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

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

Ariel Singerman and Pilar Useche^{1*}

Abstract

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 outcome, was lower compared to that of a lottery. Moreover, we found some evidence that the uncertainty perceived by farmers within the strategically uncertain setting increased as the size of the group increased. In addition, we also found evidence that farmers' strong beliefs about neighbors not coordinating negatively impacted their choices. A measure of strategic uncertainty was also found to influence the likelihood of growers to actually participate in area-wide pest management. Thus, our results help explain why participation in area-wide pest management to control the vector of citrus greening across Florida has not been as widespread as expected; the strategic uncertainty involved in relying on neighbors has made many of them choose self-reliance in spraying despite the lower payoff.

Keywords: Area-wide pest management, citrus greening, global games, public goods, strategic uncertainty

JEL: D03, Q18

¹ The authors contributed equally to this study

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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 as a consequence of individual producers or households not being capable of adequately dealing with the challenge posed by certain mobile and threatening pests (Klassen 2000). In addition, area-wide pest management may also contribute to reduce the risk of developing pesticide resistance (Vreysen, Robinson, and Hendricks, 2007). Farmers coordinating pest control may internalize externalities and increase the productivity of pest-control inputs.

There is a long history of area-wide pest control programs in the United States and elsewhere, which have been used to control pests as diverse as the grape phylloxera in Europe (Kogan, 1982), the cottony cushion scale in California (Dout, 1958), cattle ticks and screwworm in the U.S. (Cole and MacKeller, 1956; Knipling, 1979), the melon fruit fly in Japan (Vreysen *et al.*, 2000) and the Mediterranean fruit fly in the U.S. (Faust, 2008). Current programs include those targeting the pink bollworm and the cotton boll weevil (Ervin and Frisvold, 2016; Dickerson and Haney, 2001). However, in many cases, the implementation of area-wide pest management programs can encounter resistance due to concerns over methods, free riding, general public opposition, and, importantly, uncertainty about stakeholder participation (Mumford, 2000; Klassen, 2000). The program implemented in Florida to deal with the insect that spreads citrus greening is no exception.

Citrus greening or Huanglongbing (HLB) is a devastating bacterial disease caused by the bacterium *Candidatus Liberibacter asiaticus* and vectored by a highly mobile insect, the Asian citrus psyllid. HLB has affected major commercial citrus production areas worldwide and, to date, there is no treatment or management strategy to cure the disease. First found in Florida — the largest orange-producing state in the United States — in 2005, HLB spread rapidly across the state and reached epidemic proportions (Singerman and Useche, 2017). 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 Florida citrus industry to address HLB, voluntary area-wide psyllid control management programs, known as Citrus Health Management Areas (CHMAs), were established in 2010. Citrus yields of blocks located in a CHMA with higher participation were found to be significantly higher compared to the yields of blocks located in a CHMA with lower participation (Singerman, Lence and Useche 2017). 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 benefits 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 the evidence regarding their superior performance. At the end of 2015 there were 55 CHMAs in Florida, but only 19 of them were actively coordinating sprays. Singerman, Lence and Useche (2017) found that the top reason stated by citrus growers in Florida for not participating in coordinated sprays was that they believed other growers did not participate. Their findings suggest that strategic uncertainty — defined as uncertainty regarding the actions and beliefs of others — is a key consideration in growers' pest-control decision making.

When analyzing the barriers to herbicide-resistant management, Hurley and Frisvold (2016) pointed out that economic factors are not farmers' only incentive; multiple non-monetary factors influence farmers' weed and insect management decisions. In addition, gains from cooperation do not always result in a cooperative outcome (Loehman and Dinar 1994). As argued by Miranowski (2016, p. 2), "behavioral and socioeconomic factors may challenge rational economic behavior — profit maximizing — on the part of farmers and landowners and these factors may lead to a form of market failure."

In this study, we specifically analyze the role of strategic uncertainty in area-wide pest management participation decisions by Florida citrus growers. We conceptualized the problem of

strategic uncertainty using the framework of global games to guide our empirical analysis and capture the role of higher order beliefs in participation decisions. 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. Hence, 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.

In our experimental setting, we found that the average certainty equivalent in the strategically uncertain setting was higher under a low coordination requirement compared to that of a lottery in two out of the three group sizes of growers we considered; denoting that when the coordination requirement is low, some growers perceive the risk involved in coordinating actions with their neighbors to be less risky relative to a lottery. However, when the coordination requirement was high, the average certainty equivalent for the strategically uncertain setting was lower than in the lottery. And, in addition, when the coordination requirement was high, we also found some evidence that the perceived risk of the strategically uncertain alternative increased as the size of the group increased. Our findings also include evidence that farmers' strong beliefs about neighbors not coordinating and their degree of risk aversion, negatively impacted their choices. In our analysis, a measure of strategic uncertainty was also found to influence the likelihood of growers to participate in CHMAs. Thus, our results help explain why participation in area-wide pest management to control the vector of citrus greening across Florida has not been

as widespread as expected; the strategic uncertainty involved in relying on neighbors has made many of them choose self-reliance in spraying despite the lower payoff.

Our contributions to the literature can be summarized as follows. First, to the best of our knowledge, we are the first to elicit a measure of strategic uncertainty from farmers and to examine their strategic behavior in the context of area-wide pest management using the framework of global games. Second, we are able to measure the effect of coordination thresholds, group size, and public information on expected coordination payoffs. Third, we are able to analyze not only the stated behavior of growers in the choice experiment but also their actual behavior regarding spray coordination. In addition, there are only a few studies that look into farmers' willingness to cooperate to control pests (Ayer, 1997; Stallman and James Jr. 2015). Thus, a further contribution is to extend that area of the literature by examining whether, and to what extent, growers are averse to strategic uncertainty, the role such uncertainty plays on growers' participation decisions in area-wide pest management programs, and the factors related to their participation.

The insights we obtain are relevant not only for Florida — where citrus production has plummeted by 80% since the HLB was found — but also for California, which has become the largest citrus producing state in the U.S. and where the disease was recently found. California could implement area-wide pest management sooner and more effectively than Florida has. Since there is yet no cure for the disease, boosting management coordination to threshold levels that make cooperation efficient against HLB could slow down the spread of the disease.

Strategic Uncertainty and Global Games

Voluntary area-wide pest management programs can be viewed as a collective action problem analogous to that of contributing to the provision of a public good (i.e., the regional level of pest control). The basic issue underlying collective action problems is that the players' payoffs depend not only on their own actions, but also on the actions of other players; they are interdependent. Thus, the actions of players are motivated by their own beliefs about what other

players will do. 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 strategic uncertainty arises from probabilistic strategies and from the selection of players' risk types, respectively. A problem with Nash equilibrium for non-cooperative games is that there can be multiple equilibria. 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 players' 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 modeled by assuming that players behave as if they have private information about a specific aspect of the decision problem (e.g., a common payoff function). The private signals 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 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 even though they would all be better off if everyone refrained from such actions (Morris and Shin, 2006).

Within studies using global game frameworks, the main differences are with respect to the type of information that individuals have and do not have in building their beliefs about others' behavior. Carlsson and van Damme (1993) assume that players have incomplete information about monetary payoffs, yet perfect information about a common utility function. Hellwig (2002) assumes perfectly known monetary payoffs but incomplete information concerning a common degree of risk aversion; he also assumes that players make small errors. Morris and Shin (2002) assume risk neutrality and asymmetric information about monetary costs. Heinemann, Nagel and Ockenfels (2009) test global games frameworks for the cases of asymmetric information on monetary payoffs and of asymmetric information on risk aversion, and find that both versions deliver a good fit to observed data. We frame our work in the context of private information on monetary payoffs, as the following sections describe.

