Paper Title	IS AREA-WIDE PEST MANAGEMENT USEFUL? THE CASE OF CITRUS GREENING

Contributed Paper prepared for presentation at the 91st Annual Conference of the Agricultural Economics Society, Royal Dublin Society in Dublin, Ireland

24 - 26 April 2017

Abstract

Huanglongbing (HLB) currently poses a severe threat to citrus production worldwide. No cure is yet available for growers to deal with the disease. While working on developing short- and long-term treatments, scientists recommend controlling the vector of the disease. In this regard, area-wide pest management has been proposed as a superior alternative to individual pest management. We analyze a unique dataset of farm-level yields in Florida that allowed us to test such hypothesis, and quantify the differential economic benefit in two areas with different implicit level of participation. Our findings provide evidence on the efficiency of well-performing areas to deal with HLB. In addition, we present survey data that provide insights about producers' preferences and opinions regarding area-wide pest management. Despite the relatively high benefit we found well-performing areas can provide, the strategic uncertainty involved in relying on neighbors seems to impose too high of a cost for most growers, who end up not coordinating sprays.

Keywords	Area-wide pest management, citrus greening, common property, externalities, pest management
JEL Code	Q18

I. Introduction

Citrus greening or Huanglongbing (HLB) is a bacterial disease affecting groves in major citrus production areas in the world, including the U.S., Brazil, Asia, Africa, and the Arabian Peninsula (USDA-APHIS, 2015). Caused by the bacterium Candidatus Liberibacter asiaticus and vectored by the Asian citrus psyllid (ACP), HLB is considered to be the most devastating citrus disease worldwide (FAO, 2015); it affects citrus trees' vascular system, limiting nutrient uptake, negatively affecting yield, fruit size and quality, tree mortality, and cost of production. To date, there is neither a cure nor an economically sustainable option for managing HLB-infected trees.

Florida is the largest orange producing state in the U.S. In fact, Florida alone is the third-largest orange producer in the world, behind Brazil and China. First found in Florida in 2005, HLB has spread rapidly across the state and reached epidemic proportions. It is estimated that, on average, 90% of the acreage in a citrus operation in Florida is currently infected with HLB (Singerman and Useche, 2016).

Since HLB was found in Florida, orange acreage and yield have decreased by 28% and 44%, respectively.[1] HLB has had a major impact on the profitability of orange production. Despite the fact that on-tree prices for oranges have increased from $2.89 to $9.34 a box (USDA-NASS, 2016), the cost of production per box has increased by a higher percentage (CREC, 2016a) because growers changed the management of their groves in an attempt to slow down the disease's progress and infection rate.

The conventional protocol to manage HLB has consisted of routinely inspecting trees for symptoms, as well as controlling the ACP by means of insecticide sprays. If symptoms are found on a tree, removal of such tree has been recommended to ensure the elimination of the inoculum (Bové, 2006). However, growers in Florida have been reluctant to eradicate symptomatic trees

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[1] Even though HLB was first found in Florida in 2005, the initial figures we use next to illustrate its impact on the industry correspond to 2004 because they provide a better estimate of the scale of the industry prior to HLB. Florida was hit by four hurricanes between August and September of 2004. A little over a year later, in October 2005, another hurricane hit the state. Those hurricanes had a significant negative impact on yield and, therefore, production of oranges statewide in 2005, 2006, and 2007.

that were still productive. Therefore, as an alternative management strategy to eradication, they started applying foliar applications of nutrients in an attempt to bypass the blockage of phloem vessels HLB causes (Spann et al., 2010). Thus, sprays for the vector of the disease, the ACP, and enhanced nutritional programs for citrus trees account for the bulk of the increase in the costs of producing oranges in Florida.

Pest Mobility and Area-Wide Pest-Control Management

Management of localized pest populations by individual farmers on a field-by-field basis has been the most widely used strategy for pest control (Klassen, 2008). However, the effectiveness of individual uncoordinated sprays is compromised by the mobility of pests (Vreysen, Robinson, and Hendricks, 2007). In fact, recent work on the characteristics and mobility capabilities of the ACP call for an area-wide perspective in pest control. While it has been hypothesized that the ACP can be carried by air masses over long distances, scientists recently found the ACP is capable of traveling 2 kilometers within 12 days (Lewis-Rosenblum et al., 2015).

As opposed to individual farm pest management, area-wide pest management is based on the premise of addressing the pest population of an entire area, not just a single farm. The idea underlying such efforts is that it provides a larger and more lasting effect relative to individual (uncoordinated) farm sprays. Area-wide pest management is also aimed at reducing the risk of developing pesticide resistance (Vreysen, Robinson, and Hendricks, 2007). Yu and Leung (2006) found evidence that area-wide pest management is superior to individual farm pest spraying in the presence of pest mobility.

It is due to their mobility that pests can also be viewed as common property. Neighboring growers share the pest; therefore, crop damage is dependent not only on the individual farm pest population, but on the total pest population in the region. Due to reinfestation from neighboring farms, actions on individual farms have little effect on the density of the pest in future periods in that farm (Lazarus and Dixon, 1984). Thus, individual pest management results in underprovision of pest control from a societal perspective (Yu and Leung, 2006), creating a disparity between private and social optima (Reguev, Gutierrez and Federer, 1976). As pointed out by Miranowski and Carlson (1986), collective pest-control may result in a higher level of welfare relative to individual optimization.

By coordinating pest control, groups may internalize externalities and increase the productivity of pest-control inputs. However, area-wide pest management programs are not without challenges. Despite the desirable technical, economic, and environmental attributes of area-wide pest management, the implementation of such programs can encounter resistance ranging from concern over methods, free riding, general public opposition, and lack of stakeholder participation (Mumford, 2000; Klassen, 2000).

The purpose of this study is twofold. The first objective consists of analyzing whether citrus blocks in area-wide ACP control management programs in Florida — known as Citrus Health Management Areas (CHMAs) — with higher levels of participation have attained greater economic benefits. Knowing whether growers in properly functioning CHMAs obtain greater profits than growers in CHMAs with poor participation, or who do not participate in CHMAs at all, should be important for industry stakeholders and policymakers alike. Given that there is currently no cure or successful strategy to manage HLB, should properly functioning CHMAs be found to be more profitable, more growers should join and coordinate their efforts. Furthermore, policymakers should provide additional incentives for growers to join these area-wide pest management programs, and provide support for effective communication and coordination of ACP sprays among local citrus growers and grove managers.

The second objective of the study is to examine citrus growers' attitudes toward CHMAs. Rook and Carlson (1985) examined the producer's choice between group and individual pest control, and argued that if the differential benefit of joining a group is greater than the differential cost, then the farmer should join the group. But is it reasonable to assume that a higher expected payoff will suffice to entice growers' participation? What should be included in the definition of cost? Is coordination with neighbors an issue? Better information about producers' preferences and opinions regarding CHMAs should prove useful in designing incentive mechanisms to enhance grower participation in CHMAs.

In the next sections, we first describe the context of area-wide pest management in citrus production. Then, we conceptually illustrate how insects and cultural practices of neighboring producers can affect each other. The empirical part follows, first analyzing the impact of CHMAs with different levels of participation on yields and producer benefits and, second, examining grower participation decisions in CHMAs. Finally, we consider the potential impact of the 2016 Citrus Crisis Declaration on area-wide pest management efforts in Florida before presenting our conclusions.

