CHAPTER 7

HURRICANES AND INVASIVE SPECIES

The economics and spatial dynamics of eradication policies

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Abstract. Citrus canker was established in Florida in the 1990s. The disease causes losses of yield and closure of some export markets. The U.S. government introduced an eradication policy in which growers are required to remove infected trees and receive compensation payments for doing so. Recent hurricanes have spread the disease and re-established it. This chapter examines the economic impacts of citrus canker in oranges and the eradication policy in Florida, taking into account the relationship between costs and benefits of eradication and the spatial and dynamic aspects of infestation. We evaluate both the costs of the disease and the benefits from eradication. In this evaluation we consider the implications of a future hurricane, which spreads citrus canker, for the decision about whether to adopt a strategy of eradicating initially, or after the hurricane, or both. We find that producers as a group benefit from both the disease and the eradication program, but at the expense of taxpayers, consumers and the nation as a whole. Producers benefit at the expense of consumers because both the disease and the policy to eradicate it reduce supply and drive up the price and the gross value of production. Producers also benefit at the expense of taxpayers, who pay to compensate them for their losses for having to remove trees under the eradication policy.
Keywords: citrus canker; eradication policy; invasive species; welfare economics

INTRODUCTION

Exotic pests can have significant effects on agricultural yields, product quality and costs of production, and they may introduce substantial costs through the loss of markets even when the production effect is limited. Exotic pests engender net social costs, partly because it is not worthwhile for individuals to prevent or eradicate them, even though it might be worthwhile for the industry or society. If the economic effects of an invasive species are large enough, and they involve externalities – either because the pest can spread from one farm to another, or because of effects on market access –, public policy by local, state or federal governments may be justified.

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The optimal choice of policy – to prevent, control or eradicate – will depend on the characteristics of the exotic pest, its costs, how it spreads, how easy it is to detect and eradicate, and the extent of the infestation. Intuitively, an eradication policy is more likely to be justified when the infestation is isolated or easy to isolate and the risks of spread are high; if the infestation is already spread over a wide geographic region eradication may be uneconomic. The extent of infestation may change over time, changing the policy calculus. For instance, random weather events may lead to a further dispersion of the exotic pest over a wider geographic region, thus increasing the cost of eradication and changing the nature of the externalities.

This chapter examines the case of citrus canker in oranges and the eradication policy in Florida. Citrus canker is a bacterial disease of most citrus species (including oranges, lemons, limes and grapefruit), caused by *Xanthomonas campestris* (=*axonopodis*) pv. Citri (*Xcc*). Severe infections may result in defoliation, unsightly blemishes on fruits, premature fruit drop, and general tree decline. Outbreaks of citrus canker occurred in Florida in 1986 1995 and 1997. The 1997 outbreak persists and the disease is a significant threat in California and other states (Jetter et al. 2003). The disease causes some loss of yields, but the main concern has been the potential loss of markets.

The U.S. government has sought to eradicate citrus canker since it was detected in 1995. The government inspects fruit and trees and mandates the removal of trees infected with citrus canker and trees in the surrounding areas both from residential and urban areas and commercial groves. These efforts can be undermined by hurricanes or other factors that spread the disease after it has been reduced to tolerable levels or confined to particular regions. Hurricanes in Florida in 2004 contributed to a major spread of citrus canker. As a result of these hurricanes many hundreds of thousands of additional commercial citrus trees were destroyed and hundreds of million of additional dollars were spent in compensation for growers in the broadened eradication efforts. In August 2005, further spread may have resulted from hurricane Katrina.

In previous work (Acquaye et al. 2005) we used a simple, aggregative, comparative static model to explore the implications of import tariffs and crop insurance subsidies for the consequences of citrus canker and eradication policies in the Florida orange-juice industry. That preliminary analysis abstracted from the dynamics of supply response, which are especially important for perennial crops like oranges, as well as the inherently spatial-cum-dynamic aspects of the spread of the disease. In contrast, in this chapter we use a spatially disaggregated dynamic model of farmers' planting decisions and market equilibrium. We model the economic impacts of citrus canker and eradication policies, taking into account the relationship between costs and benefits of eradication and the spatial and dynamic aspects of infestation, paying particular attention to the role of random weather events. In particular, we evaluate the implications of a future hurricane, which spreads citrus canker, for the benefits from introducing an eradication program. This aspect of our work is timely given recent events in Florida, but the issues that arise extend beyond citrus and beyond Florida to other exotic pests that may be spread by random factors.