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). 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 psyllid 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:

$$\begin{cases} \Pi_c & \text{if } k \geq \hat{k} \\ 0 & \text{if } k < \hat{k} \end{cases}$$

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 trivial optimal decision is not to participate. 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., $(1 - F(k < \hat{k}))$). At the point where individuals are indifferent between contributing and not contributing we have:

$$\Pi_c (1 - F(k < \hat{k})) = x_i \quad (1)$$

Equation (1) above helps illustrate the finding in previous studies (Van Huyck, Battalio and Beil 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. As such, strategic uncertainty diverges from risk or ambiguity, and it 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, Nagel and Ockenfels 2009). In contrast, a global games conceptualization, uses a heuristic device to define actions that enable modelers to identify which set of self-fulfilling beliefs will prevail in equilibrium. This heuristic device is a *Laplacian* characterization of actions and beliefs, which hinges upon the existence of a unique cutoff point, which solves equation (1). Thus, in the following sections, we characterize growers' beliefs in such way.

Threshold Strategies

For a fixed coordination requirement level $\hat{k}$, each farmer can be thought of as having an alternative payoff threshold x^* , or *switching point*, up to which he is willing to coordinate. That is, a farmer will coordinate sprays as long as the certain alternative payoff to coordinating is not too high for him. Intuitively, if a farmer was presented a set of alternative certain payoffs sequentially, starting at zero and increasing in value up to the maximum attainable benefit of the uncertain option, one would expect him to start by accepting the uncertain option (given a positive expected value) and at some point, switch to the certain payoff at x^* . Thus, the alternative payoff threshold or switching point (SP) can be interpreted as a farmer's certainty equivalent for strategic uncertainty in the coordination game. As it will be explained in detail in the next section, the setting in our experimental coordination games was designed so as to reflect this situation.

At any particular SP x^* , farmers' subjective beliefs regarding the likelihood that less than $\hat{k}$ individuals in the group will participate and, therefore, that 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:

$$F(k < \hat{k} | x^*) = 1 - \frac{x^*}{\pi_c} \quad (2)$$

Equation (2) implicitly defines the alternative payoff that will act as a SP as a function of the contribution threshold for successful coordination: $x^*(\hat{k})$. In other words, equation (2) denotes that farmers' behavior will depend not only on the coordination threshold and alternative payoffs but also on the beliefs they hold about the behavior of other individuals. Furthermore, for a given set of alternative payoffs, a change in the coordination requirement may induce a change in the SP that is driven by a change in the expected payoff of the uncertain alternative stemming from a change in the belief about how many others' will coordinate.

Following Morris and Shin (2002), we formalize this relationship by assuming that $x^*(\hat{k})$ is a downward sloping function — the SP (x^*) is higher (i.e.: coordination is more likely) when

the contribution threshold ($\hat{k}$) is lower. Intuitively, since x^* depends on $\hat{k}$, the willingness to coordinate decreases as the alternative payoff increases. Thus, by adding the restrictions that $\frac{x^*}{\pi c}(0) = 1$ and $\frac{x^*}{\pi c}(1) = 0$, the right-hand side of equation (2), can be interpreted as a cumulative distribution function over k . Differentiating equation (2) with respect to the coordination threshold yields the density over k at the optimal SP:

$$\frac{dF}{d\hat{k}} = - \frac{1}{\pi c} \frac{dx^*}{d\hat{k}} \quad (3)$$

Equation (3) embodies the change in a farmer's beliefs about the behavior of other farmers. Hence, assuming that $x^*(\hat{k})$ is a downward sloping function amounts to assuming that individuals are averse to strategic uncertainty, which is a testable hypothesis that we set up to analyze through our experimental game.

Farmers' Beliefs about Other Farmers

So far we provided a foundation to understand an individual farmer's behavior. Adding further structure to the model and specifying how individuals experience uncertainty enables us to analyze what can be expected in terms of aggregate cooperative behavior. In particular, following the theory of global games we combine the previously described heuristic framework with a strategic environment of incomplete information where growers behave as if they have private information about a specific aspect of the decision problem—the alternative payoff function. Thus, growers are assumed to receive private signals that help them generate beliefs about fundamentals and about others' beliefs on fundamentals. Ultimately, this enables us to derive the proportion of players that would choose to coordinate sprays and examine how this proportion varies with respect to the alternative payoff (we analyze whether the relationship holds for our sample in the empirical results section).

Let the alternative payoff (x_i) faced by growers have two components, a common component (m) and an idiosyncratic component (s_i), so that $x_i = m + s_i$. Farmer i observes x_i , but

has incomplete information about m ¹. If m is assumed to have a normal distribution with mean y and variance $1/\alpha$, and the idiosyncratic element to have a normal distribution but with zero mean and variance $1/\beta$, the proportion of individuals for whom x_i is below a certain level can be linked to the proportion of individuals that will participate as follows.²

Assume farmer i believes that others follow a threshold strategy around x^* , so 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^* . Then his subjective belief of the density over k , or the proportion of farmers who will cooperate at x^* , can be expressed in terms of the standard normal probability distribution:

$$\Phi\left(\frac{x^*-m}{\sqrt{\frac{1}{\beta}}}\right) = \Phi\left(\sqrt{\beta}(x^* - m)\right) \quad (4)$$

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

$$\Phi(\sqrt{\beta}(x^* - m^*)) = z \quad (5)$$

Equation (5) leads to a key result: the higher the common component of the alternative payoff, the lower the predicted proportion of players contributing. When $m \geq m^*$, the proportion of farmers that contribute is z or less. The distribution of the subjective density over k denoted in equation (5) and, therefore, the strategic uncertainty, depends on m^* and x^* . Such representation of the probability distribution is important for the empirical analysis, since the private signal x_i is unobservable to the researcher, who may be more readily able to observe or estimate the common component m . In addition, it illustrates how the probability of contributions at a given switching point, ultimately depends on the mean common payoff, its variance, and the

¹ The term m can be thought of as a state that summarizes uncertain economic fundamentals. The conceptualization avoids having to analyze behavior in the space of all possible infinite hierarchies of beliefs, yet is rich enough to capture the role of higher-order beliefs.

² While the Laplacian formulation utilizes a uniform prior, Morris and Shin (2006) generalize the result to include any general priors.

variance of the idiosyncratic element of the private signal. In practical terms, this speaks about the importance of public information in aligning farmers' beliefs, reducing strategic uncertainty and enhancing coordination. In our empirical setting, we test the influence of public information about relative payoffs on strategic behavior.

III. Experimental Design

To test our conceptual hypotheses, we conducted an integrated choice experiment and survey during a meeting of Florida citrus growers in April 2016.³ 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 SP 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).

