The Role of Strategic Uncertainty in Area-wide Pest Management Decisions of Florida Citrus Growers

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We conducted a choice experiment based on the theory of global games to analyze the impact of strategic uncertainty on participation decisions of Florida citrus growers in area-wide pest management programs to control the vector of citrus greening. We found that the farmers' average certainty equivalent in a strategically uncertain setting under a high coordination requirement for obtaining a Pareto superior payoff, was lower compared to that of a lottery. Moreover, we found some evidence that the perceived risk of farmers in the strategically uncertain alternative increased as the size of the group increased. Thus, our results help explain why, despite the efficiency of area-wide pest management to control the vector of citrus greening across Florida, farmers' participation is not as widespread as one would expect. To avoid the strategic uncertainty involved in relying on neighbors, many farmers choose self-reliance in spraying despite the lower payoff. As a recommendation for policy makers, we propose a top-down regulation so as to generate a bottom-up collective action to deal with the issue of strategic uncertainty in area-wide pest management to avoid the sub-optimal outcome.

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I. Introduction

The premise underlying area-wide pest management is that pests are more effectively controlled by addressing the pest population of an entire area rather than independently by each farm. Such collective efforts provide a larger and more lasting effect relative to individual (uncoordinated) farm sprays. Many area-wide pest management programs were developed precisely when individual producers or households were not capable of adequately dealing with the challenge posed by certain mobile and threatening pests (Klassen 2000). By coordinating pest control, groups may internalize externalities and increase the productivity of pest-control inputs. Importantly, however, the implementation of area-wide pest management programs can encounter resistance due to concerns over methods, free riding, general public opposition, and lack of stakeholder participation among others (Klassen, 2000).

Citrus greening or Huanglongbing (HLB) is a bacterial disease caused by the bacterium *Candidatus* Liberibacter asiaticus and vectored by the Asian citrus psyllid (ACP). No treatment or management strategy is yet available for growers to cure the disease. First found in Florida — the largest orange-producing state in the U.S. — in 2005, HLB spread rapidly across the state and reached epidemic proportions. Hodges et al. (2014) estimated the economic impact of HLB at a loss of $7.80 billion in cumulative industry output over the period 2006/07 through 2013/14.

As part of the strategic plan for the state's citrus industry to address HLB, voluntary area-wide ACP control management programs, known as Citrus Health Management Areas (CHMAs), were established in Florida in 2010. Singerman, Lence and Useche (2017) found that citrus yields of blocks located in a CHMA with higher participation were significantly higher compared to the yields of blocks located in a CHMA with lower participation. As a result, citrus blocks in CHMAs with higher levels of participation attained greater economic benefits. Their findings provided evidence about the efficiency of well-performing area-wide management areas to deal with HLB.

Economists argue that farmers should participate in area-wide pest management if the benefit of doing so outweigh the costs (Rook and Carlson, 1985; Ayer, 1997; Stallman and

James Jr., 2015). However, participation in CHMAs has not been commensurate with such evidence. At the end of 2015 there were 55 CHMAs in Florida, but only 19 out of the 55 were actively coordinating sprays. The limited participation seems counterintuitive given the significance of Singerman, Lence and Useche findings on differential yields (and associated revenue) in well-performing CHMAs. The authors also found the top reason stated by citrus growers in Florida for not participating in coordinated sprays was that other growers do not participate. That is, growers perceived (correctly or not) that other growers were reluctant to coordinate efforts to control the pest. The findings suggest that strategic uncertainty is a key consideration in growers' pest-control decision making.

In this study, we specifically analyze the role of strategic uncertainty in area-wide pest management participation decisions by Florida citrus growers. The benefits and costs and, therefore, the individual incentive for participating in an area-wide pest management program can vary across growers. This is due to multiple factors, but chiefly among them is the potentially different local level of infection and dynamics of the pest population. Therefore, to examine the impact of strategic uncertainty on growers' participation decisions in CHMAs, we designed and conducted a choice experiment that holds the above aspects constant across growers, while varying factors that others (Heinemann, Nagel and Ockenfels, 2009; Ostrom, 2010) found to influence strategic uncertainty, such as group size and coordination requirement (the latter being the percentage of growers needed for achieving a higher payoff under coordination). We also elicit responses to measure the risk growers are willing to take in a lottery and compare it to their responses in a setting in which they face strategic uncertainty instead.

Our contributions to the literature can be summarized as follows. First, to the best of our knowledge, we are the first to elicit choices from growers to examine strategic behavior in the context of area-wide pest management using the framework of global games to capture the role of higher order beliefs in participation decisions with a simple choice experiment. In addition, there are only a few studies that look into farmers' willingness to cooperate to control pests. Thus, our second contribution is to extend the discussion on factors affecting farmers' decisions to cooperate to control pests; in particular, we examine whether, and to what extent, Florida citrus growers are averse to strategic uncertainty, the role such uncertainty plays on growers' participation decisions in area-wide pest management programs, and the factors that are related to their aversion. Third, we are able to compare the stated behavior of growers in the choice experiment with their actual behavior in spray coordination.

Collective action problems

If voluntary, area-wide pest management programs can be viewed as a collective action problem analogous to that of the contribution to the provision of a public good (i.e.: the regional level of pest control). In turn, the provision of public goods can be viewed as a particular kind of consumption externality in which all agents involved must consume the same amount of the good due to its non-excludability trait. In fact, public goods are particularly troublesome externalities because market based solutions do not work well and agents have to settle on a common amount for the provision of the good (Varian, 2006). Thus, according to Loehman and Dinar (1994), there has been an emphasis on prescribing decentralized noncooperative solutions to externality problems likely due to the problems of implementation related to free-riding and coordination problems; Loehman and Dinar argue that the issues involved in coordination problems can be as serious as those of free-riding for achieving cooperative solutions.

