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Analysis

Valuing tradeoffs between agricultural production and wetland condition in the U.S. Mid-Atlantic region

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ABSTRACT

This study uses the directional output distance function, a multi-output economic production frontier model, to value the physical tradeoffs between agricultural production and wetland condition in the U.S. Mid-Atlantic region Nanticoke River watershed. We combine detailed ecological indicator data to measure wetland condition with satellite imagery land use data on agricultural production in the watershed. Our estimation procedure adapts the bootstrap methods originally developed by Simar and Wilson (1998) for nonparametric efficiency estimates to the quadratic directional output distance function. We find substantial variation in tradeoff values across the watershed, which could be used to target wetland conservation efforts in the region.

1. Introduction

Wetlands provide numerous ecosystem services that support a variety of human activities. In the lower 48 conterminous U.S. states, less than half of the estimated 220 million wetlands that existed prior to European settlement remain today, and many of these are considered degraded (U.S. EPA, 2009). Primary sources of wetland degradation, particularly in rural areas, include many of the activities that support agriculture, such as drainage and tilling for crop production, stream channelization and fertilizer runoff (Dahl, 2011).

Current U.S. environmental policy seeks to protect and recover wetland areas, primarily through the Clean Water Act (1977), which regulates the dumping of dredge and fill materials, by funding wetland restoration projects using the North American Wetlands Conservation Act (1989), and by purchasing voluntary land use easements through programs such as the USDA's Wetlands Reserve Program (WRP) and Conservation Reserve Program (CRP). Under these policies, the granting of pollution permits and the selection of projects for conservation funding rely on an implicit understanding of the associated costs and benefits of wetland management to society, even when these values are not directly observed.

In this study, we examine the relationship between wetland condition and agricultural production in the Nanticoke River Watershed, which supports a significant and ecologically diverse system of wetland communities in the Mid-Atlantic region of the United States. Agriculture and timber production account for the majority of the land use in the study watershed, and their associated drainage and channelization activities can significantly alter the hydrological function and biological integrity of surrounding wetland areas (Whigham et al., 2007). Wetland condition supports an array of wetland ecosystem services in the watershed, including flood control, water filtration, biodiversity, and riparian habitat.

To estimate the value of this tradeoff at the watershed scale, we model an ecological index of wetland condition jointly with agricultural output as part of an economic production process, using a directional output distance function (Chambers et al., 1996) approach. The directional output distance function is a multi-output production frontier model that is also dual to the revenue function in production theory. We exploit that duality to estimate the value of marginal wetland condition improvements in terms of their opportunity cost to agricultural

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production. We find in our application that the tradeoff between condition and production is relatively costly for many of the wetland sites in the watershed. Conceivably, this price information could be used to prioritize wetland conservation efforts and influence land use policy in the watershed, by identifying the sites where best management practices such as riparian buffers and habitat remediation could achieve greater improvements to wetland condition at a lower cost of foregone agricultural production.

Our use of production theory presents a relatively novel approach to valuing this tradeoff in terms of ecological condition rather than wetland area, which we believe is the major contribution of this study. This framework allows us to evaluate the tradeoffs between agricultural production and wetlands, using scientific measures of wetland condition change that are familiar to environmental managers in practice. While numerous studies have examined the value of wetland areas,[1] few address the value of changes in wetland quality (Acharya, 2000; Ragkos et al., 2006). We know of no other studies that examine the question of condition, using wetland indicators similar to those used in this study. Moving away from the case of wetlands, we more generally present a way to incorporate quantitative ecological indicator data into an economic valuation model that could be applied to other tradeoffs between production activities and the environment.

The next section outlines the theory supporting this approach, followed by a discussion of our estimation procedure. We then present the results of our application to the Nanticoke River watershed in the United States Mid-Atlantic region.

2. Underlying Theory

To estimate the tradeoff between wetland condition and agricultural production, we model their joint production on land within a watershed area. Let $P(x)$ denote the feasible output set for the vector of outputs $y = (y_1, \ldots, y_M) \in \Re_+^M$ given inputs $x = (x_1, \ldots, x_N) \in \Re_+^N$, so that

$$P(x) = \{y : x \text{ can produce } y\}. \quad (1)$$

In this context, outputs include an ecological index of wetland condition and the value of nearby agricultural production. The index of wetland condition is comprised of ecological indicators for separate aspects of wetland condition, including hydrology, vegetation and soil condition. Watershed land area constitutes the shared input in this joint production process.

