A Market-based Mitigation Program for Wind-borne Diseases

Anton Bekkerman, Nicholas E. Piggott, Barry K. Goodwin, and Kenrett Jefferson-Moore

Wind-borne diseases can spread rapidly and cause large losses. Producers may have little incentive to prevent disease spread because prevention may not be welfare-maximizing. This study proposes a market-based mitigation program that indemnifies producers against disease-related losses and provides an incentive to neighboring producers to take preventive action, which can substantially mitigate infestations, reduce the likelihood of catastrophic losses, and increase social welfare. An equilibrium displacement model simulates introduction of the program for U.S. soybeans. Simulations reveal that the market-based solution contributes to minor market distortions but also reduces social welfare losses and could succeed for other at-risk commodities.

Key Words: check-off, equilibrium displacement model, invasive species, soybean rust, welfare effects, wind-borne disease

Plant and animal diseases are a common perennial hazard to agricultural producers, and in recent years, wind-borne diseases have posed serious threats to major U.S. crops. For example, citrus canker in the Florida citrus industry led to significant crop and economic losses (Goodwin and Piggott 2009), karnal bunt caused substantial yield losses in the southwestern United States (Animal and Plant Health Inspection Service 2010), and soybean rust has become an annual threat in major U.S. soybean production regions (Bekkerman, Goodwin, and Piggott 2008). Consequently, significant efforts have been made to study the economic risks and impacts associated with wind-borne diseases, which have been found to be difficult to detect, to spread rapidly, and to lead to substantial production losses. For example, see Livingston et al. (2004), Brown and Hovmeller (2002), Goodwin and Piggott (2009), and Gottwald et al. (2001).

Currently, producers have access to several sources of information and revenue-loss protection mechanisms for managing wind-borne diseases. An important example is the Integrated Pest Management (IPM) Pest Information Platform for Extension and Education (PIPE), which provides producers with spatial and temporal information about invasive species. Producers who employ IPM strategies can reduce disease-related costs by preventing and preparing for infestations. Livingston (2010) provides an overview of the economic benefits associated with the IPM PIPE system for soybean producers. However, use of the system may be limited because producers may not be aware its existence, may choose not to use it (especially if infestation risk is low), or may not know how to implement the strategies. Another form of protection is federally subsidized, multiple-peril crop insurance, which provides indemnity payments if a wind-borne disease is an insurable source of loss and losses cause production to fall below an insurance-guarantee level. However, when such losses are not large enough to trigger crop insurance indemnities, producers bear these losses entirely. In such more common scenarios (and even if an insurance indemnity is paid), producers treat and eradicate the disease only after an infestation has occurred, thereby increasing the probability that a wind-borne disease will spread to nearby locations. That is, *ex ante* disease treatments

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fail to reduce the likelihood of propagation. When environmental conditions are favorable for spreading the disease, large-scale infestations can result, causing potentially catastrophic production losses, major disruptions to agricultural markets, price instability, and food security concerns.

Actions that mitigate the spread of wind-borne disease can reduce the likelihood of large-scale infestations and possibly avert considerable production losses. However, such preventive actions often have large private costs, and the benefits of prevention are not necessarily observable.[1] Moreover, private actions are likely to be less effective if neighboring producers do not participate in preventing spread (Cornes 1993). Therefore, the current market structure does not provide adequate incentives for the majority of producers to take mitigating actions. Because the losses and market disruptions that can follow a widespread outbreak can often be substantial, an insufficient level of preventive efforts is socially suboptimal.

A number of studies have proposed market-based solutions for reducing invasive species infestations and associated production losses. Costanza and Perrings (1990) and Shogren, Herriges, and Govindasamy (1993) discussed the potential advantages and disadvantages of using performance bonds to penalize parties who fail to meet certain environmental objectives. Richards et al. (2008) presented a market structure in which insect-derivative securities could be used to offset risks associated with infestations. Furthermore, Horan and Lupi (2005) introduced the concept of a tradable risk permit, which penalizes a producer when the population of an invasive species exceeds a permissible level, and Richards et al. (2010) compared market structures that use such permits to ones that institute a tax when insect infestations exceed a trigger population level.

We propose a market-based program that seeks to increase preventive effort incentives to producers whose crops are significantly at risk of infection to use prevention strategies. The program would first establish a mandatory, self-sustainable check-off that would collect a small percentage of producers' revenue to create an indemnity fund. Then, upon discovery of an infestation, producers who are directly affected would receive payments from the fund to compensate losses related to the infestation and treatment costs. Producers in close proximity to areas found to be infested (and so at higher risk of infestation through wind-borne transmission) would also receive payments for preventive actions. This second set of payments increases the incentive to mitigate.[2]

This study investigates the market and welfare effects of implementing such a market-based approach for mitigating wind-borne disease infestations. First, we present a stylized representation of market changes occurring in response to the introduction of a check-off and welfare effects associated with those changes. We use this representation to depict the effects of a wind-borne disease infestation under the existing market structure and under the proposed structure. Then, an equilibrium displacement model simulates an infestation of soybean rust and quantifies the welfare effects of the market-based mitigation program on U.S. soybean producers. These simulations indicate that instituting the check-off would minimally affect producers' revenues and lead to small deadweight losses. Furthermore, the mitigation program would help reduce yield losses from soybean rust by up to 4.47 percent and avert up to $1.7 billion in lost annual producer surplus. These results provide important evidence that the market-based disease-mitigation program proposed in this study can reduce the likelihood of serious economic disruptions, thereby mitigating losses to both producers and consumers. Furthermore, because the proposed program is market-based and self-sustainable, it can be an effective prevention mechanism that does not depend on increasingly scarce government funds.