The basic issue underlying collective action problems is that the players' payoffs depend not only on their own actions but also on those of other players; they are interdependent. Thus, the actions of players are motivated by their own beliefs about what other players will do. So a player needs to take (his beliefs about) the beliefs of others into account when deciding what is his optimal course of action. In other words, each player chooses an action that is the best response to their belief regarding the proportion of other players that will choose each action (Morris and Shin, 2006).

Strategic interaction problems have been typically examined using frameworks such as Nash equilibria (pure and mixed) and Bayesian game equilibria, where subjective uncertainty —

defined as uncertainty regarding the actions and beliefs of others — arises from probabilistic strategies and from the selection of players' risk types in the latter two frameworks, respectively. A problem with Nash equilibrium for noncooperative games is that there can be multiple equilibria; in coordination games, there are typically two pure Nash equilibria; one in which agents choose to cooperate — and is Pareto optimal — and another equilibrium in which they choose not to, with lower resulting payoffs. The dilemma is whether to opt for the Pareto optimal equilibrium or, given the strategic uncertainty involved, opt for the Pareto inferior equilibrium instead (Carlsson and Van Damme, 1991). Such dilemma can also be viewed as a conflict between risk dominance and payoff dominance, which arises from the magnitude of the payoffs for each strategy and their relative difference, and influences the subjective beliefs about other player's actions (Harsanyi and Selten, 1988).

Carlsson and Van Damme (1993) introduced global games as an alternative framework to analyze strategic uncertainty and showed how rational players are forced into picking the risk-dominant equilibrium over the payoff dominant equilibrium. In the theory of global games, strategic uncertainty is modelled by assuming that players behave as if they have private information about a specific aspect of the decision problem (e.g.: about common payoff function). The private signals — which include a small amount of noise assumed to be common knowledge — that players observe about uncertain economic fundamentals, generate beliefs, both about fundamentals and about other players' beliefs about fundamentals. Thus, even in equilibrium, one agent cannot perfectly predict the probability of another agent contributing/coordinating because he does not know for certain what the private signal of others is. Global games capture the idea that players may be pushed into taking an action because of their belief about other players taking such actions. Therefore, inefficient outcomes may be forced on the players despite that they would all be better off if everyone refrained from such actions (Morris and Shin, 2006).

II. Conceptual Framework

Given the voluntary character of CHMAs in Florida, we conceptualize our model of area-wide pest management as a voluntary contribution game following Morris and Shin (2002). Thus, each farmer has to decide whether to coordinate insecticide sprays but benefits only if a critical mass of farmers, $\hat{k}$, coordinates. This setup introduces an uncertainty element. If the critical mass requirement is not met, the higher level of ACP control fails, and those that coordinated may obtain lower payoffs compared to those that did not. However, if the critical mass requirement is met, the payoff for everyone will be higher. Thus, not coordinating sprays provides a safer option for an individual but the social outcome may be sub-optimal. It should then be clear the key role that higher order beliefs play in farmers' decisions about area-wide pest management participation; farmers would only coordinate if they believed that enough of their fellow growers will coordinate as well.

Formally, the payoff to farmer *i* from not contributing is an amount x_i that does not depend on the number of individuals who contribute *k*, whereas the payoff from contributing is:

$$\begin{cases} \Pi c & if\ k \geq \hat{k} \\ 0 & if\ k < \hat{k} \end{cases}$$

Individuals maximize their profit by comparing the expected benefits from contributing with those of payoff x_i. Preliminarily, if $\Pi c \leq x_i$ the decision is trivial. In the non-trivial case where $\Pi c - x_i \geq 0$, the optimal choice depends on the probability that player *i* assigns to k exceeding the threshold $\hat{k}$ (i.e.: $(1 - \mathrm{F}(k < \hat{k}))$. At the point where individuals are indifferent between contributing and not contributing we have:

$$\Pi c\ (1 - \mathrm{F}(k < \hat{k})) = x_i \qquad (1)$$

Equation (1) above helps illustrate the finding in previous studies (Van Huyck et al. 1990, 1991) that successful coordination is more difficult to achieve when the required threshold for success is higher, and that it also depends on the size of the threshold relative to the alternative payoff.

The concept of strategic uncertainty originates in recognizing that the distribution function $F(\cdot)$ in equation (1) is subjective. In other words, it depends on the farmer's individual beliefs about others' behavior. Thus, the concept of strategic uncertainty is associated with the potential existence of multiple equilibria, since standard equilibrium analysis under common knowledge of rationality fails to predict a unique behavior strategy (Van Huyck, Battalio and Beil 1990; Heineman *et al.* 2009). As such, strategic uncertainty diverges from risk or ambiguity.

Threshold Strategies

Adapting the explanation provided by Morris and Shin (2002), for a fixed coordination requirement level $\hat{k}$, each farmer can be thought of having an alternative payoff threshold x*, or *switching point*, up to which he is willing to coordinate. That is the farmer will coordinate sprays as long as the alternative payoff to coordinating is not too high for him. As it will be explained in detail in the next section, the setting in our experimental coordination game was designed so as to reflect this situation.

Farmers' subjective beliefs regarding the likelihood that less than $\hat{k}$ individuals in the group will participate at any particular switching point $x^*$and, therefore, coordination will fail, can be denoted by $F(k < \hat{k}|x^*)$. From expression (1), the condition denoting a farmer that will be indifferent between participating and not participating at x^* can be re-written as:

$$\mathrm{F}(k < \hat{k}|\, x^*) = 1 - \frac{x*}{\Pi c} \qquad (2)$$

Equation (2) implicitly defines the alternative payoff that will act as a switching point as a function of the contribution threshold: $x^*(\hat{k})$, and provides the behavioral counterpart to the strategic uncertainty faced by individuals because it embodies the beliefs growers' hold about others' actions.