In our experimental setting, we had each grower play three different games and, then, re-play one game after receiving additional, public information on estimated yield and economic benefits from coordination. In each game, growers were presented with hypothetical per acre net benefits for two alternatives at a time, one involving a certain payoff and one involving an uncertain payoff. Each game consisted of ten such binary choices, in which the level of the certain payoff increased monotonically while the level of uncertainty was kept fixed throughout. In the first game, the uncertain alternative was a simple lottery, resembling the type of risk aversion elicitation formats pioneered by Binswanger (1981). Thus, growers had to choose between option A, with a certain payout starting at \$150 in the first binary choice, which increased by \$150 in each of the following choices, reaching \$1,500 in choice 10. Option B

³ Our experiment resembles that conducted by Heinemann, Nagel and Ockenfels (2009). However, ours was applied to capture specific features of a real and current (agricultural) issue and the subjects were farmers (instead of students) who actually make the type of participation decisions featured by the experiments and, therefore, directly face consequences from those decisions.

consisted of the chance of obtaining \$1,500⁴ with 67% probability and zero otherwise. Therefore, the expected payout was \$1,000 throughout the ten B choices.

In the second and third games of the experiment (from now on, referred to as strategic games 1 and 2, respectively), growers faced a similar setting to that of the lottery game, but the payoff of the uncertain option (option B) depended on what growers thought about the behavior of others. In particular, option B was framed as a CHMA participation decision, where the expected payoff depended on the grower's belief about the number of individuals who were willing to coordinate sprays. Analogously to the lottery game, we asked growers to choose between two options; ten times in each game. To identify the change in individual behavior related to strategic uncertainty, we kept all factors fixed between strategic games 1 and 2 and only changed the coordination requirement. In strategic game 1, option B offered a payout of \$1,500 if at least 1/3 of the growers in the CHMA coordinated sprays, and zero otherwise. In strategic game 2, option B offered a payout of \$1,500 if at least 2/3 of the growers in the CHMA coordinated sprays, and zero otherwise. Thus, consistently with our model, growers had to make a choice between a certain payout (option A) and a payout dependent not only upon their own action but also upon their beliefs regarding their neighbors' actions (option B).

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 which we asked them to play strategic game 1 again. The idea was to evaluate whether the awareness of the magnitude of such findings would make growers change their choices to coordinate sprays, and if so, to what extent.

Since the size of the group has been found to be a variable that can influence the decision to coordinate (Ostrom, 2010; Olson, 1965; Sandler, 2015; Carlson and Wetzstein, 1993), we included such variable in our experimental design by randomly assigning growers into three different groups: 15, 30, or 45 growers (i.e.: we had three versions of the experiment for games

⁴ 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 (Singerman, Lence and Useche, 2017).

two and three). These numbers of growers in a CHMA, which we will refer to as CHMA group sizes from now on, were chosen based on recommendations of University of Florida, Citrus Research and Education Center extension entomologists and the coordinator of the CHMA program.

To reduce hypothetical biases and align growers' responses with their actual preferences, we provided the following monetary incentive. Before the experiment started, it was announced that one of the participants would have the chance to win up to \$150 at the end of the experiment based on his/her responses in the lottery game. Since each form had an identifying number, first, a number would be drawn to select a grower among all of the participants. The selected grower would then draw a number from 1 to 10 from a bag to randomly pick which of the scenarios from the lottery game was going to be played. If the grower choice in that scenario was alternative A, the grower would instantly win 10% of such amount. If the grower choice in that scenario was alternative B instead, he/she would draw one out of three pieces of paper from a bag for a 67% chance of winning 10% of \$1,500. The prize was given to only one grower, but a University of Florida merchandise clipboard was given to all respondents as a gift for their participation.

Other information collected through the survey included growers' demographic variables (age, education, responsibility, etc.) and farm data (location and size) as well whether they were participating in CHMAs. Importantly, as part of the survey, we also asked CHMA participants and non-participants to rank, using a Likert scale, the reasons they thought were obstacles to increase participation and the reasons for not participating in coordinated sprays, respectively.⁵

Descriptive Statistics

There were 310 attendees to the event in which the data was collected, including growers, researchers, extension agents, media, and state officials. The number of growers was 140. The

⁵A graph summarizing such responses was originally presented by Singerman, Lence, and Useche (2017).

number of completed forms by growers was 123, giving a response rate of 88%. The growers who responded to the survey represented 153,278 acres, which accounts for approximately one-third of the citrus acreage in Florida. The form is reproduced in Appendix I. From the total number of completed forms returned by growers there was missing information for 12 and, following the conceptual framework described above, we only considered the responses of those growers who played threshold strategies.⁶ A total of 83 growers provided answers satisfying such criteria.

In Table 1 we provide a comparison of the type of farms in our sample with respect to that of the state. Table 1 shows that while the sample may not be representative of the entire citrus grower's population,⁷ we captured a high percentage of larger growers (e.g., approximately 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. Thus, the sample is particularly informative regarding larger growers' characteristics and behavior, who can be very influential and act as industry trend setters.

The demographic characteristics of the respondents are summarized in Table 2 disaggregated by survey version; each corresponding to one of the three different group sizes to which farmers were randomly assigned to as part of the experiment (15, 30, or 45 growers). Table 2 also summarizes the participant's risk profiles as described in the previous section. To establish whether there was a difference in the mean of each of the variables across the different CHMA groups, we performed an analysis of variance for a one-way layout. In this test, a large p-value denotes that we fail to reject the null (e.g.: the means across groups are equal). The results in Table 2 show that, on average terms, the groups of individuals are fairly comparable, with the exception of two characteristics. First, there is some heterogeneity among the different groups in

⁶ Threshold strategies are defined as those in which the grower (1) chose the uncertain option B at least once in any of the games (recall that option B offered the chance of obtaining \$1,500 with a 67% probability in the lottery game, whereas in the coordination games option B offered a payout of \$1,500 if they thought that at least 33% or 67% of the other growers in their CHMA also chose option B; (2) switched from option B to option A during that game; (3) after switching to option A, did not switch back to option B.

⁷ 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.

terms of acreage (group 45 has considerably fewer acres compared to the other two). Despite of the p-value being large for that variable, one of the assumptions of the analysis of variance for a one-way layout is that the variances across groups are the same. When this assumption is violated, then the results of the test are not valid; we found that the variance of acreage across groups violated the assumption of equal variance for such test. However, as we will later show, acreage did not turn out to be a statistically significant variable in explaining coordination in the strategic games or in CHMA participation. Second, there is also heterogeneity among the different groups with respect to their risk profile. 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 30, respectively. In group 30, there are 20% and 16% more risk-loving individuals than in groups 15 and 45, respectively.

IV. Empirical Strategy

Our empirical strategy for understanding individual farmer's choices for participating in area-wide pest management and, in particular, the role that strategic uncertainty plays in such decisions is three-fold. In the first part, we assess the average willingness of growers to coordinate sprays by comparing the aggregate average number of B-choices in the different games by CHMA group size. The number of times growers choose option B in each of the strategic games denotes the willingness to forgo payoffs that are certain. Or, equivalently, their willingness to coordinate under strategic uncertainty. In the second part of our empirical strategy, we perform two regression analyses; one regression to explain the coordination behavior in the games, and a second regression to examine the actual participation choices in CHMAs. The regressions keep alternative payoffs constant across individuals and can be used to test, controlling for other factors, hypotheses derived from our conceptual framework, such as whether there exists a negative relationship between the coordination requirement and the SP, and whether the beliefs about neighbors' behavior influences coordination behavior (equations (1) to (3)). We also test whether our measure of strategic uncertainty is related to real life

coordination behavior in CHMA's. In the final part of the empirical methods, we analyze aggregate behavior by graphically comparing the proportion of players that chose to coordinate at each specific level of alternative payoff and test whether this proportion declines as the payoff increases (equation (5)).

