Defining the Costs of an Outbreak of Karnal Bunt of Wheat

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Abstract
In determining the economic impact of a possible outbreak of the quarantinable wheat disease Karnal Bunt, an examination was made of the detailed components of the costs involved. The costs were classified as: (a) Direct costs (yield and quality losses); (b) Reaction costs (export bans, quality down-grading, seed industry costs); and (c) Control costs (quarantine zones, fungicides, spore destruction). The relative importance of each of these cost components is measured for a hypothetical outbreak of Karnal bunt in the European Union, as a means of ensuring that the policy responses to such an outbreak are appropriate considering the costs involved.

Key words: disease / quarantine / cost / wheat

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1. Introduction

The fungus *Tilletia indica*, the cause of Karnal bunt of wheat, can lead to serious economic losses. Because it is seed-borne and the spores are known to survive for many years, the pathogen is difficult to control. Karnal bunt (KB) has long been known to occur in India, Pakistan, Afghanistan, Iraq and Mexico. More recently, it has been detected in the USA in 1996 and in South Africa in 2000. As a result of concern regarding its possible entry into Europe through trade pathways, the pathogen was added to the EC Plant Health Directive list of quarantine organisms in 1997. A project "Risks associated with *Tilletia indica*, the newly-listed EU quarantine pathogen, the cause of Karnal bunt of wheat", funded under the European Commission's Fifth Framework for Research, has been undertaken to assess the risk of KB spreading to Europe.

There has been international debate as to whether *T. indica* poses a significant risk to wheat production and whether it therefore should be listed as a quarantine organism by any country or Regional Plant Protection Organisation. While many markets restrict imports from regions with KB, others contend that *T. indica* does not have significant effects on yield or quality and that the closure of export markets for countries where it occurs is inappropriate. For example, Beattie and Biggerstaff (1999) questioned whether the actions taken by the US authorities in response to the detection of KB in south-western USA in 1996 were appropriate. They argued that: (a) KB is not a serious plant disease; (b) the 1996 US regulatory action was taken in response to politically motivated economic interests outside the quarantine region; and (c) those actions were costly. They argued that, since KB "has no known health risks to humans or animals, poses no serious agronomic difficulties in the form of reduced plant yield or other harm, and likely cannot be eradicated" (p. 6), it has become a political disease. Thus they suggested that the quarantine measures were a form of "rent-seeking", using non-tariff barriers to preserve an economic advantage. More recently, Cardwell *et al.* (2003) have also argued that KB continues to be a minor disease in both Asia and North America. They argued that, since KB spreads very slowly and causes no direct crop production loss, most of the economic cost is due to the quarantine status of the disease.

Clearly, there is a need to examine the likely economic costs involved in a disease outbreak before appropriate decisions about the level of risks faced can be addressed properly. The overall objective of this paper is to outline the ways in which the costs of the potential socio-economic impacts of *T. indica* in the EU can be estimated. A particular objective is to examine in detail the components of the economic and social costs of a possible outbreak of KB in the EU, and to assess the relative importance of the different elements of costs.

The following section presents the materials and methods, defines the cost components and explains the economic framework for estimating the effects of an outbreak of KB. The data on the cost components are then described, and the estimation procedures outlined. The scenario analysed in this paper is then specified, and in the subsequent section the results of the analysis are presented. The results are followed by a discussion of their implications, and some conclusions are drawn.

2. Defining the Costs of Karnal Bunt

In determining the economic impact of the threat of KB in the EU, it was necessary to identify the actual cost components involved in the control of the pathogen. These cost components were identified by examining information from countries in which KB has occurred to determine the key socio-economic parameters which it was necessary to evaluate for the EU (Brennan and Kelly 2001).

Examination of the policies and arrangements that are in place in countries where KB occurs allows the cost components associated with a KB outbreak and occurrence to be classified as:

- Direct costs;
- Reaction costs;
- Control costs.

