A Rational Risk Policy for Regulating Plant Diseases and Pests

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This paper examines the Federal quarantine established by USDA in 1996 to prevent the spread of Karnal bunt, a minor disease of wheat. During the early stages of its regulatory strategy, USDA made extensive use of probabilistic risk assessments to determine the efficacy of various quarantine protocols. However, there was less careful consideration given to the costs and benefits of the actions. If risk had been incorporated directly into the cost/benefit analysis, different conclusions would likely have been drawn about the expected impact of the regulations. This paper develops a methodology for combining these two analyses to improve future regulatory decision-making.

Key words: *Risk assessment, cost-benefit analysis, regulatory decision-making*

The U.S. Department of Agriculture (USDA) has had responsibility for implementing plant quarantines since 1912 (Palm 1999). Under the Federal Plant Pest Act and the Plant Quarantine Act, USDA has the authority to impose restrictions on the interstate movement of any article believed to be infested with exotic pests or diseases. There are currently 17 federal quarantines in place, ranging from restrictions affecting peach orchards in Pennsylvania infected by the plum pox virus to hardwood forests in the Eastern United States infested with gypsy moths (table 1). The range of the combined quarantines cover most of the United States and affect most crops produced there. The federal cost to maintain these quarantines is estimated to be almost $50 million in 2000 (USDA 2000).

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The costs attributable to plant pests and diseases in the United States in lost productivity and expenses for protection and control have been estimated to be as much as $41 billion annually (U.S. GAO 1997). Although these loss estimates are controversial, the threat of foreign pests and diseases to U.S. crop production has long been used to argue for strict import regulations and broad domestic quarantine authorities.[1]

Aside from benefits, however, quarantines can impose substantial costs on producers, handlers and others affected directly by regulations as well as potentially adversely affecting consumers and others through restrictions in supply (James and Anderson 1998). Federal quarantine policy has generally followed guidelines developed by the National Plant Board in 1931.[2] These guidelines state that: (1) the pest concerned must be of such nature as to offer actual or expected threat to substantial interests; (2) the proposed quarantine must represent a necessary or desirable measure for which no other substitute, involving less interference with normal activities, is available; (3) the objective of the quarantine, either for preventing introduction or for limiting spread, must be reasonable of expectation; (4) *the economic gains expected must outweigh the cost of administration and the interference of normal activities*. (Sim 1998, emphasis made by the authors).

Assessing the economic effects of quarantines is oftentimes difficult because of the uncertainty surrounding the risks that the quarantine policy seeks to mitigate (James and Anderson 1998). Yet even when probabilistic risk assessments exist, regulators often consider the costs and benefits separately. Ignoring the underlying distribution of costs and benefits not only overstates the certainty of the analysis, but it can potentially lead to regulatory actions where the expected costs exceed the expected benefits.

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[1]For example, estimates of the costs of invasive species to the United States range from $1.1 billion annually (Office of Technology Assessment 1993) to $137 billion (Pimentel et al. 2000). See also Pinstrup-Anderson (1999) and Orke et al. (1996).

[2]The National Plant Board is an organization of state plant pest regulatory agencies created in 1925 to promote efficiency and uniformity in the promulgation and enforcement of plant quarantines and plant inspection policies (Sim 1998).

This paper examines the Federal quarantine established by USDA in 1996 to prevent the spread of Karnal bunt, a minor disease of wheat. During the early stages of establishing its regulatory strategy, USDA made extensive use of probabilistic risk assessments to determine the efficacy of various quarantine protocols. However, there was less careful consideration given to the costs and benefits of the actions. In early press releases and Federal Register Notices, the benefits were expressed largely in terms of the value of the U.S. wheat market believed to be at risk (e.g., 61 FR 12058, Docket No. 96-016-1). Likewise, when the regulatory impact analysis for the final rule was published on May 6, 1997, the costs and benefits of the regulations were discussed without consideration of the distribution of potential outcomes. If risk had been incorporated directly into the cost/benefit analysis, it is likely that different conclusions would have been drawn about the expected impact of the regulations.

The paper is organized as follows. Section 1 presents a brief history of Karnal bunt and the events leading to the establishment of the federal quarantine in 1996. In section 2, a model of quarantine policy is developed that relates the expected costs of quarantine actions to the expected benefits. Section 3 utilizes the probabilistic risk assessments undertaken in 1996 to assess how proposed regulatory actions mitigated the risks of Karnal bunt. In section 4, the potential benefits and costs of the regulations are considered. Section 5 examines the expected costs and benefits of regulations incorporating information on the distribution of potential outcomes given various regulatory actions. Conclusions are presented in the last section.

Regulatory History

Karnal bunt is a disease affecting wheat, rye, and triticale (a hybrid of wheat and rye) caused by the fungus *Tilletia indica* Mitra (Bonde et al.). Karnal bunt can cause production losses to wheat in the form of reduced yields due to the infestation of kernels and reduction in the quality of the wheat flour. Generally, wheat containing more than 3 percent bunted kernels is considered unsatisfactory for human consumption because of a fishy odor that makes wheat products unpalatable (Warham 1986), but it poses no risk to human health.

Karnal bunt was first reported in 1931 in the Indian State of Haryana in wheat-growing areas near the city of Karnal, from which the disease gets its name. From that time through the early 1970s the disease went largely unnoticed and was believed to be limited in its distribution to similar environments in Pakistan, Iraq, Afghanistan, Nepal and Iran (Singh et al. 1998) In 1970, Karnal bunt appeared in Mexico, but caused little economic loss until the early 1980s, when disease incidence increased sharply. Initially found in Sonora, the disease spread south into the neighboring states of Sinaloa and Baja California Sur (Brennan and Warham 1992).

In 1982, diseased wheat kernels were intercepted in wheat imported from Mexico. Following confirmation of Karnal bunt in Mexico, USDA took action to prevent the importation of host plant material (including seed and grain) and any other articles that might spread the disease (Poe 1997). These actions were made permanent in October 1983 by adding Mexico and other countries where Karnal bunt was known to occur to the list of countries in the Wheat Disease subpart of the Foreign Quarantine Notices (7 Code of Federal Regulations 319.59). All of the major wheat exporting countries followed suit. In 1982, only four countries had phytosanitary trade restrictions involving Karnal bunt. Following the U.S. action against Mexico, that number jumped to 22 (Beattie and Bickerstaff 1999).

A risk assessment of Karnal bunt completed by USDA in 1988 concluded that because of the close proximity of wheat growing areas of Arizona and California to infested areas in northwestern Mexico and the flow of prevailing winds, "transport of the Karnal bunt pathogen is extremely likely" (Schall 1988). A subsequent pest risk analysis conducted in 1991 concluded that Karnal bunt was a high risk pest, primarily because "wheat from infested areas would probably be denied or restricted access in the export market"[3] (Schall 1991). Because of its potential adverse effects on exports, the analysis recommended that in the event of introduction of the Karnal bunt pathogen USDA should establish and maintain quarantines to restrict distribution.

[3] An economic analysis conducted by USDA in 1994 indicated that annual crop losses due to Karnal bunt in Arizona, Texas, New Mexico and California would total between $406 thousand and $1 million per year and that annual losses in export markets could total over $57 million for Arizona and Texas alone (cited in Podleckis 1995).