An interesting feature of our results is that producers as a group can benefit both from an outbreak of citrus canker and from policies to eradicate it. This happens because the supply-reducing effects of the disease and the eradication policy both drive up the price of oranges, and it takes some time for supply response to undermine this effect. This *de facto* supply control aspect means that the interests of producers as a group directly oppose those of society as a whole. That finding has implications for the design of the eradication policy.

A SIMULATION MODEL

This section describes the elements of our simulation model of the market for Florida oranges. We model production of oranges at the level of counties in Florida. Complications arise because we explicitly model the age distribution of the population of orange trees, which is an important element of both the dynamics of supply response to price and the time path of the consequences of both the disease and the eradication policies. The dynamics of the industry are long-term, such that it is necessary to conduct market simulations over many years to see the full effects of disease outbreaks and eradication policies.

Supply of Florida oranges

The annual production of oranges in Florida depends on age-specific, weather-dependent, yields and the age distribution of trees. This may be specified as:

$$O_t = \sum_{c=1}^{N} \sum_{i=0}^{M} Y_{c,i,t} A_{c,i,t} \,, \tag{1}$$

where O_t is total production, $Y_{c,i,t}$ is the per-acre yield and $A_{c,i,t}$ is the area of trees in county c aged i years in year t. Normal yields of mature bearing trees in year $b+n$ (YM_{b+n}) are defined by yields in the base year (YM_b), an exponential growth rate (y) and a random annual proportional shock (μ):

$$YM_{b+n} = (1+y)^n YM_b (1+\mu_{b+n}). \tag{2}$$

A set of fixed weights (γ_i) define the age-specific yields as a fraction of mature yields:

$$Y_{i,b+n} = \gamma_i YM_{b+n} \,, \tag{3}$$

which are adjusted by a county-specific proportional yield shock (cc) associated with citrus canker:

$$Y_{c,i,b+n} = Y_{i,b+n} (1+cc_{c,b+n}). \tag{4}$$

The age distribution of trees is determined by past plantings (*PL*), and tree removals (*R*, determined exogenously in our model) and new plantings:

$$A_{c,i,t} = \begin{cases} PL_{c,t-1} & \text{if } i = 1 \\ A_{c,i-1,t-1} - R_{c,i-1,t-1} & \text{if } i > 1 \end{cases}. \tag{5}$$

The normal removal rates are assumed to be 2.3 % per year for trees less than 25 years of age, and 5.6 % per year for trees aged 25 years and older, based on the average in Table 1 of Brown and Stover (2002). We assume that removal of acreage associated with citrus canker is distributed proportionately across all age classes.

New plantings are based on profit-maximizing behaviour with a rational expectations formulation borrowed from Gray et al. (2005) and extended. Specifically,

$$PL_{c,t} = a_{0,c} + a_{1,c} E_{c,t} NPV. \tag{6}$$

In this equation, $PL_{c,t}$ is the number of acres planted in county c in year t, $E_{c,t}NPV$ is the expectation formed in time t of the net present value of planting an acre of oranges in county c in year t. Expectations are formed based on projections of the population of bearing trees, yields and demand. We conduct iterative stochastic simulations in which we derive distributions of projected outcomes for quantities and prices and so on, take expected values, and impose a model closure condition, requiring that the series of planting decisions is based on the expected net present values implied by the model given these planting decisions. Finally, $a_{0,c}$ and $a_{1,c}$ are parameters. Specifically, $a_{0,c}$ is the number of acres planted if the expected net present value from an acre of plantings is zero, and $a_{1,c}$ is the change in plantings for a unit change in expected net present value of an acre of plantings. Values for these parameters were derived by estimating a linear model for each county, in which annual county-specific plantings are regressed against budgeted estimates of the present value of a 50-year stream of profit per acre, using data for the years 1978 to 2002.