Sensibly assuming that $x^*(\hat{k})$ is a downward sloping function implies that the switching point (x^*) is higher when the threshold for successful coordination ($\hat{k}$) is lower. Intuitively, since x^* depends on $\hat{k}$, the willingness to coordinate decreases as the alternative payoff increases.

Adding the restrictions that $\frac{x*}{\pi c}(0) = 1$ and $\frac{x*}{\pi c}(1) = 0$, the right hand side of equation (2), $1 - \frac{x*}{\Pi c}$ can be seen as a cumulative distribution function over *k*, which embodies the beliefs of an individual farmer about the behavior of other farmers. The density over *k* is obtained by differentiation of this function at the optimal switching point:

$$\frac{dF}{dk} = -\frac{1}{\Pi c}\frac{dx^*}{d\hat{k}}$$

The alternative payoff threshold or switching point (x^*) can be interpreted as a farmer's certainty equivalent for strategic uncertainty in the coordination game. Therefore, it would be reasonable to expect $k < \hat{k}$ for a majority of "strategic uncertainty averse" farmers; when the threshold for successful coordination is high, any farmer that is averse to strategic uncertainty will prefer to opt out and obtain the lower alternative payoff instead.

Farmers' Beliefs about Other Farmers

Assuming that farmers have private information on the alternative payoff they face (x_i), a natural way to start to examine individual beliefs on the likelihood of success is by exploiting the relationship between the switching point and the coordination requirement. Further assuming that farmers' alternative payoff has two components, a common component (m) that represents uncertain economic fundamentals and an idiosyncratic component (s_i), $x_i = m + s_i$. Suppose that the common element *m* has a normal distribution with mean *y* and precision α, and the idiosyncratic element also has a normal distribution, but with zero mean and precision β. The subjective density over k of a typical farmer allows to derive the strategic uncertainty facing the growers.

Assume that farmers believe that others follow a threshold strategy around x^*. Thus, the function that specifies an action for every possible private signal is such that any farmer with an alternative payoff below (above) x^* will (not) participate of the collective action. Suppose farmer

i's alternative payoff is exactly x^*, we will derive this player's subjective (belief) of the density over k (the percentage of coordinating growers). The cumulative distribution function over k conditional on x^* provides the answer to the question: What is the probability that k is less than z?

Given the common alternative payoff component m, the proportion of farmers who will cooperate can be expressed in terms of the standard normal probability distribution:

$$\Phi\left(\frac{x^*-\mathrm{m}}{\sqrt{\frac{1}{\beta}}}\right) = \Phi\left(\sqrt{\beta}(x^* - m)\right) \quad (3)$$

Letting m^* be the level of the common component at which the proportion of farmers is equal to z, one can describe the link between the level of m and the share of individuals who contribute as:

$$\Phi\left(\sqrt{\beta}(x^* - m^*)\right) = z \quad (4)$$

Equations (3) and (4) lead to two key results. First, the higher the common component of the alternative payoff, the lower the predicted proportion of players contributing. Second, there is a direct link between m^* and F(z). When $m \geq m^*$, the proportion of farmers that contribute is z or less. Thus, the proportion of individuals for which $k \leq z$ – that is, who believe that fewer than z will contribute – can be expressed in terms of the proportion of individuals for which the common element of the alternative payoff is higher than a threshold, $m \geq m^*$. The distribution of the subjective density over k denoted in equation (4) and, therefore, the strategic uncertainty, depend on m^*, which will make the density shift around the switching point.

III. Data Collection and Experimental Design

We conducted the choice experiment during a meeting of Florida citrus growers in April 2016. There were 310 attendees to the event, including growers, researchers, extension agents, media, and state officials. The number of growers in the audience was estimated at 140. The number of completed forms by growers was 123, giving a response rate of 88%. The growers who responded to the survey represented approximately one-third of the citrus acreage in Florida.

Our choice experiment was based on the conceptual framework presented in the previous section, which is in turn based on the theory of global games. Thus, we elicited responses from growers in games in which they had to choose whether to coordinate under different fixed coordination requirement levels $\hat{k}$ or obtain an alternative certain payoff. The objective was to find the individual's switching point up to which the farmer was willing to coordinate. The rationale being that the farmer will coordinate sprays in CHMAs as long as the alternative payoff for coordinating is not too high for him (i.e.: given his beliefs about others' coordinating). With a few exceptions, farmers did follow threshold strategies.

Our experiment resembles that designed by Heinemann, Nagel and Ockenfels (2009). However, unlike theirs, ours was applied towards a current agricultural issue and the subjects were Florida citrus growers, not students. In our experimental setting, we presented growers with hypothetical per acre net benefits for two alternatives at a time, for ten different scenarios, in three different games. In the first game (lottery), growers had to choose between option A that consisted of a certain payout in excess of expenses starting at $150 in scenario 1, and increased by $150 in each scenario, reaching $1500 in scenario 10. Option B consisted of the chance of obtaining $1,500[1] with 67% chance with an expected payout of $1,000 (=$1,500 x 67%).

In the second and third games of the experiment, we also asked growers to choose between two options; option A was identical to that described above, but option B resembled a CHMA decision. Since the size of the group and coordination requirement – the latter being the percentage of growers needed for achieving a higher payoff under coordination – have been found to influence the decision to coordinate (Ostrom, 2010; Olson, 1964; Sandler, 2015;

[1] The maximum amount of $1,500 was based on the estimated cumulative net differential benefit of a well-performing CHMA relative to a not so well-performing CHMA when making ground applications (Singerman, Lence and Useche, 2017). By assuming ground applications, as opposed to aerial application, we made use of a more conservative estimate of net differential benefit.

