The Economic Challenges of Dealing with Citrus Greening: The Case of Florida

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Abstract

While pest management decisions are made at the farm level, a distinctive characteristic of the pest management of invasive species is its public-good nature. Here, we examine the challenges that a vector-disease pathosystem such as Diaphorina citri Kuwayama (Hemiptera: Liviidae)—citrus greening, creates for the adoption of prevention and collective management practices from an economic perspective. Those economic challenges originate from the choices and behavior of individual growers, which can impact not only their own payoff but also the choices, behavior and payoffs of other growers; influencing, for example, the spread of the disease, the vector population dynamics, and the adoption of proposed scientific solutions. While for most people the economics of invasive species is limited to calculating damage or control costs, economics is more than that. Economics can provide insights on the interactions between human behavior and natural processes, enabling a better understanding of the rationale of individual growers’ choices, which are key for the design and implementation of effective public policies to deal with invasive pests and diseases.

Key words: citrus greening, pest management, public goods

Citrus greening (Huanglongbing, HLB) is an incurable disease that affects citrus trees. It is caused by the bacterium Candidatus Liberibacter asiaticus (CLas) and vectored by the Asian citrus psyllid (ACP), Diaphorina citri Kuwayama (Hemiptera: Liviidae) (Bové 2006). HLB is regarded as the most devastating citrus disease worldwide (FAO 2015), and was found in Florida—the largest orange-producing state in the United States—in 2005 (Bové 2006). Since then, citrus production in Florida has decreased by 74% (USDA 2019a). As a consequence, growers have (on average) been facing losses and the entire industry has been downsizing. The number of citrus growers in Florida decreased from 7,389 in 2002 to 2,775 in 2017 (USDA 2002, 2017), the number of juice processing facilities decreased from 41 in 2003/2004 to 14 in 2016/2017, and the number of packinghouses decreased from 79 to 26 during the same period (Singerman et al. 2018).

Before the symptoms of HLB are first seen in the canopy of the tree (Bové 2006), the root abundance declines by 40–50% (Johnson et al. 2014). The incubation period of the symptoms lasts between 6 and 12 mo (Bové 2006), causing the spread and impact of the disease to occur over multiple years. However, more recently, using experiments and simulations, Lee et al. (2015) showed that groves could become infected in less than a year before most tress show any symptoms. Plant pathologists’ recommendations to deal with HLB include using insecticides to control ACP populations, inspecting trees for symptoms and, if symptoms are found, removing the tree to eliminate the source of inoculum (Bové 2006).

Despite scientists’ recommendations, due to several factors that are described in detail in subsequent sections, many growers in Florida opted to keep their affected trees early on. Without inoculum removal, HLB spread rapidly across the state, where it has become endemic. Florida growers have tried several strategies to deal with the disease and the vector—including the use of enhanced foliar nutritional applications, the intensive use of insecticides to control the ACP, the use of antibiotics, a voluntary area-wide pest management program, and thermotherapy of diseased trees—with little, if any, success so far. Thus, the question becomes whether Florida citrus growers’ choices and behavior in dealing with the disease have been rational from an economic perspective. The ACP had been present for approximately 7 yr before HLB was found. Despite ACP being a minor pest when HLB is not present (Halbert and Manjunath 2004), should not growers have tried to organize themselves collectively to control the vector before the arrival of the disease? What can be learned from the experience in Florida? And, what public policies or institutions could be helpful to deal with HLB (and similar vector-borne diseases)?

The objective of this article was to elucidate the challenges that a disease-vector pathosystem such as HLB-ACP creates for the adoption of preventive and collective management practices from an
economic perspective. Those economic challenges originate from the choices and behavior of individual growers, which can impact not only their own payoff but also the choices, behavior, and payoffs of others; influencing, for example, the spread of the disease, the vector population dynamics, and the adoption of proposed scientific solutions. Therefore, gaining understanding of the rationale for individual growers’ choices and behavior is key to design and implement effective public policies to deal with HLB.