A Market-based Mitigation Program

Plant and animal wind-borne diseases are often highly contagious and can lead to widespread infestations. The likelihood of transmission for most plant diseases is largely conditional on meteorological factors. For example, wind, precipitation, temperature, and air moisture affect both transmission of disease and its germination

[1] When a wind-borne outbreak fails to spread, it may be difficult to determine whether it was contained by preventive measures or failed to expand for some other reason.

[2] The level of mitigation effort can also be brought to a social optimum by penalizing or taxing producers who do not attempt to prevent disease spread. However, asymmetric information available to the tax assessor (principal) and the producer (agent) may reduce the incentive for producers to report an infestation because a lack of mitigation effort would result in a penalty. This disincentive to report infections may exacerbate a disease's spread.

(Roelfs 1989, Palm 2001, Davis 1987, Shiyomi and Koizumi 2001). Moreover, many invasive species can infect multiple hosts, which substantially increases the speed and breadth of a disease's spread. Consequently, agricultural markets facing a wind-borne infestation can experience large and even catastrophic disruptions that adversely affect both producers and consumers.

To characterize market and welfare effects from a wind-borne disease outbreak, we consider four groups most likely to be affected: (i) producers directly affected by an infestation who incur eradication costs and potential production losses; (ii) consumers who face higher prices due to the reduction in supply associated with production losses; (iii) nearby farmers who may need to consider costly preventive efforts; and (iv) taxpayers who sustain increased taxes if eradication costs and production losses are compensated by subsidized crop insurance or ad hoc disaster relief plans.

Currently, only producers directly affected by a disease have an opportunity (primarily through crop insurance) to receive indemnities for production losses. However, these indemnities are paid only when such losses exceed a minimum trigger level. If the losses are not large enough to trigger insurance payments, producers must bear the entire loss burden. Furthermore, because insurance indemnities are provided only to producers directly affected by an infestation, the other three groups affected by the outbreak are not compensated for their losses.

As an alternative to existing loss indemnification and pest management programs, we propose a market-based solution. First, producers of an at-risk commodity would be required to contribute a small fraction of their revenues (as a check-off) to a collective fund. Upon identification of an infested location, the fund would then provide indemnification for disease-related yield losses and curative costs incurred by the producers.[3] Furthermore, all of the producers in close proximity to the infestation site—those whose crops are most likely to be infected—would receive payments to take actions that would prevent infestation on their farms. These payments increase incentives to neighboring producers to raise the level of mitigation and help minimize future infestations and production losses and substantially reduce total adverse welfare effects for all four impacted groups.[4]

The benefits of the proposed program can be characterized by drawing a parallel to subsidized influenza vaccinations. Influenza is a highly mobile and infectious communicable disease that can lead to various health complications and acute respiratory illnesses. For individuals, insurance companies, and federally subsidized medical care programs, influenza-related illnesses are often associated with high treatment costs. Wood, Alexseiv, and Nguyen (1999) showed that these costs can be significantly minimized through preventive options such as vaccinations. Furthermore, providing vaccinations to individuals who may not be able to privately obtain them can increase social welfare because carriers of influenza can transfer the disease to individuals whose treatment costs are paid by an insurance company or government agency. Insurance companies and government medical agencies, therefore, have strong incentives to fund influenza prevention programs. Similarly, agricultural producers may have incentives to participate in wind-borne disease-mitigation programs through check-off contributions. By paying a small amount to a collective fund, producers can help provide the measures necessary for executing a disease mitigation strategy. Even producers with limited overall risk may benefit, because the program could further reduce or eliminate the likelihood of their crops being infected during a widespread outbreak.[5] Moreover, mitigating infestation can contribute to

[3] Developing optimal methods for identifying and detecting the presence of wind-borne infections under the check-off program is a topic of future research. Examples of potential disease identification methods include early-detection systems such as sentinel plots and pest detection databases that track infestation reports.

[4] We acknowledge that payments under this system could go to producers who would have implemented curative or preventive methods on their own without additional incentives. However, Johansson et al. (2006) and Livingston (2010) provide evidence that welfare losses associated with producers failing to properly manage invasive species outbreaks are large and likely outweigh the potential costs of providing fungicide to producers who are already managing disease spread. Moreover, because the check-off structure requires a mandatory, actuarially fair payment from each producer, fungicide applications may become more efficient if producers begin using preventive methods only when the likelihood of infestation is greatest. The economic and environmental efficiency of fungicide use under various market structures is beyond the scope of this study but is a topic for future research.

[5] This is especially true when considering large-scale producers. For example, the Midwest is home to a number of large commercial soybean operations but the risk of a soybean rust infestation is small overall (Bekkerman, Goodwin, and Piggott 2008), but during years in which weather conditions are favorable for widespread transmission, Midwest soybeans are at risk. Because large producers are likely to suffer substantially greater losses, they have an incentive to reduce the risk of a wind-borne infection.

important positive externalities associated with reducing infections in wild hosts. That is, although diseases can propagate among uncultivated hosts, mitigation strategies by commercial producers can minimize intra-host dispersion (i.e., transmissions from a cultivated host to a wild host and from a wild host to a cultivated host), further reducing the likelihood of spread.[6] In this manner, small reductions in revenue are exchanged for a lower probability of widespread, catastrophic outbreaks.

