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Analysis

Policy dilemma of innovation: An info-gap approach

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ABSTRACT

New ideas or technologies are often advocated because of their purported improvements on existing methods. However, what is new is usually less well-known and less widely tested than what is old. New methods may entail greater unknown dangers as well as greater potential advantages. The policy maker who must choose between innovation and convention faces a dilemma of innovation. We present a methodology, based on info-gap robustness, to deal with the innovation dilemma. We illustrate the approach by examining the policy decisions for managing the light brown apple moth in California.

1. Introduction

Many policy decisions require choice between options where one of the options is potentially better in the outcome but markedly more uncertain. This is particularly prevalent when the putatively better option employs innovations that are more uncertain by virtue of their newness. Policy makers face an "innovation dilemma" when choosing between a more promising but more uncertain option and a less promising but better known option. This paper presents an approach to dealing with this dilemma, based on info-gap theory.

Innovation dilemmas are quite common in policy analysis and we now discuss several examples.

The decision whether to introduce new agricultural production technology, and what concomitant actions to take, is often an innovation dilemma. Adoption of new agricultural production technology reduced labor use but increased the use of manufactured inputs such as fertilizers, pesticides, and machinery, and, more recently, genetically engineered seed varieties and information technology (Carlson and Castle, 1972; Osteen and Szmedra, 1989; Weibe and Gollehon, 2006). Agricultural productivity increased (Ball et al., 1997), but some innovations caused unanticipated and undesirable human health and environmental effects such as water pollution, pest resistance to pesticides, or food safety concerns, resulting in new laws and programs to reduce those effects (Fernandez-Cornejo et al., 1998; Osteen and Padgitt, 2003). Some innovations include intentional introductions of exotic species such as food crops, ornamentals, animals, or biological pest controls, that have uncertain production, consumption, or environmental benefits, and also uncertain risks because some intentionally introduced species have become damaging pests (Osteen and Livingston, 2011). Policy responses include pest risk assessments before deciding whether to allow introduction of new species (Australian Government, 2008; United States Department of Agriculture, 2011a,b).

Increased international trade of agricultural commodities can also create innovation dilemmas. International trade can contribute to lower prices and increased consumption choices. However, international trade may also facilitate the unintentional movement of invasive crop pests and foreign animal or zoonotic diseases that damage production or increase costs in new countries and regions, where natural pest or disease controls might not exist. This may threaten export markets if other countries restrict or ban imports that potentially carry quarantine pests or communicable diseases (Livingston et al., 2008; Mumford, 2002). Some exotic organisms, including pests or diseases, move to new locations without the aid of human commerce (Botkin, 2001). The policy maker must decide whether to

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increase international trade, aiming to achieve new benefits despite new risks, or to remain with current trading restrictions with current benefits and relatively better-known risks. Specifically, policy responses to protect agricultural production and other values include programs to prevent the entry of pests, such as import restrictions or bans, but also programs to eradicate or manage pests or disease that do enter new locations (Livingston et al., 2008; Mumford, 2002).

Eradication and control programs also present innovation dilemmas. The intended better outcomes of eradication or control programs can include higher productivity by preventing production losses, reducing grower pest control costs, maintaining or opening interstate or foreign export markets by keeping areas pest or disease free, or reducing environmental damage. However, these desired outcomes are quite uncertain because some pests are not as damaging as originally estimated, or some programs do not successfully prevent or control the pest and can become ineffective uses of public funds, or have undesirable environmental consequences, or result in unanticipated public controversies. Whether to intervene is the crux of the problem that public agencies face when addressing exotic pest introductions. “Doing nothing” is the same as “no control”, or letting the growers address their pest infestations without a government pest control program. It is standard procedure in the economics of pest control to compare a control program (or practice) to “no control”, especially if no alternative program or practice is available, because “no control” can be economically superior. For example, the economic threshold concept is based on the idea that pesticides should only be applied when damage reductions exceed the costs of material and application, otherwise it is economically efficient to accept the pest damage without control. Examples of controversial programs implemented in the United States to protect commercial agricultural production include eradication programs for citrus canker in Florida, Mediterranean fruit flies, and, more recently, light brown apple moth in California (Carey, 1992; Florida Department of Agriculture and Consumer Services and Division of Plant Industry, 2004; Garvey, 2008). The citrus canker program involved the destruction of commercially- and residentially-owned citrus trees at large public expense, angering many residential land owners, while the Mediterranean fruit fly and light brown apple moth programs involved public outrage with public aerial pesticide spray programs affecting residential areas.