II Area-Wide Pest Management in Brazil and Florida

Florida's main competitor as orange-juice producer is Brazil. The largest orange producing area in Brazil is the state of São Paulo, where HLB was found in 2004. To date, the magnitude of the impact of HLB in Brazil has not been as dramatic as in Florida, mainly because Brazilian growers adopted tree eradication (inoculum removal) at the beginning of the outbreak. However, despite its lower spread relative to Florida, HLB still imposes a significant economic burden on Brazilian producers in terms of costs of scouting for psyllids, tree removal, and insecticide applications (Belasque et al., 2010).

Bassanezi et al. (2013) showed evidence of the ineffectiveness of combining inoculum removal and sprays for ACP in non-area-wide control areas. Contrastingly, they also found that combining those strategies in an area-wide management program was effective in reducing the disease epidemics. An interesting case study of cooperation for ACP control in Brazil was reported by Johnson and Bassanezi (2016), in which a large (corporate) grower started an ACP control program beyond his grove borders. Having noticed increasing infection rates on the edges of his groves, the grower offered neighboring small growers and backyard citrus homeowners – within a 2.5-mile radius of their operations – to spray their trees monthly. Alternatively, homeowners were also offered replacement fruit trees other than citrus. According to the authors, the grower obtained a return of $30 for every dollar spent in the program during the first two years.

The establishment of an area-wide management program for ACP in the state of Florida was proposed as part of the strategic plan for the state's citrus industry to address HLB (National Academy of Sciences, 2010). Thus, CHMAs were created around 2010, as voluntary groupings of growers to work cooperatively to coordinate insecticide application timing and mode of action to control the spread of ACP across neighboring commercial citrus groves in Florida. CHMAs were originally proposed to encompass areas of 10,000 to 50,000 acres. There were 35 active CHMAs in Florida in 2012. By 2015 the number of CHMAs had increased to 55, which were distributed across 26 counties. However, only 19 of those CHMAs were estimated to be active (CREC, 2016b).

Besides citrus growers, key participants in CHMAs are the University of Florida's Institute of Food and Agricultural Sciences (UF/IFAS), the Florida Department of Agriculture and Consumer Services (Division of Plant Industries), and the U.S. Department of Agriculture's Animal and Plant Health Inspections Service (USDA-APHIS) (through the Citrus Health Response Program (CHRP) under Plant Protection and Quarantine (PPQ)). The former institution is in charge of facilitating communication of information between researchers and scientists, whereas the latter two provide ACP scouting data and mapping of CHMAs. Growers, scientists, and UF/IFAS extension agents cooperated to delineate areas. The criteria included infection rates, psyllid control practices, tree removal practices, presence of abandoned groves, location of groves following organic practices, as well as target markets for the fruit (Rogers et al., 2010).

III. Conceptual Framework

To illustrate the pest management externality occurring across neighboring farms, consider two adjacent growers A and B, and assume all inputs other than pest control are identical. The following two equations exemplify the individual profit functions for growers A and B, respectively, and highlight that insects and cultural practices of neighboring producers can affect each other (Norgaard, 1976).

$$(1) \qquad \pi_A = p\, F_A(X_A, X_B) - r\, X_A,$$

$$(2) \qquad \pi_B = p\, F_B(X_A, X_B) - r\, X_B,$$

where p is the price of output, $F_i(\cdot)$ denotes the amount produced by grower i, X_i represents the level of pest control input used by grower i, and r is the price of such input. Importantly, the amount produced by grower A ($F_A(X_A, X_B)$) depends not only on her amount of input used (X_A), but also on the amount of input used by grower B (X_B), and vice versa. Thus, even though grower A can only choose her own pest management inputs, grower B's input choice also enters into grower A's profit function.

Typically, producers do not coordinate their use of inputs with their neighbors. That is, growers usually choose the amounts of inputs to maximize their own farm's profits. Thus, since growers do not take into account the effect of their choices on their neighbors, the individual "myopic" first order necessary conditions for optimization for growers A and B are represented by equations (3) and (4), respectively,

$$(3) \qquad \frac{\partial \pi_A}{\partial X_A} = p\, \frac{\partial F_A}{\partial X_A} - r = 0,$$

$$(4) \qquad \frac{\partial \pi_B}{\partial X_B} = p\,\frac{\partial F_B}{\partial X_B} - r = 0.$$

Equation (3) implies that farmer A will choose the amount of input X_A so as to equate her individual marginal revenue ($p\ \partial F_A/\partial X_A$) to her individual marginal cost (r), disregarding the fact that her input choice also affects her neighbor's marginal revenue (because $F_B(X_A, X_B)$ is a function of X_A). Equation (4) has an analogous implication regarding farmer B's input choice.

Under an area-wide management plan, farmers agree on the pest management program and coordinate efforts. Thus, the following joint maximizing problem takes place:

$$(5) \qquad max_{X_A, X_B}\ \pi = p\ F_A(X_A, X_B) + p\ F_B(X_A, X_B) - r\ X_A - r\ X_B - c\ X_A - c\ X_B,$$

where c denotes the cost of the coordination efforts per unit of input. In this instance, the first order conditions are given by:

$$(6) \qquad \frac{\partial \pi}{\partial X_A} = p\,\frac{\partial F_A}{\partial X_A} - r + (p\,\frac{\partial F_B}{\partial X_A} - c) = 0,$$

$$(7) \qquad \frac{\partial \pi}{\partial X_B} = p\,\frac{\partial F_B}{\partial X_B} - r + (p\,\frac{\partial F_A}{\partial X_B} - c) = 0.$$

By comparing expressions (3) and (4) to (6) and (7), the terms in parentheses that appear in the latter two equations denote the additional marginal profits to farmer B and A, respectively, derived from the pest control actions in the neighbor's farm. Thus, if the marginal value product of the neighbor's pest control on the grower's farm is greater than the cost of coordination ($p\ \partial F_B/\partial X_A > c$, $p\ \partial F_A/\partial X_B > c$), the marginal benefit of coordination is positive. Therefore, in this case coordinating the use of inputs to control the pest as in (6)-(7) outperforms the solution obtained under individual optimization given by (3)-(4).

To achieve the joint profit maximization outcome under area-wide pest management, all (or, at least a majority) of growers would need to optimize in the same manner; that is, participate in the area-wide pest management program. Should a significant number of growers in an area use the individual maximization criterion instead – making participation fall below a minimum threshold – the resulting pest control would be lower compared to the efficient outcome, and therefore, a higher pest population should be observed in that area.

To illustrate how critical the level of participation in an area-wide pest management program can be for its success, consider figure 1. This graph shows the average number of ACPs found by the USDA-APHIS-PPQ-CHRP in the two CHMAs for which we have the production data described in the next section.[2] With a few exceptions, it is clear from the figure that CHMA 2 has a lower average number of ACPs through the entire series compared to CHMA 1. The production data available for these two CHMAs is described next, and analyzed econometrically in the following section.

IV. CHMA Production Data and Analysis

In this section we test the underlying hypothesis that a CHMA with higher level of participation – where more growers coordinate their pest-control management efforts – results in a differential yield level compared to an area in which growers do not coordinate as much. Our goal is to quantify the differential economic benefit derived from a higher level of participation in CHMAs.

Data

Our production data pertain to two sets of Valencia orange blocks, each located in a different CHMA. The first set of data includes six blocks comprising 221 acres located in CHMA 1. The second set includes five blocks with a total of 161 acres located in CHMA 2. The data on annual

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[2] The USDA-APHIS-PPQ-CHRP started scouting and monitoring ACPs within CHMAs in August 2011.

yields include production by block for crop years 2008/09 to 2014/15, constituting a panel data set for those blocks.