Comparing Games Choices

We start the first part by comparing choices in the lottery game and strategic game 1, reflecting growers' choices under risk and under low strategic uncertainty, respectively. We compare their certainty equivalents under both situations. A grower choosing a lower (higher) alternative certain payoff in the lottery compared to the strategic uncertainty scenario evidences that he perceives additional (lower) risk under the former. 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.

An important aspect within the assessment of strategic uncertainty aversion, is that, as opposed to the typical computations for the expected payoff of a lottery in which probabilities are given, in a strategic game we do not know the probabilities that each individual farmer assigns to others coordinating. Thus, even though it is useful to examine the growers' relative assessment of strategic uncertainty and risk aversion by using the same reference point in terms of number of B choices, such reference point might not necessarily provide an accurate measure for establishing strategic uncertainty aversion; the reason being that the probability that a farmer attaches to other farmers participating is not only not observed but may also depend on the farmer's characteristics. For this reason, our next comparison keeps every aspect of the problem constant, including a farmer's characteristics, while only changing the coordination requirement. This enables us to do a better assessment of farmers' strategic uncertainty aversion, which is consistent with the conceptual framework.

We assess the average willingness of growers to coordinate by comparing growers' choices in strategic games 1 and 2, which have low and high coordination requirements, respectively. From the results of this comparison, we are able to observe whether, in line with our conceptual hypothesis (see equation 3), farmers display a lower SP for a higher coordination requirement, which would confirm average strategic uncertainty aversion. The rationale for growers displaying strategic uncertainty aversion is based on the idea that as the threshold required to obtain the uncertain payoff increases, they will change their beliefs about the number of other growers who would be willing to coordinate (expecting it to decrease). Thus, their beliefs about others' behavior would lead them to expect a lower benefit from option B when the coordination requirement is higher; driving them to switch to the certain alternative earlier on. Finally, we compare growers' willingness to coordinate in the same exact game (strategic game 1) before and after being presented with information about the positive benefits of CHMA participation found in a scientific study.

Explaining Coordination Choices in Games

To better understand determinants of growers' coordinating choices in the strategic games of our experiment, we set up the following OLS clustered model:

Number B choices

$$\begin{aligned}
&= \alpha + \beta_1 \text{Coord.req.} + \beta_2 \text{Belief neighbor} + \beta_3 \text{CHMA group 30} \\
&+ \beta_4 \text{CHMA group 45} + \beta_5 \text{Group size} \cdot \text{coordination req.} \\
&+ \beta_6 \text{Educ.} + \beta_7 \text{Experience} + \beta_8 \text{Responsibility} + \beta_9 \text{Perc.income} \\
&+ \beta_{10} \text{Farm size} + \beta_{11} \text{Location} + u
\end{aligned} \tag{6}$$

Coordination requirement is a dummy variable that takes the value of zero for the game with 1/3 coordination requirement and 1 for the game with 2/3 coordination requirement. Thus, the coefficient β_1 allows us to test the hypothesis postulated in the conceptual framework section,

that individuals are averse to strategic uncertainty or, equivalently, that the SP $x^*(\hat{k})$ is a downward sloping function. We expect the coefficient on *Coordination requirement* to be negative. As also mentioned in the conceptual framework, farmers' choices are expected to depend on the beliefs they hold about the behavior of others. Thus, the variable *belief neighbor* in our regression is the result of transforming the responses of growers that agreed with the statement "neighbors do not participate" (ranked with a 5 on a Likert scale) by making it equal to 1, and zero otherwise. We expect the coefficient on *belief neighbor* to be negative.

The size of a group has long been argued to conspire against the probability of successful coordination in collective action problems. This is so mainly for two reasons; first, as group size increases, individuals believe their free riding becomes less noticeable and relevant to successful coordination. Second, there are higher transaction costs involved in reaching an agreement within larger groups (Ostrom, 2010; Olson, 1965). Thus, *CHMA group 30* and *CHMA group 45* are dummy variables denoting the CHMA group size of the grower in the experiment (i.e.: 15, 30, or 45); we expect those variables to negatively affect the number of times growers choose option B. Finally, we also include the interaction between *CHMA group* and *Coordination requirement* so as to establish whether there is any significant combined effect of these two variables.

The demographic characteristics of the respondents included in the regression are the following. *Education* is a categorical variable that takes on the values (1) high school; (2) 2-year college; (3) 4-year college; (4) graduate school. *Experience* denotes the number of years of a grower in the industry. *Responsibility* is a dummy variable that takes the value of 1 if the respondent was owner, or owner and manager; or owner and other; and zero otherwise. *Percent income* from citrus is a 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%. The characteristics of the operation include *farm size*, which denotes the total acreage of the operation, and *Location* is a dummy variable that takes the value of 1 if the operation comprises farms in more than one region (e.g.: Florida's central region and Southwest Florida) and zero when the operation comprises farms within a single region.

In a second competing model to that in expression (6), we also include the categorical variable: *risk profile*, which is based on the growers' number of B-choices in the lottery game. Since the expected payoff of the lottery was \$1,000, we constructed *risk profile* so as to take the value (1) for respondents that show risk aversion by choosing option B less than six times; (2) for respondents that are risk neutral, who chose option B six times; and (3) for respondents that are risk lovers by choosing option B more than 6 times. Should there be any relationship between risk aversion and strategic uncertainty aversion, we expect it to be positive. Therefore, we expect the sign on *risk profile* in the regression to be positive.

Explaining Actual CHMA Participation Choices

To examine the determinants of the actual decisions of growers to coordinate sprays, we set up a logit model with CHMA participation as the dependent variable. We particularly explore whether strategic uncertainty aversion, as measured in our games, influences growers' decisions. As hinted at the beginning of this section, using the same reference point (in terms of number of B choices) as that for risk aversion is not an accurate measure for establishing strategic uncertainty aversion, furthermore, it can be confounded with risk aversion. Thus, and as suggested by equation (3) in our theoretical model, we use the relative change in the switching point (or change in the number of choices from strategic game 1 to strategic game 2) as a measure of strategic uncertainty aversion. This is equivalent to observing the change in the SP of a farmer due to an increase of 1/3 in the coordination requirement, $\frac{\Delta x^*}{\Delta \hat{k}}$, and is the behavioral counterpart to the change in strategic uncertainty faced by farmers.

After computing $\frac{\Delta x^*}{\Delta \hat{k}}$, we create dummy variables for different levels of strategic uncertainty aversion. Recall that one less B-choice in strategic game 2 denotes a decrease in the expected certain payoff by \$150, two fewer B-choices reflect a decrease by \$300, and so on. Thus, the dummy $SUA_1 = I(\frac{\Delta x^*}{\Delta \hat{k}} \leq -\$150)$, takes the value 1 for any grower who chose B one less time or more in strategic game 2 relative to strategic game 1, and zero otherwise. We similarly define $SUA_2 = I(\frac{\Delta x^*}{\Delta \hat{k}} \leq -\$300)$, $SUA_3 = I(\frac{\Delta x^*}{\Delta \hat{k}} \leq -\$450)$, and $SUA_4 = I(\frac{\Delta x^*}{\Delta \hat{k}} \leq -\$600)$,

where the latter contains the set of most uncertainty averse growers. We run separate regressions to test which of the strategic uncertainty levels is most relevant to explain CHMA participation.⁸ In addition to controlling for the variables in our first regression model, we add the number of B-choices in strategic game 1 as a decision variable, since it determines the starting point from which a farmer changes his behavior. Since this variable is endogenous, we use its fitted value (computed by using the regression specification in expression (6) that also controls for risk profile).