2.1 Direct Costs

KB causes only small yield losses (Brennan and Warham, 1990; Brennan *et al.,* 1992; Murray *et al*., 1996; Kehlenbeck *et al*., (1997)). There may be different yield impacts on durum, feed and bread wheats. It was also necessary to specify the geographical disaggregation of this data for major producing regions in the EU. In order to determine the total cost associated with yield affects from a KB outbreak it was also necessary to identify total area and production of wheat, by wheat type, and by region.

Direct quality losses are a substantial direct cost associated with a KB outbreak. These occur when *infected* wheat is considered unsuitable for food uses and as a result is down-graded to feed[1] wheat. There can be a considerable economic cost associated with the loss of value of food wheat (both bread and durum) when it is down-graded to feed wheat and it is therefore essential and this component is captured in the analysis (Murray and Brennan, 1998).

2.2 Reaction Costs

In addition to the specific direct costs associated with a KB outbreak, there are also "reaction costs" which must be taken into consideration. These costs arise as a result of some components of the market reacting to the fact that KB has been detected in a particular region. These reaction costs include indirect quality losses, loss of exports and seed industry costs.

As well as the *direct* quality losses mentioned above, which are associated with the down-grading of infected wheat, there can also be *indirect* quality losses associated with the down-grading of unaffected grain. As these indirect quality losses are associated with *unaffected* grain they are treated as reaction costs rather than direct costs.

The loss of export markets is another significant economic consequence of KB. Murray and Brennan (1998) estimated that the loss of export sales represented 45% of total costs per tonne if KB were found in one region in Australia. The extent of the losses associated with an export ban following an outbreak of KB will depend initially on the level of exports from a region prior to the KB outbreak and also on the types of wheat produced within a region. The reaction of markets to grain from a KB- affected region will also have a significant effect on costs associated with an outbreak. A detailed examination was made of the import

[1] "Feed" wheat is wheat that is only suitable for animal feed and is traded on the feed grains market.

specifications from a wide range of countries to determine the proportion of import markets that imposed restrictions on wheat from areas where KB had been detected.

Because the presence of KB can affect the quantities of bread wheat and feed wheat available to the market, the response of prices to shifts of possibly large amounts of wheat from the food category to the feed category is important. Prices for "clean" food-quality grain are likely to be affected as well as for feed grains, especially if there is a substantial amount of grain from a KB-infected region going into the feed market.

In the event of an outbreak of KB, any seed production within the affected area is also likely to suffer losses, from the inability to sell seed from the affected area. Therefore, the cost of the lost seed sales and other costs imposed on the seed industry also need to be estimated (Murray and Brennan, 1998; Brennan and Warham, 1990).

2.3 Control Costs

In addition to direct and reaction costs there are also control costs associated with an outbreak of KB (Brennan and Warham, 1998; Kehlenbeck *et al.,* 1997). These costs are associated with the efforts that occur in an attempt to control and/or eradicate the disease. The separation of control costs from other categories of costs associated with KB is important when assessing the potential impact of the disease. The subsequent results provide an indication of the appropriate level of investment in measures designed to prevent the spread of the pathogen. The costs and benefits of the policies need to be considered in relation to the losses prevented by those policies (Brennan and Warham 1990).

If there were an outbreak of KB, widespread testing and surveillance programs would be undertaken, so that testing and surveillance costs would be incurred. The cost items to be considered here are not the already extensive current costs of surveillance at the border and the current regular grain testing costs, but rather the increase in costs of the additional testing that would be carried out in the event of an outbreak. In addition, the cost of any surveys to define the presence of the pathogen or to define the limits of its spread also needs to be incorporated into the cost estimates.

In addition, containment and/or eradication costs would be incurred in the event of an outbreak of KB. For example, it is likely that there would need to be fumigation of harvesting, transport and handling machinery and equipment, and there may be a need to treat mill by-products from the milling of infected grain, and possibly treatment for animal manure from animals fed KB-infected grain. If restrictions were placed on the crops that farmers could grow within the quarantine zone, or if seed treatments were required for seed sown within the zone (Brennan and Warham, 1990), such costs would also be containment and/or eradication costs. There are also likely to be costs of ensuring compliance with any regulations and policies introduced to control or eradicate KB. The costs of administering the controls and of ensuring compliance with any regulations are considered as control cost items.