In instituting and enforcing the proposed program, two concerns are important. One concern is equitable participation by all producers. Historically, many check-off programs have overcome equity issues through mandatory participation, thus eliminating free-rider problems (Becker 2008). The second issue is ensuring that neighboring producers who receive payments from the fund actually take preventive action rather than simply collecting the payments. A natural barrier to such fraudulent behavior is community-based incentives. That is, because a private action is less likely to be effective without similar actions by nearby producers (Cornes 1993), community-based pressure is likely to encourage the use of funds as intended to maintain good standing among professional and social peers. Another effective enforcement method is administrative and monitoring efforts, such as collecting receipts for fungicide purchases and/or randomly inspecting operations that recently received payments.[7] If producers shirked their disease-prevention responsibilities, appropriate penalties would be assessed.[8]

Welfare Effects of the Program

A visual depiction of market conditions under the current and proposed programs is useful in illustrating the potential benefits of mitigating disease spread through a check-off. Figures 1a, 1b, 2a, and 2b show the welfare effects of a wind-borne disease infestation in an agricultural market with and without such a program. Figures 1a and 1b show the current system (no check-off) under two market conditions: (1a) initial market equilibrium with no disease infestation, and (1b) a shock to the market due to an outbreak of a wind-borne disease. Figures 2a and 2b depict the effect of the check-off program: (2a) the effect of introducing a check-off program prior to an outbreak, and (2b) the impact of a wind-borne disease when the mitigation program is in place.[9] In each case, welfare effects are depicted using consumer surplus (*CS*), producer surplus (*PS*), producer cost (*PC*), and deadweight loss (DWL).

In Figure 1b, lack of a mitigation program results in a socially inefficient quantity of mitigation effort and substantial production losses. These losses are represented by movement of the quantity supplied from an initial equilibrium of Q_0 to Q_{0+WBD} with an associated increase in price from P_0 to P_{0+WBD}. As a result, both producer surplus and consumer surplus decrease. Furthermore, the infestation contributes to uncompensated costs for the producer (shown by an unchanged *PC*) who must use expected quantities demanded to make planting decisions that generate expenses.[10]

Figure 2b shows the effects of an actuarially fair, ad valorem check-off (*CO*) on producers. The check-off is assessed at the first point of sale and can be viewed as a rotation of the supply curve from S_0 to S_{CO}, which results in a decrease of quantity supplied, Q_{CO}; a higher price paid by consumers, P_{CO}; and a lower price received by producers, P^P_{CO}. The revenue collected from the check-off is represented by the rectangle labeled *Check-off Fund* and the deadweight loss is shown as the triangle labeled *DWL*. Figure 2b shows the effects of a wind-borne disease outbreak in a

[6] Theoretically, wild hosts of a particular wind-borne disease can be fully eliminated. However, for many wind-borne diseases, eliminating wild host organisms would require an unreasonably large amount of resources and would likely not be feasible. Therefore, effectively minimizing the spread of a disease to and from wild host organisms is likely to be the next-best solution.

[7] Although we present a model that uses an actuarially fair check-off rate, it is straightforward to generalize the study to include a small loading factor that offsets the cost of administrative and monitoring efforts.

[8] Note that the likelihood of producers' not taking preventive action after a payment is conditional on (i) the information they have about the probability of their farms becoming infested, and (ii) farmers' willingness to speculate whether shirking behavior would be detected. Because the existing literature has repeatedly shown that farmers are generally risk-averse, appropriate monitoring mechanisms are expected to successfully minimize fraudulent behavior.

[9] All wind-borne disease infestations are modeled as *ceteris paribus* quantity-supplied shocks.

[10] Smith and Goodwin (1996) indicated that producers incur the majority of variable costs during the planting period.

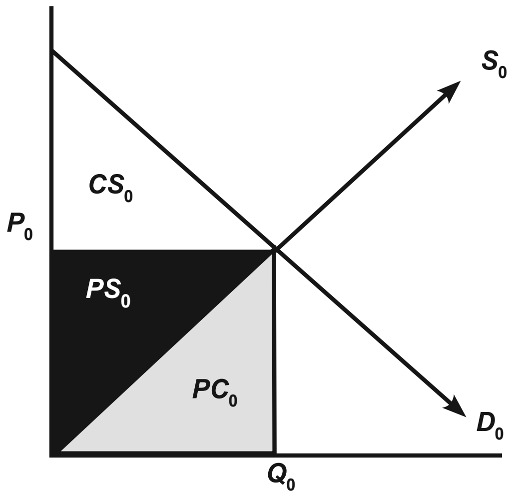

Figure 1a. Depiction of an Agricultural Market at Initial Equilibrium with No Mitigation Program

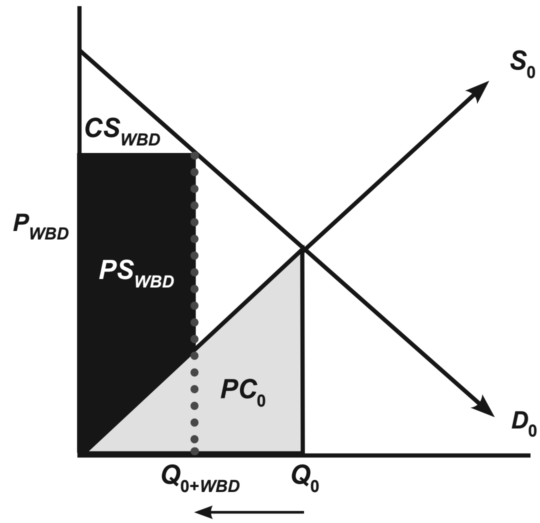

Figure 1b. Depiction of an Agricultural Market with No Mitigation Program after a Disease Infestation

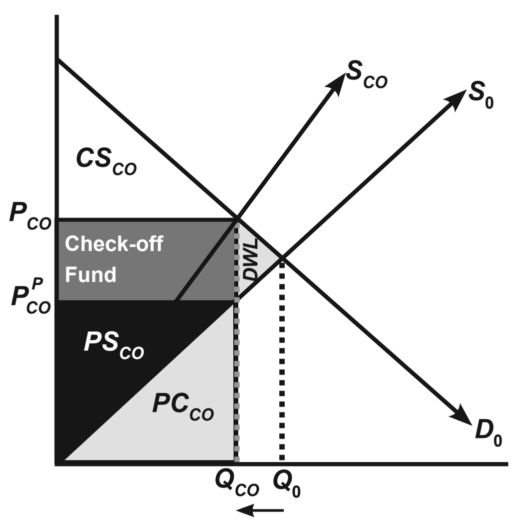

Figure 2a. Depiction of an Agricultural Market after Implementation of a Check-off to Fund a Mitigation Program