On March 8, 1996, Karnal bunt was detected in Arizona during a seed certification inspection done by the Arizona Department of Agriculture.[4] On March 20, 1996, the Secretary of Agriculture signed a “Declaration of Extraordinary Emergency” authorizing USDA to take emergency action under 7 U.S.C. 150dd with regard to Karnal bunt within the States of Arizona, New Mexico and Texas. The quarantine was extended to Imperial and Riverside counties in California on April 12, 1996. In an interim rule effective March 25, 1996 and published in the Federal Register on March 28, 1996, the Animal and Plant Health Inspection Service (APHIS) established the Karnal bunt regulations and quarantined all of Arizona and portions of New Mexico and Texas because of Karnal bunt. The regulations defined regulated articles and restricted the movement of these regulated articles from the quarantined areas.

The imposition of Federal quarantine and emergency actions was seen by USDA as a “necessary, short-run measure taken to prevent the interstate spread of the disease to other wheat producing areas in the outbreak area, so that eradication could be eventually achieved” (62 Federal Register 24754-24755). USDA described its objectives as three-fold: (1) to protect U.S. wheat producers in Karnal-bunt free areas, (2) to protect U.S. export markets, and (3) to provide the best possible options for producers in quarantined areas who are affected by the Karnal bunt detections (USDA APHIS1997).

USDA’s initial actions were to require producers in New Mexico and Texas who had planted fields with infected seed to plow down their crop immediately. Because crop development was further along in Arizona and California, plowing down crops was not considered viable. Instead, a number of regulations were implemented that affected persons or entities that produced wheat in the regulated area and/or moved certain articles associated with wheat out of a regulated area (table 2). These articles were subject to regulatory actions to minimize the risk of spreading the pathogen to other uninfected areas.

Regulated articles itemized in the Karnal bunt protocols included:

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[4]Checks of seed lots dating back to 1993 from the same area in Arizona revealed the presence of Karnal bunt teliospores at low levels (Nelson 1996).

1. Farm machinery and equipment used to produce wheat;
2. Conveyances from field to handler, such as farm trucks and wagons;
3. Grain elevators, equipment and structures at facilities that store and handle grain;
4. Conveyances from handler to other marketing channels, such as railroad cars;
5. Plant and plant parts, such as grain for milling, grain for seed, and straw;
6. Flour and milling byproducts;
7. Manure from animals fed wheat/wheat byproducts from quarantine area;
8. Used sacks;
9. Seed-conditioning equipment;
10. Byproducts of seed cleaning;
11. Soil-moving equipment;
12. Root crops with soil;
13. Soil.

All wheat fields within the regulated areas of Arizona, California, New Mexico and Texas were sampled at harvest for Karnal bunt teliospores. Any wheat shipped outside of the regulated area was again tested for Karnal bunt teliospores. Grain that tested positive for Karnal bunt was prohibited from moving out of the regulated areas, but could be milled or fed to cattle within the regulated area. Other contaminated articles were required to be cleaned and sanitized before movement out of the regulated area. To determine whether Karnal bunt was present in areas outside of the quarantined areas, a comprehensive national survey of wheat elevators was planned for the fall of 1996.

Commercial seed intended for planting or for breeding and seed development purposes was prohibited from moving outside the regulated areas. Wheat seed could be planted within the quarantined areas, but only if tested negative for Karnal bunt teliospores and was treated prior to planting. Grain that tested negative was permitted to move outside of the regulated areas under limited permit. Grain was required to be shipped in sealed railcars and the railcars had to be sanitized after the grain was delivered to its destination. Grain that was exported received a phytosanitary certificate from USDA certifying that the grain had been tested twice and found negative for Karnal bunt.[5]

Negative-testing grain was permitted to move to approved domestic flour mills. Due to the grinding process and intended use, the risk of spread of the disease through movement of the flour was viewed by USDA as negligible. In the milling process, however, a considerable amount of byproduct or millfeed is produced. The millfeed is typically sold as cattle feed which represents about 10 percent of the value of the milled wheat. Because of the risk that manure from the cattle could be deposited on wheat fields and thus potentially be a pathway for spread of Karnal bunt, USDA required that mills heat the millfeed to 130 degrees F for 30 minutes or steam-treat to 170 degrees F.

As will be seen in a later section, the protocols imposed large costs on the southwestern wheat industry. As the full extent of the quarantine became understood, opposition within the quarantine area grew and many questioned whether an eradication strategy was appropriate[6]. USDA maintained that the principal rationale for the quarantine was to assure foreign wheat importers that they could import wheat from the United States that was from areas where Karnal bunt was not known to occur. This paper revises the original analyses (both risk assessment and the economic analysis) to assess this view. In order to assess whether the expected benefits of the quarantine exceed the costs, a model of quarantine policy must be first developed.

A Model of Quarantine Policy

The model presented here is similar to a model of disease control outlined in Rendleman and Spinelli (1999). Let W_D be the welfare in the event of a disease outbreak and W_N be the welfare in the

[5]Grain originating from outside of the regulated areas received phytosanitary certificates certifying that the grain was from areas where "Karnal bunt was not known to occur."

[6]In a position statement released in August 1996, the American Phytopathological Society questioned the "zero tolerance" requirement for teliospores in seed lots and concluded that "experience from countries where this disease has occurred would suggest further that it is a minor disease, and what little risk does exist can be effectively managed without the use of quarantines."

event of no outbreak such that $W_N > W_D$. If an the outbreak occurs with probability *p*,

then the expected welfare, *EW*, can be written[7]:

$$EW = pW_D + (1 - p)W_N \tag{1}$$

Now consider a quarantine policy, *f*, that affects the probability of an outbreak and welfare such that:

$$EW(\ ) = p(f)W_D(f) + (1 - p(f))W_N(f) - C(f) \tag{2}$$

where *C(f)* is the cost of implementing the quarantine. An optimal regulatory policy can be described by maximizing (2) with respect to *f* such that:

$$\frac{d\mathrm{E}W(f)}{df} = 0 \tag{3}$$

$$\begin{aligned} p'(f)W_D(f) + p(f)W_D'(f) - p'(f)W_N + \\ (1 - p(f))W_N'(f) - C'(f) = 0 \end{aligned} \tag{4}$$

Rearranging terms, it can be shown that with an optimal quarantine policy *f**, the marginal change in benefits are equal to the marginal change in costs.

[7] A more general form can be written $EW = \int_{-\infty}^{\infty} W(J)f(J)dJ$ where f(*q*) is the probability density function of the risk of outbreak.

$$p'(W_D - W_N) = C' - [pW'_D + (1 - p)W'_N] \qquad (5)$$

The left hand terms reflects the net change in welfare due to the change in probability–the benefits of reducing the risk of outbreak. The right hand terms reflect the expected change in welfare due to the quarantine policy–the costs of implementing the quarantine.

The optimal quarantine policy can be shown in figure 1. A, B, C, D, E and F are quarantine policies with associated costs and benefits. Policies A, C, D and F lie on an efficient frontier of policy alternatives; that is, for a given cost, these policies result in the maximum possible benefits. Policies B and E are inferior policies. Policy C is the optimal quarantine policy, f^*, that satisfies equation (5). At this point, the marginal benefit of the quarantine policy is equal to its marginal cost.

Assessing the probability of outbreak

To estimate the effects of various quarantine protocols on the likelihood of outbreaks of Karnal bunt in areas outside the quarantined area, USDA relied on a number of probabilistic risk assessments conducted prior to discovery of Karnal bunt in Arizona (Schall 1988, 1991; Podleckis 1995) and in the first two months following the outbreak (Podleckis and Firko 1996a, 1996b, 1996c, 1996d). Probabilities of outbreak were estimated for a variety of potential pathways including millfeed, export elevators, seed originating in the quarantined area, railcars transporting grain from the quarantined area to domestic mills and export elevators, grain storage facilities, and combines and other harvesting machinery.