Dealing With Invasive Species

The introduction of synthetic pesticides in the second half of the 20th century allowed growers to deal effectively and cheaply with many pests (Smith et al. 1976). Thus, the use of chemicals enabled growers to control pests independently on their farms without regard for their neighbors’ opinions and actions. Uncoordinated chemical pest control became widely adopted during the last 60 yr (Vreysen et al. 2007). Despite these control actions, invasive insect species cost US$70 billion per year globally (Bradshaw et al. 2016).

An insect control action is only justified once the insect pest population reaches a certain level. Formally proposed by Stern et al. (1959), the economic injury level is the number of insects that cause an amount of injury in terms of yield losses equal to the insect management costs. Since it is desirable to begin the control before the pest actually reaches the economic injury level, the economic threshold determines the pest density at which control should be taken. While such threshold is the basis for integrated pest management (IPM) recommendations in crop production (Metcalf and Luckman 1975), it is site specific (Faust 2008). The limitations of using an economic threshold to control the spread of a pathogen vector, such as the ACP, are acknowledged by Monzo and Stansly (2017); in their study on economic injury levels for ACP, the authors present evidence on the benefits of using threshold treatments for spraying HLB-affected mature groves in Florida but mention (p. 22): ‘Threshold-based management as we define it here is limited to HLB infected mature trees and thus does not take into account risk of HLB infection to newly planted trees.’ The authors further argue that it would be necessary to integrate an effective young tree programs to apply threshold-based management over an area that would include citrus of all ages and levels of HLB incidence. Therefore, the problem with growers using a site-specific economic threshold is that they do not take into account the impact they have on their own young trees or on neighboring groves. This is so because the effectiveness of individual uncoordinated pest control is compromised by the mobility of pests (Vreysen et al. 2007).

Due to their mobility, pests can be viewed as common property. Since neighboring growers share the pest, crop damage is dependent not only on the individual farm pest population, but also on the pest population in the region. Because of reinfection 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). Several studies showed that the ACP can disperse widely (Aubert 1990, Boina et al. 2009, Tiwari et al. 2010, Hall and Hentz 2011, Lewis-Rosenblum et al. 2015, Martini et al. 2018). As with other pests, such mobility compromises the effectiveness of individual actions because the ACP can move freely across and between farms. Therefore, crop damage and the level of infestation depend on the regional pest population. However, the problem is not simply that of dealing with a highly mobile insect pest, but that posed by a highly mobile vector of a disease (for which there is no cure) that affects citrus groves in terms of yield, tree mortality, and cost of production. Thus, following only site-specific best management practices ignores the collective nature of the problem. The ability of individual farmers to control the ACP and HLB depends critically on the actions of neighboring growers (Filho et al. 2016, Singerman et al. 2017), which creates a public-good dilemma.

Public Goods

The issues involved in eradicating invasive species are similar to those found in the provision of public goods. Such goods are characterized by being nonexclusive and nonrival. They are nonexclusive because once provided, no individual can be excluded from benefiting from them, and they are nonrival because the additional cost of another individual benefiting from them is zero. Examples of public goods include national defense, lighthouses, and highways. A public good should be provided if the sum of each individual’s willingness to pay for it is greater than its cost. However, when individuals are asked to voluntarily contribute to the provision of a public good, they have an incentive to free ride on the contribution of others and enjoy its provision anyway due to its nonexclusive trait. This means that, if their provision were to be determined by market forces, public goods would be undersupplied. Thus, in those cases, markets fail to allocate resources efficiently; ending up with a lower quantity compared with what is socially desirable. That is the reason for which public goods are typically provided by the government.

To exemplify the public-good nature of controlling the risks of biological invasions, consider the typical example of a country establishing a quarantine to protect against an invasive pathogen. The quarantine reduces the risk of infection to everyone within the country, and the benefit from the absence of the pathogen is neither rival nor exclusive. However, a quarantine illustrates an uncoordinated control measure imposed by a central authority, who evaluates the trade-offs between benefits and costs. But, the effective control of invasive alien species often requires a collective action by unmonitored individuals who do not face the full consequences of their decisions, which are motivated by private economic interest (Hennessy 2008). Therefore, the control of biological invasions has been modeled as a weakest-link public good (see, for example, Cornes and Sandler 1984, Cornes 1993, Barrett 2007, Ervin and Frisvold 2016). Such characterization implies that the provision of the public good (i.e., the regional level of pest control) will be given by the individual who contributes the least: the weakest link in the chain. In such a case, there is no incentive for individuals to free ride because doing so would result in no provision, but the collective action is jeopardized by the potential decision of any individual to become a noncontributor (Sandler 2015).