Demand for Florida oranges

Florida oranges may be sold for fresh consumption on either the domestic (*D*) or export markets (*E*), or for processing into orange juice (*J*). That is:

$$O_t \equiv D_t + E_t + J_t. \tag{7}$$

We include explicit demand equations for domestic and export fresh sales:

$$D_{b+n} = \left(d_0 + d_1 w_{b+n}\right)(1+d)^n (1 - V_{b+n}) \tag{8}$$

$$E_{b+n} = \left(e_0 + e_1 w_{b+n}\right)(1+e)^n (1 - Z_{b+n}) . \tag{9}$$

In these equations, quantities demanded depend on the wholesale price for fresh oranges (w), underlying exponential growth in the demands (at rates d and e), and demand shifters (V and Z) that reflect policy changes and other factors such as response to an outbreak of citrus canker. The fresh market is presumed to command a fixed premium (m) over the processing market price (w^p):

$$w_t = w_t^p + m. \tag{10}$$

The demand for processing use of Florida oranges is derived from the demand for orange juice from Florida taking into account processing costs and the yield of juice from oranges. We assume a fixed yield of juice (k gallons per box) and a fixed per-unit processing cost (w_0 \$/box) such that:

$$FOJ_t = kJ_t \text{ and } P_t = \left(w_0 + w_t^p\right)/k , \tag{11}$$

where FOJ is production of orange juice (in gallons) from Florida oranges (in boxes) and P is the price of Florida orange juice (\$/gallon). The demand for orange juice produced by Florida is equal to the demand for orange juice for current consumption (C) plus the demand for net changes in stocks (S_t – S_{t-1}), minus the supply of net imports (I) and the supply from other U.S. states (OOJ, which we treat as exogenous and fixed):

$$FOJ_{b+n} \equiv C_{b+n} + \left(S_{b+n} - S_{b+n-1}\right) - I_{b+n} - OOJ. \tag{12}$$

We define equations to represent each of the endogenous elements as follows:

$$C_{b+n} = \left(c_0 + c_1 P_{b+n}\right)(1+c)^n \tag{13}$$

$$I_{b+n} = \left(i_0 + i_1 (P_{b+n} - \tau)\right)(1+i)^n \tag{14}$$

$$S_{b+n} = \left(s_0 + s_1 P_{b+n}\right)(1+s)^n , \tag{15}$$

where τ is the per-unit tariff on imports (29.72 cents per gallon single strength equivalent, SSE), and c, i and s are exponential growth rates in the functions. (We allow for the tariff but we ignore crop insurance, which was modelled by Acquaye et al. (2005) as equivalent to an output subsidy of 5.15 cents per gallon SSE.)

Substituting (13) – (15) into (12) yields an equation for the demand for Florida orange juice as a function of the price of orange juice and the parameters of demand.

$$FOJ_{b+n} = f_0 + f_1 P_{b+n} - S_{b+n-1} - OOJ, \text{ where}$$
$$f_0 = c_0(1+c)^n + s_0(1+s)^n - (i_0 - \tau i_1)(1+i)^n, \text{ and} \quad (16)$$
$$f_1 = c_1(1+c)^n + s_1(1+s)^n - i_1(1+i)^n.$$

Substituting (11) into (16) yields an equation for the demand for processing use of Florida oranges (J) as a function of the price of oranges used for processing (w^p):

$$J_{b+n} = (FOJ_{b+n})/k = \left(f_0 - S_{b+n-1} - OOJ \right)/k + f_1(w_0 + w^p_{b+n})/k^2. \quad (17)$$

Equation (7) solves the model by equating supply (from equation (1)) with total demand (the sum of equations (8), (9) and (17)) for Florida oranges.

Parameters of the model and baseline prices and quantities

Tables 1 and 2 show the baseline quantities used to parameterize the model. The corresponding baseline price of oranges for processing was \$3.89/box, the price of fresh oranges was \$5.91/box, and the price of orange juice was \$1.22/gallon (all prices in 2003 dollars).

Table 1*. Production and utilization of Florida oranges (1997 – 2002 average)*

	Florida production	Share of Florida total	Share of Florida in U.S. total
	(*million boxes*)	(*percentage*)	
Fresh			
Domestic	10.01	4.5	24.04
Net export	0.70	0.3	6.55
Processing	209.87	95.1	95.90
Total	220.59	100.0	81.33

Source: Authors' computations based on data obtained from Florida Agricultural Statistics Service

Table 2*. U.S. production and consumption of orange juice (1997 – 2002 average)*

	Production	Share
	(*million gallons*)	(*percentage*)
Net imports	143.47	9.5
Florida production	1,340.67	88.3
Other U.S. production	56.52	3.7
Change in stocks	-22.61	-1.5
Total	1,518.04	100.0

Source: Authors' computations based on data obtained from Florida Agricultural Statistics Service

These baseline quantities and prices were combined with elasticities of supply and demand and other parameters (in Table 3) to initiate the model in 2004. The values for the elasticities were assumed, based on a review of estimates in the relevant literature, combined with knowledge of the industry and the structure of its markets. The critical parameter is the elasticity of demand for orange juice in the United States, and a value of -0.5 is representative of relevant estimates in the literature (e.g., see US International Trade Commission 2005).