The two CHMAs are located in neighboring counties in Central Florida and the blocks have comparable management and climatic conditions. A salient feature of our data is that the same grower owns all the blocks, which have been managed under the same practices (i.e., number of sprays, nutritional programs, and fertilizer applications) and have similar characteristics in terms of production region, tree age, tree density, and reset plantings.[3] However, participation of fellow growers in the two CHMAs is different; CHMA 2 has had a substantially higher level of participation compared to CHMA 1.[4] In addition, the grower who provided the data is the leader (i.e., the coordinator) in both CHMAs. Given the characteristics of this data set, the differing "treatment" across blocks is the level of participation in the area-wide pest-control management program.

Analysis

To assess whether there was any statistically significant difference in the mean level of yield attained in the two sets of blocks before CHMAs were established, we conducted a t-test using yield data for the year 2008/09. The results, reported in table 1, provide no evidence that yields were different between the two sets of blocks previous to the establishment of the CHMAs.

To determine whether yields between blocks differed after establishing the CHMAs, we performed a regression of the yield (in boxes per acre) for block j in year t as a function of dummy variables representing crop years 2009/10 through 2014/15, and dummy variables interacting crop years and CHMA 2 (CHMA2 · year). In this way, the coefficients of the crop year dummy variables encompass the overall incidence that weather, pests and disease had on that year's yield (on CHMA 1). Since there were no extreme weather events during those years,

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[3] Characteristics for which we do not have data include soil quality and soil pH.

[4] From personal communication with CHMA leader

it can be sensibly argued that any effect to be found during those years is due to HLB. The interaction dummy variables (CHMA2 · year) are intended to capture the differential yield per acre of CHMA 2 through time.

We analyzed the data using two methods, a random effects model and a pooled OLS model with clustered standard errors. The implicit assumption underlying the former model is that the unobserved effects are uncorrelated with all explanatory variables. To account for the serial correlation in the errors, we computed the random effects estimator (i.e., the feasible Generalized Least Squares (GLS) estimator described on pp. 470-471 of Wooldridge, 2003). For comparative purposes, we also estimated a pooled Ordinary Least Squares (OLS) regression with clustered standard errors, which provides robust standard errors to correlation among errors of the same block and heteroscedasticity over time.

Regression results are shown in table 2. The estimated coefficients are similar in both models, and the same variables are found to be statistically significant. However, to be conservative, we discuss the results of the random effects model because they provide somewhat less favorable results to CHMA 2 than the pooled OLS model with clustered standard errors. All of the coefficients from year 2012/13 onwards are negative and significant at standard levels. In contrast, the coefficients corresponding to the years prior to 2011/12 are not significantly different from zero. The lack of significance for the coefficients corresponding to these earlier years is not surprising, because the effects and rate of infection of HLB were not as widespread then as they have been in more recent years. In addition, CHMAs were merely starting to be organized at the time. However, it is interesting to note that the coefficient for year 2011/12 is positive and significant, denoting an increase in yield relative to the base year. This result can be explained in the light of the freezes that occurred in 2010/11, which actually ended up causing minor damage to the crop, but fears of a shortage in supply caused a 24% increase in the average season (on-tree) price. Since growers typically adjust their level of grove caretaking expenses in the same direction of price changes, it is likely that the higher yield in 2011/12 was a consequence of such behavior. As denoted by the dummy variables year 2012/13, year 2013/14, and year 2014/15, yields in CHMA 1 decreased with respect to 2008/09 by 61.0, 140.1, and 183.7 boxes per acre, respectively; all three coefficients are both statistically and economically significant.

Figure 2 illustrates the regression results reported in table 1, but in terms of total boxes per acre by CHMA. It is worth noting that our finding of significantly higher yields in 2011/12 but lower yields starting in 2012/13 in CHMA 1 is in line with the pattern in average Valencia oranges yield observed for the state. Figures 3 and 4 show USDA-NASS (2016) estimates on Florida's average yield and percentage of fruit drop, as well as the number of fruit per box; two of the major symptoms of HLB are increased fruit drop and smaller fruit size.

Another key result from our regression estimation is the magnitude and significance of the coefficients corresponding to the interaction variables. The dummy CHMA2 · Year 2012/13 (CHMA2 · Year 2013/14) [CHMA2 · Year 2014/15] shows that the yield in 2012/13 (2013/14) [2014/15] was, on average, 72.5 (134.5) [137.0] boxes per acre higher in blocks located CHMA 2 compared to those located in a CHMA 1. Therefore, the partial offsetting effect of CHMA 2 against the negative impact of HLB on yields is increasing over time (at a decreasing rate). This finding is consistent with the general idea that benefits from investments in area-wide programs accrue over a multi-year time horizon (Klassen, 2008).

To obtain a measure of the differential annual economic revenue accruing to CHMA 2 over CHMA 1, we multiply the differential annual yield obtained above by the corresponding price per box. Thus, we combine -25.8 (72.5) [134.5] {137.0} boxes per acre with the annual average on-tree price per box for processed Valencias in 2011/12 (2012/13) [2013/14] {2014/15}, which was \$11 (\$8.60) [\$10.75] {\$10.50} (USDA-NASS, 2016). By doing so, we obtain an estimated differential gross economic benefit per acre of -\$284 (\$624) [\$1,446] {\$1,439} in 2011/12 (2012/13) [2013/14] {2014/15}.

To estimate the direct cost of CHMA participation, we assume the program of CHMA 2 consists of 8 sprays, which can usually be aerial and cost $8 per acre each. Clearly, in this case the cumulative net benefit is positive. However, even if a grower needed to perform ground applications, which cost $25 per acre assuming a stand-alone application (although a tank mix with other chemicals is used instead to make application cheaper) plus the average cost of materials at $18 – for a total of $43 each – the cumulative net benefit is still positive and substantial. Furthermore, the cumulative net benefit is not only positive in years in which a statistically significant differential benefit is observed, but also if we compute the cumulative cost across years since CHMAs started in 2010/11 and assume no differential yield during the first year. Hence, our analysis provides evidence regarding the efficiency of CHMA 2 to deal with HLB, and enhance the individual growers' profitability at a time when margins are becoming increasingly narrow.

V. CHMA Participation

To the best of our knowledge, there are no data available about participation in CHMAs. But, as mentioned above, the majority of CHMAs across the state are not active, which is startling given the magnitude of our findings (even if they represented a best-case scenario) and the impact of the disease across the state.

Given the dearth of information about grower participation in CHMAs, we recently conducted a paper-based survey with Florida citrus growers to learn more about their behavior related to CHMAs and their attitudes toward the area-wide pest management program. The survey took place at a meeting of Florida citrus growers in April 2016. The purpose of the meeting was to summarize the scientific advances and recommended practices to manage HLB. 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 survey forms were distributed at the entrance; each attendant had one as s/he entered the room. The moderator reminded the audience several times during the session to complete the survey. Thus, participants filled out the forms on their own before, in between, and after the talks. They handed back the survey once the session was over. The number of completed surveys by growers was 123, giving a response rate of 88%. The high response rate was likely due to the fact that a University of Florida merchandise clipboard was given to all respondents as a token of appreciation. The growers who responded to the survey represented 153,278 acres, which accounts for approximately one-third of the citrus acreage in Florida.

The survey form is reproduced in the Appendix. Succinctly, questions were designed to gather information on the following. First, whether the grower was participating in CHMAs at the time of the survey. Second, if not participating, growers had to rank their level of agreement with statements describing their reasons for not participating. And, if they did participate, growers had to rank their level of agreement with statements describing what they thought were the main obstacles to increase CHMAs effectiveness. Third, CHMA participants were also asked about the level of participation in coordinated sprays.