The risk assessment presented here is based on the USDA risk assessments. However, unlike the USDA analysis which focused on measuring risk of individual pathways, this risk assessment focuses on the overall level of risk of outbreak from any source.[8] The probability of an

[8]A more detailed description of the risk assessment model is summarized in the appendix.

outbreak of Karnal bunt occurring outside the quarantined area, p^*, can be written as:

$$p^* = 1 - (1 - p_1)(1 - p_2)(1 - p_3)(1 - p_4)(1-p_5) \text{ where} \tag{6}$$

p_1 probability of an outbreak of Karnal bunt outside the quarantined area from millfeed

p_2 probability of an outbreak of Karnal bunt in host fields outside the quarantined area from grain in transit to mills or export elevators

p_3 probability of an outbreak of Karnal bunt outside the quarantined area from combines or other harvesting machinery

p_4 probability of an outbreak of Karnal bunt outside the quarantined area from railcars after grain is unloaded at mills or export elevators

p_5 probability of an outbreak of Karnal bunt outside the quarantined area from seed

In general, the probability of outbreak via a given pathway is positively related to the number of railcars or other conveyances transporting grain or seed outside of the quarantined areas. The number of railcars leaving the quarantined area is, in part, determined by the incidence of infested fields within the quarantined area. The higher the infestation of Karnal bunt within quarantined area means less negative-testing wheat available for export or domestic milling purposes and a lower probability of outbreak outside of the quarantined area.[9]

The overall level of risk tends to be influenced by the riskier pathways. Changes in the probability of outbreak in a given pathway may be large in absolute terms, but have little effect on the overall level of risk. By focusing on individual pathways, the risk reducing potential of the protocol may be overestimated. For example, in the initial analysis the controversial requirement to

[9]This assumes that the probability of teliospores surviving shipment outside of the quarantined area is uncorrelated with the incidence of infection within the quarantined area.

heat treat millfeed was justified by USDA on the basis of the relatively sharp reduction in the risk of outbreak from contaminated millfeed. Yet when we separate this out, the results indicate that while the millfeed treatment requirement reduced the mean risk of Karnal bunt outbreak from contaminated millfeed from 1 in 15,175 to 1 in 60 million, the effect of the protocol was negligible in reducing the overall level of risk (table 3). Likewise, restrictions on the movement of negative-testing seed also had a relative small effect on the overall risk of outbreak. One of the pathways with the highest probability of outbreak was p_4–the probability of outbreak of Karnal bunt in elevators that received grain that had been transported in contaminated railcars. The mean risk of outbreak from this pathway assuming that railcars were not required to be cleaned after delivery was 1 in 35. This risk was significant since a contaminated elevator would potentially be identified when sampled in the national survey of wheat elevators.

The USDA analysis also ignored the level of ambient risk that had existed prior to the discovery of Karnal bunt in Arizona. Podleckis (1995) had estimated that the probability of outbreak in the United States from contaminated Mexican boxcars was as high as 2.59×10^{-3} (1 in 386). This ambient risk was higher than the risks of outbreak from contaminated railcars from the regulated areas, millfeed, or negative-testing seed, and potentially reduced the effect any such protocols might have in mitigating the overall risks of outbreak.

In the analysis that follows, eight quarantine options were considered. The options were based on the following protocols: 1) the restriction on the movement of negative-testing seed outside of the quarantine area; 2) the requirement that railcars be cleaned after delivery of wheat from the quarantined area; and 3) the requirement to heat treat millfeed. These protocols were chosen because they imposed large costs on the wheat industry in the southwest and, as a result, were controversial. Option 1 reflects the least restrictive option where the quarantine protocols were limited to restrictions on the movement of positive-testing grain. Grain and seed that twice tested negative for Karnal bunt teliospores would be free to move to export and domestic locations with no additional restrictions. Railcars would not be required to be cleaned. Option 8 reflects protocols put in place by APHIS in March of 1996 following the discovery of Karnal bunt in Arizona. The other options reflect various combinations of the three protocols, plus the baseline option.

The effects of the options on the risk of outbreak are presented in table 4. The probabilistic risk assessments provide estimates of the probability of outbreak with an estimated mean and distribution. The table presents two measures of central tendency (median and mean) and the ninety-fifth percentile value. Current APHIS policy uses the 95^{th} percentile value in making regulatory decisions (Firko et al. 1996). Viscusi (1998) discusses the potential for a "conservatism" bias when the 95^{th} percentile value is used for every component of the estimate. In the risk assessment presented here, the 95^{th} percentile value was drawn from the joint distribution $p*$, not from a combination of the 95^{th} percentile values for the individual p_i.

Of the individual protocols considered, railcar cleaning had the largest effect on the overall level of risk of outbreak because of the relatively high risk of contamination through railcars. Restrictions on the movement of negative-testing seed and millfeed treatment requirements had minimal effects on the overall level of risk. Taken together, the three protocols reduced the level of risk by almost 99 percent relative to the baseline level.

Estimated Benefits and Costs of the Federal Quarantine Program

To assess the welfare effects of the quarantine actions, we must first calculate the welfare effects in the event of an outbreak of Karnal bunt outside of the regulated area. From the initial detection of Karnal bunt in Arizona and USDA's subsequent announcement of a declaration of extraordinary emergency, protection of U.S. export markets was articulated as a primary goal of USDA's regulatory efforts (Glickman 1996). The United States typically exports about 1.2 billion bushels of wheat annually, with an estimated value of about \$3 to \$4 billion. About half of U.S. wheat exports were to countries that at the time Karnal bunt was discovered in Arizona maintained restrictions against wheat imports from countries where Karnal bunt was known to occur. USDA argued that failure to implement the quarantine would jeopardize trade with those countries. Benefits of Federal quarantine, therefore, were regarded largely as the avoided losses in the export market.

It its Regulatory Impact Analysis published on May 6, 1997, USDA estimated that a 50-percent reduction in U.S. wheat exports would likely reduce U.S. wheat prices by 30 percent, and lower net sector income by $2.7 billion. This estimate takes into account the dampening effect on domestic wheat prices, as wheat for export is diverted into the domestic consumption market, animal feed outlets, and ending stocks.

The reduction in U.S. wheat exports, however, would likely be less than 50 percent. Not all countries that have restrictions against Karnal bunt would, in practice, strictly prohibit wheat imports from the United States. (Italy and Germany currently import wheat from countries where Karnal bunt is known to occur despite European Union regulations to the contrary). Second, while some markets would be captured by wheat from exporting countries that are free of Karnal bunt, U.S. wheat exports to countries that have no restrictions against Karnal bunt would likely increase. In the long run, the effects could be minimal depending on whether the market were to treat Karnal bunt as a quality issue and develop discounts for Karnal bunt.

In the impact analysis, USDA estimated that the impact of Karnal bunt on exports, because of substitution effects, would likely result in a 10-percent reduction in U.S. wheat exports. A decrease of 10-percent in exports would cause a 22-cent per bushel drop in the wheat prices and a drop in annual wheat sector income of $545 million. The effects of decreases in wheat exports of various percentages are presented in Table 5.

While the effect on prices and incomes would likely affect all producers of wheat, it is noteworthy to point out that the majority of benefits from Federal quarantine actions were received by producers outside of the regulated areas who produce over 95 percent of the wheat grown in the United States. Beattie and Bickerstaff (1999) have recently argued that the regulations were largely the result of rent-seeking behavior on the part of wheat producers outside of the regulated areas. It is certainly true that wheat producers outside the quarantine area were strong supporters of USDA quarantine actions[10].