In the discussion above, there is no distinction between insect pests and insects that are vectors of pathogens. In fact, the weakest-link public good characterization is valid for the eradication efforts of dealing with both insect pests and vectors. However, it would be reasonable to expect that disease vectors would be managed more strictly, particularly if there is no cure or management strategy for the disease, as it is the case for HLB. As the options for therapeutic treatment for the management of a plant disease decline, the benefits of using an economic threshold are reduced (Higley and Peterson 2009). According to Gullan and Cranston (2005), the appearance of either the vector or the symptoms of a disease that causes significant economic damage requires that precautionary measures be taken before any economic threshold is reached. In such a case, the economic threshold may be the first appearance of the insect because once a plant is infected it becomes a source of inoculum that contributes to the spread of the disease. Therefore, for the case of ACP and HLB, the public-good nature of the problem is generated by growers who...
decide not to coordinate actions with their neighbors and (unintentionally) end-up imposing a cost on those who do coordinate.

The Role of Economics in Dealing with Invasive Species

As noted by Perrings et al. (2002), the susceptibility of an ecosystem to an invasion depends not only on the ecosystem itself but also on multiple factors such as human behavior, land use, demographics, market and institutional structures, the regulatory framework, and the control strategies. Thus, economics—the allocation of scarce resources—is key for effective policymaking on invasive species (Shogren 2000). In fact, the roles of economists and biological scientists complement each other. According to Venette and Koch (2009), the management of invasive species must begin with a definition of goals, but decisions regarding what goals to pursue must be the reflection of societal values. The authors argue that while biologists are well trained to make the tactical decisions, they are generally less experienced in soliciting and incorporating public input to formulate a goal. It is the role of economists and social scientists to formulate management goals and allocate resources to achieve those goals.

So, while for most people the economics of invasive species is limited to calculating damage or control costs, economics is more than just that “[i]t is a framework for understanding the complex causal interactions between human behavior and natural processes, and for finding institutional and behavioral solutions to seemingly intractable environmental problems.” (Perrings et al. 2002, p. 1). Thus, the risk of introduction, establishment, and impact of invasive species is both a biological and economic issue because economic and environmental systems are jointly determined; human actions affect nature and vice versa (Finoff et al. 2006). In other words, while agriculture is inherently a product of socio-ecological factors, understanding how such factors combined to generate the particularly negative impact that HLB has had on the Florida citrus industry is key for developing policies and institutions to deal more effectively with such an invasive species than the Florida citrus industry has so far. A recent report from the National Academy of Sciences (2018) reviews the research efforts made thus far to deal with HLB in Florida. The authors of the report not only recognize the importance of economic and sociological factors on the decisions and behavior of growers but also emphasize the influence of such factors in the likelihood of adoption and success of HLB management efforts.

Understanding Growers’ Decisions: Preventive Versus Control Measures

The risk of invasions depends on the human response to the threat (Perrings et al. 2002). Such response can be in terms of prevention (which reduces the odds that a species will establish or spread) or control (which consists in making adjustments in behavior to reduce the impact of the establishment or spread of a species), while both are intertwined, the former reduces the likelihood of the impact whereas the latter reduces the magnitude of the impact (Shogren 2000).

Despite pest invasions being low probability events, they can potentially lead to fundamental changes in an ecosystem, which may impose high costs on stakeholders (Perrings 2001). Thus, it would be reasonable to expect a cautious grower to use more prevention relative to control to keep invaders out, but this is not typically the case (Sandin 1999, Foster et al. 2000, Finoff et al. 2007). In general, resources are mostly used to control existing invaders and limit the damages rather than to prevent new invasions (Leung et al. 2002, Carlton and Ruiz 2005). Finoff et al. (2007) argue that such paradoxical decisions can be understood by recognizing the link between typical human risk bearing preferences and risk-reduction technology. Most people (growers included) are risk averse, which means they are willing to accept a somewhat lower level of average income in exchange for lower variability (i.e., uncertainty) of income (Frisvold 2019).

