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Estimating population dynamics without population data ☆

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ABSTRACT

We develop a biologically correct cost system for production systems facing invasive pests that allows the estimation of population dynamics without *a priori* knowledge of their true values. We apply that model to a data set for olive producers in Crete and derive from it predictions about the underlying population dynamics. Those dynamics are compared to information on population dynamics obtained from pest sampling with extremely favorable results.

Introduction

Accurate representation of supply–response relationships is essential to the scientific management of natural-resource industries. An important challenge to modeling supply–response in many of those industries is the lack of population data for the biological entity that affects output. For example, the population of invasive pests is an important determinant of both pest damage and crop harvest (Lichtenberg and Zilberman, 1986; Babcock et al., 1992; Underwood and Caputo, 1996; Bulte and Rondeau, 2007; Coburn et al., 2011). But data on pest populations are typically unavailable in many practical instances. This creates a dilemma. Use models that ignore this basic biological component of the technology. Or, maintain biologically correct models that cannot be estimated without extreme assumptions on population behavior.

This paper, following Chambers and Strand (1999), proposes a potential solution. The key observation is that the separability properties of many biologically grounded models of the underlying production processes, when combined with information on rational producer supply response, can be used to circumvent this obstacle. While biologists have focused on the development of accurate yield–response relationships, economists have concentrated on developing estimable production systems. Natural synergies should emerge from combining these efforts into a common framework. We show how biological models can be combined with information on supply response to make inferences on population dynamics and to estimate correctly specified biological production response behavior *even in the absence of direct observations on underlying population variables.*

The intuition is unabashedly simple: if a yield–response relationship is correctly specified, then once other factors affecting production levels (for example, input use and size of supply) are properly controlled for, yield effectively indexes the underlying biological population. We use agricultural data to illustrate and evaluate our procedures. And so, for concreteness sake, the conceptual treatment is for an agricultural producer facing an invasive pest species. But because the

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basic principle behind our approach is so simple, the procedures outlined here can be readily extended, after suitable adaptation, to a host of other applications. If biological populations truly affect supply response, information on supply (as well as derived demands) should mirror that effect and thus provide an avenue for recapturing information on the underlying population.

In what follows, we first specify the production model and the producer's objective function. Then we briefly characterize optimal producer behavior to establish a direct link between population variables and observable economic phenomena such as prices, supply, and derived demand. We then follow with a parametric specification of pest damage to crops and show how that choice yields a variable-cost function, consistent with biological behavior, that is estimable without direct knowledge on pest population. It also yields a procedure for approximating pest-population dynamics. An empirical specification and description of the data is followed by an empirical application of our ideas. That empirical application takes advantage of a unique characteristic of our data set, direct observations on population variables. Those data are *not* used in estimation, but they allow us to compare the population dynamics our procedure yields with actual population dynamics. Once our empirical results are presented, we then discuss the related literature. In particular, we compare our empirical results with those from an alternative approach that is grounded in the biological literature but that is applied to our data set. The paper then concludes.

The model

Structure of production and producer objective

Production of a single crop, y, in period t is characterized by

$$y = g(b,z)f(x,K,t)$$

where $x \in \mathbb{R}^J_+$ represents variable productive inputs, $K \in \mathbb{R}^K_+$ quasi-fixed productive inputs, $b \in \mathbb{R}_+$ the pest population, $z \in \mathbb{R}_+$ a damage-control or abating input, $f(x,K,t)$ is (maximal) potential supply in the absence of pests, and $g(b,z)$, $g:\mathbb{R}^2_+ \to (0,1]$, represents the percentage of maximal potential output that is realized in the presence of pest population b when the damage-control input is applied at level z.

The producer's short-run problem is to choose variable productive and damage control inputs (x,z) to maximize profit. Notationally,

$$\max_{x,z}\{pg(b,z)f(x,K,t) - w'x - v'z\} \tag{1}$$

where $p \in \mathbb{R}_{++}$ is the output price, $w \in \mathbb{R}^J_{++}$ is a vector of variable productive input prices, and $v \in \mathbb{R}_{++}$ is the damage-control input price.

We rewrite this problem as

$$\begin{aligned}\max_{x,z}\{pg(b,z)f(x,K,t) - w'x - v'z\} &= \max_{y,x,z}\{py - w'x - v'z : y = g(b,z)f(x,K,t)\}\\ &= \max_{y,x,z}\left\{py - w'x - v'z : \frac{y}{g(b,z)} = f(x,K,t)\right\}\\ &= \max_{y,z}\left\{py - c\left(w, \frac{y}{g(b,z)}, K, t\right) - v'z\right\},\end{aligned} \tag{2}$$

here

$$c(w,f,K,t) := \min_x\{w'x : f = f(x,K,t)\}$$

is the minimum variable-cost associated with the productive inputs, x, producing f in the absence of pests. The first-order conditions for an interior solution to (2) require

$$pg(b,z) = c_f\left(w, \frac{y}{g(b,z)}, K, t\right),$$

$$c_f\left(w, \frac{y}{g(b,z)}, K, t\right)\frac{yg_z(b,z)}{g(b,z)^2} = v,$$

where $c_f(w, y/g(b,z), K, t)$ denotes the partial derivative of $c(w,f,K,t)$ with respect to f. Solving gives

$$py\frac{g_z(b,z)}{g(b,z)} = v. \tag{3}$$

Expression (3) can also be obtained directly as a first-order condition for (1). The solution to these first-order conditions yields: optimal product supply, $y(p,w,K,t,v,b)$, and optimal derived demands for x and z, $x(p,w,K,t,v,b)$ and $z(p,w,K,t,v,b)$, respectively.