The impact analysis failed to consider changes in consumer welfare. Based on the price and domestic demand levels in table 5 and an implied domestic demand elasticity of -0.7, consumer surplus effects were estimated. Subtracting consumer gains and any additional government price support payments due to low prices, annual net welfare effects ranged from $261 million for a 10 percent loss in exports to $976 million assuming a 50 percent reduction in exports.

Since the potential adverse effects of an outbreak of Karnal bunt on export markets may last longer than a year, we calculated the net present value of benefits assuming losses over a 10 year period using a 7 percent discount rate. Based on the annual net welfare losses in table 5, the discounted welfare effects ranged from $2.1 billion to $7.8 billion. This should be viewed as a conservative assumption. In the long run, if export losses due to Karnal bunt remained large and prices depressed, many wheat producers would likely switch to alternative crops, mitigating sector losses. Because of the factors mentioned above, it is likely the long term losses would be less than $2 billion.

In its regulatory impact analysis, USDA estimated that the costs of the Karnal bunt regulations in 1996 incurred by producers, handlers and other affected parties was $44 million (table 6). It was estimated that about 8 percent of the 1996 crop wheat produced in the regulated area tested positive for Karnal bunt. This wheat was largely diverted to feed use in the regulated area resulting in an estimated loss to producers and handlers of $4.2 million.

Regulatory requirements to treat millfeed caused many domestic mills to drop contracts with producers and handlers of grain from the quarantined areas, resulting in a decline in prices for

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[10] A number of agricultural commissioners from wheat producing states were concerned, however, that the quarantine actions themselves were having an adverse impact on trade (Sim 1998). Indeed, a number of wheat importing countries that had no prohibitions on Karnal bunt prior to the Declaration of Extraordinary Emergency, soon afterwards adapted the requirement that U.S. wheat contain additional phytosanitary certificate certifying that the wheat was from an area where Karnal bunt was known not to occur.

negative-testing wheat within the regulated areas. In the absence of the regulatory requirement on millfeed, domestic wheat millers would have likely purchased negative-testing grain from the infected areas. Although some millers were reluctant, the high quality of the durum wheat produced within this area would have helped counter their reluctance to the purchase of uninfected grain. However, the requirement that millfeed be treated and railcars sanitized increased the costs of milling wheat from the regulated area and prompted many contracts with grain producers and handlers to be canceled. The estimated loss in value due to producers and handlers of negative-testing wheat was estimated to be $28 million.

Under the 1996 quarantine and emergency actions, wheat seed produced in the regulated areas was prohibited from sale outside of the regulated areas. Wheat seed intended for planting within the regulated areas had to be sampled and tested for Karnal bunt, and for seed originating in a regulated area, treated prior to planting. These restrictions were estimated to have a significant impact on the seed industry, largely due to the high value that is commanded by wheat sold for seed relative to grain. It is estimated that 1.5 million bushels of wheat seed sustained loss in value of $5 to 6 million. Seed developers, who earn returns on their investment in research and development of wheat varieties, also claim potential long-term losses in royalties; by receiving plant variety protection (or patent rights), seed developers then obtain royalties on future sales of wheat that are developed and sold for propagative purposes. Other economic losses suffered by the seed industry, but are difficult to quantify, include additional handling, storage, and finance costs on seed that could no longer be sold outside the regulated areas and costs to relocate wheat breeding operations outside of the regulated areas.

In a report submitted as an exhibit in a lawsuit brought by the Arizona Wheat Growers Association against USDA, Beattie (1996) argued that the quarantine had adverse effects on wheat seed development. He estimates that the loss in productivity due to the quarantine likely cost producers and consumers between $177 and $357 million on a net present value basis.

The USDA impact analysis also enumerated losses to other parties such as wheat straw producers, custom harvesters, and producers who were required to destroy their crops prior to harvest because of the regulations. These losses were estimated to total approximately $5 to 6 million in 1996.

Estimated Expected Costs and Benefits

In the Regulatory Impact Analysis accompanying the final Karnal bunt regulations on compensation, USDA concluded that:

> ...our quarantine measures were appropriate and justifiable when compared with the magnitude of the benefits achieved. Even a 10-percent reduction in wheat exports would have a significant effect on wheat sector income. It is estimated that a 10-percent decline in wheat exports would cause a decline in wheat sector of over $500 million. (62 FR 24765)

But can these conclusions be justified if one examines the expected costs and benefits of the regulations?

Benefit-cost analysis for alternative quarantine options can be completed under the assumptions given above (table 7). For the baseline (option 1), the costs of diverting positive-tested wheat to feed markets and destroying any crops planted with contaminated seed is $5.4 million ($4.2 million plus $1.2 million). The probability of an outbreak outside the quarantine area was reduced from certainty with no protocol to 0.0567. For a 10-percent diversion of exports with present value of costs $2,098 million, the expected loss due to an outbreak of Karnal bunt outside of the quarantined area is $119 million (0.0567 * 2.098), and the welfare gain from utilizing the baseline option is $1,979 million dollars (i.e., $2,098 million – $119 million). Each of the other options also shows a large expected benefit/cost ratio when considered individually. However, from figure (2), options 1, 2, 5, and 8 were the most efficient policies in providing the most benefits for a given level of outlays.

Table 8 presents the marginal benefits and costs of options 2, 5 and 8 assuming various levels of export market effects due an outbreak of Karnal bunt. Under the baseline option, a minimal quarantine is put into place that regulate positive-testing grain, but the marginal benefits are large relative to the costs. Likewise, the addition of option 2--railcar cleaning--provides from $115 to $427 million in additional benefits for additional costs less than $1 million. The addition of protocols restricting the movement of negative-testing seed (option 5) imposed direct costs of additional $6 million, while the reduction in expected welfare loss was only $3 million assuming a 10 percent loss in exports over 10 years and when evaluated at the mean probability estimates. If export losses were as high as 50 percent annually over 10 years, the expected marginal benefit rises to $11 million. The seed protocol is likewise marginally cost effective when evaluated using the more conservative 95th percentile value for the risk of outbreak. However, when one includes the potential loss in productivity as estimated by Beattie, the seed protocol costs far exceed its benefits at any measure of risk. The costs of the millfeed treatment requirement (option 8) exceed the expected benefits even under the most conservative assumptions (i.e., 50-percent loss in exports over 10 years evaluated at the 95th percentile of risk of outbreak).

Conclusions

While USDA continues to regulate for Karnal bunt, many of the original areas placed under quarantine have been deregulated. During a national survey of elevators in the fall of 1996, USDA detected Karnal bunt-like spores in a number of grain facilities in the Southeast. It was determined that the teliospores were those of a fungus that infects ryegrass but not wheat. Because the spores were indistinguishable from Karnal bunt teliospores, USDA did not impose a quarantine. In 1997, USDA changed the standard for defining regulated areas based on the presence of bunted kernels rather than Karnal bunt teliospores. The immediate effect of the regulatory change was remove the millfeed treatment requirement. In 1998, USDA relaxed the quarantine to allow commercial seed to move outside of the regulated area. These changes have allowed much of the original regulated area to return to more normal marketings and losses in recent years have been small and confined to positive-testing grain. While the number of countries requiring phytocertificates on U.S. wheat has increased to 54 countries, importing countries have generally accepted the changes.