To examine the link between typical human preferences for risk and the technology of risk reduction, Finoff et al. (2007) simulated the prevention and control strategies of individuals with increasing levels of risk aversion. Their results illustrate that risk aversion can lead to less prevention and more control because a risk-averse individual values a dollar spent on control more highly than a dollar spent on prevention. In other words, prevention is technologically a riskier input relative to control. This is so because prevention only reduces the chance of invasion, it does not eliminate it. Control, on the other hand, is a safer investment because removing invaders is less risky compared with reducing the chance of an invasion that, even without prevention measures, may not occur. Similar behavior has been observed for managing pesticide resistance: some farmers choose not to manage pesticide resistance because the costs of management are immediate and certain, while the benefits come later and are uncertain (Hurley 2016, p. 5). These economic arguments help explain the rationale underlying individual Florida citrus growers’ decisions regarding their lack of adoption of preventive measures to deal with HLB and also help address the first of the questions posed in the introduction of whether growers should have tried to organize themselves collectively to control the vector before the arrival of the disease. A well-organized collective action for controlling the ACP would have dealt with the behavioral issue derived from the risk preferences of growers and would have likely contributed to slow down the spread of the disease.

Understanding Growers’ Decisions: Other Factors

The discussion above on growers’ risk preferences and their influence on their behavior helps address the question of whether growers were rational when choosing not to spray for the ACP as a preventive measure prior to the finding of HLB. It can also help explain growers’ reluctance to eradicate affected trees as recommended by plant pathologists. But, three additional arguments can also contribute to explain the decision of many Florida citrus growers not to eradicate trees. First, the failure of the statewide mandatory canker eradication program that ended in 2006. Second, the heterogeneity of growers’ individual preferences and their groves’ infection. And, third, the high opportunity cost to eradicate productive trees. We explain each of these in detail next.

Canker Eradication Failure

The Florida Department of Agriculture and Consumer Services (FDACS), Division of Plant Industry (DPI), and the United States Department of Agriculture (USDA) implemented a tree eradication program in response to a citrus canker outbreak in 1995. The program called for the removal and destruction of diseased trees as well as any other citrus trees within a certain radius of the affected tree; originally, the radius was 125 ft, but in year 2000, it was extended to 1900 ft (Gottwald et al. 2002). But, homeowners that owned backyard citrus trees in certain counties challenged the rule and were able to temporarily halt the eradication program. Without a fully functional eradication program in place, the four hurricanes and tropical
storm that hit Florida in 2004 and 2005 contributed to spread citrus canker throughout the state’s main citrus production regions (Irey et al. 2006). In 2006, the state’s canker eradication program was terminated and the disease was classified as endemic (Gottwald and Irey 2007). Thus, the futility of the efforts to eradicate canker despite the nearly $1 billion spent (Gottwald and Irey 2007)—which further highlight the riskiness of prevention measures—have contributed to discourage federal and state agencies as well as many growers from pursuing similar efforts against HLB. In fact, Florida never implemented any mandatory regulations to remove HLB-infected trees; the only mandatory regulation was for nursery trees to be grown within protected structures so as to supply growers with HLB (and canker)-free trees (Halbert et al. 2008). More recently, there were some efforts by the HLB Multi-Agency Coordination (MAC) and the Florida Department of Agriculture and Consumer Services (FDACS) to remove abandoned groves, but only an estimated 20,000 acres of abandoned groves were removed (Singerman 2016, USDA 2019b) out of 130,000 (USDA 2016).