***Table 3**. Elasticities of supply and demand and growth rates*

Elasticities	
Elasticity of domestic demand for fresh Florida oranges	-1.00
Elasticity of demand for Florida exports of fresh oranges	-4.00
Elasticity of demand for orange juice in the U.S.	-0.50
Elasticity of demand for orange juice stocks in the U.S.	-0.50
Elasticity of supply of orange juice imports	5.00
Annual growth rates in supply and demand	(*percent*)
U.S. demand for fresh Florida oranges (*d*)	1.25
Export demand for fresh Florida oranges (*e*)	-4.68
U.S. demand for orange juice (*c*)	1.90
U.S. demand for orange juice stocks (*s*)	1.99
Yield of Florida oranges (*y*)	1.56
Import supply of orange juice (*i*)	-11.00

Source: Annual growth rates are past average growth rates over the period 1991 through 2002, computed by the authors using data obtained from Florida Agricultural Statistics Service

SCENARIOS SIMULATED AND SIMULATION RESULTS

The model is initiated in the year 2004 and runs for 50 years. In reality the disease is spread over time from tree to tree within and among farms and between urban back yards and farms, but here and for now, to simplify the problem and focus on the essential issues we treat the disease as either present within a region (involving several counties) or not. The eradication policy entails uprooting of infected trees, for which growers are paid compensation, financed by the federal government (Jetter et al. 2003). 'Eradication' does not eliminate the disease from the affected region, but for simplicity eliminates its impact. A hurricane causes the disease to spread from the infected region to neighbouring regions and re-establishes the disease in the initially infected region.

Benefits from eradication in the absence of hurricanes

In the first scenario we simulate the time path of prices, quantities and economic surpluses in the absence of citrus canker. In the second scenario we simulate the same variables with an outbreak of citrus canker in the Central region of Florida in

2011 (i.e., the 7th year of the simulation). A minor outbreak causes an immediate 10 % reduction in yield for 1 % of the orange acreage in the Central region of Florida. A severe outbreak causes an immediate 10 % reduction in yield for 10 % of the orange acreage in that region. In both cases, the outbreak results in a 50 % reduction in export demand for fresh Florida oranges. These impacts are sustained permanently in the absence of an eradication program.

In the third scenario, we simulate the same variables given an eradication program introduced in the year of the outbreak 2011. For simplicity, under the eradication program demand for fresh Florida oranges and yields are unaffected by the outbreak. The eradication program entails immediate removal of 15 % of the orange acreage (distributed at random across age classes) in the region, with no replanting for a further two years. Farmers receive compensation of $9,646 per acre lost as a result of eradication.

Table 4 summarizes the results of these scenarios in terms of the net present values of welfare impacts over the 50-year period 2004 – 2053, in 2003 dollars, expressed as the equivalent annual value of a perpetuity. The first two columns of numbers show the annual effects on welfare of the minor and severe outbreaks *without* eradication (i.e., comparing the first two scenarios). A minor citrus canker outbreak (column 1) causes a producer loss of $1.5 million, and a small loss to U.S. taxpayers, reflecting a slight reduction in imports of orange juice and thus in import tariff revenue. These losses are partially offset by a benefit to U.S. consumers of $0.9 million (from the lower domestic processing and fresh prices resulting from the reduction of demand for fresh exports), such that the net national loss is $0.5 million.

Column (2) shows the effects of a severe outbreak with no eradication. The citrus canker outbreak causes a producer gain of $5.5 million. This initially surprising result reflects the fact that overall demand for oranges is inelastic so revenue rises with the price increase caused by lower yields. Furthermore, the reduction in supply (from yield losses) is greater than the reduction in demand (from the loss of some fresh export markets) in this instance, such that producer revenue increases. U.S. taxpayers also gain slightly, reflecting an increase in imports and import tariff revenue because the loss in production is greater than the fall in exports of oranges. The resulting U.S. consumer loss from higher prices more than offsets the gains to producers (and taxpayers), resulting in a net national loss of $2.7 million per year.