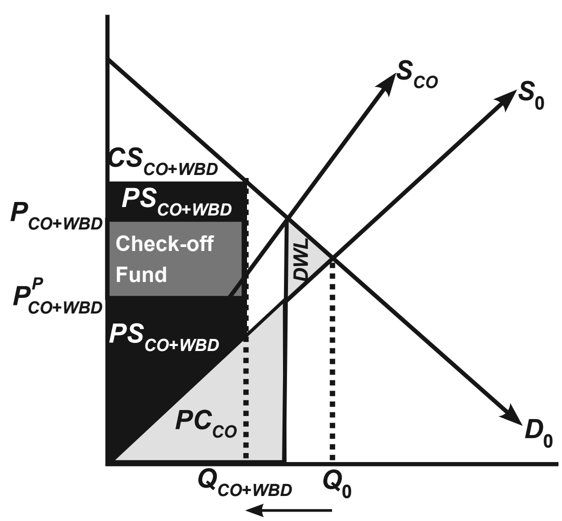

Figure 2b. Depiction of an Agricultural Market with a Check-off Mitigation Program after a Wind-borne Disease Infestation Occurs

Table 1. Variable Descriptions and Baseline Values

Variable	Description	Baseline Value
B	Total soybeans produced (million bushels)	2,585.00
B^D	Soybeans sold in United States (million bushels)	1,815.00
B^E	Soybeans exported (million bushels)	1,155.00
M	Soybean meal produced (million pounds)	43,014.00
M^D	Soybean meal sold in United States (million pounds)	33,750.00
M^E	Soybean meal exported (million pounds)	9,450.00
O	Soybean oil produced (short tons)	20,940.00
O^D	Soybean oil sold in United States (short tons)	18,450.00
O^E	Soybean oil exported (short tons)	3,000.00
P_B	Farm price of soybeans (U.S. dollars per bushel)	\$10.15
P_M	Price of soybean meal (U.S. dollars per pound)	\$0.52
P_O	Price of soybean oil (U.S. dollars per short ton)	\$335.00
λ	Crushing margin for soybeans	3.76
α_M	Proportion of meal produced per unit of soybean (percent)	79.70
α_O	Proportion of oil produced per unit of soybean (percent)	18.80
ψ	Damages due to soybean rust	–

Source: Baseline data are projected 2007/08 values from *World Agricultural Supply and Demand Estimates* (Economics, Statistics, and Market Information System 2007).

market that funds mitigation efforts.[11] Although some welfare losses still occur (indicated by the reduction of quantity supplied to Q_{CO+WBD}, a rise in the price paid by consumers to P_{CO+WBD}, and changes in consumer surplus and deadweight loss), total surplus is greater than when there is no mitigation program (Figure 1b). The substantially lower yield losses are directly related to disease-mitigation efforts that were incentivized by the program.[12]

Characterizing the Equilibrium Displacement Model

We use an equilibrium displacement model to approximate the welfare effects associated with each of the four scenarios depicted in the figures. Equilibrium displacement models are used extensively to simulate effects of hypothetical shocks and resulting changes in agricultural markets (Muth 1964, Gardner 1975, Mullen, Wohlgenant, and Farris 1988, Duffy and Wohlgenant 1987, and Piggott, Piggott, and Wright 1995). The model is relatively easy to implement, the data required for solving it typically are readily available, and the resulting inferences are intuitive.

Our model evaluates the national U.S. soybean market and approximates welfare effects associated with a soybean rust infestation.[13] The model is comprised of nine endogenous quantities and four endogenous market-clearing prices. The thirteen-equation system that defines the market is shown in equations (1A) through (13A) of the Appendix (available from the authors) and the associated variables are defined in Table 1. Equations (A12) and (A13), reproduced here, show how damage

[11] Mitigation payments in year t are made from check-off funds collected in year $t – 1$. Because we assume a national check-off rate, loss probabilities vary minimally across time.

[12] It is possible to envision scenarios in which social welfare would be equivalent regardless of the mitigation and compensation structure. For example, social welfare is the same if no mitigation structure is in place and no disease-related losses occur. Even when producers are fully indemnified by crop insurance payments and an infestation of nearby farms does not occur, social welfare still may be reduced through adverse supply shocks and associated price changes.

[13] See Johansson et al. (2006), Bekkerman, Goodwin, and Piggott (2008), and Roberts et al. (2009) for an overview of soybean rust's pathological characteristics and disease effects within the United States. For examples and descriptions of other wind-borne diseases in the United States, see Roelfs (1989), Palm (2001), Davis (1987), and Shiyomi and Koizumi (2001).

from a wind-borne disease and the per-unit check-off system are incorporated into the model.

(A12) Quantity supplied of soybeans:

$$B = B(P_B^P, \psi)$$

(A13) Check-off per unit levied on producers:

$$P_B - P_B^P = \theta$$

The term B represents the quantity of soybeans supplied, P_B is the price paid by consumers, and P_B^P is the price received by producers for soybeans. The term ψ represents the supply shock associated with a wind-borne disease outbreak, and θ is the per-unit check-off assessed on producers at the time of the first sale. The check-off is assumed to be incorporated into producers' information sets and, therefore, to affect their production decisions and prices. This relationship is endogenously accounted for in the approximation. Furthermore, we assume that the adverse effects represented by the disease-related shock ψ do not change over time but can vary with applications of preventive methods and technological advances. That is, from one period to the next, average losses of yield associated with an outbreak are the same. If no preventive or curative methods are used, a wind-borne outbreak that results in an average loss of yield of 10 percent in year t at location i will result in the same 10 percent loss of yield in year $t + 1$ at location i. This assumption reflects conclusions from the ecological literature that wind-borne infestations often expand spatially but not temporally (there is no increase in the magnitude of their potential for destruction over time).