The cost imposed by the quarantine has been controversial since the quarantine was established in March 1996. To increase cooperation, USDA agreed to pay producers, grain handlers and other affected parties compensation for losses suffered due to the federal quarantine action. Compensation payments have totaled more than $40 million since 1996.

A larger issue has been the regulatory status of Karnal bunt as a plant disease. Even at the time Karnal bunt was discovered in Arizona in 1996, many scientific bodies (e.g., American Phytopathological Society) considered Karnal bunt to be a minor plant pest that could be controlled much like other wheat pests, i.e., without the use of quarantine measures. In 1997, USDA convened an international symposium on Karnal bunt with the intent of convincing other nations to deregulate Karnal bunt. To date, no countries have agreed to change their phytosanitary restrictions on wheat imports containing Karnal bunt.

From the analysis presented here, a number of conclusions can be drawn concerning USDA's Karnal bunt quarantine policy. From the late 1980s, USDA has made extensive use of probabilistic risk assessments to guide regulatory decisions. In the case of Karnal bunt, the risk assessments have been comprehensive in their analysis of the effects of various quarantine policies on the probability of outbreak along potential pathways. However, in their analysis of risks associated with Karnal bunt, USDA tended to focus on risk mitigation for individual pathways, seemingly without regard to the effect on the overall level of risk. As a result, the effects of individual protocols were arguably overstated.

In their regulatory impact analyses, USDA ignored the effects of the quarantine policies on consumers which tended to overestimate the benefits of the quarantine. Their analysis also failed to look at the expected marginal benefits and costs of various quarantine alternatives. Had they considered the expected marginal effects in their decisions, it is likely that at least two of the more controversial and costly protocols–seed restrictions and the millfeed requirement–would have received closer scrutiny and possibly rejected as viable options.

Since the establishment of the Karnal bunt quarantine in 1996, USDA has established new quarantines to control the Asian Longhorn beetle and plum pox, and it has increased the scope of the quarantine to control citrus canker in Florida. Like Karnal bunt, these quarantines have been justified on the basis of the potential liability worth billions of dollars. Yet, like Karnal bunt, these quarantines also impose large costs on those who are regulated as well as consumers and taxpayers more indirectly affected by the quarantine actions.

Bridging the gap between regulatory analysis and risk assessment has become increasingly more important in public policy due to the complex array of supporting documents that the regulatory decision maker must consider during the decision making process. The method used here departs from most USDA analysis which historically have separated the risk assessment from the economic analysis. We offer this analysis as potential way that future analysis, when appropriate can be combine so as to improve the analysis and aid in the regulating rule making process.

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Figure 1

Optimal quarantine policy

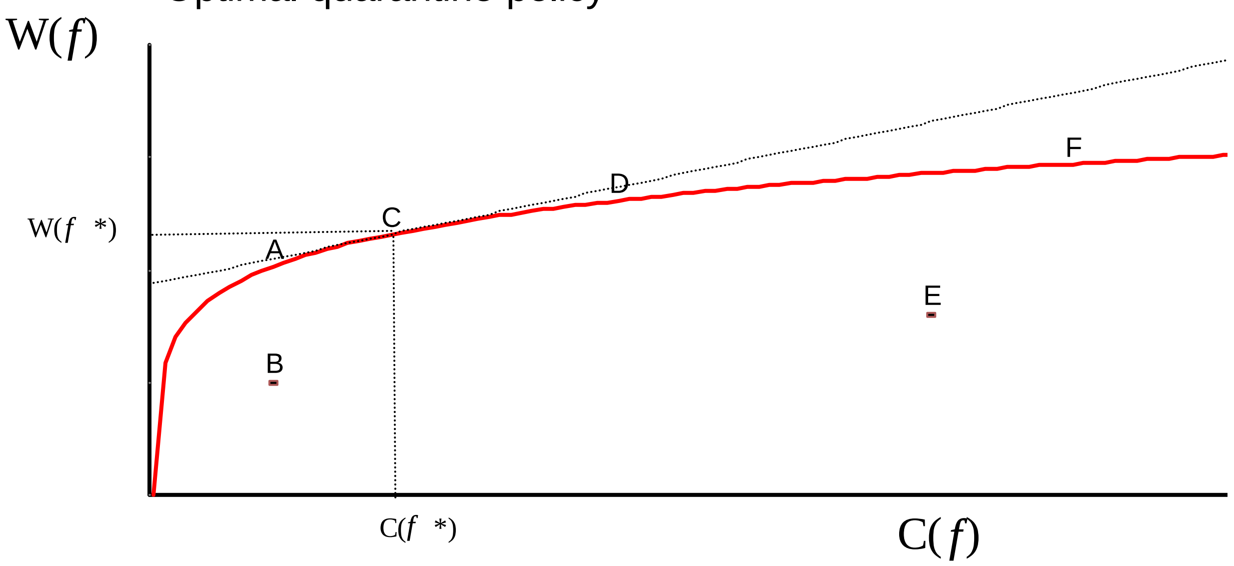

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Figure 2
Karnal Bunt Quarantine Alternatives

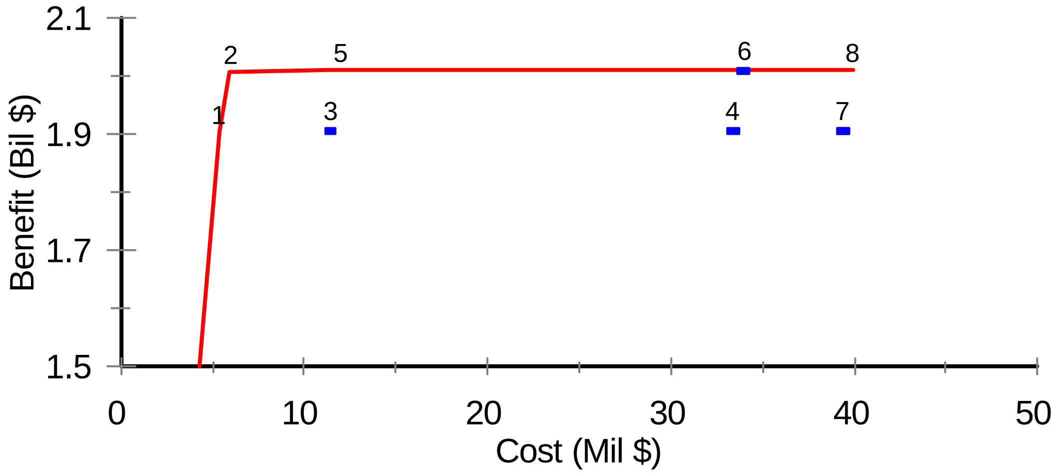

Table 1–Federal domestic quarantines

Plant pest	Year initiated 1/	Crops potentially affected	Regulated area
Pink bollworm	1967	cotton, kenaf, okra	AZ, AR, CA, NM, OK, TX
Witchweed	1970	corn, sorghum, sugarcane, rice	NC, SC
Golden nematode	1972	potatoes	NY
Japanese beetle	1979	ornamentals, tree fruits, row crops, turf	AL, CT, DE, DC, GA, IL, IN, KY, ME, MD, MA, MI, MN, MO, NH, NJ, NY, NC, OH, PA, RI, SC, TN, VT, VA, WV, WI
Sugarcane diseases	1983	sugarcane	HI, PR
Mexican fruit fly	1983	tree fruits	CA, TX
European larch canker	1984	Larch trees	ME
Citrus canker	1985	citrus fruit	FL
Black stem rust	1989	wheat and small grains	48 conterminous states and DC
Mediterranean fruit fly	1991	fruit, vegetables	CA, FL
Pine shoot beetle	1992	pine trees	IL, IN, MD, MI, NY, OH, PA, WV, WI
Imported fire ant	1992	impedes harvest and cultivation	AL, AR, CA, FL, GA LA, MS, NM, NC, OK, PR, SC, TN, TX
Gypsy moth	1993	hardwood forests	CT, DE, DC, IN, ME, MD, MA, MI, NH, NJ, NY, NC, OH, PA, RI, VT, VA, WV, WI
Oriental fruit fly	1993	fruits, vegetables	CA
Karnal bunt	1996	wheat, rye, triticale	AZ, CA, TX, NM
Asian longhorn beetle	1997	hardwoods	IL, NY
Plum pox	2000	stone fruit	PA

1/ Reflects year that current regulatory policy was implemented.