When asked about CHMA participation, we obtained 120 responses; 45 (37.5%) of the growers stated they do not currently participate, whereas 75 (62.5%) stated they do. Out of the 75 CHMA participants, 57 answered the question asking the extent to which they participate in coordinated sprays. Only 23 growers (40% of those who responded to the question) self-reported that they participated in coordinated sprays 100% of the time. The majority of growers (60%) stated that they participated less than 100% of the time: 14 (25%) growers participated between 76 to 99% of the time, 10 (18%) participated between 51 to 75% of the time, and 10 (17%) participated less than 50% of the time (see figure 5).

The lack of participation in coordinated sprays can be explained, to some extent, by the current lack of profitability in citrus production; during the last three seasons, the average Florida citrus grower was only able to break even (see figure 6). Moreover, the comparison of annual citrus production budgets shows that growers are reducing caretaking inputs, particularly insecticide applications (CREC, 2016a). However, given the evidence we presented above, reducing coordinated sprays might end up imposing a compounding cost, rather than savings, on those growers as well as on their neighbors. In this regard, larger operations might be at an advantage compared to smaller operations, since the former are less dependent upon the willingness of neighboring growers to participate in CHMAs.

Another question asked in the survey to non-CHMA participants concerned their reasons for not participating in coordinated sprays. Figure 7 shows graphically their responses on a Likert scale. The top reason growers mentioned for not participating in CHMAs was that other growers do not participate. That is, most growers perceive (correctly or not) that other growers are reluctant to coordinate efforts to control the pest. The second top reason, following closely the first one, was "I prefer to spray on my own timing," implying growers' own reluctance to coordinate efforts with other growers. In addition, "too much effort to coordinate" was the reason receiving the third-largest percentage of "agree" responses from non-CHMA participants.

The responses from CHMA participants regarding obstacles to increase CHMAs effectiveness are summarized in figure 8. Like non-participants, CHMA participants stated neighbors not participating as the top obstacle to increase CHMAs effectiveness. Interestingly, as depicted in figures 7 and 8, other than their agreement on neighbors' participation, CHMA participants and non-participants diverged on their opinions on whether it is too much effort to coordinate; it is too costly to spray; the usefulness of spraying; and the benefit of CHMAs. Of course, participants have actual experience regarding spray coordination, have incurred in the cost of CHMAs' sprays, and are aware of the effectiveness of spraying and its benefits. However, the divergence of opinion between participants and non-participants makes the latter's motives for not joining stand out even further.

Overall, it is clear from the survey responses that (lack of) coordination has been a major obstacle for the establishment and correct operation of CHMAs. In the case of non-CHMA participants, their responses suggest that strategic uncertainty — defined as uncertainty regarding the actions and beliefs of others — is a key consideration in growers' pest-control decision making. As Morris and Shin (2002) put it, "the idea is that even a small seed of doubt concerning the ability of the players to close ranks to achieve the good outcome will start to undermine the resolve of an individual player to stick to the cooperative strategy, and opt out".

VI. Potential Impact on CHMAs of the 2016 Citrus Crisis Declaration

In March 2016, the Florida Commissioner of Agriculture declared a citrus crisis under the Emergency Exemptions provisions of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA, 2016). The main goal of the declaration was to allow growers across the state to use anti-bacterials in foliar applications to attempt to enhance the health of trees infected with HLB. Given that the expected enhancement of anti-bacterials on HLB-infected trees is not yet proven — particularly given that most of the compound sprayed is not absorbed by the tree but lost in the environment or leeched into the soil — the citrus crisis declaration provides yet more evidence of the dire situation faced by Florida citrus growers due to HLB.

Quite interestingly, ACP population data suggest that the declaration has had the unintended effect of increasing the ACP infestation. As shown in figure 1, the two CHMAs analyzed above experienced a substantial spike in the average number of ACP per block in 2016, reaching record levels in both CHMAs. More importantly, figure 9 shows that this spike occurred statewide, and that the average ACP population in Florida achieved an all-time high in 2016. Significantly, such spike occurred shortly after the citrus crisis announcement allowing for the use of anti-bacterials in Florida, which suggests that growers are likely substituting insecticide applications with anti-bacterials. This substitution would imply that growers are getting away from the strategic uncertainty that CHMAs pose, and taking instead the risky/uncertain outcome that the self-managed strategy of anti-bacterials presents (which they evidently perceive to be lower).

The basic tenet of allowing for the use of anti-bacterials to manage HLB (i.e., that anti-bacterials might improve the condition of the trees infected with HLB) requires little coordination among growers. Thus, if anti-bacterials are eventually found unable to enhance the health of HLB-infected trees, encouraging its use now may severely hamper the chances to control HLB, not only because of anti-bacterials' ineffectiveness, but also because of their lack of reliance on the coordination required for CHMAs' success.

VII. Conclusions and Policy Implications

In our analysis of data on yields of Valencia oranges from blocks located in two CHMAs with different levels of participation, we found that the number of boxes per acre decreased significantly from 2012/13 through 2014/15. Since there were no extreme weather events such as hurricanes or freezes during those years, we argue that those variables capture mainly the increasing negative impact of HLB on yields. We also found that the yields of blocks located in the CHMA with higher participation were significantly higher compared to the yields of those blocks located in the CHMA with lower participation during those same years. Moreover, such partial offsetting effect found in the higher participation CHMA against the negative impact of HLB on yields has increased over time.

Our findings provide evidence on the efficiency of a well-performing CHMA to deal with HLB. However, CHMAs present growers with strategic uncertainty. In fact, regarding this issue, we found that the top reason stated by growers for not participating in CHMAs was their belief about their neighbors not participating. The second most important reason given for not participating in CHMAs was the grower's preference for self-reliance in spraying. These results help explain why participation in CHMAs and, therefore, their success is not as widespread across Florida as one would expect. Despite the relatively high benefit we found CHMAs can provide, the strategic uncertainty involved in relying on neighbors seems to impose too high of a cost for most growers, who end up not coordinating sprays.

Florida's recent approval of the use of anti-bacterials to manage HLB presented growers with a new alternative to combat the disease. It is still unclear whether such compounds will prove effective against HLB, but it seems they might have had an unfortunate side effect on CHMAs, the one strategy for which we found evidence that works to manage HLB. Thus, efforts should be made at the state level not only to prevent the cooperation among growers achieved in some areas from vanishing, but also to increase coordination to threshold levels that make cooperation among producers efficient against HLB across all citrus growing regions in Florida.

In the case of the Florida citrus industry, some form of cost-sharing spray program (subsidy) or tax-break could be required to increase the participation of growers in CHMAs by means of a classic intervention approach. Any such policy would benefit not only Florida citrus growers but also all Florida residents. The impact of the significant increase in chemical use in the last few years across the industry has not yet been measured nor analyzed. Less-intensive ACP control programs applied area-wide have been found to be as efficient as, or more efficient than, more intensive programs in non-area-wide control areas (Bassanezi et al., 2013). Furthermore, their success may lower the overall use of other chemicals, including nutritionals, fertilizer, or anti-bacterials. In addition to financial incentives, Pretty et al. (2001) suggest the use of processes that support communication and learning among farmers as an incentive for them to adopt sustainable practices more permanently, rather than only during the duration of the program.

Successful adoption of an area-wide pest management scheme may also enable producers to pool resources to use technologies, information systems, and expertise that are otherwise too expensive for individual producers. The pooling of resources would, for example, enable improved specialized analysis of pest immigration patterns and help implement approaches to prevent or retard the development of insecticide resistance (Klassen, 2000). Finally, the results of the present study also indicate that it would be important for future research to examine the effect that the underlying strategic uncertainty involved in area-wide pest management has on growers' participation decisions.