Comparative statics measures are calculated by taking logarithmic differential approximations to equations (A1) through (A13). Equations (A14) through (A26) result from rearranging terms such that endogenous variables appear on the lefthand side and exogenous variables on the righthand side. We characterize changes in the quantity of soybeans supplied due to a soybean rust infestation and a check-off in equations (A25) and (A26).

$$\text{(A25)} \qquad \widetilde{B} - \varepsilon_{BB}\,\widetilde{P}_B^P = \varphi_{B\psi}\widetilde{\psi}$$

$$\text{(A26)} \qquad (1 + \tau)\,\widetilde{P}_B - \widetilde{P}_B^P = \tau\widetilde{\theta}$$

The term $\widetilde{B} = d \ln B \approx \Delta B / B = (B^1 - B^0) / BA^0$ represents the proportional change in the quantity of soybeans where 0 and 1 denote the initial and new values of B. Similarly, $\widetilde{P}$, $\widetilde{P}_B^P$, $\widetilde{\psi}$, and $\widetilde{\theta}$ are proportional changes in the price paid by soybean consumers, the price received by producers, the proportion of losses associated with the wind-borne disease (the supply-side effect of the disease), and the per-unit check-off. The total proportional change to the quantity of soybeans supplied due to the disease outbreak is denoted by the term $\varphi_{B\psi}\widetilde{\psi}$ where $\varphi_{B\psi}$ is the elasticity between the U.S. soybean supply and the damage related to soybean rust. Because the disease has only recently entered the United States, we could not obtain data that would allow us to separately estimate the two individual components, $\varphi_{B\psi}$ and $\widetilde{\psi}$. However, the data set is sufficient for determining the total effect ($\varphi_{B\psi}\widetilde{\psi}$), and those estimates are presented by Roberts et al. (2006) under curative, preventive, and no-treatment scenarios.

The term τ in equation (A26) represents a proportional tax rate on the price received by producers, P_B^P. This rate can be specified as a function of the per-unit check-off and the market clearing price paid by consumers, P_B, as

$$\tau = \theta / P_B^P = zP_B / (1 - z)P_B = z / (1 - z)$$

where z denotes the proportional tax rate on P_B. For example, when representing the existing 0.5 percent National Soybean Check-off program, $z = 0.005$.

We specify equations (A14) through (A26) of the Appendix in matrix notation as $\mathbf{M}Y = X$, and these matrices are shown in equations (A27) through (A29) of the Appendix. Proportional changes in quantities and prices due to changes in τ and ψ can be solved by setting $Y = \mathbf{M}^{-1}X$. For U.S. soybeans, quantity and price adjustments can be measured using domestic and export elasticities and associated consumption shares. Domestic demand elasticities (η_{MM} and η_{OO}), export demand elasticities (μ_{BB}, μ_{MM}, and μ_{OO}), and the supply elasticity of soybeans (ε_{BB}) are estimated using traditional econometric methods. Specifically, annual data from 1975 through 2007 are used to estimate the relationship between the quantity of a commodity demanded and the quantity supplied based on the commodity's price, the price of substitutes, national average income levels, and other variables considered to be relevant shifters of demand and supply.[14] Maximum likelihood is used to estimate linear, double-log, autoregressive models and Box-Cox-transformed quantity-demand and quantity-supply specifications.[15]

The estimated domestic demand and supply equations fit the data well (all R-square values are greater than 0.79), and the price coefficients are statistically significant at the 5 percent level, implying relatively precise long-run elasticity measures: $\varepsilon_{BB} = 0.359$, $\eta_{MM} = -0.232$, and $\eta_{OO} = -0.234$. Export demand equations for soybeans and soybean meal have a lesser fit (R-square measures for the preferred specifications are 0.63 for soybeans and 0.50 for soybean meal) and also have statistically significant price coefficients: $\mu_{BB} = -0.448$ and $\mu_{MM} = -0.313$. Export demand for soybean oil is the only regression in which the price coefficient is statistically insignificant, which may reflect the presence of unobservable global factors that affect soybean export demand. Due to the poor fit of the soybean oil model, we use an export demand elasticity estimated by Kim et al. (2008): –0.79.[16]

Calculation of the **Y** vector in equation (A27) requires baseline estimates for demand, supply, price, and domestic shares of U.S. soybean components. In this study, baseline estimates are projected 2007/08 values issued in *World Agricultural Supply and Demand Estimates* (*WASDE*), a report by the U.S. Department of Agriculture's (USDA's) Economics, Statistics, and Market Information System (2007).

Simulation Model Setup

We simulate market conditions and quantify the welfare effects shown in the figures in three steps. First, a wind-borne disease infestation is simulated by shocking a commodity's projected baseline supply. Next, an actuarially fair check-off is incorporated into the model by augmenting the term τ in equation (A26), and a simulation is performed to determine the responses of producers and consumers. Lastly, a simulation of a wind-borne infestation is repeated within the market structure that includes a check-off and associated mitigation efforts. This third simulation provides inferences about the manner in which markets are impacted by a wind-borne disease under the current and proposed market structures.