The EU contingency plans on such control actions are assumed for the purposes of this analysis but the assumptions can be readily modified in light of additional information regarding the actual contingency plan that would be most appropriate given an outbreak scenario. The cost components identified are summarised in Table 1.

Table 1: Cost Components for an Outbreak of Karnal Bunt

Direct Costs
Yield losses
Down-grading affected milling wheat to feed
Reaction Costs
Down-grading unaffected milling wheat to feed
Price and export effects
Seed industry costs
Quality assurance costs
Control Costs
Survey and identification costs
Administrative - Compliance costs
Cropping restrictions
Yield reduction from tolerant variety
Additional fungicide costs
Value of standing crop destroyed
Costs of destroying growing crop
Value of affected grain destroyed
Costs of destroying affected grain
Treatment of mill by-products
Grain processing costs (heat treatment)
Livestock industry costs
Machinery cleaning costs
Facility cleaning costs

3. Economic Analysis of Changes in Quality of Wheat Production

3.1 Conceptual Framework

One of the key effects of KB is the effect on the marketability of wheat in the affected region, so that affected wheat can no longer be sold as milling wheat. Thus, there is a down-grading of some wheat from milling to feed quality. Re-classifying wheat from one type to another is equivalent to a shift of the supply curve for each wheat type (Brennan, Godyn and Johnston, 1989). The economic effects of such a change are measured as changes in the "Producer surplus" (PS) and the "Consumer surplus" (CS), which are measures of the economic welfare of each of the two industry groups[2].

Changing milling wheat to feed wheat is equivalent to a shift of the supply curve for each wheat type in the affected region:

[2] Alston *et al.* (1995, pp. 43*ff*) provide a brief review of the definition and limitations of the concepts of producer and consumer surplus measures.

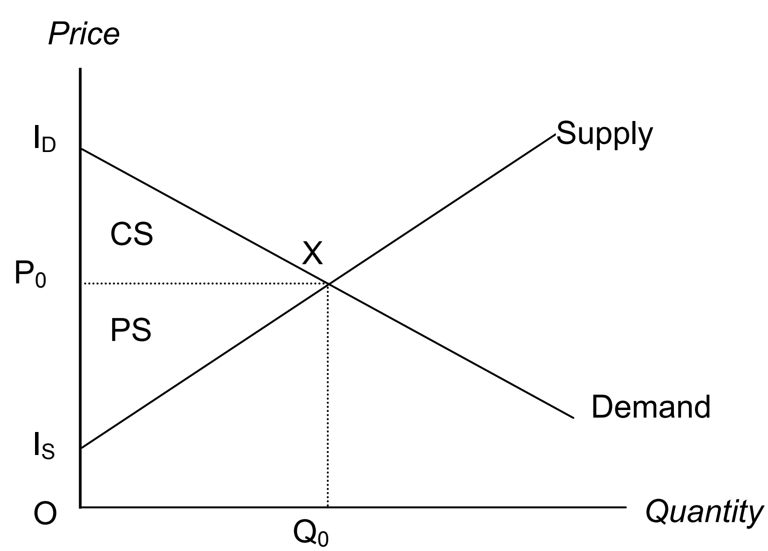
- A shift to the left in the supply curve for milling wheat, as quantities of wheat are taken out of the milling wheat market
- A shift to the right in the supply curve for feed wheat, as down-graded milling wheat is added to the feed wheat market

The analysis measures the difference in PS and CS in the presence of KB and the surpluses that would apply if there were no KB. The net welfare benefits depend on the net effect of PS and CS in each of the milling and feed wheat markets.