V. Results

Experimental Results

In Table 3 we present the average number of times growers chose option B in each game and the corresponding SP. In Table 4 we present the changes in these variables between games. The numbers within parentheses denote the standard deviation of their responses. Recall that a higher number of B-choices denotes a higher willingness to assume risk in the lottery and a higher willingness to coordinate in the strategic games. The average number of times growers chose option B in the lottery game were 4.25, 5.20, and 4.46 in the 15, 30, and 45 CHMA group, respectively. This means that they switched to the certain alternative at average payoffs \$787.50, \$930 and \$819, denoting that growers are, on average, risk averse in all groups (recall that the lottery's expected payoff is \$1000). However, in line with our descriptive statistics, which show that there is a larger ratio of risk-loving individuals in group 30, the average individual in this group is less risk averse than those in the other two groups.⁹

For CHMA group sizes 15 and 45 the average number of times growers chose option B in the strategic game 1 was higher than for the lottery game. This result denotes that those growers, on average, perceived the strategic game with the coordination requirement with 1/3 of their

⁸ A table showing descriptive statistics for $\frac{\Delta x^*}{\Delta k}$ is shown in Appendix 3

⁹ This group had growers that were, on average, younger and with the lowest level of formal education, which are characteristics that are generally correlated with risk loving behavior.

fellow CHMA growers to have a larger expected payoff than the lottery (\$163.5 more per acre for group size 15 and \$144 for group size 45). In contrast, group 30 is the group that chose option B an average of about 0.32 times less. It is also interesting to note that the standard deviation of the responses in all three groups of growers was higher for strategic game 1 compared to the lottery game, denoting greater heterogeneity in their choices in the strategic game and reflecting significant heterogeneity in the subjective probability assessments. In contrast with the previous comparison, the average number of B-choices in strategic game 2 is lower than in the lottery, denoting a lower expected payoff; yet the standard deviation still increases relative to the lottery. Nevertheless, such increase is not as large as in the comparison of strategic game 1 with the lottery (Table 4). The reason for the relatively smaller increase is because in the largest group there is less heterogeneity in behavior, denoting more consensus regarding the lower expected payoffs when the coordination requirement is high.

When comparing growers' decisions for the strategic uncertainty games under two different threshold scenarios, Tables 3 and 4 show that as the coordination threshold to obtain a high payoff increases by 1/3, farmers' beliefs regarding the number of other growers who are willing to participate in coordination decrease; leading them to expect a lower benefit from coordination, and driving them to switch from option B to option A earlier. On average, and across CHMA group sizes, the number of B-choices (and switching point) in the strategic game with a low threshold is always larger than in the strategic game with a high threshold, showing that the average farmer displays strategic uncertainty aversion. Moreover, in strategic game 2 the average number of B-choices and standard deviation decrease as the group size increases, which suggests an interaction between the coordination requirement and the group size (the decrease in the expected payoff, relative to game 1 is -\$172.5, -\$174 and -\$276, for group sizes 15, 30 and 45, respectively). Thus, coordination among 2/3 of growers within a group is perceived to involve more uncertainty than playing against nature, and the uncertainty is also perceived to be higher if there are more growers within a group to coordinate with.

The last two rows on Table 3 show the number of B-choices and the switching points for the last game, which is a repeat of strategic game 1, after farmers were presented with the case-study results reported by Singerman, Lence and Useche (2017) regarding the positive differential yield and economic benefit achieved in a well-performing CHMA. The comparisons with the lottery and the same game with strategic uncertainty, but without information, provide evidence that additional information on yield benefits increases average expected payoffs in general. Gains are especially consistent when compared against a game with nature. When compared to the same game but without information, only in the two smaller groups the average payoff increase; by \$21 per acre for group size 15 and \$66 for group size 30. For the larger group, expected benefits decrease by \$39 per acre. Table 5 shows the number (and percentage) of growers that kept and changed their threshold number of B choices in the repeated game. While the majority of growers (50% or more) in all three CHMA groups chose the same switching threshold as in the original strategic game 1, the second-largest share of growers — 28%, 36% and 27% in groups 15, 30, and 45, respectively — increased their threshold after receiving information on positive differential yield and economic benefit found for other CHMA participants. It could be argued that after seeing the results of actual successful coordination those growers' beliefs might have made them deem successful spray coordination a more attainable outcome than they had originally thought (i.e.: denoting a change in the probability of success $(1 - F)$ in our conceptual framework). Alternatively, the increase in their coordination choices could also be the result of finding the collective action payoff (i.e.: Π_c) higher than they had thought and, therefore, more enticing. Interestingly, the group with the largest percentage swing was CHMA group 30, who had originally chosen the lowest average number of B-choices and is comprised of more risk loving individuals. A minority of growers in all CHMA groups chose a lower threshold relative to their original responses; the rationale for their choices is unclear.

Regression Results for Coordination Games

Table 6 shows the results of three competing models of ordinary least squares clustered by farmer based on expression (6), in which the dependent variable is the number of B-choices in each of the coordination games. The results of the first and second models (Base and Risk profile) in columns (1) and (2), include choices for strategic games 1 and 2. The difference between them is that the latter also controls for risk profile. The model in column (3) also includes the results for the repeated game.

The variable *coordination requirement* is negative and significant at the 1% level across models, a finding that is consistent with the results of Heinemann, Nagel and Ockenfels (2009). More specifically, we find that, on average and controlling for other factors, an increase in the coordination requirement from 1/3 to 2/3, decreases the number of coordination choices by 1.52; reflecting an average change in growers' expected payoff of -\$228 ($= -1.52 \cdot \150). This result confirms the assumption implied by equation (3) of our conceptual framework that $x^*(\hat{k})$ is a downward sloping function, and can be related to the belief that it will be harder to successfully coordinate among a larger proportion of growers within a CHMA. In fact, making use of equation (3) and our estimated impact of *coordination requirement* on the switching point, we can obtain the (average) change in growers' subjective beliefs that coordination will fail due to a change in coordination need from 1/3 to 2/3: $\frac{dF}{d\hat{k}} = -\frac{1}{1500} (-1.52 \cdot 150) = 0.152$, which is approximately 15%. This percentage can also be interpreted as the share of the total obtainable benefit per acre that would be expected to be lost due to an increase in the requirement. If this increase operated monotonically as the coordination threshold increases, one would expect that a 100% coordination requirement would decrease the expected maximum payoff per acre by 30%.

The variable *belief neighbor* is also negative and significant at the 5% level across the three models. The coefficient of this variable in the base model denotes that growers that have strong beliefs about others not participating in CHMAs, on average, chose option B 1.57 fewer times. Finding the belief about neighbors not participating to be negative and statistically

significant is not surprising. The assurance, or lack thereof, that an individual's actions will be matched by others is one of the variables Ostrom (2009) identified as affecting the likelihood to achieve a sustainable self-organization of resources.