Table 2-- Impact of Karnal Bunt Quarantine Actions

Action	Regulated Article	Affected Entities	Numbers Affected	Types of Impacts due to KB and Quarantine Actions
Plow-down & Seed Plot destruction	• Fields planted with infected seed at pre-boot stage	• Certain producers in Texas and New Mexico	• 4100 acres • 73 producers	• Loss in value of wheat crop destroyed
Cleaning/ Disinfection	• Tools and Farm Equipment	• Wheat producers in RA	• 145 growers	• cost of cleaning
	• Harvesters	• Farmer owned and custom combines	• 389 combines	• cost of cleaning
	• Grain Trucks	• Grain haulers from field to grain elevators	• 976 trucks	• cost of cleaning
	• Grain storage and loadout facilities	• Grain handling firms	• 17 elevators	• cost of cleaning
	• Harvesters	• Combine harvester owners	• 36 to 40 combines	• Excess wear and tear on equipment
	• Harvesters	• Combines involved in pre-harvest sampling	• 5 to 10 combines	• Down-time on harvesters due to field testing
	• Harvesters	• Custom combine companies	• 5 companies	• Loss of income due to termination of contracts outside the RA
	• Railcars	• Grain handling firms	• 10,880 cars (511 for positive grain)	• cost of cleaning

RA - Regulated Area

Table 2 - Continued   Impact of Karnal Bunt Quarantine Actions

Action	Regulated Article	Affected Entities	Numbers Affected	Types of Impacts due to KB and Quarantine Actions
Restriction on Use or Marketings	• KB-positive milling wheat	• Producers • Grain handling firms	• 145 growers • 6 handlers	• Loss in value of KB-positive wheat
	• KB-negative milling wheat	• Producers in RA • Handlers in RA	• 664 producers • 26.7 million bushels	• Loss in value of KB-negative wheat in RA
	• Millfeed	• Millers, millfeed processors	• 108 mills • 45,644 tons	• Millers reluctance to mill KB-negative wheat from RA
	• Movement restrictions on wheat seed	Seed producers, researchers, and companies	• 15 producers • 9 research firms • 20 seed marketers	• Loss in premiums • Loss in market value • Loss in royalties
	• Straw, Manure, Millfeed	• Straw producers and Handlers-Users of Straw • Livestock producers using wheat or straw produced in the RA • Flour millers • Millfeed processors/users	• 25 growers • 3 contractors • 1 straw user, making of straw mats for erosion • control • 7 millers in 5 States 2 millfeed processors	• Loss in income • Increased cost of production
	• Moratorium on wheat production on KB-positive fields	• Producers with KB-positive properties	• 109 growers • 13,674 acres	Loss in income from wheat
	• Soil on root crops grown on infected properties	• Vegetable producers on KB-positive properties	• Unknown number	• Increased cost of production
	• Used seed sacks • Seed-conditioning equipment • Byproducts of seed	• Seed research and marketing companies	• 9 research firms • 20 seed marketers	• Increased cost of production

Source: Karnal Bunt Regulatory Flexibility Analysis and Regulatory Impact Analysis published in the Federal Register, May 6, 1997.

Table 3–The effects of various protocols on the risk of Karnal bunt outbreak

Protocol	Probability of an outbreak 1/	
	For that pathway	Overall
Railcar cleaning:		
- with	6.43×10^{-4}	2.14×10^{-3}
- without	5.18×10^{-2}	5.67×10^{-2}
Restrictions on the movement of negative-testing seed:		
- with	0	5.53×10^{-2}
- without	1.40×10^{-3}	5.67×10^{-2}
Millfeed treatment:		
- with	1.66×10^{-8}	5.66×10^{-2}
- without	6.59×10^{-5}	5.67×10^{-2}

1/ Evaluated at mean.

Table 4–Probability of an outbreak of Karnal bunt under alternative quarantine options

Quarantine Option	Probability of outbreak 1/		
	Median	Mean	95th percentile
Option 1--Baseline 2/	2.92E-02 (---)	5.67E-02 (---)	1.93E-01 (---)
Option 2--Railcar cleaning	1.11E-03 (0.038)	2.14E-03 (0.038)	7.43E-03 (0.038)
Option 3–Restrictions on seed movement	2.78E-02 (0.951)	5.53E-02 (0.976)	1.92E-01 (0.994)
Option 4–Millfeed treatment	2.91E-02 (0.997)	5.66E-02 (0.999)	1.93E-01 (1.000)
Option 5–Railcar cleaning; restrictions on seed movement	2.32E-04 (0.008)	7.08E-04 (0.013)	2.45E-03 (0.013)
Option 6–Railcar cleaning; millfeed treatment	1.05E-03 (0.036)	2.07E-03 (0.037)	7.35E-03 (0.038)
Option 7–Restrictions on seed movement; millfeed treatment	2.77E-02 (0.949)	5.53E-02 (0.975)	1.92E-01 (0.994)
Option 8–Railcar cleaning; restrictions on seed movement; millfeed treatment	1.91E-04 (0.007)	6.40E-04 (0.011)	2.29E-03 (0.012)

1/ Expressed in scientific notation; e.g., 2.92E-02 = 2.92×10^{-2} = .0292.
2/ Includes prohibition of movement of positive testing grain and seed from quarantined area; all negative testing grain and seed moved in sealed hopper cars; all combines disinfected before leaving quarantined area.
( ) denote level of risk relative to baseline

Table 5–Estimated net welfare effects of reduced exports due to an outbreak of Karnal bunt outside of the regulated area 1/

Item	Unit	Reduction in Exports			
		0%	10%	25%	50%
Exports	mil. bu.	1,200	1,080	900	600
Total use	mil. bu.	2,462	2,394	2,295	2,138
Price	$/bu	3.85	3.63	3.29	2.68
Value of production	mil. dol.	9,543	8,998	8,146	6,637
Government payments 2/	mil. dol	1,815	1,815	1,815	1,943
Gross income	mil. dol.	11,358	10,813	9,961	8,580
Variable expenses	mil. dol.	4,823	4,823	4,823	4,823
Net cash income	mil. dol.	6,536	5,990	5,138	3,758
Welfare effects:					
Producer losses	mil. dol.	---	- 545	- 1,397	- 2,778
Consumer gains	mil. dol.	---	284	747	1,674
Change in government payments	mil. dol.	---	0	0	128
Net welfare	mil. dol.	---	- 261	- 650	- 976
Over 10 years 3/	mil. dol.	---	- 2,098	- 5,214	- 7,830

1/ Estimates based on 1997/98 marketing year.
2/ Includes AMTA payments ($1,815 million) plus loan deficiency payments.
3/ Discounted at 7 percent annually.
Adapted from: Karnal Bunt Regulatory Flexibility Analysis and Regulatory Impact Analysis (Federal Register, 62:24755, May 6, 1997)

Table 6–Estimated Costs Due to Karnal Bunt Regulations, 1996 Crop Year

Item	Estimated Costs (mil. dollars)
Plowdown of NM and TX fields planted with infected seed	1.2
KB-positive grain diverted to animal feed market	4.2
Cleaning and disinfecting railcars	0.6
Loss in value of seed	6.0
KB-negative grain that experience loss in value	28.0
Other 1/	4.1
Total	44.1

Adopted from: Karnal Bunt Regulatory Flexibility Analysis and Regulatory Impact Analysis (Federal Register, 62:24755, May 6, 1997)
1/ Includes losses related to cleaning and disinfecting combine harvesters, sanitizing storage facilities, and loss in value of straw.