3.2 Calculation of Producer and Consumer Surplus
In calculating the impact of such supply shifts, it is difficult to rely on a direct adaptation of the neat algebraic analysis of shifts in supply curves developed for analysis of research impacts (as in Alston *et al.* 1995), because the shift in the milling wheat sector is such that there can be no milling wheat produced after the occurrence of KB. Thus, rather than the area between two supply curves (with and without KB), it is necessary to calculate the producer surplus without KB directly, since all PS may be lost in the milling wheat market in the affected region.

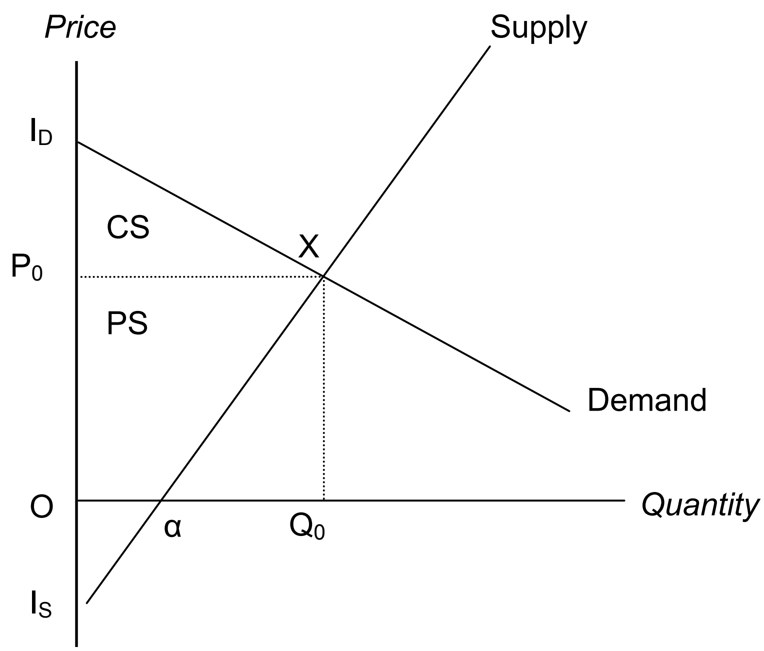
To calculate the PS, we first need to estimate the equation for the supply curve from the available data. P_0, the initial price, and Q_0, the initial quantity supplied, are observable data, and an estimate of the supply elasticity, e_S, can be obtained from other sources. A simple closed market situation is illustrated in Figure 1. The initial producer surplus is estimated (see algebraic exposition in Appendix A) as ½ P_0 Q_0 (1/ e_S).

Figure 1: Producer and Consumer Surplus with Elastic Supply Curve



However, this approach creates computational problems when the price intercept I_S is negative (as illustrated in Figure 2), as it overstates the producer surplus. If the supply curve is vertical, the producer surplus by these estimates would be infinite (since (1- e_S)/e_S would approach infinity as e_S approached zero). The maximum that PS can be is P_0 Q_0. Thus, the calculations need to be modified to ensure that only PS above the horizontal axis is calculated.

Figure 2: Producer Surplus with Less Elastic Supply Curve



One means of carrying this out operationally is to calculate the PS as the difference between the maximum possible and the area under the supply curve (see Appendix A). Thus, the producer surplus is calculated as:

Where $\alpha < 0$ (that is, if $e_S > 1$), as illustrated in Figure 1, then

$$PS = \tfrac{1}{2} P_0 Q_0 (1/e_S) \qquad (1)$$

Where $\alpha > 0$ (that is, if $e_S < 1$), as illustrated in Figure 2, then

$$PS = \tfrac{1}{2} P_0 Q_0 (2 - e_S) \qquad (2)$$

In a parallel way to that for producer surplus, the initial consumer surplus (CS) can be estimated from the available data on P_0, Q_0 and the demand elasticity, e_D (see Appendix A for details), as:

$$CS = - \tfrac{1}{2} P_0 Q_0 (1/ e_D) \qquad (3)$$

3.3 Changes in Welfare with Karnal Bunt

The situation where there is a removal of production from the milling wheat market onto the feed wheat market is illustrated in Figure 3. The market for milling wheat *without* KB is shown with producer surplus = PS_{M0}, and consumer surplus = CS_{M0}, and the situation *with* KB is shown with producer surplus = PS_{M1}, and consumer surplus = CS_{M1}. The loss of producer surplus for milling wheat is $PS_{M0} – PS_{M1}$, while the gain in consumer surplus for milling wheat is the difference between CS_{M1} and CS_{M0}. Similarly, for feed wheat, the gain in producer surplus is PS_{F1} - PS_{F0}, and the gain in consumer surplus is CS_{F1} - CS_{F0}.

Algebraically, the shifts in the supply curves are estimated as follows:

(a) Milling wheat

- Initial milling wheat production = Q_{M0}

- If *x*% of the milling wheat is destroyed and *y*% is down-graded to feed because of KB, then the shift *to the left* in milling supply curve is $(x + y)\ Q_{M0}$.

(b) Feed wheat

- Initial feed wheat production = Q_{F0}
- With *y*% of the milling wheat down-graded to feed, the amount moving to the feed market is $y\ Q_{M0}$, so that the curve shifts to the right by this amount
- At the same time, if *z*% of the feed wheat is destroyed because of KB with the destruction of some infected feed wheat, the curve is pushed to the left by $z\ Q_{F0}$.
- Thus, the shift *to the right* in the feed wheat supply curve = $y\ Q_{M0} - z\ Q_{F0}$.

3.4 Transmission of Price Effects through Spillovers

The shifts in supply in the affected region as a result of KB are likely to have some impact on the world price for the relevant types of wheat. The extent of those price effects depends on the extent of the supply shifts (and the own-price elasticities of supply and demand in the wheat market). If the amounts of wheat in the affected region are small compared to the world market, the price effects are likely to be minimal; however, if substantial proportions of the production of the EU are likely to be affected, significant price effects could be felt outside the affected areas.

The framework used in this analysis is based on Edwards and Freebairn (1984). The world markets for each crop are disaggregated into two major component regions, namely the EU and the Rest of the World (ROW). Following Stansbury *et al.* (2002), the EU is further sub-divided into regions, as follows:

- The affected region in which the outbreak is detected
- The rest of the country in which the outbreak occurs
- The rest of the EU.

The following assumptions are made for the analysis of the impact of price effects:

(a) All countries other than the EU are grouped into the Rest of the World;
(b) All supply and demand curves are linear;
(c) All shifts in supply within the component markets are defined as parallel shifts;
(d) Aggregate supply curves, as for the affected country, the EU as a whole and the World market, are horizontal additions of shifts in the component markets (and thus can have "kinks" in them – see Edwards and Freebairn 1982); and
(e) Similarly, producer and consumer surplus are estimated in the component regions, and the aggregate surpluses, as for the affected country, the EU as a whole and the World market, are determined as the sum of surpluses in the component markets.

For each of the quality types, the price effects will be determined in a framework similar to that illustrated in Figure 4. The re-classification of milling wheat to feed leads to a shift in the feed wheat supply curve for the affected region from S_0 to S_1. Although supply curves are not affected in other parts of the EU, there is a shift in the aggregate EU supply curve, and consequently a shift in the aggregate supply curve for the World. The shift in the world supply leads to a price fall from P_0 to P_1, given that there has been no change in the demand curve. The lower price feeds back to each region, so that each region faces a changed equilibrium price as well as the shift in the supply curve. A similar impact occurs for milling wheat, except that the shifts in the supply curve for the affected region, the EU and the World are to the left rather than to the right, and the price rises rather than falls. All sectors of the milling wheat market are affected by the price rise.