Column (3) shows the effects of the outbreak *with* eradication (i.e., comparing the first and third scenarios). Relative to no outbreak, the citrus canker outbreak with eradication entails a producer gain of about $163 million, which is more than offset by losses to U.S. consumers and taxpayers totalling $188 million, such that national loss is about $25 million. The consumer losses here are caused by higher prices that result from the reduction of supply. The supply reduction is caused by the combination of the outbreak and the eradication program, where eradication has the larger effect. The taxpayer losses reflect both a slight increase in tariff revenue and significant expenditure on compensation to producers for tree removals.

Table 4. *Welfare change from a citrus canker event and eradication policy*

	Benefits from a minor event with no eradication (1)	Benefits from a severe event		
		No eradication (2)	Eradication (3)	Benefits from eradication (4)
Changes in	(*annual values in millions of 2003 dollars over 50 years*)			
Producer surplus	-1.45	5.50	162.80	157.31
Consumer surplus	0.94	-8.21	-176.00	-167.80
Fresh oranges	0.05	-0.29	-6.69	-6.39
Processed oranges	0.89	-7.91	-169.32	-161.40
Taxpayer surplus	-0.01	0.03	-12.17	-12.20
Tariff	-0.01	0.03	1.99	1.96
Compensation	0.00	0.00	-14.16	-14.16
Total domestic surplus	-0.51	-2.68	-25.37	-22.69
Foreign surplus	-0.25	-0.25	-0.25	0.00
World surplus	-0.76	-2.93	-25.62	-22.69

The benefits from eradication, in column (4), are computed as the differences between the values in columns (2) and (3) (i.e., equivalent to comparing the second and third scenarios). The eradication policy yields a benefit to producers of $157 million, a loss to U.S. consumers of $168 million and a loss to U.S. taxpayers of $12 million, such that the net national loss is $23 million. The consumer losses are again caused by higher prices that in this case result from the restoration of foreign demand but mostly from the reduction of supply caused by the eradication program.

The eradication policy in this instance benefits producers at the expense of consumers of fresh and processed oranges and taxpayers, and the losses to other domestic interest groups exceed the benefits to U.S. producers such that net national (and, indeed, global) benefits from the production and consumption of Florida oranges are reduced by the implementation of the policy. Ironically producers are compensated even though, as a group, they are net beneficiaries from eradication because tree removal causes price and revenue to rise.

A much simpler, static model of short-run supply and demand provides some intuition about the main factors behind these results. In Figure 1, *S* is the short-run supply of oranges in Florida, which is perfectly inelastic. An outbreak of citrus canker causes yield losses, and as a result supply shifts from *S* to *S'*. Since demand is inelastic, the effect of this shift is to increase both price and industry revenue (comparing the equilibrium at point *a* with the equilibrium at point *b*). At the same time, however, demand shifts from *D* to *D'*, reflecting the loss of some export markets. This shift results in a reduction in price and industry revenue (comparing point *b* and point *c*), offsetting the effects of the yield-related supply shift. As the figure is drawn the demand shift more than offsets the price and revenue effects of the supply shift (comparing points *c* and *a*), though it need not do so in every case we model, such that the price and producer revenue are lower than in the absence of citrus canker.

An eradication policy results in a further shift in supply to the left, from *S′* to *S″*, and a restoration of demand at *D*, such that the final equilibrium is at point *e*, with a smaller quantity but a higher price and a larger industry revenue than in the absence of the citrus canker outbreak and the eradication policy (i.e., comparing points *a* and *e*). Given an inelastic demand, producer surplus is greater at point *e* than at point *a*. Consumer surplus is lower as a result of the higher price, and the net effect, combining the consumer loss and the aggregate producer gain, is a loss equal to area *Q″eaQ*. In addition, however, taxpayers pay compensation to producers as part of the eradication program, such that the aggregate producer benefit is even greater, at the expense of both taxpayers and consumers. These types of effects drive the results in Table 4, though those results reflect a much more complicated dynamic supply and demand structure than we have used in Figure 1; the same factors also drive the further results that follow, which also involve complications from hurricanes.