Carlson, and Wetzstein, 1993; Van Huyck, Battalio and Beil, 1990; Heineman, Nagel and Ockenfels, 2009), we included those variables in our experimental design. Thus, in the second game, option B offered a payout of $1,500 if at least 1/3 of the growers in their CHMA coordinated sprays, and zero otherwise. Thus, growers had to make a choice between a certain payout (option A) and a payout dependent not only upon their action but also their beliefs regarding their neighbors' behavior (option B). In the third game, option B offered a payout of $1,500 if at least 2/3 of the growers in a CHMA coordinated sprays, and zero otherwise.

To analyze whether the number of growers in a CHMA has any effect on participation decisions, there were three versions of the experiment for games two and three, in which the group size of the CHMA differed; they had 15, 30, or 45 growers, respectively. The numbers of growers within a CHMA were chosen based on recommendations of University of Florida, Citrus Research and Education Center extension entomologists and the coordinator of the CHMA program. The three different versions corresponding to the three different group sizes were distributed randomly across participants.

By offering growers a choice between a certain payoff and a risky lottery, first, and, then, between a certain payoff and a strategically uncertain lottery, we compare their certainty equivalents under both situations. Thus, a grower choosing a lower (higher) alternative certain payoff in the structural uncertainty scenario compared to the strategic uncertainty scenario evidences that he perceives additional (lower) risk under the former (latter). By eliciting several choices from the same growers as we increased the alternative certain payoff, we were able to establish the growers' degree of risk aversion in the lottery game, and a similar measure of aversion for the case of strategic uncertainty. In this way, we were able to estimate whether there was any relationship between the two measures, and link it to their propensity to participate in area-wide pest management.

IV. Results

The total number of completed forms returned by growers was 123, but 12 of them did not provide any choices for the games. In addition, following the conceptual framework described above, for our analysis we took into account the responses of those growers who played "threshold" strategies, which we define as those in which the grower 1) chose option B at least once in any of the games 2) switched from option B to option A during that game, and 3) after switching to option A, did not switch back to option B. A total of 83 growers provided answers satisfying the above criteria.

As shown in Table 1, 78 threshold respondents disclosed their operations' acreage. While the sample is not representative of the entire citrus grower's population,[2] we captured a high percentage of larger growers (e.g.: 25% of the growers with acreage between 1,001 and 3,000 and 17% with more than 3,000 acres) and a significant percentage of the state's citrus acreage. Despite the small size, the sample is informative regarding larger growers' characteristics and behavior, who can be very influential and act as industry trend setters.

Table 2 summarizes the demographics by the three different versions corresponding to the three different group sizes of CHMA (e.g.: 15, 30, or 45 growers). Education is a categorical variable that takes on the values (1) high school; (2) 2-year college; (3) 4-year college; (4) grad school. Responsibility is also a categorical variable that measures whether the respondent was (1) owner; or owner and manager; or owner and other; (2) manager; (3) caretaker[3]; (4) owner and caretaker; or owner, manager and caretaker; (5) manager and caretaker. Thus, the scale measures how "far" from the ownership of land the participant was. Location denotes whether the participant's operation was located in (1) the Florida central region; (2) the Florida central region and in Southwest Florida; (3) Southwest Florida. Percent income from citrus is another categorical variable taking the values (1) less than 20%; (2) 20 to 40%; (3) 41 to 60%; (4) 61 to 80%; (5) 81 to 100%. CHMA participation is a binary variable denoting whether growers were

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[2] Given the increasingly significant impact of HLB since the 2012 USDA-NASS census data was released, it is very reasonable to assume that the population of growers has decreased, and more so for smaller growers.
[3] Caretaker refers to those growers that are contracted to take care of the crops of others on their behalf.

participating in coordinated sprays. And, yield loss measures the percentage yield loss the participant has experienced in his groves since the onset of HLB.

Table 2 also summarizes the participant's risk profiles based on the growers' number of B-choices in the lottery. Since the expected payoff of the lottery was $1,000, respondents that chose option B less than six times show risk aversion; those that chose option B six times are risk neutral, and those that chose option B more than 6 times are risk lovers. We constructed a risk profile categorical variable based on such criterion.

The results in table 2 show that there is some heterogeneity among the different groups in terms of acreage (group 45 has considerably less acres compared to the other two), CHMA participation (the growers in group 30 participate 15% less than those in group 15, and 21% less than those in group 45). In addition, group 15 has roughly 16% more risk averse growers compared to the other two groups whereas group 45 has 12 and 15% more risk neutral growers relative to group 15 and 20, respectively. In group 30, there are 20 and 16% more risk loving individuals than in groups 15 and 45, respectively.

Table 3 shows the average number of times growers chose option B out of the ten scenarios, for each of the three games. The numbers in parentheses denote the standard deviation of their responses. The average number of times growers chose option B in game 1 (lottery) were 4.25, 5.20, and 4.46 in the 15, 30, and 45 group size, respectively. For group sizes 15 and 45 the average number of times growers chose option B in game 2 was higher than for game 1. This result denotes that those growers, on average, perceived the coordination requirement with 1/3 of their fellow CHMA growers to be less risky than the lottery. In contrast, group 30, which had the largest percentage of risk lovers, is the group that chose option B an average of about 0.32 times less in game 2 compared to game 1. Interestingly, the CHMA group of 30 had, on average, the lowest level of formal education, growers were younger, and there were more owners relative to the other two groups; the CHMA group of 30 also had the lowest average in actual level of participation in CHMAs. It is also interesting to note that the standard deviation of the responses in all three groups of growers was higher for game 2 compared to game 1, denoting greater heterogeneity in their choices of the former game.

