Analysis

When ignorance is not bliss: Pest control decisions involving beneficial insects

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ABSTRACT

Recent survey data revealed that many California citrus growers did not know whether or not important beneficial insects were found on their fields while other growers were relying heavily or even entirely on these insects for pest control. Some pesticides are toxic both to the targeted pest and the predaceous or parasitic insect that could provide pest control. Alternative pesticides with fewer or no negative effects on the beneficial insect often exist but can be more expensive. Additionally, some beneficial insects are commercially available and can be purchased and released in the field. This paper models the pest control decisions of a grower who utilizes a pesticide and a predaceous insect to control the crop pest and compares these decisions to that of a grower who does not know that the predaceous insect exists. The results show that the latter grower will drive the predator population to zero and will overutilize chemical control. When the predator is known and utilized, the optimal decisions involve entirely mitigating the negative effects of the pesticide as well as releasing additional predators.

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1. Introduction

Between 2000 and 2008, pesticide expenditures increased by 37.6% in the United States, and 2008 nationwide pesticide expenditures were 5.8% of the total nationwide expenditures on commercial agricultural inputs (USDA, 2009). Since pest control expenditures are a significant and growing share of production costs, achieving efficient pest control will significantly benefit growers. In addition to monetary costs, the use of pesticides can have a variety of negative agricultural, environmental, and health effects, totaling an estimated $12 billion for the United States alone (Pimental, 2009). A reduction in pesticide use necessarily reduces these damages.

While many growers rely on chemical control, growers can also make use of biological control, which involves the use of organisms, often insects, to control crop pests. Common biological controls include predators and parasitoids of crop pests, which provide natural pest control services through their trophic interactions with the pest. Unfortunately, many common pesticides are toxic to beneficial insects. Growers can conserve naturally occurring populations of beneficial insects by avoiding pesticides that are toxic to them and can support the populations by providing habitat and supplemental resources. Additionally, some of these insects are commercially produced, allowing growers to purchase and release them on their fields.

A recent survey of California citrus growers revealed that only about 58% of respondents with *Aonidiella aurantii* (California red scale) on their fields knew whether or not *Aphytis melinus*, a parasitic wasp that provides control of *A. aurantii*, was present on their fields (Grogan and Goodhue, 2012b). Only about 51% of all respondents knew whether or not *Rodolia cardinalis*, the primary form of pest control for *Icerya purchasi* (cottony cushion scale) was present, and only about 43% knew whether or not *Euseius tularensis*, a predator of *Panonychus citri* and *Scirtothrips citri*, was present (Grogan and Goodhue, 2010).

This lack of knowledge about the presence of beneficial insects raises an important question: How do pest management decisions differ between growers who are and are not aware that predaceous or parasitic insects are present? Using a dynamic bioeconomic model, this paper addresses this question and shows that a lack of knowledge in almost all cases results in local extinction of the beneficial insect and complete elimination of the associated pest control services. Since these services are both free and cause little to no external damages, these lost services are economically significant.

This work fits within a larger body of literature that considers optimal pest control decisions in a dynamic framework. Some of the earlier work in this area analyzes the effects of a pest's growing resistance to the pesticide on the optimal use of the pesticide over time (Plant et al., 1985; Regev et al., 1983). More recent work focuses on optimal management of invasive species across time and space (Brown and Zilberman, 2002; Ceddia et al., 2009). Some work has added a predaceous

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insect population, but without considering pesticide toxicity to the predator (Marsh et al., 2000; Schumacher et al., 2006).

Several papers outside of the economics literature consider the effects of pesticide toxicity on the predator in agricultural systems. Trumper and Holt (1998) and Sherratt and Jepson (1993) use landscape level models to determine the effect of pesticide toxicity to the predator on pest populations. They find that pest resurgences after pesticide applications increase as the pesticide's toxicity to the predator increases. Increased predator dispersal helps to dissipate this effect and helps enable the predator to persist in the system despite applications of the pesticide.

In the economics literature, three previous papers address the question at hand. Work by Harper and Zilberman (1989) and Harper (1991) examine pesticide use decisions for static and dynamic models, respectively, that include a primary pest, a secondary pest, and a predator of the secondary pest which is negatively affected by the pesticide used to control the primary pest. They find that growers who ignore the effect of the pesticide on the predator will overuse the pesticide. Feder and Regev (1975) examine pesticide use decisions using a model containing one pest and one predator. They compare optimal decisions made by a central decision maker who considers environmental effects as well as population dynamics to decisions made by an individual who only considers one period at a time. The latter decisions are inefficient due to both stock and environmental externalities.

