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An auction mechanism for the optimal provision of ecosystem services under climate change

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A B S T R A C T

The provision of many ecosystem services depends on the spatial pattern of land use across multiple landowners. Even holding land use constant, ecosystem service provision may change through time due to climate change. This paper develops an auction mechanism that implements an optimal solution for providing ecosystem services through time with multiple landowners who have private information about the net benefits of alternative uses of their land. Under the auction, each landowner has a dominant strategy to truthfully reveal their private information. With this information a regulator can then implement the optimal landscape pattern, which maximizes the present value of net benefits derived from the landscape, following the rules of the auction mechanism. The auction can be designed as a subsidy auction that pays landowners to conserve or a tax auction where landowners pay for the right to develop. Our mechanism optimizes social adaptation of ecosystem management to climate change.

1. Introduction

The provision of ecosystem services often depends on the land-use decisions of multiple landowners. Many ecosystem services, such as carbon storage that contributes to climate regulation, filtration of nutrients and pollutants that contribute to water quality, or provision of habitat that supports wildlife, are not traded in markets and landowners generally receive little benefit from managing their land in ways that increase the provision of these services. Therefore, under-provision of ecosystem services occurs in the absence of a policy mechanism to internalize the external benefits to the landowner. The problem of internalizing the provision of ecosystem services benefits is made more complex by dynamics where ecosystem service benefits change through time both as a function of on-going land-use decisions and climate change.

This paper develops an auction mechanism that implements an optimal solution for the provision of ecosystem services in an environment that changes over time. Our mechanism contributes to conservation policy aimed at social adaptation of ecosystem management to climate change. There are five important elements to the problem of internalizing landscape-scale externalities under climate change: i) spatial dependencies, ii) asymmetric information, iii) dynamics that change the net

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benefit function over time, iv) uncertainty about future net benefits, and v) irreversible decisions. Prior literature has dealt with a subset of these issues, but no prior paper – to the best of our knowledge – has dealt with all five issues.

Knowledge of the ecological production function is necessary to optimally provide ecosystem services (NRC, 2005; Barbier, 2007; Polasky and Segerson, 2009) and many production functions are characterized by spatial dependencies – the contribution of one parcel of land to the provision of an ecosystem service depends on the land use on spatially proximate land (Mitchell et al., 2015a, 2015b). For example, the contribution of a patch of habitat to species conservation depends on fragmentation and connectivity with other patches of habitat (Fahrig, 2003; Armsworth et al., 2004). Robinson et al. (1995) provides empirical evidence that the success of breeding birds on a piece of forestland depends on the fragmentation of nearby forestland, and recent global analyses have highlighted that current levels of forest fragmentation may be close to a critical threshold where further forest loss greatly accelerates fragmentation (Taubert et al., 2018). The "Where to Put Things" approach developed in Polasky et al. (2008) illustrates a production possibilities frontier characterizing efficient outcomes for species conservation and market returns to landowners, where species conservation depends on landscape pattern (i.e., spatially-dependent benefits).

Optimal provision of a spatially-dependent ecosystem service relies on a decision-maker, such as a land-use planner (hereafter called the regulator), having complete information about net benefits of land-use alternatives. However, the opportunity cost of conserving a piece of land – a necessary piece of information to implement the "Where to Put Things" approach – is typically private information. The opportunity cost of choosing to conserve a parcel of land depends in part on landowner skills, knowledge, expectations, preferences, attachment to and history with the land. Having a regulator dictate outcomes will likely yield an inefficient outcome if landowner-specific benefits and costs are not incorporated. Voluntary approaches that give decision-making power to landowners can overcome this problem. However, without full information on landowner benefits and costs, landowner decisions under voluntary incentive programs are unlikely to be socially optimal (Lewis et al., 2011).

Polasky et al. (2014) – hereafter PLPN – developed an auction mechanism in which landowners have a dominant strategy to truthfully reveal private information, which the regulator can then use to implement an optimal land-use pattern. The auction mechanism in PLPN builds from the work of Vickrey (1961), Clarke (1971), and Groves (1973), and extends it to the case of multiple landowners whose actions jointly determine spatially-dependent net benefits. An important result from PLPN is that spatially-dependent ecosystem service benefits require information across multiple landowners so that internalizing the externality requires a mechanism in which landowners truthfully reveal private information.

This paper's primary contribution is to develop a dynamic extension of the PLPN auction mechanism and apply it to the problem of providing spatially-dependent benefits under climate change. The PLPN mechanism is static and not well-suited to dealing with three key characteristics of internalizing landscape-scale externalities under climate change. First, the spatial dependencies that affect ecosystem service provision from land are likely to change over time. For example, the suitable range of many species is expected to shift under a changing climate (Thomas et al., 2004; Thuiller et al., 2005; Lawler et al., 2009; Staudinger et al., 2013) and there may be significant barriers to species migration to new locations including unsuitable habitat between old and new habitat locations and the speed of movement (Opdam and Wascher, 2004; Lawler et al., 2013). Second, future provision of ecosystem services is typically uncertain. Uncertainty arises both because of uncertainty about future climate and how ecological systems will change with climate change (e.g., Millar et al., 2007; Nordhaus, 2014). Several papers analyze the optimal solution of spatial-dynamic resource problems (e.g., Sanchirico and Wilen, 2005; Costello and Polasky, 2008; Smith et al., 2009; Wätzold et al., 2015), but this literature assumes the planner has complete information (i.e., no asymmetric information), and often assumes there is no uncertainty.

Third, many land-use changes (e.g. development to urban uses, cutting old-growth forest, etc.) are irreversible, or only reversible at large cost or with a long time lag. The failure to prevent land-use changes that are costly to reverse reduces the ability to manage adaptively under an uncertain future (Albers, 1996). Analysis of the land conservation problem under uncertainty and irreversibility dates back to the seminal article by Arrow and Fisher (1974). Maintaining flexibility and avoiding irreversible decisions gives rise to option value (Arrow and Fisher, 1974; Henry, 1974). Subsequent studies extended and refined the concept of option value (Hanemann, 1989; Dixit and Pindyck, 1994; Albers, 1996; Traeger, 2014), applied the concept to urban development (Mills, 1981) and biodiversity conservation (Kassar and Lasserre, 2004; Leroux et al., 2009), and more recently have argued for its importance to the problem of conservation planning under climate change (Mezey and Conrad, 2010).

This paper develops an auction mechanism that implements an optimal solution to the problem of provision of ecosystem services subject to spatial dependencies, asymmetric information, dynamics, uncertainty, and irreversible decisions. The auction mechanism combines four classic strands of economic literature associated with Pigou, Coase, Arrow-Fisher, and Vickery-Clarke-Groves. The auction mechanism builds off Vickery-Clarke-Groves mechanisms and works as follows. Each landowner simultaneously submits a two-part bid for how much they would need to be paid to forgo development on their land today and in the future (e.g., converting natural habitat for farming or housing). A landowner's bid will be accepted by the regulator if and only if the expected contribution to ecosystem service benefits with conservation is at least as large as the value of development as revealed by the bid. If the bid is not accepted, the landowner can develop the parcel and earn returns from the development. If the bid is accepted, the landowner is prohibited from developing their parcel in the current period and receives a Pigouvian payment from the regulator based on the parcel's contribution to current ecosystem service benefits and option value. In the future period, whether development is prohibited or allowed depends on whether the gain in social