The variable *risk profile* was included as an explanatory variable in models 2 and 3. We find that such variable is statistically significant at the 1% level in both models. This denotes that risk-averse growers are also less likely to coordinate with others. Very interestingly, the magnitude of the coefficients for the coordination requirement and for the beliefs about neighbors have a larger effect in the repeated game, while the risk profile effect and the coefficient of the fixed unobservable components decreases. This suggests that providing more information leads farmers to focus more on coordination parameters while reducing the effects of the risk profile and other unobservable factors. Finally, despite having found some evidence suggesting that the interaction between group size and coordination requirement affect the number of coordination choices (shown in Table 3), we did not find such interaction variable to be significant in our regression analysis.

Regression Results for CHMA Participation

Table 7 shows the results of the logit model with CHMA participation as the dependent variable. These results show that neither the absolute level of coordination choices in strategic game 1 (*predicted B-choices*) nor the risk aversion profile have any effect on CHMA participation. However, our measure of strategic uncertainty does. In particular, individuals with the high aversion to strategic uncertainty — denoted by the variables *SUA_3* and *SUA_2* — tend to participate significantly less in CHMAs.¹⁰ The magnitude of the negative effect on CHMA participation decreases as strategic uncertainty aversion decreases. Indeed, very mild strategic uncertainty aversion (*SUA_1*) has no significant effect on Florida CHMA participation. Other

¹⁰ Due to the low number of observations at the most strategic uncertainty averse range, *SUA_4* appears significant at the 11% level only.

variables that significantly and positively influence CHMA participation are the number of years of experience that a grower has and the percent of his income coming from citrus.

Aggregate Results

Figure 1 shows the percentage of growers within each CHMA group that chose option B at each of the different levels of certain payoff for each of the strategic games. Panels A, B and C depict the choices for CHMA group 15, CHMA group 30 and CHMA group 45, respectively. These graphs show that, as predicted by our conceptual model (equation 5), for all group sizes the proportion of players choosing option B declines as the common alternative payoff increases. They also show that in all cases, coordination under $k=1/3$ dominates coordination under $k=2/3$; that is, the proportion of growers coordinating is equal or larger for $k=1/3$ relative to $k=2/3$ at any level of alternative payoff. Interestingly, only for the smallest group size there is a payoff level at which there is no change in the proportion of individuals choosing B option in the two games despite the increase in the coordination threshold (panel A, payoffs \$1050-\$1200). This is consistent with findings in the collective action literature that coordination is easier to achieve in smaller groups (Ostrom, 2010; Olson, 1965; Sandler, 2015; Carlson and Wetzstein, 1993).

For all group sizes, the percentage of coordinating growers decreases sharply for alternative payoffs between \$450 and \$900; then the curves show a change in slope (flattening), around \$1050. In fact, \$1050 is the payoff that is closest to the expected utility of the lottery for a risk neutral individual. For all graphs, there is an inflection point at or around this point, with such inflection starting at lower payoffs when $k=2/3$. At \$1050, there are still about 20% of individuals willing to coordinate in all groups when the coordination requirement is $1/3$, denoting they believe others will coordinate as well at such high level of alternative payoff. However, this proportion drops to 12% and 0% at the same payoff for group sizes 30 and 45, respectively, when the coordination requirement increases to $2/3$.

Comparing the distributions for the same coordination threshold but along the group size dimension, there is no clear dominance of any group size in terms of cooperative behavior. The only dominance is partial in the sense that it only occurs for payoffs above \$900 when $k=2/3$; in

such cases, the larger the group, the lower the proportion of individuals cooperating. In fact, no grower in CHMA group 45 chose option B for levels of alternative payoff higher than \$900 in the $k=2/3$ coordination game. Thus, despite not finding the CHMA group size (or the interaction between CHMA group size and coordination requirement) to be a significant covariate in the regressions, the interaction between group size and cooperation occurs, but only at high levels of alternative certain payoff.

Figure 2 shows the proportion of B-choices in the three games. Comparing strategic game 1 ($k=1/3$) to the lottery game, one can observe that the distribution of the former spreads more than that of the latter. However, this spread is not mean preserving; thus, it cannot be said that strategic uncertainty is simply perceived as an increase in risk by individuals. Rather, the spread is mean increasing, with the main shift to the right occurring at the highest levels of alternative payoffs (the last column in Table 3 shows that the mean SP payoff for the lottery and game 1 are, respectively, \$845.50 and \$932, and the corresponding standard deviations are \$237.50 and \$356.50). In fact, there are individuals who are still willing to coordinate when the certain payoff reaches \$1,500, which equals the maximum possible uncertain payoff. Thus, for a low coordination requirement, a strategically uncertain setting is mostly seen as more favorable, in terms of expected payoffs, relative to a game against nature. This suggests that some individuals are willing to bet on cooperation; trusting others will cooperate as well.¹¹ Or, alternatively, this could be hinting the existence of non-monetary coordination benefits, characterized by altruism (Levine 1998) or inequality aversion (Fehr and Schmidt 1999; Bolton and Ockenfels 2000).

Comparing the distribution of the two strategic games, the increase in the coordination requirement generates a drastic shift to the left of the whole distribution but it slightly decreases its variance (as displayed in Table 3, the mean SP payoff decreases from \$932 in game 1 to \$724.50 in game 2, the standard deviation from \$356.50 to \$347.50). This shows that in this

¹¹As Hägg (1994, p.449) puts it: “A relation of trust exists when one actor ex ante has to decide whether to engage in an action in which the outcome depends on the performance of another actor.”

situation growers not only expect lower average payoffs, but also that there is more consensus among them regarding the occurrence of such lower payoffs. This denotes that high levels of coordination are perceived by growers as difficult or costly. However, as it was the case for $k=1/3$, there is an exception on the right tail of the distribution for $k=2/3$, showing that a share of individuals is willing to cooperate even at high levels of alternative payoffs. Examining further the average changes by group size (Table 3) reveals that the decrease in expected payoff is larger as group size increases. Interestingly, only for the largest group size the standard deviation decreases, showing that it is the consensus of lower returns in this group what drives the decrease in the average standard deviation. In smaller groups, coordination may be more likely, increasing the divergence of growers' beliefs regarding a payoff reduction due to a coordination threshold increase. Thus, an increase in the cooperation threshold affects the beliefs about the likelihood of successful cooperation more similarly among growers of a larger group.

Finally, the distribution for the repeated game, after receiving information on yield gains from coordination, has a larger mean compared to that of the original game. It also has a smaller overall standard deviation. Similarly to the distributions of the other two strategic uncertainty games, the distribution for the repeated game resembles more a multimodal rather than a unimodal distribution; with a lower mode for one group of individuals between \$600 and \$900, and another mode around \$1350. In the repeated game, the standard deviation decreases for CHMA groups 30 and 45, and the expected payoff decreases slightly for the largest group. Overall, increases in information about the benefits of coordination can lead to increased coordination and less divergence among growers regarding the outcomes.

VI. Discussion and Conclusions

We conceptualized voluntary area-wide pest management programs, such as that put in place in Florida to combat the psyllid that spreads HLB, as a voluntary contribution game using a global game framework. Such framework helps explain why growers may choose the inefficient (non-

cooperative) management alternative. The integrated economic experiment and survey we conducted among Florida citrus growers allowed us to learn more about the uncertainty they faced and its implications on their coordinating behavior. We found that the most important deterrents for successful coordination under strategic uncertainty are the coordination threshold, the beliefs about others not coordinating, and risk aversion.

