We apply a modified ROA approach to the ex post economic assessment of the management of a notorious section of coastal transport infrastructure in the UK, part of the London-Penzance railway line in Devon that connects South Devon and Cornwall to the rest of the country. The coastal section of this line between Dawlish and Teignmouth stretches 4.2 miles and is currently protected by extensive coastal defences (Dawson et al., 2016). The defences and track are heavily impacted (i.e. overtopped and damaged) by storms and high waves during winter months and require periodic maintenance and improvement. The largest impact event in living memory saw the line closed for two months in 2014 (Network Rail, 2014), when a stretch of track was destroyed. This event should be seen in the context of recent (e.g. 20th and 21st century) sea-level rise that has resulted in increased overtopping events (see Dawson et al., 2016), as the distance between mean sea level and the crest of the defences is gradually reduced. Furthermore, based on observations and analysis, current projections of future sea-level rise will result in further increases in the frequency of these events (Dixon and Tawn, 1995; Haigh et al., 2011). This will result in higher associated repair costs to the network operator, as well as the disruption to passenger travel, and the prospect of the southwest region of England being left periodically without a main railway line for