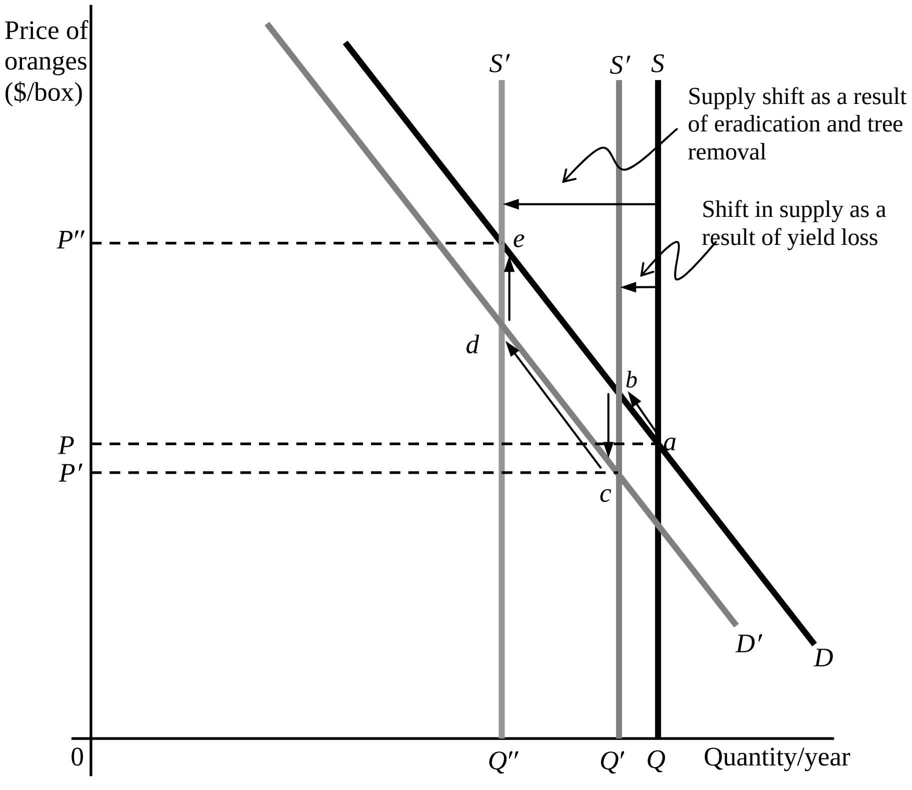

Figure 1. *Effects of a citrus canker outbreak and eradication policy in Florida*

Incorporating the effects of hurricanes

The cases in Table 4 do not allow for the effect of hurricanes. Further simulations replicate the second and third cases (i.e., a severe outbreak of citrus canker in 2011 with or without an eradication program) but with a hurricane in 2016. This timing of the hypothetical hurricane, five years after the outbreak, corresponds loosely to the actual history with an outbreak of the disease and introduction of an eradication program in the mid to late 1990s followed by a hurricane in 2004.

We assume the hurricane re-establishes citrus canker in the Central region – even if it had been "eradicated" some residual infection, sufficient to re-establish it, remains – and spreads the disease from the Central region either (a) to two other regions (the Northern and Western regions), if an eradication program *had* been introduced in 2011, or (b) to all six regions in Florida, if an eradication program *had not* been introduced in 2011. Given the scenarios of (a) an outbreak of citrus canker in 2011, after which the government may or may not introduce an eradication program, and (b) a hurricane in 2016, after which the government once more may or may not introduce an eradication program, we can contemplate four combined scenarios, each of which implies a different set of values for the parameters of the model. These scenarios and the corresponding parameters are summarized in Table 5. In every case, citrus canker causes a yield loss of 10 % on the infected acres, but the different scenarios have different numbers of acres affected and different implications for demand.

Column (1) in Table 5 shows the parameters that apply in the case when an eradication program was not introduced after the initial outbreak in 2011. After the hurricane, citrus canker affects 15 % of the orange acreage in every region of Florida, and, with no eradication program in 2016, this effect continues in perpetuity. Alternatively, if an eradication program is introduced in 2016, the rate of infection progressively declines from 15 %. At the same time, export demand progressively returns as embargoes are removed. The initial outbreak in 2011 results in a 50 % loss of export markets, and we assume that when an eradication program is introduced after the hurricane, the market gradually grows until 'normal' export demand is restored.

Column (2) shows the parameters that apply in the case when an eradication program is introduced after the initial outbreak in 2011. After the hurricane, citrus canker now affects only 10 % of the orange acreage in a smaller number of regions. If an eradication program is not introduced in 2016, this effect continues in perpetuity, but if an eradication program is introduced in 2016, the rate of infection progressively declines. Further, if an eradication program is not introduced the new infection results in a 50 % reduction in export demand for fresh Florida oranges.

