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Adaptation, mitigation and risk: An analytic approach[☆]

Amos Zemel[*]

Department of Solar Energy and Environmental Physics, The Jacob Blaustein Institutes for Desert Research, Ben Gurion
University of the Negev, Sede Boker Campus 8499000, Israel

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ABSTRACT

The adaptation vs. mitigation dilemma is considered by analyzing a simple dynamic model of managing a polluting process subject to the risk of abrupt occurrences of harmful events. The occurrence hazard can be mitigated by reducing the polluting emissions, while the occurrence damage can be controlled via investments in adaptation activities. A full dynamic characterization of the optimal mitigation/adaptation processes is presented. The adaptation and mitigation policies interact strongly, and the evolution in time of each is affected by the option to implement the other. The conditions under which adaptation investments should begin promptly, take place after some delay or be avoided altogether are derived in terms of some key model parameters.

1. Introduction

Aware of the possibility that future developments might entail undesirable consequences, a far-sighted planner should consider various means and methods of avoiding the damage. An obvious response would call for action to reduce the probability that the harmful event will indeed occur. In many situations, such *mitigation* activities can reduce the risk but not eliminate it completely. In such cases an alternative course of action might involve investments to reduce the loss inflicted upon occurrence. This type of response, aimed at decreasing the damage from the harmful events, should they occur in spite of the efforts to mitigate the risk, is usually referred to as *adaptation*. An obvious management problem addresses the optimal mix and the relative timing of implementing the two types of response. The problem, then, can be described as the 'mitigation/adaptation dilemma' (Smit et al., 2000; Tol, 2005; Shalizi and Lecocq, 2010; Crépin et al., 2012; Konrad and Thum, 2014).

Problems of this type are encountered at all levels of human activity. For example, a single household or a small firm can use locks, build fences and install alarm systems to protect its property. Such self-protection measures can reduce but not

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[*] Tel.: +972 8 6596925; fax: +972 8 6596921.
E-mail address: amos@bgu.ac.il

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eliminate the probability of an illegal entry, so the firm can purchase insurance at the market, or else take steps to reduce the possible damage from a future burglar in-break. The latter, adaptation-type activity is also known as self-insurance (see Ehrlich and Becker, 1972). As another example, we consider vehicle safety. Improved braking, steering, lighting and signalling systems, as well as modern on-board radar-based alarm devices, all contribute to reduce the chance of a road accident, hence can be classified as mitigation. On the other hand, safety belts, air-bags and reinforced structural elements are important to reduce the damage that such accidents entail, hence contribute to adaptation. The mitigation/adaptation problem in this case assumes the form of choosing an optimal combination of safety devices within a manageable budget. On a national level, a government may be concerned by the prospects that some deadly disease will infiltrate its borders. As a precaution, it can enforce tight inspection procedures at its airports and other points of entry or initiate a large scale advance vaccination program to mitigate the risk. As adaptation measures, it might accumulate a stock of appropriate medicines or prepare local medical personnel to control the disease, should it, nonetheless, arrive.

A recent problem of global concern relates to the possibility of climate change. It is now widely recognized that mitigating global environmental problems requires international cooperation which is hard to achieve and sustain. Suspecting that mitigation policies may not suffice to prevent the harmful outcomes, an economy can invest resources in adaptation efforts to moderate these outcomes. For example, a flat coastal country might conclude that global efforts to reduce CO_2 emissions are not intense enough to avoid a sea-level rise and the catastrophic floods it entails. A possible response can take the form of investments in the protective dike system as well as in improved pumping capacities and inland transfer of essential infrastructure.

The mitigation/adaptation problem involves complex dynamic aspects. When the occurrence time can be predicted well in advance, it is relatively simple to evaluate the benefits of adaptation and compare them with its cost. However, when this time is subject to uncertainty, interesting tradeoffs arise. First, we have the usual considerations of investment under uncertainty, namely the tradeoff between the advantage of early investment and the value of the option to wait. Second, the limited investment resources must be allocated between adaptation and mitigation. In fact, these two kinds of tradeoffs interact, and the option to implement one type of response strongly affects the other (Kane and Shogren, 2000). A well known example of such interactions, in the context of the insurance example discussed above, is the moral-hazard phenomenon: feeling secure after some coverage is purchased, the household may be induced to neglect self-protection because the damage costs are transferred to the insuring agency or reduced by self-insurance. The present work offers a dynamic analytic framework to study such interactions.

In many real-world applications the solution can be obtained only by numerical methods. Integrated Assessment Models are powerful tools to analyze the complex dynamics of the multidimensional systems involved. Recent work, e.g., van der Ploeg and de Zeeuw (2013) and Bosello et al. (2013) and references therein, incorporate adaptation activities into such models to study numerically whether these activities are complementary or substitute the mitigation efforts and what is the effect of the state of development of the economies in question on the dynamic tradeoffs between the two types of policy response.

In this work we adopt an analytic approach in order to investigate explicitly the mechanisms driving such tradeoffs. Since the dynamic optimization problem is rather involved, the first attempts in this direction included only one of the policy measures as a fully dynamic variable. An important step is presented in Tsur and Withagen (2013) who study optimal adaptation activities in a growing economy. Their model, however, ignores the role of mitigation. A complementary research effort is presented in de Zeeuw and Zemel (2012), where the optimal mitigation of the occurrence hazard is derived. The model of de Zeeuw and Zemel (2012) also includes adaptation investments, but the latter take the simple form of a single instantaneous purchase of off-the-shelf adaptation technology in order to reduce the damage before it is inflicted. The dynamics of the adaptation policy reduces, therefore, to the determination of the optimal time (prior to occurrence) to buy the technology. Nevertheless, the analytic results reveal the strong interaction between adaptation and mitigation and show how the implementation of one affects the other.

The first analytic study in which both mitigation and adaptation are treated as fully dynamic variables is Bréchet et al. (2013) where the dependence of the optimal policy on the stage of economic development is derived. The present work incorporates also uncertainty (in the form of occurrence probability) as yet another dynamic variable. Thus, the pollution stock affects the occurrence hazard (rather than the utility function as in Bréchet et al., 2013) hence mitigation (reduced emission) is directly aimed here at decreasing the risk. Moreover, our attention in this work is focused on the dynamic structure of the optimal adaptation process which determines the damage upon occurrence. We derive conditions under which adaptation begins promptly, is initiated after some delay, or is avoided altogether. A particularly interesting manifestation of the interaction between the two policy measures is the non-monotonic evolution of the pollution process or of the adaptation capital stock, established here under some conditions. For example, if the initial pollution stock is exceedingly large, adaptation investments proceed at the maximal rate and bring the adaptation capital to well above its steady state stock. Only after mitigation has decreased pollution (and the associated hazard) considerably, can the adaptation investment be reduced to a correspondingly moderate rate so as to allow the capital stock to shrink back to its stationary value.

The model developed in the following section is presented as the optimal management of a stock of pollution. This is done for the sake of clarity of exposition and to help build an intuition for the roles played by the various components of the model. In fact, our aim here is to study the dynamic tradeoffs of mitigation, adaptation and uncertainty in a general setting, abstracting from any consideration that might be relevant only to some particular application. The resulting parsimonious