Heterogeneity of Growers’ Preferences and Groves’ Infection
By 2006, Florida citrus growers had begun implementing HLB management programs. Some of them followed the University of Florida and the Division of Plant Industry recommended management practices, which included spraying multiple times to control the ACP, scouting every tree at least four times a year to locate HLB symptoms, and eliminating symptomatic trees as soon as possible (Halbert et al. 2008). Those growers were focused on reducing the odds that HLB would spread. However, other growers chose alternative strategies. A grower in Southwest Florida became notorious after deciding not to remove HLB-affected trees in his grove as early as 2006, arguing that would mean removing the entire grove. Therefore, he opted for using foliar nutritional applications under the premise those would contribute to keep trees productive (Spann et al. 2011). But by doing so, the grower also hindered the efforts of those that were eradicating trees due to the public-good nature of the spread of the disease. By 2010, a significant proportion of growers followed suit, adopting the use of foliar nutritional applications to try to maintain the productivity of their trees (Gottwald et al. 2012). However, the usefulness of foliar nutritional sprays to keep trees productive has been a subject of a heated debate among scientists and industry stakeholders (Spann et al. 2011, Gottwald et al. 2012, Stansly et al. 2014). A factor that has likely contributed to the long-range spread of the disease among groves in Florida during the early stages of the epidemic was the production of Murraya paniculata in large commercial nurseries in southern Miami-Dade County (Halbert et al. 2008).

High Opportunity Cost
Opportunity cost is an economic concept that takes into account the income forgone from choosing an action instead of an alternative. The multiple hurricanes and freeze that hit Florida in 2004/2005 and 2005/2006 reduced citrus supply significantly, causing fruit prices to increase during the following seasons. Thus, the prevalent high prices at the time made the opportunity cost of eradicating HLB-affected trees (i.e., being able to sell the fruit of trees that were still productive) too high for many, particularly for smaller growers (Halbert et al. 2008). As argued by Singerman et al. (2017), the recommendation to eradicate HLB symptomatic trees presented growers with an economic problem. Affected trees were still productive during early infection, so they had to choose between 1) eradicating trees to obtain a potential benefit in the future and 2) not eradicating trees to obtain a benefit in the present, disregarding (or at least minimizing) future impact. In other words, growers had to choose between current and future economic profit; many chose the former.

Collective Action and Its Challenges
Agricultural problems involving public-good attributes are typically dealt with using a top-down regulation or collective action. However, neither at the federal, state, or county level there have been significant governmental efforts to develop policies, institutions, or incentives to specifically deal with the problems derived from the public-good nature of the ACP and HLB.

Collective action has been studied extensively by Ostrom (1990, 2009, 2010), who focused on addressing how to cope with free riding, commitment problems, and monitoring to avoid opportunistic behavior. Ostrom (1990) advocated the idea of enhancing the capabilities of those involved in managing a common resource so as to change the rules of the game rather than to view them as helpless individuals, who acting on short run self-interest, end-up behaving in a way that makes those involved worse-off in the long run. When discussing the determinants for the success or failure of collective action, Ayer (1997) points out that the financial constraints of governments, and the resistance that top-down regulation typically encounters, also makes the alternative of farmers’ collective action more attractive. However, as noted by Loehman and Dinar (1994), cooperative solutions may not be adopted without the appropriate institutions. In fact, that was the case in Florida as explained next.

Florida citrus growers failed to cooperate not only in the prevention of the spread of the disease but also in its control. The reasons for the failure of the former were discussed in the previous section. Regarding cooperation for the control of the vector (and, in turn, of the disease), a voluntary area-wide management program for psyllid control was part of the strategic plan of the Florida citrus industry to address HLB (National Academy of Sciences 2010). Such a program was created in 2010 for growers to coordinate the timing and mode of action of insecticide applications to control the spread of the ACP across neighboring commercial citrus groves. Even though the program was found not only to be useful to mitigate the impact of HLB but also profitable, its voluntary character contributed to make it unsuccessful (Singerman et al. 2017); the authors found that growers’ beliefs about their neighbor’s lack of coordination conspired against the success of the program. According to Hurley (2016), understanding both pest biology and socio-economics is key to create resilient pest management programs; the reason being that while profitability is a major consideration of growers when adopting a management practice or technology, other factors such as simplicity, flexibility, and time saving also influence growers’ pest management decisions (Carpenter and Gianessi 1999, Fernandez-Cornejo et al. 2005, Hurley et al. 2009, Hurley and Mitchell 2017).