From the results of our experiment, we found that when the coordination requirement for a successful outcome is low, most growers see the strategic uncertainty posed by human interaction as more favorable in terms of expected payoffs than a game against nature. In contrast, when the coordination requirement is high, most growers expect lower payoffs and choose to coordinate less; expecting lower payoffs either because they deem coordination more difficult or costly. In all cases, though, the divergence in behavior of growers involved in a strategic setting is larger than in a lottery. Given the importance that a lower threshold for obtaining the Pareto optimal results could have on fostering higher participation, we consulted with entomologists to find out what that threshold should be but they were not aware of any study establishing it. Therefore, to examine whether a voluntary area-wide pest management program against the psyllid is likely to succeed, it is key to perform entomological studies to establish the level of threshold participation needed.

Regarding the impact of the beliefs about others' in decisions to coordinate, an encouraging finding is that approximately 30% of the growers chose to coordinate more (by increasing their original threshold) after receiving information of the benefits realized in a well-performing area. This suggests that those growers either changed their beliefs (about others) regarding the chances of achieving successful coordination, deeming it more plausible, or found the difference between the collective action payoff and its alternative worth taking the risk. Hence, providing information about positive outcomes publicly can be helpful to increase the expected payoff and decrease the uncertainty about others' behavior. In fact, in the global games literature, public information can convey strategic information on the individuals' beliefs of

others (Morris and Shin, 2006). This finding highlights the importance of extension activities in publicly disseminating positive outcomes to foster cooperation.

In our experimental game, individuals who were more willing to participate in coordinated management were also less risk averse. This correlation denotes that risk aversion and strategic uncertainty could be confounded in empirical analyses and highlights the importance of controlling for risk aversion to capture the actual effect of strategic uncertainty on behavior. Controlling for risk aversion when analyzing actual choices to coordinate sprays, we found that strategic uncertainty aversion was indeed a key determinant that negatively affected growers' decisions to participate in the program.

Despite not finding the size of the group to be a statistically significant variable in our regression, we did find some evidence that as the group size increased growers chose to coordinate less when the coordination requirement was high. This denotes that it is more difficult to achieve successful coordination in larger groups, which is in agreement with the existing literature (Baland and Platteau, 1999; Ostrom, 2010; Olson, 1965). Creating smaller sized areas may foster higher participation but presents the challenge of finding the optimal area size (while also dealing with natural borders, residential areas, and neighboring grove proximity). In addition, should the optimal size be small, it would present the additional challenge of dealing with an impractical large number of areas.

There are multiple arguments in the literature indicating that heterogeneity deters cooperation (Bardhan, 1993; Hardin, 1982; Isaac and Walker, 1988; Johnson and Libecap, 1982; Seabright, 1993). From our analysis on actual choices to coordinate sprays, we learned that the percent of income coming from citrus positively and consistently influenced the choice to coordinate sprays. To a lesser extent, the number of years of experience also influenced growers' choices to coordinate CHMAs sprays. Since we found that some individuals are willing to cooperate even for high levels of opportunity costs, those growers could potentially be recruited as natural leaders who may be able to influence their neighbors to enhance participation. Our findings on heterogeneity are also consistent with the technology adoption and innovation

literature, which poses that innovation leaders tend to be more experienced, more invested and less risk averse (Aldana *et. al*, 2011).

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. Moreover, the financial constraints of governments, and the resistance that top-down regulation typically encounters, also makes collective action more attractive (Ayer, 1997). However, the design principles Ostrom (1990) identified as characterizing robust common-pooled resource institutions require monitoring and graduated sanctions for non-compliers. In Florida, the advanced state of infestation together with the lack of a threshold of adoption needed for an area-wide psyllid management program to be effective and the impact of the beliefs about others' being reluctant to participate, have contributed to make a purely voluntary program unsuccessful. Thus, given the significant impact of HLB in Florida and the urgent need of answers for growers, the replacement of the voluntary character of the program with a mandatory component may be necessary.

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

	Farm size (in Acres)							Total
	<4.9	5 to 50	51 to 100	101 to 500	501 to 1,000	1,001 to 3,000	>3,000	
Number of Citrus Operations in Florida	955	1,710	310	483	86	65	30	3,639
	26%	47%	9%	13%	2%	2%	1%	100%
Total Citrus Acreage in Florida	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
	1.28%	15%	13%	35%	9%	21%	6%	100%
Survey Respondents as % of Florida Citrus Growers	0.1%	0.7%	3.2%	5.6%	8.1%	24.6%	16.7%	

¹ Only 78 out of 83 respondents disclosed their operations' acreage
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
	Equality of means ¹	P(F>F α) =			0.47
Education	mean	2.03	1.72	1.88	1.89
	std. dev.	0.81	0.89	0.73	0.81
	Equality of means ¹	P(F>F α) =			0.37
Experience (Years)	mean	27.19	28.83	30.65	28.79
	std. dev.	15.18	18.38	14.82	15.95
	Equality of means ¹	P(F>F α) =			0.72
Responsibility	mean	1.72	1.84	1.83	1.79
	std. dev.	0.77	0.9	0.87	0.83
	Equality of means ¹	P(F>F α) =			0.83
Perc. Citrus Income	mean	2.26	2.29	2.46	2.33
	std. dev.	1.63	1.88	1.77	1.73
	Equality of means ¹	P(F>F α) =			0.91
Acres (10)	mean	136.24	138.83	79.95	120.44
	std. dev.	308.39	313.84	98.85	264.51
	Equality of means ¹	P(F>F α) =			0.69 ²
Location	mean	0.26	0.33	0.23	0.27
	std. dev.	0.44	0.48	0.43	0.45
	Equality of means ¹	P(F>F α) =			0.71
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

¹We ran an Analysis of Variance for a one-way layout to test for the equality of means across the different CHMA groups

²The test for equal variances across CHMA groups was rejected for this variable

Table 3. Average Number of B-Choices and Payoff Switching Point (Standard Deviation in Parenthesis) by CHMA Group Size for each Game

			CHMA group size			Total Average
			15	30	45	
Coordination games	Lottery Game	Number of B-choices	4.25 (1.24)	5.20 (1.76)	4.46 (1.75)	4.64 (1.58)
		Payoff Switching Point	\$787.50 (\$186.00)	\$930.00 (\$264.00)	\$819.00 (\$262.50)	845.50 (\$237.50)
	Strategic Game 1 (k=1/3)	Number of B-choices	5.34 (2.38)	4.88 (2.35)	5.42 (2.40)	5.21 (2.38)
		Payoff Switching Point	\$951.00 (\$357.00)	\$882.00 (\$352.50)	\$963.00 (\$360.00)	932.00 (\$356.50)
	Strategic Game 2 (k=2/3)	Number of B-choices	4.19 (2.79)	3.72 (2.39)	3.58 (1.77)	3.83 (2.32)
		Payoff Switching Point	\$778.50 (\$418.50)	\$708.00 (\$358.50)	\$687.00 (\$265.50)	724.50 (\$347.50)
	Repeated Strategic Game 1 (k=1/3)	Number of B-choices	5.48 (2.38)	5.32 (2.15)	5.16 (2.1)	5.32 (2.21)
		Payoff Switching Point	\$972.00 (\$357.00)	\$948.00 (\$322.50)	\$924.00 (\$315.00)	948.00 (\$331.50)