Appropriately modeling a shock to the quantity supplied requires information about expected total losses associated with a wind-borne disease infestation. This involves modeling bioeconomic factors related to the spread of a wind-borne disease. That is, the model should incorporate information about biophysical properties and farmers' behavior associated with the infestation, spread, and management of an invasive species. We characterize a straightforward expected-loss function in which the expected total loss in period t is a function of the initial quantity supplied, yield losses associated with the initial infestation, yield losses at nearby farms after disease spread, and the probability of disease spread. This loss function provides a reduced-form characterization of bioeconomic interactions because yield losses after infestations and the probability of disease spread are conditional on information sets that account for the numerous bioeconomic aspects.[17]

We assume that expected total losses in an agricultural sector can be characterized by the following function:

$$E[L(Q,\delta^*,\delta,\omega)] = Q\cdot\delta^*$$
$$+\sum_{t=2}^{\infty}\Bigg[(Q\cdot\delta)\cdot(1-\delta^*)\cdot\omega^{t-1}$$
$$\cdot I\left\{1/\delta-\sum_{u=1}^{t-2}\omega^u - I\left\{\sum_{u=3}^{t-1}\omega^u\delta^{u-2}\right\}_{(t>3)}\right\}_{(t>2)}\Bigg].$$

[14] We collected historical data from various sources. Full elasticity estimation results are omitted for brevity but are available upon request.

[15] We use a simple autoregressive error specification, $y_t = \boldsymbol{x}'\beta + (\varepsilon_t - \phi_1 v_{t-1} - \phi_2 v_{t-2} - \cdots)$ where $\varepsilon_t \sim N(0, \sigma^2)$. The three specifications are used to gauge the robustness of the alternative specification and the sensitivity of the elasticity estimate to each functional form. Elasticities that are calculated from the Box-Cox model are not constant. This is analogous to a linear elasticity system, which is a linear approximation model. We choose the estimated elasticity from the specification that best fits the data and has the most precision in the estimated coefficients. Estimates are excluded to conserve space but are available from the authors upon request.

[16] The estimates by Kim et al. (2008) are consistent with estimates of U.S. soybean export demand elasticities in Piggott and Wohlgenant (2002) and from the Food and Agricultural Policy Research Institute (2004).

[17] For example, wind-borne disease spread probabilities have been shown to be functions of spatio-temporal, meteorological, and pest management factors (several recent examples include Bekkerman, Goodwin, and Piggott (2008), Goodwin and Piggott (2009), and Aultman et al. (2010)). It is possible to appropriately incorporate this information into a loss function by estimating the probability conditional on the relevant factors and using predicted spread-probability values directly in the loss function.

The term Q is the initial quantity of the commodity, δ^* is the percentage of yield loss after the initial infection, δ is the percentage of yield loss at nearby locations after spread, ω is the probability of spread to nearby farms, and subscripts t and u indicate time periods. The term $I\{\cdot\}_{(\cdot)}$ indicates that the equation inside of the brackets must be evaluated only if the condition in the parentheses is true; otherwise, the term is set to 1.

The loss function can be used to determine expected total losses under the existing market structure and the proposed mitigation program conditional on appropriate identification of the bioeconomic components of the loss function. We assume that the existing structure does not provide appropriate incentives for producers to seek preventive strategies against a wind-borne disease primarily because of the substantial uncertainty associated with disease infestation and the high cost of prevention. Therefore, each new infestation is assumed to result, on average, in the same proportion of production loss. For the case of soybean rust, we follow the existing literature and specify yield losses as $\delta^* = \delta = 7$ percent of the total expected yield in every infected location.[18] Under the mitigation program, losses associated with an initial infestation are assumed to be greater than losses at nearby locations because the program provides producers with an incentive to take preventive action. In the case of soybean rust, we assume that the initial yield loss is $\delta^* = 7$ percent and any subsequent losses are $\delta^* = 1$ percent of the total expected yield.[19] In our analysis, we specify the "initial infestation" location as the county in which the first instance of an infection is reported and "nearby infestation" locations as farms in adjacent counties.

We first calculate the expected total yield loss without a mitigation program by setting Q to the baseline soybean production value specified in the *WASDE* report. Then, after accounting for market changes associated with introduction of a check-off, we determine the expected total loss of yield by setting different values for the initial and subsequent yield losses. For both the existing and proposed programs, we assume that the probability of soybean rust spreading to nearby farms, ω, is the same. We empirically determine this probability by the frequency with which a new infestation was reported at a nearby location. Specifically, we examine farm-level disease-inspection data collected by USDA, the National Plant Diagnostic Network, and the National Agricultural Pest Information System.[20] The data consist of 32,089 reported inspections from 1,097 U.S. counties located mostly in states along and east of the Great Plains.

We screen the data of soybean rust infestations for duplicate infection reports occurring on the same day.[21] However, the screening process may not fully prevent multiple reports of the disease for the same location on subsequent days. Therefore, we cannot directly observe the frequency with which soybean rust spreads. We consider three scenarios for determining the prevalence of spread, each of which employs a waiting period (in days) prior to counting an additional soybean rust report in a county as a unique infection at a nearby farm. For example, at time t_0 an infection is reported in county i. If another infection is reported in county i on the following day, t_1, we cannot determine whether this second report came from the same location. Therefore, only infestations reported after a waiting period of w (at $t > t_w$) are considered unique and treated as indicators of disease spread. We assume waiting periods of zero, three, and five days and find that the associated spread probabilities are 59.3 percent, 39.4 percent, and 33.3 percent respectively. Accordingly, we use these values to specify ω in the expected total loss function.[22]

Lastly, we simulate institution of the market-based mitigation program using an actuarially fair check-off rate. Bekkerman, Goodwin, and Piggott (2008) estimated county-level, actuarially fair premium rates by modeling soybean rust infestation probabilities as functions of various spatio-temporal meteorological factors and farmer

[18] Initial losses and losses after spread are the same because farmers apply curative fungicide after finding a soybean rust infestation. Johansson et al. (2006) simulated yield losses under various treatment scenarios and Livingston (2010) estimated those yield losses, and both studies showed that curative actions resulted in an average 7 percent yield loss. Expected initial yields are *WASDE* (Economics, Statistics, and Market Information System 2007) baseline estimates.