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Appendix

2016 Florida Growers Institute Survey

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

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

2) 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 ACP	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)

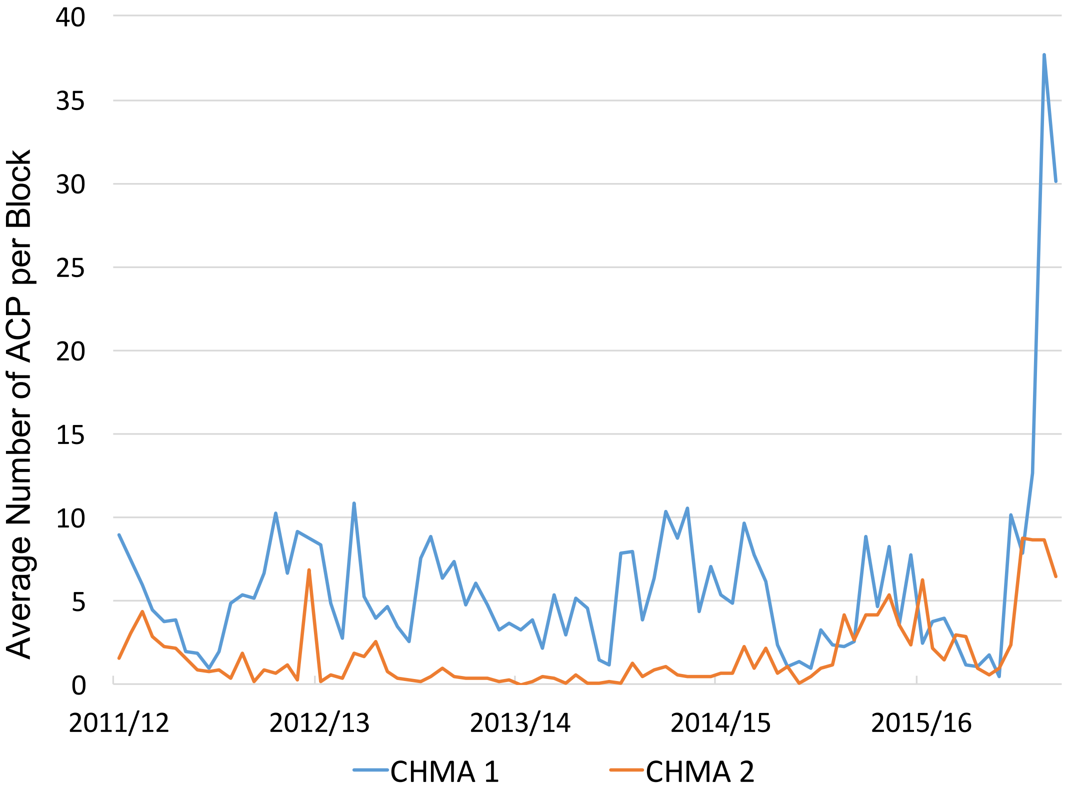
	Disagree		Somewhat Agree		Agre	
Neighbors do not participate	1	2	3	4	5	N/A
Too much effort to coordinate sprays	1	2	3	4	5	N/A
It is too costly to spray	1	2	3	4	5	N/A
Decreasingly effective to spray for ACP	1	2	3	4	5	N/A
Benefit (yield) decreasing	1	2	3	4	5	N/A

3) How many times did you spray for ACP during 2015/16 (without including CHMAs sprays)?_________

4) How many times did you participate in coordinated sprays as part of CHMAs during 2015/16?_________

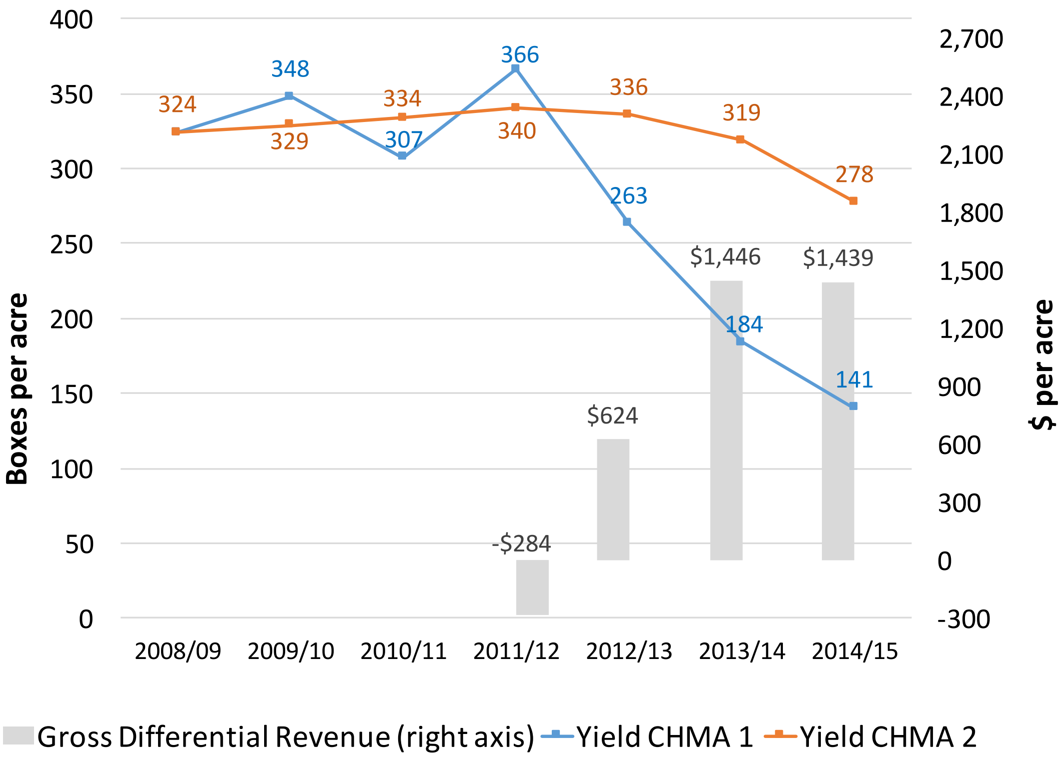
5) What percentage of times did you participate in coordinated sprays when an email from the CHMAs captain was sent during 2015/16?___________%