Table 3 also shows that the average number of B choices in game 3, which required 2/3 of the growers within the group to coordinate, was lower than for the lottery for all group sizes whereas the standard deviation was higher. Moreover, in game 3 the average number of B choices and standard deviation decrease as the group size increases denoting an interaction between coordination requirement and group size. Thus, coordination among 2/3 of growers within a group is perceived to be riskier than playing against nature, and the risk is also perceived to be higher if there are more growers within a group to coordinate with.

As the final part of the experiment, we presented growers the case-study findings reported by Singerman, Lence and Useche (2017) regarding the differential yield results achieved in a well-performing CHMA, after that we asked them to play game 2 again. Table 4 shows growers' choices; the largest percentage of growers in all three CHMAs groups chose the same switching threshold as in the original game 2. In all three groups, some growers chose a lower threshold relative to their original responses; the rationale for their lower threshold choice is not clear. However, 28%, 36% and 27% of growers in CHMA groups 15, 30, and 45, respectively, increased their original threshold after seeing the results of higher yields in well-performing CHMAs. It could be argued that after seeing the results of actual successful coordination, and in the spirit of global games, their beliefs about the probability of others coordinating increased. In other words, their perception of the strategic uncertainty involved in CHMAs decreased; the case-study might have made them deem successful spray coordination a more attainable outcome than they originally thought.

Figure 1 shows the proportion of growers within each CHMA group that chose option B at each of the different levels of certain payoff from choosing alternative A for each of the three games. Figure 1, panel A depicts the choices for CHMA group 15. Interestingly, in the lottery, no grower chose option B when alternative certain payoffs were above $1,050. However, some growers did so in both coordination games, denoting they believe others will coordinate as well.

In fact, for the alternative payoffs of $1,050 and $1,200, the percentage of growers was the same for both coordination thresholds.

In Figure 1, panel B it can be seen that the percentage of growers in CHMA group 30 choosing option B in the lottery was higher than in the coordination game with k=1/3 until the certain alternative payoff of option A reaches $1,050; for higher payoffs, the percentage of growers choosing option B is higher in the k=1/3 coordination game. The curve denoting the percentage of B choices in the coordination game with k=2/3 shows a change in slope (flattening) when the alternative payoff reaches $750, denoting that also in this group some growers believe in successful coordination even for high levels of alternative certain payoffs. Figure 1, panel C shows that in CHMA group 45 there is a change in growers' choices for option B once the alternative certain payoff reaches $1,050 in all three games. In particular, no grower chose option B after that threshold in the k=2/3 coordination game; very few did so in the lottery (in fact, no one did after the alternative payoff was $1,200), and the percentage of growers choosing option B starts decreasing as the payoff approaches $1,500 in the k=1/3 coordination game.

Figure 1 also illustrates that – common to all CHMA groups, and as anticipated in the theoretical model – the higher the (common) alternative certain payoff, the lower the proportion of players coordinating. However, in all three groups, some growers chose coordination over the alternative payoff when the latter was $1,050 or higher, particularly in the k=1/3 game but, interestingly enough, also in the k=2/3 game. And, in all three groups, that proportion of growers (in the k=1/3 game) was higher compared to those that chose option B in the lottery game. Those growers' beliefs about others' behavior are such that they assign a higher probability of success to coordinating sprays and obtaining the higher payoff. Finally, figure 1 also illustrates that the k=1/3 game is preferred over the k=2/3 game for all values of the certain alternative payoff for all three groups; and for groups 30 and 45, for all values of the certain alternative payoff, the lottery is preferred over the k=2/3 game.

A total of 11 growers across the three groups chose alternative B in the k=2/3 coordination game when the alternative payoff was $1,050 or higher. We examine their characteristics to better understand what distinguishes those growers who are willing to coordinate the most. Eight had the survey version in which the CHMA group had 15 growers and three the version in which there were 30. Their demographic characteristics are summarized in table 5. The main differences with respect to the original three CHMA groups are the following. First, there are more owners. Second, on average, they are older and have a higher level of experience compared to the main groups. Third, at 1,764 acres, the average size of their farms is also larger than the average for each of the three main CHMA groups. Fourth, their average income coming from citrus is lower than that of the main groups; four out of eleven growers had less than 20% of their personal income coming from citrus whereas other four had 81 to 100% of their income coming from citrus. Regarding their risk profiles, there are, on average, a lower proportion of risk averse growers and a higher proportion of risk neutral and risk loving growers.

Perhaps the most interesting characteristic of the growers showing a higher degree of willingness to coordinate in the choice experiment is that only 55% of them actually participate in CHMAs. One out of the five growers who did not participate, mentioned he did not have/belong to a CHMA; another grower mentioned he sprayed weekly (implying that because of that, he did not need to coordinate). Two others explained their lack of participation by ranking their reasons in the Likert scale as follows. One grower assigned a 5 to neighbors not participating, too much effort to coordinate and the preference for spraying in his own timing. The other grower assigned a 5 to the reasons related to timing and effort. The fifth grower, did not explain his choice of not participating. Thus, excluding the grower that stated having no CHMA, 4 out of 10 growers do not actually participate in coordinated sprays despite their choices denoting willingness to coordinate in the experiment. This denotes a divergence between those growers stated choices (in the game) and observed choices (in CHMA participation) behavior.

Table 6 shows the results of three competing models of clustered ordinary least squares by farmer in which the dependent variable is the number of B-choices in the coordination games. The difference between the first and second model is that in the former we use the number of times a grower chose B in the lottery game as an explanatory variable, whereas in the second we include instead the risk profile as an explanatory variable (measured as a categorical variable from 1 to 3 for risk aversion, risk neutrality, and risk loving behavior respectively based on the number of B-choices in the lottery). In the third model, we also include the responses to the repetition of game 2. The results of the three models show that the same variables are statistically significant; the coefficient on education is negative and significant at the 1% level. Thus, the higher the level of formal education of a grower, the less likely the grower is to coordinate (more on this result below).