The model that follows differs from previous work in several ways. First, this model allows the grower to mitigate the effect of the pesticide on the predator and even allows the grower to augment the predator population, allowing for a more thorough analysis of possible optimal solutions. Second, this paper considers three types of decisions: pest control without the predator present, pest control with the predator present but with its pest control services attributed to an unknown factor, and pest control with a known predator. Harper and Zilberman (1989) compare the first and third cases, but do not consider the intermediate case. Harper (1991) considers a myopic case where the predator is present and consumes the secondary pest, but the grower does not consider the damage caused by the secondary pest in their optimization problem. This essentially eliminates the predator from the optimization problem. Lastly, the analysis presented here thoroughly examines how varying economic and biological parameters affects the divergence between the non-myopic and myopic solutions, and to the best of my knowledge, is the first to demonstrate that field-level beneficial insect populations will be driven to zero under most circumstances when growers are unaware of their presence.

This paper proceeds as follows. First, the bioeconomic model is presented. A discussion of the non-myopic pest management decisions follows. This is followed by a discussion of the myopic decisions that do not account for pest control services to the predator and the decisions for the case with no predator population. Next, the decisions for a wide variety of possible parameter values are considered, and finally, conclusions and policy implications are provided.

2. Methods

The model that follows combines a biological model with an economic model to form a bioeconomic model of pest control decisions and pest and predator populations.

2.1. Biological Model

The model contains one pest and one predator of the pest. Unlike previous work, this analysis does not contain a secondary pest. Previously, conventional thought assumed that chemical control was used to control primary pests and biological control was only used for secondary pests, as demonstrated in Harper and Zilberman (1989) and Harper (1991). Now, biological control is also being used for primary pests, making such analysis relevant (Grogan and Goodhue, 2012a).

The pest and predator interaction is modeled using a Lotka–Volterra predator–prey model with logistic pest growth, following Trumper and Holt's (1998) analysis of pesticide toxicity on predator populations. In the absence of human intervention, the pest, N_t, and predator, P_t, growth functions are:

$$\dot{N}_t = \gamma N_t (1-(N_t/K)) - \mu P_t N_t \tag{1}$$

$$\dot{P}_t = \alpha \mu P_t N_t - \beta P_t \tag{2}$$

where γ and α are the pest's and predator's intrinsic growth rates, respectively, K is the pest's carrying capacity, μ is the predation rate, and β is the predator death rate. The pest carrying capacity, K, is implicitly determined by the potential crop output, described below. The predator does not have an exogenous carrying capacity because its population is constrained by the pest population, which changes over time (Tschirhart, 2009).

In the absence of human intervention, this system reaches an equilibrium where $\dot{N}_t = \dot{P}_t = 0$, which occurs when:

$$N_t = \beta/\alpha\mu \tag{3}$$

$$P_t = (\gamma/\mu)(1-(\beta/(\alpha\mu K))). \tag{4}$$

For the predator to persist in equilibrium, it must be the case that $\beta/(\alpha\mu K) < 1$. Since K is likely to be large and β is less than one, the predator will persist in most cases.

2.2. Economic Model

Following previous literature, the grower produces a crop that, in the absence of the pest, could achieve an output of $\bar{y}$, but the pest damages a proportion of the crop, N_t/K (Brown and Zilberman, 2002; Ceddia et al., 2009; Marsh et al., 2000). To control the pest, the grower has a range of pest control options. The base pesticide, referred to as level of chemical effort, E_t, has a unit price of w. This is the least expensive option, but it is toxic to the predator. The grower can mitigate this toxic effect by substituting more expensive but less toxic pesticides (with respect to the predator) that have equal pest control efficacy as the base pesticide. The level of mitigation chosen, M_t, has a unit price of v in addition to the cost of the chemical effort. The price of mitigation can be thought of as the price differential between the base pesticide and more selective options. The grower can partially mitigate the effect on the predator ($M_t < E_t$), completely mitigate the effect ($M_t = E_t$), or can choose mitigation such that the toxic effect is entirely mitigated and predators are commercially purchased and released ($M_t > E_t$). While M_t can differ from E_t, only the level of E_t determines the effect of chemical control on the pest. This situation is similar to the case of California red scale control in citrus. Growers can apply an inexpensive pesticide such as chlorpyrifos to control the scale, but this pesticide is toxic to *A. melinus*. Growers can apply more expensive insect growth regulators, which have no effect on *A. melinus*, or they can apply the insect growth regulator and purchase and release *A. melinus* (Grafton-Cardwell et al., 2008).[1] The grower's profit in each period is:

$$\pi_t = p\bar{y}(1-(N_t/K)) - wE_t - vM_t. \tag{5}$$

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[1] The grower could also potentially rely entirely on *A. melinus* for control. I assume that this is not the case for the model's pest. This assumption holds for cases where the biological equilibrium with augmentation exceeds the threshold population level at which growers apply a pesticide.