Table 5. *Parameterization of the model under various scenarios*

	Without eradication in 2011 (1)	With eradication in 2011 (2)
Areas infected after hurricane in 2016	All six regions in Florida	Central Florida plus two other regions
Yield consequences for infected acreage	10 % yield loss on infected acreage	10 % yield loss on infected acreage
	Consequences without eradication in 2016	
Proportion of acreage infected in affected regions	15 % of acreage in perpetuity	10 % of acreage suffers a 10 % yield loss in perpetuity
Effects on export demand for fresh oranges	50 % reduction in 2011 is sustained in perpetuity (i.e., no new demand shift caused by the hurricane)	permanent 50 % reduction in demand resulting from the new spread caused by the hurricane
	Consequences with eradication in 2016	
Proportion of acreage infected in the affected regions	15 % of acreage initially, but declining progressively by half of the previous level each year to approximately zero by 2030	10 % of acreage initially, but declining progressively by half the previous level each year to approximately zero by 2030
Effects on export demand for fresh oranges	Export demand grows progressively to reverse the 50 % reduction in demand from the 2011 outbreak by 2021	No demand shift
Effects of eradication on orchards	20 % of acreage in affected counties removed from production, no replanting for two years and compensation of $9,646 per acre	15 % of acreage in affected counties removed from production, no replanting for two years and compensation of $9,646 per acre

As before, the eradication program itself also entails reductions in supply associated with mandated removal of trees. We assume that when an eradication program applies after the hurricane, 15 % of the orange acreage in the affected regions will be removed if an eradication program had been previously established, or 20 % of the orange acreage in the region if an eradication program had not been previously established. In each case, when trees are condemned and removed under the eradication program growers must not replant for two years and they receive compensation of $9,646 per acre lost.

Benefits from eradication in the presence of hurricanes

Based on these simulations, we evaluate the effects of an eradication program introduced after the hurricane in 2016, with and without an initial eradication program after the outbreak in 2011. The results from the various combinations of policies are summarized in Table 6.

Column (1) in Table 6 replicates the last column in Table 4, to show the benefits from eradication after the initial outbreak in 2011, if there will not be a subsequent hurricane. All of the other columns in Table 6 refer to simulations with a hurricane in 2016. The results in column (1) were explained above. The key point is that eradication is beneficial for producers but expensive for taxpayers, mainly because of compensation payments, and for consumers, because of reduced supply and higher prices, and ultimately for the nation as a whole. Reflecting the same main factors at work, the same pattern of results can be seen in all of the other columns except column (3), for reasons that will be explored next.

Columns (2) and (3) show the benefits from eradication following the outbreak in 2011 given that there will be a subsequent hurricane-induced outbreak in 2016 that will be either eradicated (column 3) or not (column 2). Comparing column (2) with column (1) a hurricane that reintroduces the pest in 2016 reduces the benefits from eradication in 2011. This makes sense because the reintroduction of the pest effectively eliminates the stream of benefits from the eradication in 2011 that would otherwise have continued through to the end of the simulation period 2053. Column (2) shows that if we are not going to eradicate citrus canker following a hurricane in 2016, an eradication program in 2011 will still involve a net cost to consumers, taxpayers and the nation as a whole even though it would benefit producers. These, and the other effects in column (2), are similar to those of an eradication program in 2011 in the absence of a hurricane in column (1), but muted.

In contrast, all of the entries dealing with domestic and world welfare in column (3) are of the opposite sign to their counterparts in columns (1) and (2). Column (3) shows that if policy-makers are confident that the nation will eradicate in 2016 following the hurricane, it would benefit consumers, taxpayers and the nation as a whole also to eradicate in 2011. Column (2) indicates that if we are not going to eradicate in 2016 it would not benefit consumers, taxpayers or the nation as a whole also to eradicate in 2011. Eradication in 2016 reverses the consequences of eradication in 2011, yielding large gains to U.S. consumers, with U.S. taxpayers being saved the burden of large eradication costs, and large costs to U.S. producers. The essential story here is that eradication in 2016 is costly to consumers, taxpayers and the nation (as shown in columns 4 and 5), albeit beneficial to producers. Eradication in 2011 reduces all of those positive and negative consequences from eradication in 2016, and for this reason the general impacts of eradication in 2011 given eradication in 2016 are opposite those of eradication in 2011 given no eradication in 2016.