The results in table 6 also show that there is a positive and significant effect of the number of B-choices in the lottery (Num. B lottery) on the choices in the coordination game. That is, risk averse growers are less likely to coordinate with other growers. In addition, the number of B-choices in coordination games is significantly affected by the coordination requirement (Coord req. (k)); as the coordination requirement increases, the number of B-choices decreases. This is related to the belief that it will be harder to successfully coordinate among a larger proportion of growers within a CHMA. In addition, our findings on the sign and significance of coordination requirement and number of choices in the lottery on strategic coordination are in agreement with those of Heinemann, Nagel and Ockenfels (2009).

Table 7 shows the results of a logit model with CHMA participation as the dependent variable and growers characteristics as well as game parameters as independent variables. The results show that when taking into account only growers that showed threshold strategies, education is positive and also statistically significant. This result seems to contradict the finding in table 6 for the coordination games, where a higher level of education had a negative effect on coordination. The two results can be reconciled as follows. More educated growers are less likely to coordinate when they have the alternative of taking a certain guaranteed outcome (as offered in option A of the experiment). However, under the current situation in Florida, they end up coordinating because the alternative does not provide them with such guaranteed outcome. In addition, more educated growers are likely to be more aware that coordinating sprays is beneficial. The results in table 7 also show two other statistically significant variables. First, location, which is negative and denotes that the further South the operation is located the less likely it is to coordinate. This could be due to the fact that operation in the South are, on average, larger and, therefore, less dependent on neighboring growers for controlling the ACP. Second, the percentage of income from citrus, which is positive and denotes that the higher the proportion of income coming from citrus, the higher the probability of CHMA participation.

Conclusions and Policy Implications

The voluntary area-wide pest management program put in place in Florida as part of the strategic plan of the citrus industry to address HLB presents growers with a collective action problem. Despite evidence on the efficiency of well-performing (i.e.: high participation) CHMAs to deal with HLB, the strategic uncertainty involved in relying on neighbors – particularly, the belief about neighbors not participating – has deterred growers from coordinating sprays (Singerman, Lence and Useche, 2017). We conducted a survey among Florida citrus growers that allowed us to learn more about growers and their coordinating behavior (or lack thereof). By including a simple choice experiment based on the theory of global games, we were able to capture the role of grower's higher order beliefs on growers' participation decisions in area-wide pest management programs.

As pointed out by Hennessy (2008), the strategic character of biosecurity decisions is of policy relevance because lower contributions result in a Pareto inferior outcome. Collective action has been extensively studied by Ostrom (1990, 2009, 2010), who found that a community-based approach can be more effective and result in lower transaction costs relative to command-and-control or payment-based approaches. While the latter two approaches are often used and justified when modeling a central planner's efforts to manage prevention and ex-post management of invasive species, they do not take into account the behavior that gives rise to the externalities; “the decisions are often made by unmonitored individuals who do not seek to maximize social welfare as they do not face the full consequences of their decisions” (Hennessy, 2008, p. 231).

Over the years, multidisciplinary research has shown that adaptive governance systems, as an alternative to private property or government intervention, can be effective to manage resources (Dietz, Ostrom, and Stern, 2003). Ostrom’s work – which was focused on addressing how to cope with free-riding, commitment problems, and monitoring to avoid opportunistic behavior – can then be viewed as an effort on how to avoid the equilibrium that is not Pareto optimal and its associated lower payoffs. In fact, as she puts it (Ostrom, 2010 p. 159) “…the earlier image of individuals stuck inexorably within social dilemmas has slowly been replaced in some theoretical work with a recognition that individuals face the *possibility* of achieving results that avoid the worst outcomes and, in some situations, may even approximate optimality”. Thus, Ostrom (1990) advocated the idea of enhancing the capabilities of those involved in managing the resource so as to change the rules of the game rather than to view them as helpless individuals of remorseless tragedies. When discussing the determinants for the success or failure of collective action, Ayer (1997) points out that the financial constraints of governments, and the resistance that top-down regulation typically encounters, also makes the alternative of farmers’ collective action more attractive.

So what can we learn from our experiment about citrus growers in Florida that could be combined with the literature to improve upon area-wide pest management participation to control the ACP? First, it is clear that the voluntary character of CHMAs and the associated strategic uncertainty are problematic and result in low participation. It is also clear that the monitoring and implementation of a sanction system for those growers that are not spraying would be difficult, if not impossible to achieve. Therefore, the solution would need to involve a mandatory component along with a self-enforcing feature; that is, growers themselves wanting to coordinate the sprays.

To address these issues, we propose an approach involving a top-down regulation component so as to obtain a bottom-up collective action.

The top-down regulation could be implemented from the state to the fruit procuring companies (i.e.: packinghouses and processors), requiring them to provide documentation that their processed/packed fruit has been subject to coordinated sprays. The procuring companies would, in turn, require such documentation as part of their specifications for purchasing fruit from their pool of growers. Thus, growers would need to organize themselves locally to fulfill the requirement, perhaps through their associations and be assessed charges (from a third-party) for the sprays on a per acre basis. This approach would:

1) Have growers incorporate spray coordination as part of their customer specifications, instituting a mandatory character. Thus, growers' beliefs regarding their neighbors' behavior and their role in CHMAs participation decisions become irrelevant.
2) The significant impact of HLB in Florida has caused production to plummet, and the industry as a whole is shrinking as a consequence. By fostering best practices against HLB, the fruit procurement companies contribute not only to their own long-run viability but also that of the industry as a whole.
3) Solve the three major economic problems described by Carlson and Wetzstein (1993) that are unique to regional pest management; unequal pest control demand of growers (i.e.: heterogeneity), the optimal size of the organization (which becomes irrelevant), and the issue on cost sharing arrangements.