Figure 1. Average number of ACP per block by CHMA



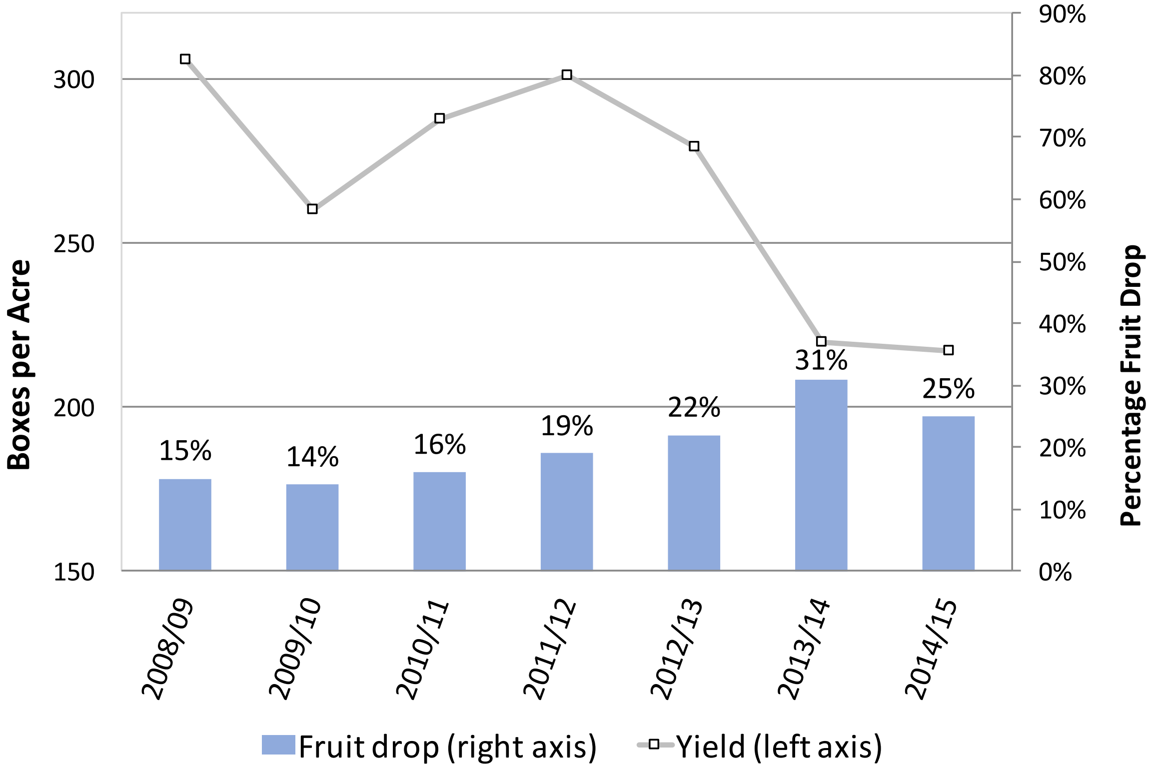
Source: USDA-APHIS-PPQ-CHRP

Figure 2. Regression results: yield per acre by CHMA class and differential revenue