Table 7–Expected costs and benefits of alternative quarantine actions assuming as 10-percent loss in annual exports (million dollars)

Quarantine Option	Expected net present value of benefits	Expected costs	Net
Option 1--Baseline 1/	1,978.8	5.4	1,973.4
Option 2--Railcar cleaning	2,093.2	6.0	2,087.3
Option 3–Restrictions on seed movement	1,981.7	11.4	1,970.3
Option 4–Millfeed treatment	1,979.0	33.4	1,945.6
Option 5–Railcar cleaning; restrictions on seed movement	2,096.2	12.0	2,084.3
Option 6–Railcar cleaning; millfeed treatment	2,093.4	34.0	2,059.4
Option 7–Restrictions on seed movement; millfeed treatment	1,981.7	39.4	1,942.3
Option 8–Railcar cleaning; restrictions on seed movement; millfeed treatment	2,096.4	40.0	2,056.4

1/ Includes prohibition of movement of positive testing grain and seed from quarantined area; all negative testing grain and seed moved in sealed hopper cars; all combines disinfected before leaving quarantined area.

Table 8–Marginal costs and benefits of alternative quarantine options (million dollars)

Quarantine option	Marginal cost	Marginal benefit assuming that an outbreak of Karnal bunt outside of the regulated area will cause annual wheat export losses of:		
		10 %	25 %	50 %
Probability of outbreak evaluated at the mean:				
Option 2--Railcar cleaning	0.6	114.5	284.5	427.2
Option 5–Railcar cleaning; restrictions on seed movement	6.0	3.0	7.5	11.2
Option 8–Railcar cleaning; restrictions on seed movement; millfeed treatment	28.0	0.1	0.4	0.5
Probability of outbreak evaluated at the 95th percentile:				
Option 2--Railcar cleaning	0.6	389.3	967.5	1,453.1
Option 5–Railcar cleaning; restrictions on seed movement	6.0	10.4	26.0	39.0
Option 8–Railcar cleaning; restrictions on seed movement; millfeed treatment	28.0	0.31	0.8	1.3

Appendix: Karnal Bunt risk assessment procedure

In this analysis we tried to be true to the original analysis (Podleckis and Firko 1996a, 1996c) upon which regulatory assumptions were based. Below we describe how the approach used in this paper differs from the original model.

The probability of at least one outbreak of Karnal bunt occurring outside the quarantined area is modeled through a series of multiplicative steps. This probability is modeled as a function of the quarantine protocols and the number of railcars or other conveyances transporting grain or seed outside of the quarantined areas. Further the number of infected railcars of grain shipped out of the quarantined area is modeled as a function of the amount of wheat testing positive for Karnal bunt either in fields, railcars or elevators in the quarantined area.

The exact pathways by which contamination can occur is detailed in figure 3. This analysis departs from the original analysis however in calculating some of the probabilities. In the original model (P8), the probability that grain going to storage was infected with Karnal bunt, was considered an additive function of the probability that the harvested grain was infected/contaminated with Karnal bunt (P3), the probability that the grain was contaminated by equipment (P6), and the probability that local conveyances were contaminated (P7). Technically this is not correct. The system of protocols must be considered together when assessing the probability of a positive find. This analysis departs from the original analysis by computing this probability as P8 = [1-(1-P3)(1-P6)(1-P7)]. Similarly in the original analysis the probability of a shipment having Karnal bunt, (P12) is modeled as an additive function of the probability that the grain going to storage had Karnal bunt (P8) and the probability that grain picked up Karnal bunt in local storage (P11). In this analysis this probability was changed to P12 = [1-(1-P8)(1-P11)].

Monte Carlo simulation is used to compute the probability of at least one outbreak of Karnal bunt outside the quarantine area. In each iteration of the model, this value is determined by the multiplicative contribution of a series of steps raised to the frequency in which either railroad cars were shipped or combines moved out of the quarantine area.

Typically these steps include the probability that a shipment had Karnal bunt P12, the probability that the Karnal bunt was in the shipment and detected (P13), the probability that viable Karnal bunt survived the shipment (P15), the probability that Karnal bunt reached a suitable host (P16) and the probability that Karnal bunt was able to become established (P17).

For each scenario, the following formula is used to calculate the probability of an outbreak:

F3= 1-(1-P12*P13*P14*P15*P16*P17)^F1

In most scenarios (F1) is the frequency of railroad cars shipped to the mill. When combine movement is being considered (F1) is replaced by (F2) which is the frequency of combines moved out of the quarantine area. F3 is the frequency of Karnal bunt outbreaks.

Probabilities were estimated for a variety of potential pathways including millfeed, export elevators, seed originating in the quarantined area, railcars transporting grain from the quarantined area to domestic mills and export elevators, grain storage facilities, and combines and other harvesting machinery. From the scenarios originally used by Podleckis and Firko (1996a), it was determined that there were nine different scenarios that would lead to the probability that at least one outbreak of Karnal bunt would occur outside the regulated area. These scenarios included:

1) Grain to the Mill, Risk of KB Outbreak in Mill State, Millfeed Un-Treated

2) Grain to Mill, Risk of KB Outbreak in Mill State, Millfeed Treated

3) Grain to Mill, Risk of KB Outbreak in Transited States, Millfeed Treated

4) Grain to Export Elevator, Risk of KB Outbreak in transited States, Millfeed treated

5) Combine/harvest equipment moved out of quarantine area risk of KB outbreak in states receiving equipment