Table 4. Simple Differences in Expected Payoffs and Standard Deviation Across Games by Group Size

			CHMA group size			Total Average Change
		Difference in:	15	30	45	
A	Game1- Lottery	Exp Payoff	\$163.50	-\$48.00	\$144.00	\$86.50
		Std.Dev.	\$171.00	\$88.50	\$97.50	\$119.00
B	Game2- Lottery	Exp Payoff	-\$9.00	-\$222.00	-\$132.00	-\$121.00
		Std.Dev.	\$232.50	\$94.50	\$3.00	\$110.00
C	Rep Game1- Lottery	Exp Payoff	\$184.50	\$18.00	\$105.00	\$102.50
		Std.Dev.	\$171.00	\$58.50	\$52.50	\$94.00
D = B-A	Game2- Game1	Exp Payoff	-\$172.50	-\$174.00	-\$276.00	-\$207.50
		Std.Dev.	\$61.50	\$6.00	-\$94.50	-\$9.00
E= C-A	Rep Game1- Game1	Exp Payoff	\$21.00	\$66.00	-\$39.00	\$16.00
		Std.Dev.	\$0.00	-\$30.00	-\$45.00	-\$25.00

Table 5. Number (Percentage in parenthesis) of Growers that Kept and Changed their Threshold of B- choices in Strategic Game 1 After Receiving Information on Yield Differentials from Case-study Results

	CHMA group size		
	15	30	45
Same threshold	18 (56%)	13 (52%)	13 (50%)
Lower threshold	5 (16%)	3 (12%)	6 (23%)
Higher threshold	9 (28%)	9 (36%)	7 (27%)

Table 6. Ordinary Least Squares Clustered by Grower of the Number of B Choices in the Coordination Games

Variable	(1) Base	(2) Risk profile	(3) Repeated game
Coord. req. (k)	-1.52*** (0.568)	-1.52*** (0.571)	-1.72*** (0.487)
Belief neighbor	-1.57** (0.674)	-1.37** (0.645)	-1.44** (0.623)
Risk profile		1.21*** (0.411)	1.13*** (0.371)
CHMA group 30	-0.46 (0.765)	-0.85 (0.716)	-0.65 (0.698)
CHMA group 45	-0.28 (0.788)	-0.61 (0.818)	-0.73 (0.727)
Group size · Coord. req.	0.00 (0.019)	0.00 (0.019)	0.01 (0.016)
Education	0.07 (0.443)	-0.02 (0.464)	0.02 (0.411)
Experience	0.01 (0.018)	0.01 (0.017)	0.01 (0.017)
Responsibility	0.08 (0.712)	0.28 (0.749)	0.43 (0.671)
Perc. citrus income	0.19 (0.218)	0.06 (0.204)	0.08 (0.199)
Acres (10)	-0.00 (0.002)	-0.00 (0.001)	0.00 (0.001)
Location	-0.54 (0.700)	-0.39 (0.670)	-0.21 (0.634)
Intercept	5.73*** (1.521)	4.58*** (1.571)	4.45*** (1.390)
Observations	114	114	170
Clusters	57	57	57
R ²	0.184	0.259	0.256

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 7. Logit Regression of CHMA Participation

Variable	(1) SUA_4	(2) SUA_3	(3) SUA_2	(4) SUA_1
Predicted B choices	0.21 (1.151)	0.15 (1.158)	0.34 (1.157)	0.23 (1.118)
SUA_4	-2.04 [†] (1.268)			
SUA_3		-1.65* (0.939)		
SUA_2			-1.48* (0.843)	
SUA_1				-0.13 (0.763)
Risk Profile	-1.22 (1.419)	-0.93 (1.364)	-1.22 (1.381)	-0.88 (1.312)
Belief neighbor	-0.39 (1.967)	-0.31 (1.964)	-0.23 (1.971)	-0.05 (1.901)
Education	0.55 (0.520)	0.75 (0.526)	0.69 (0.523)	0.77 (0.524)
Experience	0.06** (0.027)	0.05** (0.026)	0.06** (0.027)	0.06** (0.027)
Responsibility	-0.39 (1.426)	-0.27 (1.483)	-0.34 (1.473)	-0.70 (1.358)
Perc. citrus income	0.61** (0.304)	0.60** (0.294)	0.64** (0.297)	0.53* (0.281)
Acres (10)	0.01 (0.006)	0.01 (0.006)	0.01 (0.006)	0.01 (0.005)
Location	-0.07 (1.167)	-0.07 (1.171)	0.33 (1.158)	0.29 (1.128)
Intercept	-2.53 (5.983)	-2.79 (6.082)	-3.32 (6.021)	-3.41 (5.750)
Observations	57	57	57	57
pseudo-R ²	0.299	0.310	0.311	0.264

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1 [†] p=0.11

Figure 1. Percentage of B Choices for Each Certain Alternative Payoff by CHMA Group

Figure 2. Total Percentage of B-Choices for Each Certain Alternative Payoff by Game

Appendix I: Survey Form

1) Which of the following best describes your current responsibilities? (choose all that apply)

☐ Grove owner ☐ Production manager/Foreman ☐ Caretaker ☐ Other: _____

2) Age: _____

3) Level of formal education attained: ☐ High School ☐ 2-year college ☐ 4-year college ☐ Grad school

4) Number of years of experience in the citrus industry: _____

5) In what county / counties is your operation located?: _____

6) What is the approximate number of acres your operation manages? _____

7) Do you currently participate in CHMAs sprays? ☐ Yes ☐ No

If you answered NO, indicate which of the following explain your reasons for not participating:

(circle one number per row)

	Disagree		Somewhat Agree		Agree	
Neighbors do not participate	1	2	3	4	5	N/A
Too much effort to coordinate sprays	1	2	3	4	5	N/A
It is too costly to spray	1	2	3	4	5	N/A
No longer useful to spray for psyllid	1	2	3	4	5	N/A
I prefer to spray on my own timing	1	2	3	4	5	N/A
Plan on exiting the industry soon	1	2	3	4	5	N/A
Benefit (yield) not worth it	1	2	3	4	5	N/A

If you answered YES, indicate what you think are the main obstacles to increase CHMAs effectiveness against HLB:

(circle one number per row)

	Disagree		Somewhat Agree		Agree	
Neighbors do not participate	1	2	3	4	5	N/A
Too much effort to coordinate sprays	1	2	3	4	5	N/A
It is too costly to spray	1	2	3	4	5	N/A
Decreasingly effective to spray for psyllid	1	2	3	4	5	N/A
Benefit (yield) decreasing	1	2	3	4	5	N/A

8) What percentage of your personal income comes from citrus?

☐ less than 20% ☐ 20 to 40% ☐ 41 to 60% ☐ 61 to 80% ☐ 81 to 100%

Appendix II: Case-study Results from Singerman, Lence and Useche (2017) Showing Differential Yield and Economic Benefit per Acre by CHMA

Appendix III: Difference in B-choices between Strategic Game 2 and Strategic Game 1

Difference in B-choices	Frequency	Percent	Cumulative
-9	1	1.2	1.2
-6	2	2.41	3.61
-5	3	3.61	7.23
-4	4	4.82	12.05
-3	8	9.64	21.69
-2	17	20.48	42.17
-1	15	18.07	60.24
0	27	32.53	92.77
1	2	2.41	95.18
2	3	3.61	98.8
3	1	1.2	100
Total	83	100	