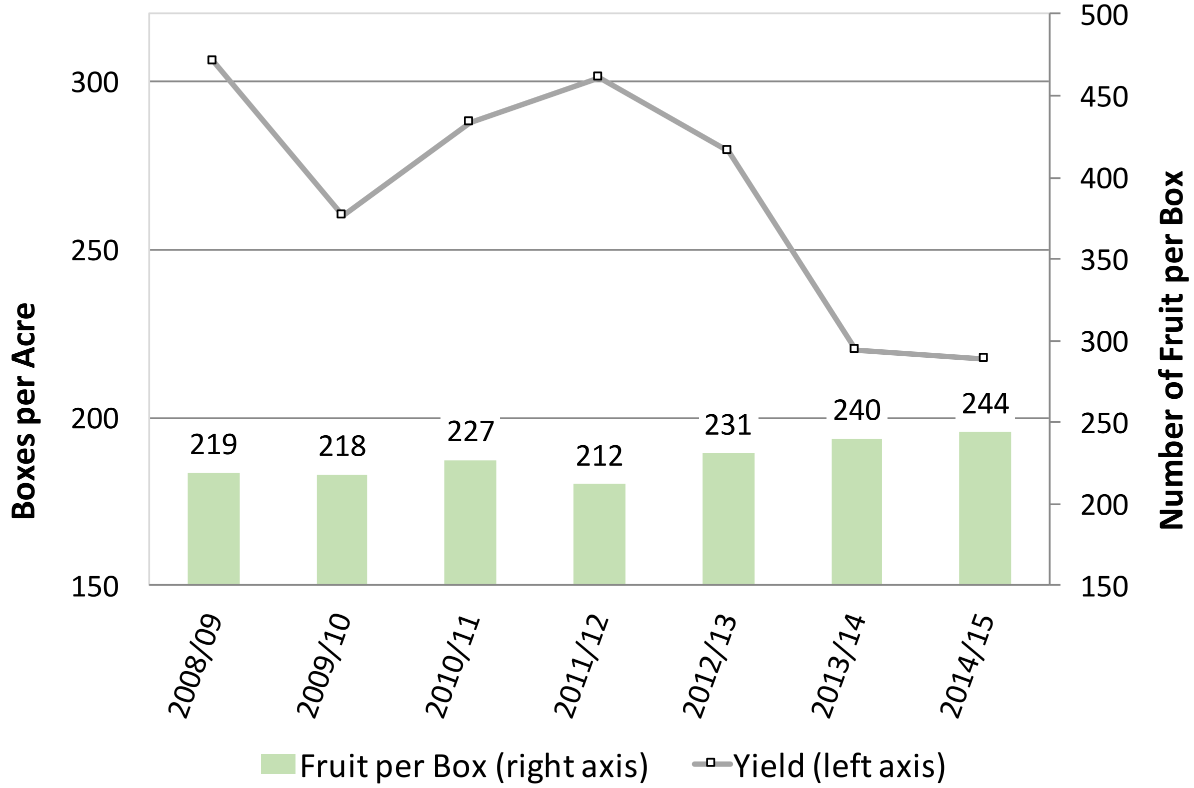
Source: Authors’ calculations

Figure 3. Yield and fruit drop of Valencia oranges in Florida



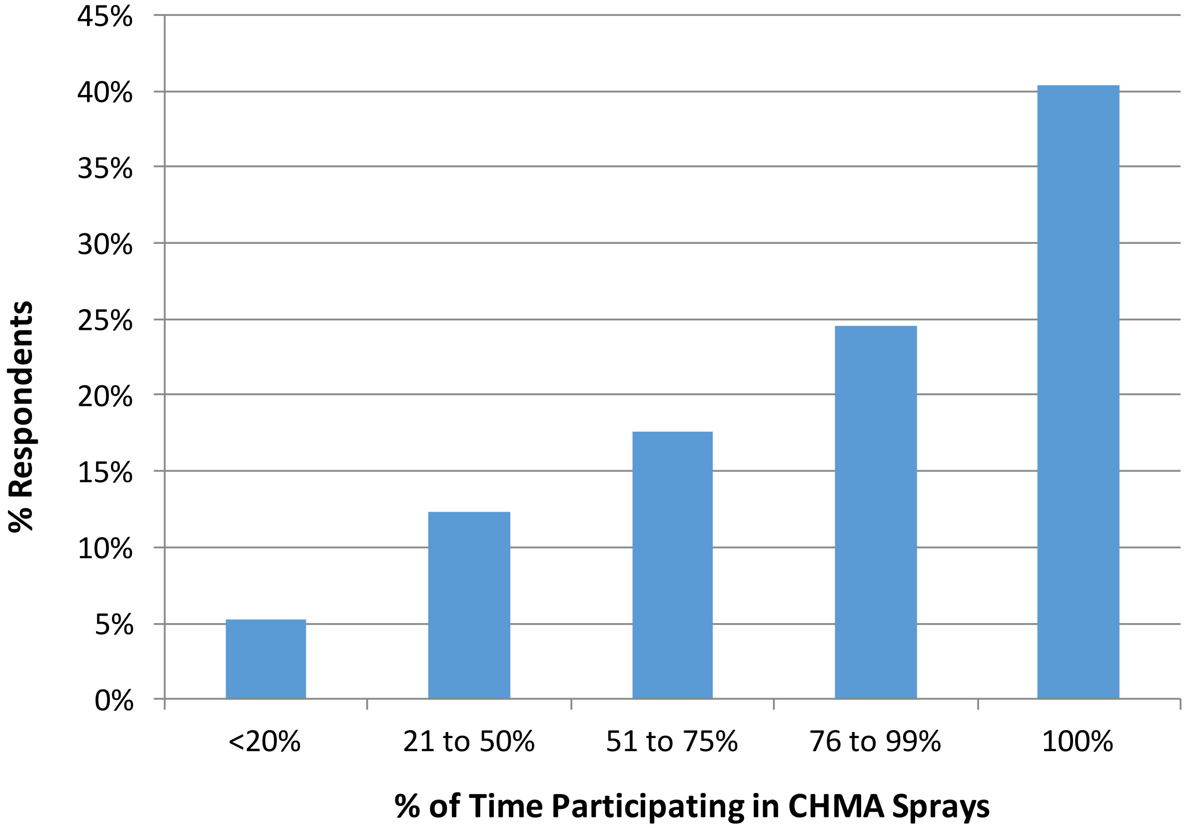
Source: USDA-NASS

Figure 4. Yield and fruit size of Valencia oranges in Florida



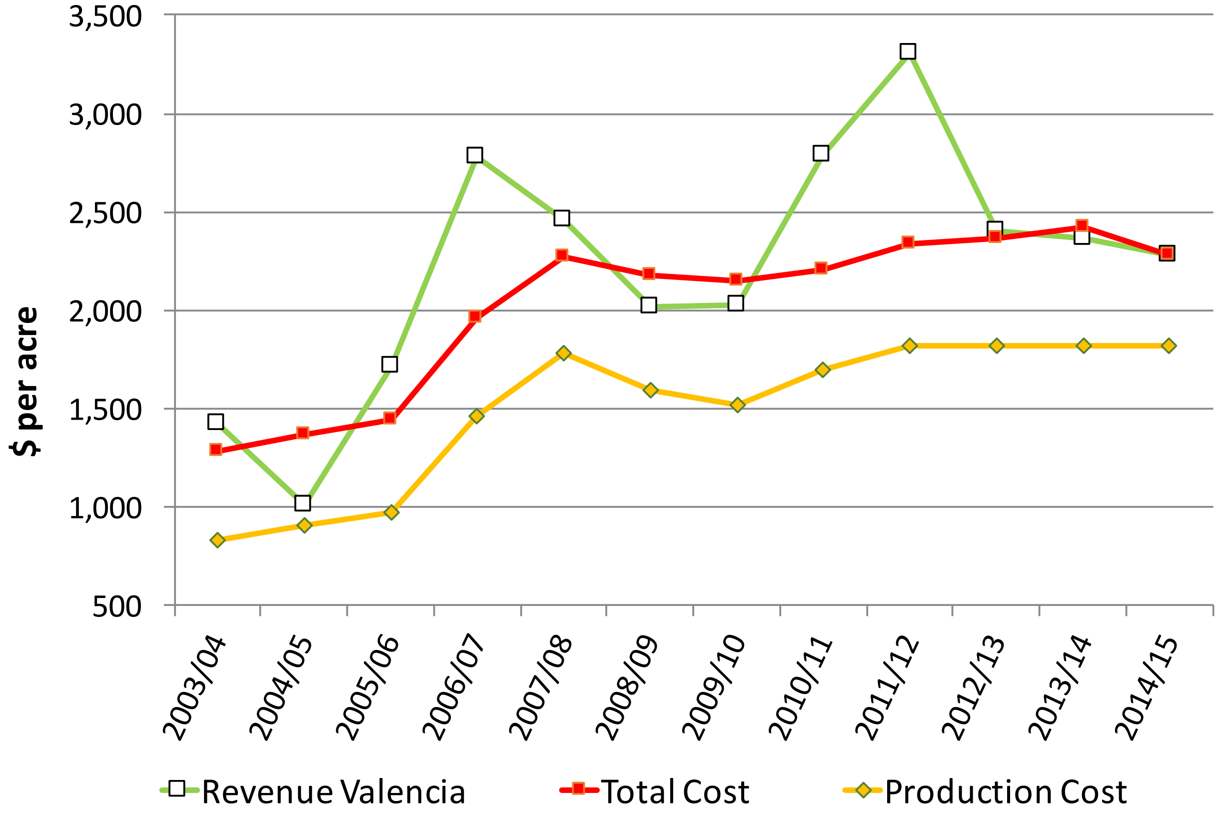
Source: USDA-NASS

Figure 5. Level of CHMA participation



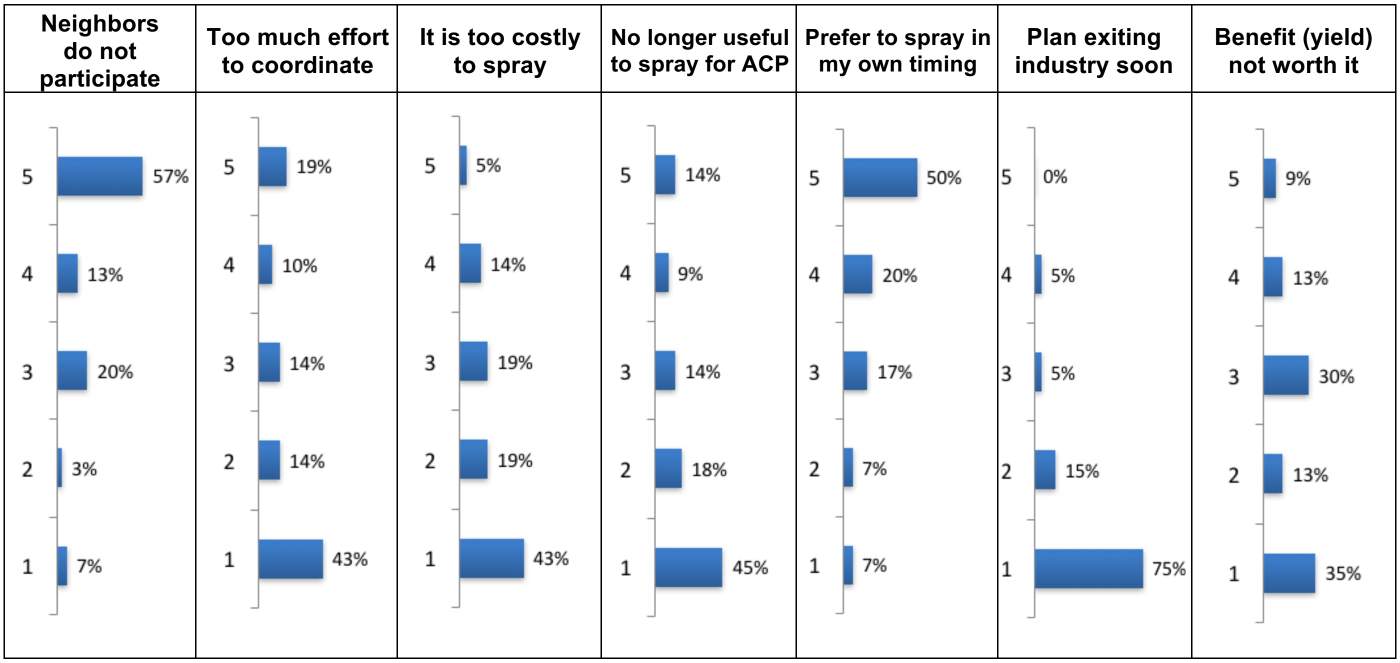
Source: Authors' survey results

Figure 6. Revenue and cost of production per acre in Central Florida



Source: Authors' calculations

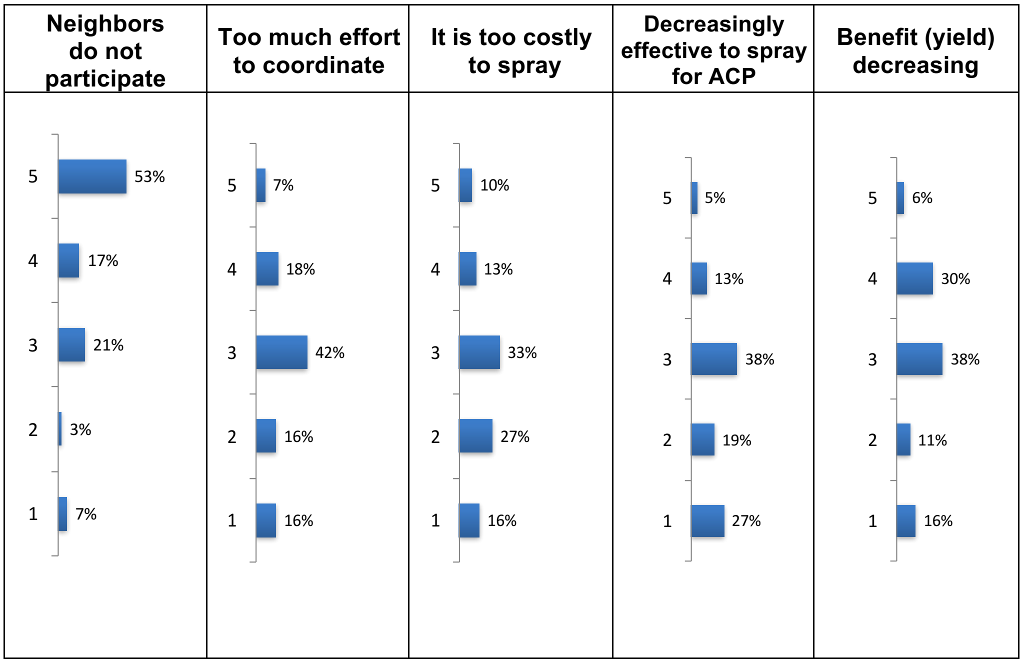
Figure 7. Reasons for not participating in CHMAs stated by non-CHMA participants



References:	Disagree		Somewhat Agree		Agree
	1	2	3	4	5

Source: Authors' survey results

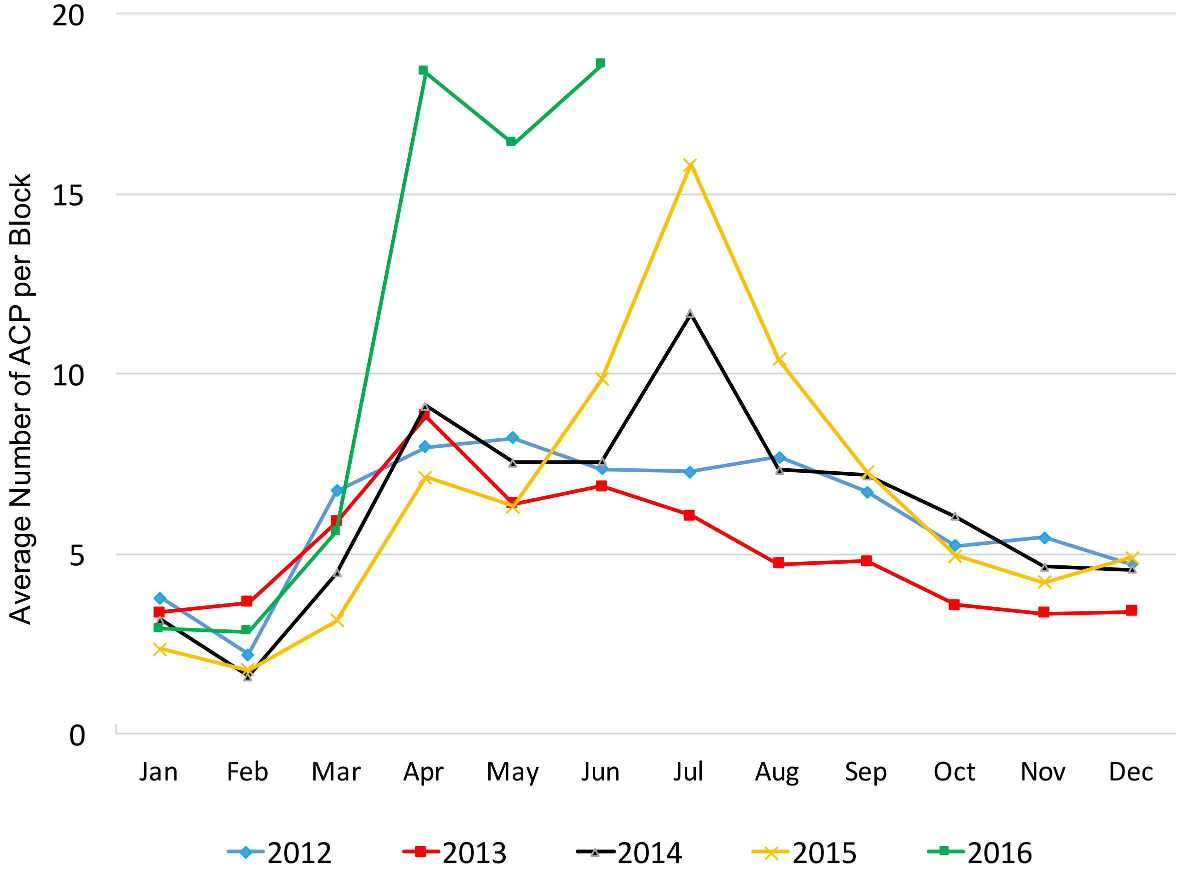
Figure 8. Obstacles to increase CHMA effectiveness stated by CHMA participants



References:	Disagree		Somewhat Agree		Agree
	1	2	3	4	5

Source: Authors' survey results

Figure 9. Average ACP population in the state of Florida



Source: CHMP and USDA-APHIS-PPQ

Table 1. T-test on equality of yield means for the year 2008/09

Group	Observations	Mean