Following an axiomatic approach, a series of standard assumptions are made to characterize the production technology in theory, and to then guide the empirical specification of the model. These include convexity, compactness and free-disposability.[2]

Given these assumptions, the directional output distance function provides a complete representation of the feasible output set (Chambers et al., 1996), as well as individual measures of performance for each of the included output observations. The directional output distance function is defined as

$$\vec{D}_O\left(x,\ y; g_y\right) = max\left\{\beta : \left[y + \beta g_y\right] \in P(x)\right\}, \quad (2)$$

where $g_y \in \Re_+^M$ is a directional vector that specifies the path of output expansion. The mathematical properties of the directional output distance function follow from the assumptions made to characterize $P(x)$, and allow for complete representation of the feasible output set. These include Representation, Monotonicity and Translation.[3] As illustrated in Fig. 1, the model measures each observation's distance, in a particular direction, to the production frontier. Thus, for observations on the frontier, $\vec{D}_O\left(x,\ y; g_y\right) = 0$, and for any observation below the frontier, $\vec{D}_O\left(x,\ y; g_y\right) > 0$. Individual performance deteriorates with distance to the frontier, so that the distance value can be interpreted as a measure of inefficiency for each observation.

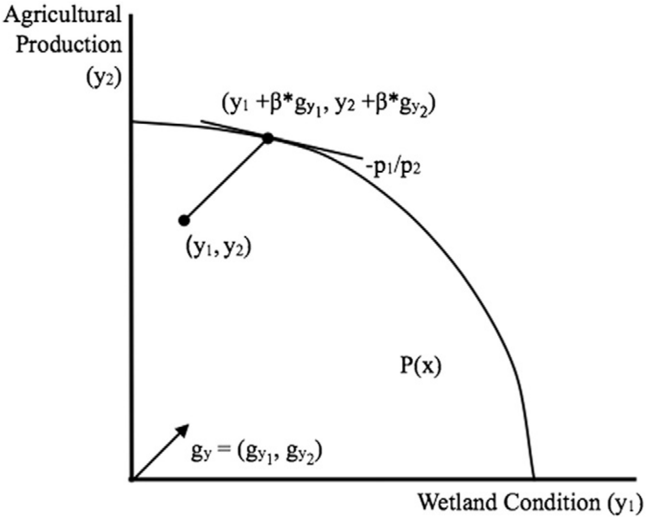

Fig. 1. Directional output distance and tradeoff value.

Inefficiency in this context implies that it is physically possible to increase both agricultural production value and wetland condition, given the observed production values of other observations in the watershed. Such a joint improvement could potentially be achieved through practices such as fallowing land to improve soil quality and reduce runoff, or by using buffers to mitigate the effects of more intensive crop production activities. While we assume that land is homogeneous in this study, in practice, some land may simply be more productive for both wetlands and agriculture due to factors such as soil composition, gradient and exposure.

Distance functions also impose no explicit functional form on the relationship between inputs and outputs, instead allowing the data to reveal the production process. This serves, in some sense, as a double-edged sword. On the one hand, the lack of an a priori functional form allows for greater flexibility in the estimation process and the potential to better understand how inputs jointly produce outputs for individual observations. On the other hand, this framework may ignore important physical relationships between inputs and outputs that could affect the resulting technology estimate.

Both points are relevant to this study. Many of the activities associated with agricultural production (e.g., drainage, chanelization and runoff) have been cited as primary contributors to degraded wetland condition in our study area. However, the biophysical relationship between agricultural production and wetland condition is not explicitly known. Instead, we use observed combinations of wetland condition and agricultural production across the landscape to better understand the underlying physical relationship and its associated opportunity cost. In the absence of a known biophysical relationship, we believe that this estimate of the technology sheds more light on the tradeoff between agricultural production and wetland condition and how this tradeoff may change for individual wetland sites across the watershed. It does not, however, directly consider the underlying ecological and socioeconomic processes driving this tradeoff.

We use this approach to construct the feasible output set for a vector of wetland condition index and agricultural production values within a watershed area, which enables environmental performance assessment for each of the observation sites (Bellenger and Herlihy, 2009, 2010). Moreover, the resulting frontier reveals the physical tradeoffs that exist between agricultural production and wetland condition in the

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[1] Refer to Brander et al. (2006) for a survey of the wetlands valuation literature.

[2] Chambers et al. (1996) discuss these properties in more detail.

[3] Chambers (1998) prove these properties for the input oriented case, and discuss their implications in more detail.