Lessons From Florida: How to Deal With the Challenges of Collective Action in ACP Control?
The risk analysis of invasive species is an interdisciplinary problem that involves both ecology and economics, and a qualitative approach to the problem can be useful for guiding policy and allocating resources efficiently (Leung et al. 2002). More specifically, Perrings et al. (2002) assert that an economic solution to invasive species has two components. The first component is to improve protection by using incentives to change human behavior. The second component is the development of institutions so as to support the weakest contributors. The validity
of those arguments is illustrated by the disparity of adoption and eventual lack of widespread success of the voluntary area-wide pest management program in Florida to deal with HLB. Without the appropriate incentives and development of institutions, growers perceived coordination with their fellow growers to be too risky.

To deal with the issues derived from the perceived risks of coordination, Singerman and Useche (2019) proposed replacing the voluntary character of the area-wide pest management program with a mandatory component along with a self-enforcing feature to guarantee participation as key policy changes to make the program successful. In particular, the authors proposed a top-down regulation intended to generate a bottom-up collective action. The top-down regulation could be implemented from the state to the fruit-procuring companies (i.e., packinghouses and processors), requiring them to provide documentation that their processed/packed fruit has been subject to coordinated sprays. Fruit-procuring companies would, in turn, require such documentation to growers as part of their specifications for purchasing their fruit. In this way, growers would need to organize themselves locally to fulfill such a requirement, perhaps through their associations and be assessed charges (from a third party) for the sprays on a per-acre basis. Third-party sprays have been successfully used for the Boll Weevil eradication program, in which aerial applicators make bids in response to the request of growers’ organizations who award contracts on a competitive basis (Smith 1998, USDA-APHIS 2013). Alternatively, the taxing authority of water management districts could be exploited to charge growers for the collective sprays.

While some stakeholders may resist a top-down regulation, given that HLB has significantly impacted all industry levels (growers, growers’ associations, packinghouses, and processors), the vast majority of stakeholders should be interested in contributing to the mitigating solution, particularly when ensured other are participating as well (Ostrom, 1990)

**Conclusions: Can Stakeholders Afford Not to Cooperate?**

The approach adopted in Florida to deal with HLB has resulted in less than optimal coordination for tree eradication and ACP control. The outcome of such lack of coordination generated an economic problem by which noncoordinating growers imposed a cost on growers who did coordinate. The significant impact of HLB on the Florida citrus industry clearly illustrates the consequences of such noncooperative behavior.

In Brazil—the largest orange-juice producer worldwide—the HLB outbreak was handled differently than in Florida. Despite that the disease was found in São Paulo in 2004 (Colleta-Filho et al. 2004), about a year earlier than in Florida, so far the magnitude of the impact of HLB has been less dramatic there. While the Brazilian citrus industry is different from that in Florida because there are (on average) larger contiguous farms, until 2009 the Brazilian government mandated growers to eradicate HLB-affected trees within their groves so as to remove the inoculum and limit the spread of the disease (Miranda et al. 2012). But, more recently, large Brazilian growers understood the need to go beyond their own farms to better manage the disease within their groves; that is, they intuitively understood the public-good nature of the problem. Having noticed that HLB infection rates were higher on the edges of their groves, those growers started offering their neighboring growers and backyard citrus homeowners to spray their trees for free on a monthly basis. Alternatively, homeowners were offered fruit trees (other than citrus) in exchange for eradicating their HLB-affected trees (Johnson and Bassanezi 2016). So, while Brazilian growers faced the same economic problem as growers in Florida, they coped with it very differently; either by increasing their neighbors’ level of pest-control inputs or buying out their affected trees. These type of solutions have been found to make society as whole better-off (Vicary and Sandler 2002).

Finally, it is important to realize that the development of appropriate institutions and incentives would still be valuable even if genetic modification to create disease-resistant trees were to be the long-term solution to HLB. This is so because there is ample evidence of the development of resistance to crops that were genetically engineered. Therefore, as argued by Hurley and Sun (2019), there is a need for creating resilient pest management strategies that integrate genetically engineered crops with pest monitoring and IPM practices, as well as networks of farmers to incentivize cooperation in pest and disease management.

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