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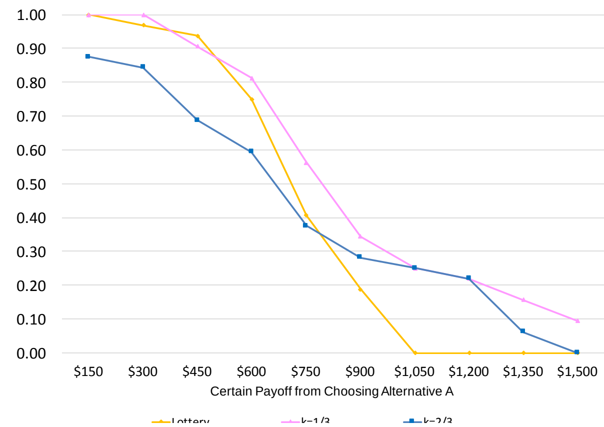
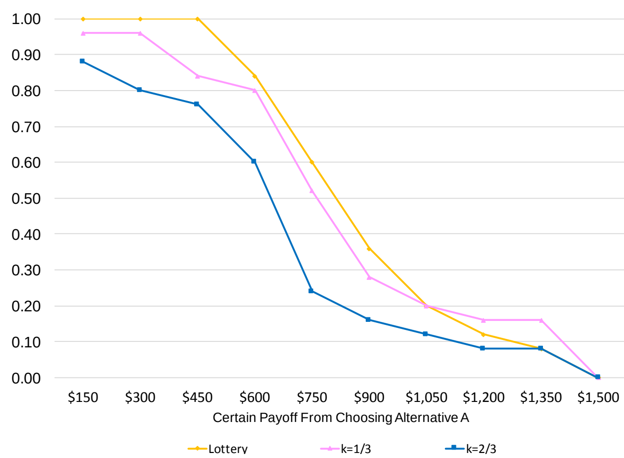
Figure 1. Average Number of Observed B Choices for Each Certain Alternative Payoff by CHMA group

A. CHMA Group Size: 15



B. CHMA Group Size: 30



C. CHMA Group Size: 45

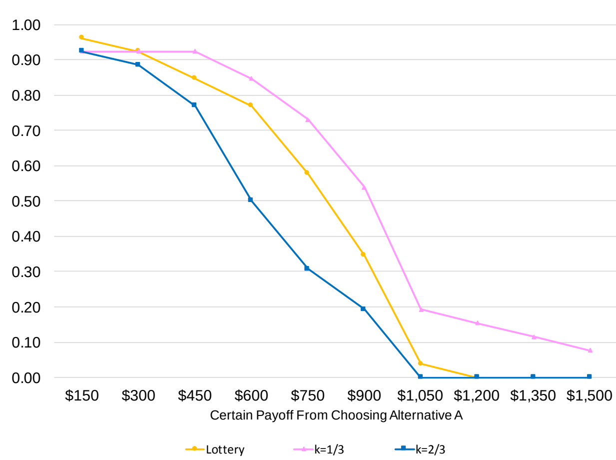


Table 1. Comparison of the Number (and Percentage) of Citrus Operations in Florida versus those Surveyed

	Farm size (in Acres)							
	<4.9	**5 to 50**	**51 to 100**	**101 to 500**	**501 to 1,000**	**1,001 to 3,000**	**>3,000**	Total
Number of Operations in Florida	955	1,710	310	483	86	65	30	3,639
	26%	47%	9%	13%	2%	2%	1%	100%
Total Acreage	1,546	30,792	21,165	99,137	56,141	103,672	226,728	539,181
	0.29%	6%	4%	18%	10%	19%	42%	100%
Number of Operations of Threshold Survey Respondents	1	12	10	27	7	16	5	78
	1.28%	15%	13%	35%	9%	21%	6%	100%
Survey Respondents as % of Florida Growers	0.1%	0.7%	3.2%	5.6%	8.1%	24.6%	16.7%	

Source: USDA-NASS. Quick Statistics Census Data 2012

Table 2. Summary Statistics of Demographic Variables and Risk Profiles by CHMA Group Size

		CHMA group size			
		15	**30**	**45**	All
Age	mean	56.54	51.81	56.14	54.96
	std. dev.	15.24	14.22	11.94	13.93
	min.	25	26	30	25
	max.	80	78	76	80
Education	mean	2.03	1.72	1.88	1.89
	std. dev.	0.81	0.89	0.73	0.81
	min.	0	0	0	0
	max.	3	3	3	3
Experience (Years)	mean	27.19	28.83	30.65	28.79
	std. dev.	15.18	18.38	14.82	15.95
	min.	1	3	1	1
	max.	65	60	64	65
Responsibility	mean	1.72	1.84	1.83	1.79
	std. dev.	0.77	0.90	0.87	0.83
	min.	1	1	1	1
	max.	3	4	4	4
Location	mean	1.81	1.86	1.81	1.83
	std. dev.	0.83	0.87	0.80	0.82
	min.	1	1	1	1
	max.	3	3	3	3
Acres (10)	mean	136.24	138.83	79.95	120.44
	std. dev.	308.39	313.84	98.85	264.51
	min.	0.5	0.2	4	0.2
	max.	1700	1500	340	1700
Perc. Income	mean	2.26	2.29	2.46	2.33
	std. dev.	1.63	1.88	1.77	1.73
	min.	0	0	0	0

	max.	4	4	4	4
Total Income	mean	2.39	2.30	2.10	2.28
	std. dev.	1.55	1.56	1.45	1.50
	min.	0	0	0	0
	max.	4	4	4	4
CHMA participation	mean	0.63	0.48	0.69	0.60
	std. dev.	0.49	0.51	0.47	0.49
	min.	0	0	0	0
	max.	1	1	1	1
Yield loss (%)	mean	50.81	50.63	48.92	50.09
	std. dev.	22.27	12.40	17.07	17.93
	min.	17	25	10	10
	max.	100	70	75	100
Risk profile	Risk Averse	81%	64%	65%	71%
	Risk Neutral	19%	16%	31%	22%
	Risk Loving	0%	20%	4%	7%
	Number obs.	32	25	26	83