[19] This may overestimate the amount of subsequent losses because the loss proportion is an upper bound.

[20] The inspection data used in our analysis are for January 2005 and November 2007. More detailed information on the data is available from the authors upon request.

[21] For example, a farmer may report two instances of a soybean rust infection that were found on different cultivars grown on a single farm. However, within the data set, this is counted as a single positive observation.

[22] Only infections reported within 30 days of the initial outbreak are assumed to be dependent on the original discovery.

management strategies. Using a weighted average of these rates, we determine a national check-off rate that implicitly contains information about the conditional infestation probabilities. Specifically, the 2008 estimated county-level rates are weighted by each county's 2008 soybean production quantity. This helps ensure that producers in counties with greater potential for losses (because their production is greater) contribute equitably to the collective fund. The resulting 2008 national check-off rate for the mitigation program is 0.7 percent.[23]

National check-offs can be advantageous because they are relatively easy to implement, can be more easily advocated to producers, and address potential free-rider problems. The proposed 0.7 percent mitigation check-off is relatively small compared to existing national rates for many other commodities. For example, proportional check-offs range from 0.09 percent in beef cattle to 0.85 percent in cotton.[24] However, it is possible to envision alternative structures; for example, the check-off rate could be conditional on spatially (geographically) heterogeneous wind-borne disease risks. This approach can substantially lower the rate in regions with relatively low risk and raise rates in regions where the risk is high. Moreover, this kind of structure can increase support from producers if variable check-off rates are perceived as better representing risk levels. However, substantially higher administrative costs can be associated with determining and enforcing heterogeneous check-off rates with the costs likely to be positively correlated with the number of geographic regions to which a unique rate is applied.

Empirical Results

We first approximate the effect on the U.S. soybean market from introduction of a 0.7 percent check-off and present those results in Table 2. The results indicate that the mitigation program reduces the quantity of soybeans supplied by 0.09 percent, increases the consumer price by \$0.048 per bushel, and decreases the producer price by \$0.023 per bushel. The deadweight loss associated with the check-off is \$0.00071 for each \$1 contributed to the collective mitigation fund. These relatively trivial changes to the U.S. soybean market indicate that the market-based program would result in minimal welfare distortion while generating adequate mitigation. This suggests that similar market-based disease-mitigation programs for other commodities are feasible.

[23] The mitigation check-off is added to the existing 0.5 percent National Soybean Check-off program assessment on U.S. soybean producers.

[24] For some commodities, check-offs are not determined as proportions of market sales revenue. In these cases, 2010 average marketing prices were used to determine the proportional check-off values.

Table 2. Approximated Effects on the U.S. Soybean Market after a 0.7 Percent Check-off

Effect	Value
Change in price received by producers (U.S. dollars per bushel)	–0.02
Change in price paid by consumers (U.S. dollars per bushel)	0.05
Change in quantity of soybeans (million bushels)	–2.13
Percentage change in price received by producers	–6.8E-3
Percentage change in price paid by consumers	4.90E-05
Percentage change in quantity of soybeans	–0.09
After-check-off price received by producers (U.S. dollars per bushel)	\$10.08
After-check-off price paid by consumers (U.S. dollars per bushel)	\$10.20
After-check-off quantity of supplied soybeans (million bushels)	2,582.87
Revenue collected by all soybean check-off programs (million U.S. dollars)[a]	\$314.59
Revenue collected by mitigation check-off program (million U.S. dollars)	\$183.41
Deadweight loss per dollar contribution to fund	\$7.10E-04
Total deadweight loss from check-off program (million U.S. dollars)	\$0.13

[a] The total check-off includes the 0.5 percent National Soybean Check-off and the proposed soybean rust mitigation check-off of 0.7 percent.

Table 3 presents the simulated market and welfare effects associated with a soybean rust infestation before and after a mitigation program is introduced for three soybean-rust-spread probabilities: 59.4 percent, 39.4 percent, and 33.2 percent. For each probability, substantial welfare benefits are associated with the market-based mitigation program relative to the current structure. Furthermore, the benefits increase monotonically with the probability of spread, suggesting that catastrophic losses and major market disruptions could be substantially reduced through mitigation in years that are favorable to the spread of wind-borne disease. For example, when the probability of spread (ω) is assumed to be 33.2 percent, the mitigation program reduces production losses by 37.55 million bushels. However, at a 59.3 percent probability, losses are reduced by more than 110.06 million bushels. Furthermore, infestations cause changes in the producer price that range from \$3.31 to \$5.23 per bushel under the current structure and from \$2.42 per bushel to \$2.70 per bushel with the mitigation program. Similarly, the consumer price change ranges from \$3.31 to \$5.23 per bushel under the current structure and from \$2.43 to \$2.72 per bushel with mitigation.

The effects of soybean rust on producer welfare under the two structures are also shown in Table 3. Under the current market structure, a disease outbreak leads to producer surplus losses of \$743 million to \$1,173 million; the mitigation program reduces these losses to between \$541 million and \$605 million. However, loss of producer surplus may not fully reflect the adverse effects of a wind-borne disease infestation. A better measure may be the sum of lost producer surplus and the costs to producers that cannot be offset due to foregone market sales caused by an outbreak. Most of the production costs are incurred at the beginning of the growing season before an infestation occurs and are expected by producers to be offset with revenue generated from market sales, so a disease infestation resulting in lost revenue would result in some costs that are not offset. When mitigation incentives are not socially optimal, total welfare losses can range from \$2.23 billion to \$3.52 billion. However, in the proposed market-based mitigation structure, these losses drop to between \$1.6 billion and \$1.7 billion—a reduction of \$0.604 billion to \$1.7 billion. This substantial mitigation of welfare losses is important evidence of the benefits created by a market-based program.