CHMA 1	6	313.13
CHMA 2	5	337.39
Difference	11	-24.26

Probability of alternative hypothesis (Ha):

Ha: Difference < 0	Ha: Difference ≠ 0	Ha: Difference > 0
Probability(T < t) = 0.23	Probability(|T| > |t|) = 0.45	Probability(T > t) = 0.77

Table 2. Regression Results on Valencia Oranges Yields

Variable	Random Effects Model	Pooled OLS with Clustered Standard Errors
Year 2009/10	23.6	15.4
	(1.39)	(0.80)
Year 2010/11	-16.9	-25.1
	(-0.99)	(-1.30)
Year 2011/12	42.0**	33.8**
	(2.47)	(2.37)
Year 2012/13	-61.0***	-69.2***
	(-3.59)	(-3.17)
Year 2013/14	-140.1***	-148.3***
	(-8.24)	(-5.50)
Year 2014/15	-183.7***	-191.9***
	(-10.80)	(-7.33)
CHMA2 · Year 2009/10	-19.0	-0.9
	(-0.78)	(0.03)
CHMA2 · Year 2010/11	26.4	44.5
	(1.09)	(0.96)
CHMA2 · Year 2011/12	-25.8	-7.7
	(-1.06)	(-0.20)
CHMA2 · Year 2012/13	72.5***	90.6**
	(2.98)	(2.37)
CHMA2 · Year 2013/14	134.5***	152.6***
	(5.54)	(3.23)
CHMA2 · Year 2014/15	137.0***	155.1***
	(5.64)	(4.35)
Intercept	324.2***	324.2***
	(17.83)	(19.81)
Observations	77	77
Number of years	7	7
Wald χ^2_{12}	300.4	
Prob > χ^2_{12}	0.0	
R^2		0.60

t-statistics within parentheses

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