***Table 6**. Effects of a hurricane on the benefits from eradication*

	Benefits from eradication in 2011 given			Benefits from eradication in 2016 given	
	No hurricane in 2016	Hurricane in 2016		Hurricane in 2016	
		No eradication in 2016	Eradication in 2016	No eradication in 2011	Eradication in 2011
	(1)	(2)	(3)	(4)	(5)
Changes in	*(annual values in millions of 2003 dollars over 50 years)*				
Producer surplus	157.31	139.27	-57.64	441.51	244.60
Consumer surplus	-167.80	-145.17	79.82	-533.78	-308.80
Fresh oranges	-6.39	-5.57	1.52	-16.84	-9.75
Processed oranges	-161.40	-139.59	78.29	-516.94	-299.05
Taxpayer surplus	-12.20	-11.90	16.35	-52.65	-24.39
Tariff	1.96	1.95	-0.23	5.32	3.14
Compensation	-14.16	-13.85	16.58	-57.96	-27.53
Total domestic surplus	-22.69	-17.80	38.53	-144.92	-88.59
Foreign surplus	0.00	-0.06	-0.03	-0.08	-0.05
World surplus	-22.69	-17.86	38.50	-145.00	-88.64

The last two columns show the benefits from eradication after the hurricane-induced outbreak in 2016. The magnitude of the welfare consequences of eradication in 2016 are affected by the decision to eradicate or not following the initial outbreak in 2011. This is so because the disease is much worse in 2016 if there was no initial eradication (it extends to a much broader area, the rate of infection is worse, and the rate of tree removal is higher). The pattern of results is similar to those in the initial eradication scenario with no hurricane, but the numbers are larger. If there was no eradication in 2011, eradication in 2016 yields large gains to U.S. producers that are more than offset by large losses to U.S. consumers and taxpayers, resulting in national losses. Comparing columns (4) and (5), the entries in column (5) are roughly half the size of their counterparts in column (4). This comparison shows that eradication in 2011 reduces by half the U.S. producer gains and U.S. consumer and taxpayer losses, and net national losses from eradication in 2016.

CONCLUSION

This preliminary analysis has significantly extended previous models, to incorporate the dynamics of supply response to prices and policies and to allow for the spatial spread of the citrus canker as a consequence of a hurricane. This analysis has yielded some interesting insights into the role of external shocks that encourage the proliferation of the exotic pest, such as hurricanes, for the economics of alternative control or eradication policies.

First, we explored the benefits and costs of an initial outbreak and an eradication policy in the absence of hurricanes. These simulations indicate that, given the parameters of the industry, its markets and the disease, Florida orange producers would benefit from eradication of the pest in Florida, but U.S. consumers, taxpayers, the nation and the world as a whole would lose. Next we explored the implications of a subsequent hurricane that results in the spread of the disease, and a further policy decision about whether to adopt an eradication program. Given a subsequent hurricane that reintroduces and spreads the disease, the costs and benefits from the initial eradication are lower, a result of the reintroduction of the pest effectively eliminating the stream of benefits and costs from the initial eradication that would otherwise have continued through to the end of the simulation period. The benefits and costs from the subsequent eradication following the hurricane are substantially higher, because the infection following the hurricane extends to several regions whereas the initial infection was confined to the Central region.

An interesting finding is that the interests of Florida orange growers are directly opposite those of the nation as a whole. Suppose the objective is to maximize national surplus. Looking at the scenarios in 2016, it would not pay the nation to eradicate in 2106 regardless of whether it had eradicated in 2011. The optimal strategy in 2011 is also not to eradicate (since eradication in 2011 involves a net social loss if we will not also eradicate in 2016). In contrast, producers would prefer to eradicate in 2016 but not to eradicate in 2011. In a political economy setting, if the government expects that it will have to introduce an eradication program following a hurricane, it would do better also to introduce one in 2011. In contrast, producers would prefer not to eradicate in 2011 if they can be confident of a program being introduced in 2016.

NOTES

1. Albert K. A. Acquaye is a project economist, Julian M. Alston is a professor, Hyunok Lee is a research economist, and Daniel A. Sumner is the Frank H. Buck Jr. Professor and Director of the University of California Agricultural Issues Center. The authors are all members of the Giannini Foundation of Agricultural Economics, and are employed in the Department of Agricultural and Resource Economics, University of California, Davis.

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