These are all examples of what we will call, generically, innovation dilemmas. They all entail the choice between a new and putatively better but relatively uncertain option, and a more familiar but less attractive option. The distinctive feature of an innovation dilemma is the severe lack of information or understanding on some critical aspects of the situation. Most pertinently, probability distributions of these aspects are lacking.

In Section 2 we present a brief overview of info-gap theory, a non-probabilistic approach for managing severe uncertainty, that underlies our proposed methodology for managing innovation dilemmas. In Section 3 we formulate the light brown apple moth (LBAM) case study that demonstrates this method. In Section 4 we identify the available policies and the uncertainties, and we define the robustness function for an application with T time periods. In Sections 5 and 6 we discuss 1- and 2-period examples. In Sections 7 and 8 we extend the example by considering first the effect of uncertain discount factor and then the influence of the decision maker's prior beliefs. Which of the implementations in Sections 5–8 a decision maker would adopt depends on the specific case: its duration and what factors—such as discounting or prior beliefs—are relevant or uncertain.

2. Overview of Info-gap Decision Theory

Knight (1921) distinguished between *risk* where uncontrolled events are described by probabilities, and *uncertainty* where probabilities are unknown. Many researchers focus on risk. Others have studied less complete information (Gilboa and Schmeidler, 1989; Kelsey, 1993) or pure Knightian uncertainty with techniques such as maximin, maximax, Laplace, Hurwicz, and minimax regret (Render et al., 2012).

Info-gap decision theory (Ben-Haim, 2006) also supports decision making with Knightian uncertainty. An info-gap is a disparity between what *is known*, referred to as the nominal model, and what *needs to be known* in order to make a reliable decision. The main decision support tool is the robustness function, which is based on three elements: a model of uncertainty, a model of the system that generates outcomes, and a performance requirement. Comparisons between info-gap theory and other methods can be found in Burgman (2005), Knoke (2008), and Hall et al. (2012).

An info-gap model represents uncertainty as an unbounded collection of nested sets. This is non-probabilistic—and hence Knightian—and requires no specification of a worst case. Many specific realizations of info-gap models are available for representing different types of initial information (Ben-Haim, 2006).

The uncertainty model, system model, and performance requirement are combined in the robustness function that supports the decision. A decision is robust if it achieves an acceptable outcome over a large range of uncertain realizations. More robustness is preferred over less robustness, so the robustness function prioritizes the available options. An info-gap robust optimal decision maximizes the robustness of an adequate outcome where ‘adequate’ is user defined. A similar notion of robustness has recently emerged in mathematical programming models of decisions in risky environments (Darinka and Ruszczynski, 2010).

Info-gap theory (Ben-Haim, 2006) originated in engineering, with applications in many areas including truss design (Kanno and Takewaki, 2006), structural optimization (Tang et al., in press), fault detection (Pierce et al., 2006), water resource management (Hine and Hall, 2010) and wireless sensing (Chinnappen-Rimer and Hancke, 2011). However, there are also applications of info-gap theory to decisions under uncertainty in many other disciplines. Applications include modeling (Ben-Haim and Hemez, 2012), forecasting (Ben-Haim, 2009), economic policy (Ben-Haim, 2010), search behavior in animal foraging (Carmel and Ben-Haim, 2005), policy decisions in marine reserve design (Halpern et al., 2006), natural resource conservation decisions (Moilanen and Wintle, 2006), forest economic policy (Hildebrandt and Knoke, 2009), energy economics (Zare et al., 2010), inspection decisions by port authorities to detect terrorist weapons (Moffitt et al., 2005) or invasive species (Moffitt et al., 2007), animal disease detection (Souza-Monteiro et al., 2012), and more (see http://info-gap.com).

We summarize here the main attributes of the info-gap robustness function, which is a plot of robustness-to-uncertainty versus required performance. This is the basic info-gap tool for prioritizing available options.

Robustness trades off against performance (Ben-Haim, 2000; Ben-Haim and Hemez, 2012). Higher performance requirements are less robust against uncertainty than lower requirements. This trade off is quantified and expressed graphically by monotonicity of the robustness curve.

Best-model predictions have zero robustness against uncertainty (Ben-Haim, 2005). It is unrealistic to prioritize one's options based on predicted outcomes of those options. Options should be evaluated in terms of the level of performance that can be reliably achieved, expressed by robustness.

Combining the trade off and zeroing properties yields realistic prioritization of options.

Prioritization of options depends on performance requirements. Prioritization of options may change as requirements change. This is called “preference reversal” and is expressed by the intersection of the robustness curves of different options. Preference reversal provides insight to anomalous behavior such as the Ellsberg and Allais paradoxes in human decision making and the equity premium puzzle in economics (Ben-Haim, 2006), and animal foraging (Carmel and