Table 3. Approximated Effects in the U.S. Soybean Market after a Soybean Rust Infestation

	Current Indemnification Program with Assumed Probability of Spread of:			Mitigation Check-off Program with Assumed Probability of Spread of:		
	33.2%	39.4%	59.3%	33.2%	39.4%	59.3%
Post-loss soybean supply (million bushels)	2,437.83	2,423.83	2,352.56	2,475.38 [37.55]	2,473.33 [49.50]	2,462.62 [110.06]
Change in price received by producers (U.S. dollars per bushel)	3.31	3.63	5.23	2.42 [–0.90]	2.46 [–1.17]	2.7 [–2.53]
Change in price paid by consumers (U.S. dollars per bushel)	3.31	3.63	5.23	2.43 [–0.88]	2.48 [–1.15]	2.72 [–2.51]
Change in producer surplus (million U.S. dollars)	–743.15	–813.81	–1,173.72	–541.55 [201.60]	–551.85 [261.96]	–605.86 [567.86]
Sum of lost producer surplus and producer costs not offset by revenues due to infestation (million U.S. dollars)[a]	–2,229.44	–2,441.42	–3,521.16	–1,624.66 [604.78]	–1,655.55 [785.87]	–1,817.57 [1,703.59]

[a] We assume that the majority of producer costs occur prior to or at planting time (Smith and Goodwin 1996). Therefore, some producer costs will not be offset due to foregone revenues resulting from infestation losses.

Note: The values in brackets are the difference between the effect under the mitigation program and the current indemnification program.

Conclusions and Policy Implications

In this study, we propose an alternative to existing methods aimed at protecting agricultural markets from adverse effects of wind-borne disease infestations. The alternative market-based program seeks to provide an incentive for producers of at-risk commodities to mitigate the spread of wind-borne diseases, thereby substantially reducing large-scale infestations, production losses, and market instabilities. Under the proposed program, producers would contribute a small percentage of market revenue into a collective fund that would be used to indemnify producers who suffer losses related to disease outbreaks and to provide payments to all nearby producers with crops that are at a high risk of infection. These payments would compensate producers for actions they take to prevent further outbreaks, reducing the likelihood of the disease's spread. Using an equilibrium displacement model, we simulate introduction of the proposed program into the U.S. soybean sector. Results of the empirical analysis reveal that the initial institution of the program contributes to minimal market distortion. Furthermore, relative to the existing structure, the proposed program reduces negative welfare effects associated with soybean rust infestations.

As agricultural markets continue to globalize, wind-borne diseases may become increasingly prevalent and adverse economic impacts from widespread infestations may be even more critical. Results of this study provide evidence that the proposed market-based mitigation program can reduce the likelihood of rapid, widespread infestation and can be a viable option for other agricultural sectors and commodities that are at risk. Furthermore, as available government funds become scarce, there is a growing need for sustainable, market-based solutions that effectively achieve the collective goals of an agricultural industry. Using the proposed check-off structure to generate adequate funds can provide the mechanism for agricultural industries to meet these goals.

Generally, producers have supported check-off programs. For example, in 2011 the National Sorghum Check-off was approved by 76.2 percent of voting producers (*Delta Farm Press* 2011); 88 percent of voting blueberry producers approved a referendum to continue that industry's existing blueberry check-off program. Additionally, there is some evidence that producer support for check-off programs can increase over time. In 2010, the National Soybean Check-off received a historically high 78 percent approval rating (*Southern Farm Network Today* 2011), and 89 percent of voting peanut producers approved continuation of their Peanut National Check-off, which was introduced in 1999 with 66 percent in support (Agricultural Marketing Service 2011).

Producers of commodities for which the risk of a wind-borne infection is high have stronger incentives to support a market-based mitigation program. As indicated by the simulation in this study, the program generates an adequate amount of indemnification and mitigation funds with minimal market and welfare distortions. Thus, producers could reduce infestation risk in exchange for small reductions in revenue. Furthermore, producers may support a group-based mitigation program because it would signal to neighboring operations their efforts to prevent further spread of a disease. Community-based incentives can be an important tool for maintaining good standing among professional and social peers.

The program's indirect benefits may also encourage support for check-offs. One potential indirect benefit is stabilization of markets, especially if prices are sensitive to changes in quantity supplied. A program that mitigates wind-borne diseases can prevent catastrophic production losses and large reductions in yield, thereby minimizing price volatility. Additionally, funds collected from a check-off can be used to develop long-term disease mitigation initiatives. These could include subsidization of early warning programs, funding of research initiatives, and maintenance of financial resources.[25] Such initiatives are necessary for developing wind-borne disease protection strategies, and market-based programs may be able to provide the long-term resources required for these endeavors.

Further research is needed to identify equitable methods for implementing check-off programs. It may be necessary to consider the heterogeneity of spatial infection risks. Although we model the proposed mitigation program using a national

[25] The USDA's Risk Management Agency and the Animal and Plant Health Inspection Service may provide initial funding for disease early-warning initiatives. However, the cost of such programs is often prohibitive, disallowing indefinite funding by government or other public agencies. For example, the tracking and sentinel plot program for soybean rust cost $1.7 million annually (Bennett 2008).

check-off rate, it would be useful to consider implementation of location-specific check-off rates. Such research would have to consider ease of implementation (a single check-off rate is generally a simpler process), perceived equity for and support by producers (producers who face little risk of wind-borne disease may not support a single rate across all geographical locations), and free-rider concerns. Additionally, further research could more accurately represent expected yield losses from wind-borne disease infestations. Disease-specific loss functions would likely require incorporating factors such as spatial heterogeneity, pathology traits, and climatological characteristics of the disease.

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