Table 3. Average Number of B Choices (and standard deviation) by Game for Different Group Sizes of CHMAs

			Coordination games	
Number of participants	CHMA group size	Game 1 (lottery)	Game 2 (k=1/3)	Game 3 (k=2/3)
32	15	4.25 (1.24)	5.34 (2.38)	4.19 (2.79)
25	30	5.20 (1.76)	4.88 (2.35)	3.72 (2.39)
26	45	4.46 (1.75)	5.42 (2.40)	3.58 (1.77)

Table 4. Change in Number (Percentage) of B responses in game 2 after showing case-study results

Number of participants	CHMA group size	Same threshold	Lower threshold	Higher threshold
32	15	18 56%	5 16%	9 28%
25	30	13 52%	3 12%	9 36%
26	45	13 50%	6 23%	7 27%

Table 5. Average of Demographic Characteristics of growers willing to coordinate the most in the choice experiment

Age	63

Education	2.00
Experience (Years)	33
Responsibility	1.64
Location	1.64
Acres (10)	176
Perc. Income	2.09
Total Income	2.80
CHMA participation	55%
Yield loss (%)	56
Risk Averse	45%
Risk Neutral	36%
Risk Loving	18%
N=	11

Table 6. Clustered Ordinary Least Squares Regression of the number of B choices in the coordination games

Variable	(1) Base	(2) Risk profile	(3) Repeated game
Education	-0.90**	-1.16***	-0.79**
	(0.374)	(0.388)	(0.337)
Experience	-0.01	-0.01	-0.01
	(0.020)	(0.020)	(0.019)
Responsibility	0.19	0.39	0.21
	(0.394)	(0.450)	(0.387)
Location	-0.28	-0.14	-0.20
	(0.366)	(0.433)	(0.323)
Acres (10)	0.00	0.00	0.00
	(0.001)	(0.001)	(0.001)
Perc. income	-0.12	-0.17	-0.11
	(0.206)	(0.216)	(0.192)
Tot. income	0.06	0.12	0.11
	(0.196)	(0.219)	(0.185)
CHMA_partic	0.23	0.05	0.48
	(0.735)	(0.789)	(0.662)
Yield loss	0.00	0.00	0.01
	(0.017)	(0.017)	(0.016)
CHMA group 30 (dummy)	-1.20 (0.761)	-1.17 (0.812)	-0.93 (0.738)
CHMA group 45 (dummy)	-0.56 (0.740)	-0.96 (0.810)	-0.68 (0.686)
Coord. req. (k)	-1.17***	-1.17***	-1.26***
	(0.274)	(0.274)	(0.245)
Num. B lottery	0.80***		0.76***

	(0.186)		(0.165)
Risk profile		1.95***	
		(0.480)	
Intercept	4.23*	5.34**	3.51*
	(2.113)	(2.325)	(1.927)
Observations	104	104	155
R^2	0.387	0.341	0.357

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7. Logit regression of CHMA participation

VARIABLES	(1) Base	(2) Risk profile	(3) Threshold	(4) Lottery choice	(5) All Growers
Education	1.55**	1.71**	1.53**	1.62**	0.51
	(0.681)	(0.717)	(0.693)	(0.700)	(0.354)
Experience	0.04	0.04	0.04	0.04	0.01
	(0.030)	(0.031)	(0.030)	(0.030)	(0.022)
Responsibility	0.44	0.42	0.49	0.49	0.29
	(0.552)	(0.566)	(0.570)	(0.595)	(0.394)
Location	-1.03**	-1.04**	-1.11**	-1.03*	-0.60*
	(0.510)	(0.516)	(0.540)	(0.531)	(0.339)
Acres (10)	0.00	0.00	0.00	0.00	0.00
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Perc. income	0.59**	0.65**	0.62**	0.65**	0.38**
	(0.270)	(0.279)	(0.277)	(0.283)	(0.192)
Tot. income	0.03	-0.03	0.02	0.01	0.19
	(0.255)	(0.263)	(0.257)	(0.262)	(0.204)
Yield loss	-0.01	-0.01	-0.01	-0.01	0.00
	(0.022)	(0.022)	(0.022)	(0.022)	(0.016)
Risk aversion		-0.59			
		(0.535)			
Coord. req. (k)			-0.10		
			(0.140)		
Num. B lottery				-0.31	
				(0.213)	
Constant	-3.58	-3.11	-2.88	-2.48	-1.59
	(2.598)	(2.672)	(2.775)	(2.713)	(1.982)

Observations	52	52	52	52	74
pseudo-R^2	0.230	0.248	0.237	0.264	0.154

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8. Probit fractional response regression of the degree CHMAs participation

VARIABLES	(1) Threshold Growers	(2) All Growers
Education	-0.93***	-0.12
	(0.286)	(0.149)
Experience	-0.03**	-0.01
	(0.012)	(0.011)
Responsibility	-0.23	-0.18
	(0.229)	(0.161)
Location	0.31	0.09
	(0.198)	(0.159)
Acres (10)	0.00	0.00
	(0.000)	(0.000)
Perc. income	-0.09	0.17
	(0.140)	(0.117)
Tot. income	0.11	0.09
	(0.105)	(0.099)
Yield loss	0.03	0.03***
	(0.020)	(0.010)
Constant	2.50*	-0.66
	(1.402)	(1.150)
Observations	28	41
pseudo-R^2	0.0828	0.108

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1