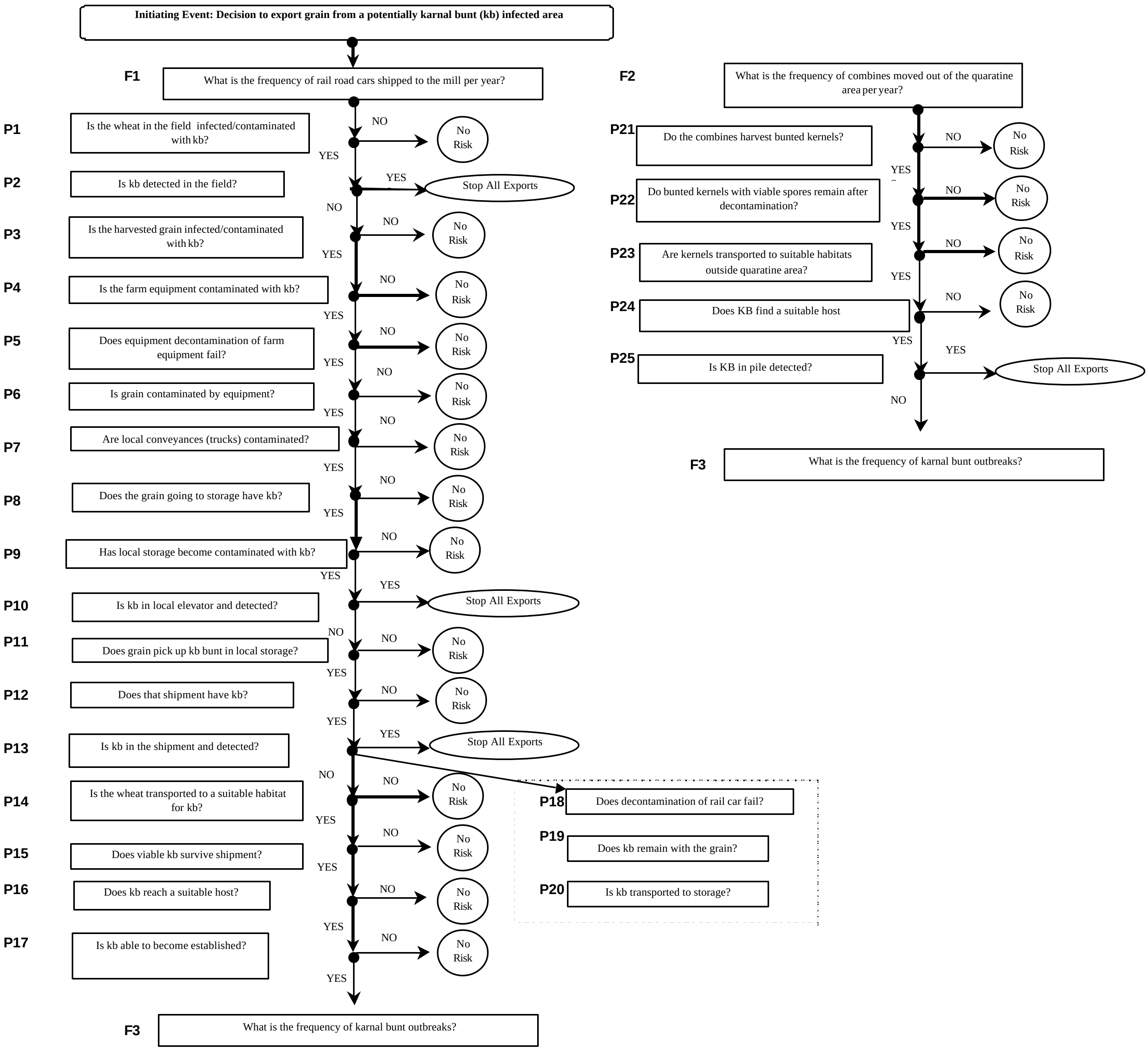

Figure 3: Scenario analysis

6) Grain to Mill, Risk of KB Outbreak in Secondary State (State Receiving rail Car after grain is unloaded at Mill)

7) Grain to mill, risk of KB contamination in storage facility in secondary state

8) Grain to Export Elevator, KB contamination in storage facility in secondary state

9) Risk of outbreak via seed harvested and planted in Arizona

To capture the effect of various combinations of options eight potential combinations of options were developed as seen in table A1.

Table A:1 Option used and changes to scenarios included

	Baseline Option 1	Rail Option 2	Seed Option 3	Mill Option 4	Rail/Seed Option 5	Rail/Mill Option 6	Seed/Mill Option 7	Rail/Seed/ Mill Option 8
Millfeed	2*	2	2	1	2	1	1	1
Transit/ elevator	3 & 4	3 & 4	3 & 4	3 & 4	3 & 4	3 & 4	3 & 4	3 & 4
Combine	5	5	5	5	5	5	5	5
Rail road car	6, P15=1 7, P14=1 8, P13=1	normal	6, P15=1 7, P14=1 8, P13=1	6, P15=1 7, P14=1 8, P13=1	normal	normal	6, P15=1 7, P14=1 8, P13=1	normal
Seed	9	9	-	9	-	9	-	-

* note numbers represent scenarios included under each option; P13, P14, P15 defined in figure;

Monte Carlo analysis was performed using the @Risk Software. Each option was run for 10,000 iterations and the random seed numbers generated were fixed at 2. The specific values used for the probabilities in the model are summarized in Table A2. The values include an unspecified mix of the variability and uncertainty that can occur under each event.

Table A2: Parameters used

F1 a b c	**Frequency of rail cars shipped per year** Frequency of rail road cars shipped to the mill per year (45% of F1) Frequency of rail road cars exported per year (55% of F1) Frequency of rail road cars shipped to seed per year (10% of F1)	Triangle Triangle Triangle Triangle	4500 2025 2475 450	5530 2488.5 3041.5 553	6500 2925 3575 650
F2	**Frequency if combines shipped per year**	Triangle	50	100	200
P1 a b	**Probability that wheat in field infected/contaminated with KB**	 Beta Beta	 1.2 4	 10 20	
P2 a b	**Probability that KB not detected in field**	 Lognormal Beta	 0.01 2	 0.025 20	
P3	**Probability that harvested grain infected/contaminated with KB**	P1xP2			
P4 a b	**Probability that farm equipment is contaminated with KB**	 Lognormal Beta	 0.05 4	 0.05 20	
P5	**Probability that decontamination of farm equipment fails**	Lognormal	0.01	0.025	
P6	**Probability that grain is contaminated by equipment**	P4xp5			
P7 a b	**Probability that local conveyances (trucks) get contaminated**	 Lognormal Beta	 0.001 4	 0.0025 20	
P8	**Probability that grain going to storage has KB**	1-(1-p3)(1-p6)(1-p7)			
P9 a b	**Probability that local storage gets contaminated with KB**	 Lognormal Lognormal	 0.01 0.0001	 0.025 0.0001	
P10 a b	**Probability that KB Is in local elevator and not detected**	 Lognormal Constant	 0.01 1	 0.025	
P11	**Probability that grain picks up KB in local storage**	P9xp10			
P12	**Probability that shipment has KB**	1-(1-p8)(1-p11)			
P13 a b	**Probability that KB in shipment is not detected**	 Lognormal Constant	 0.01 1	 0.025	
P14 a b	**Probability that grain Is transported to a suitable habitat**	 Beta Constant	 2 1	 4	
P15 a b c d	**Probability that KB survives shipment (viable KB)**	 Beta Lognormal Beta Constant	 4 0.01 5 1	 2 0.01 15	
P16 a b c d e	**Probability that KB reaches a suitable host**	 Lognormal Beta Lognormal Beta Constant	 0.001 1.75 0.0001 4 1	 0.001 25 0.0001 2	
P17 a b c	**Probability that KB is able to become established**	 Lognormal Beta Lognormal	 0.001 1.75 0.0001	 0.001 25 0.0001	
P18	**Probability that decontamination of rail car fails - Scenario 8, 9**	Lognormal	0.01	0.01	
P19	**Probability that KB remains with grain - Scenario 8, 9**	Beta	4	2	
P20	**Probability that KB is transferred to storage facility - Scenario 8, 9**	Beta	4	2	
P21	**Probability that combines harvest bunted kernels**	Lognormal	0.1	0.1	
P22	**Probability that bunted kernels with viable spores remain after decontamination**	Lognormal	0.01	0.01	
P23	**Probability that kernels are transported to suitable habitats outside quarantine area**	Beta	2	4	
P24	**Probability that decontamination of rail cars fails**	Lognormal	0.01	0.01	
P25	**Probability that KB in pile is not detected**	Beta	1.2	20	