Figure 3: Change in Producer and Consumer Surplus for When Wheat Downgrading from Milling to Feed Wheat

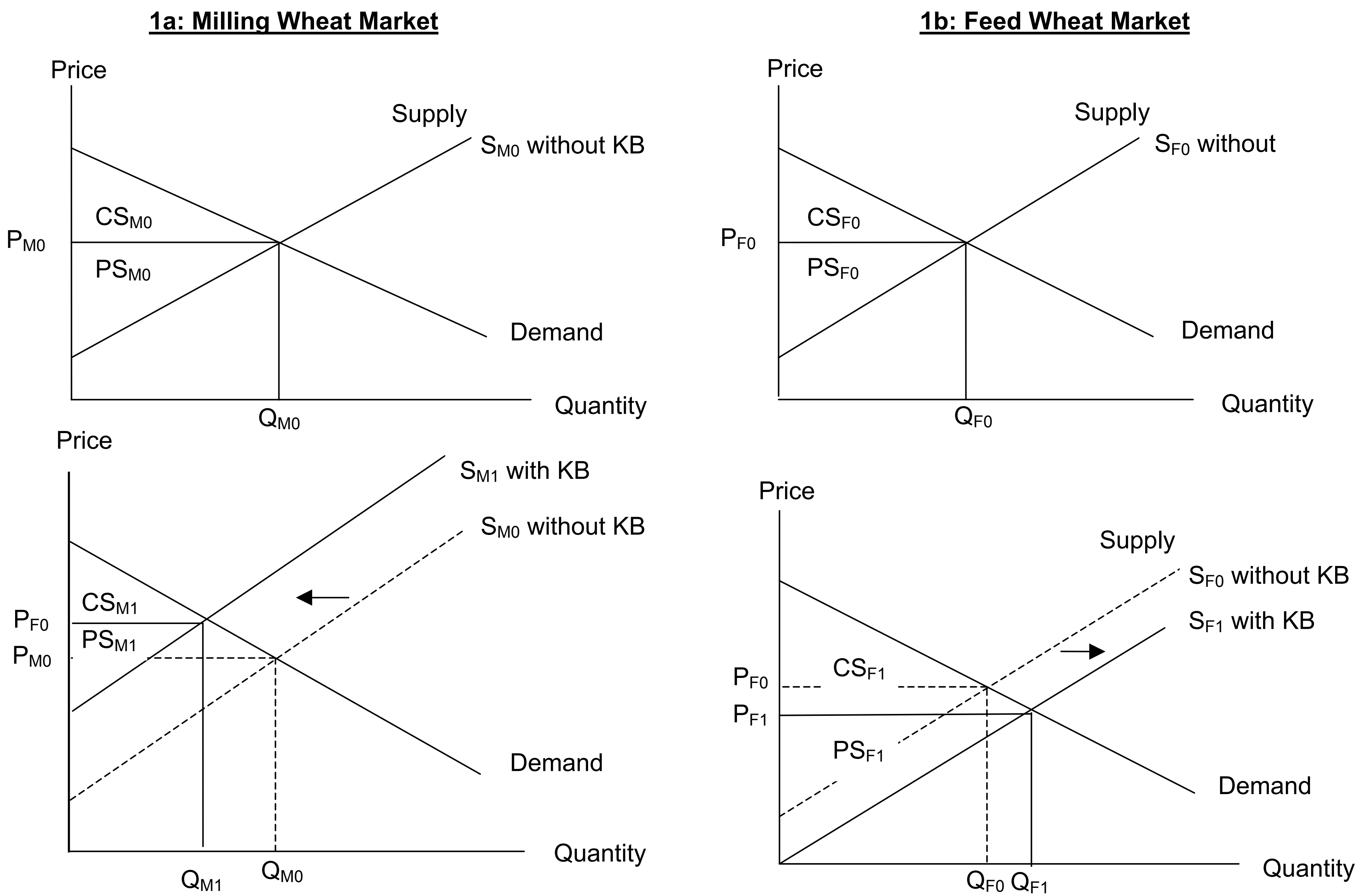
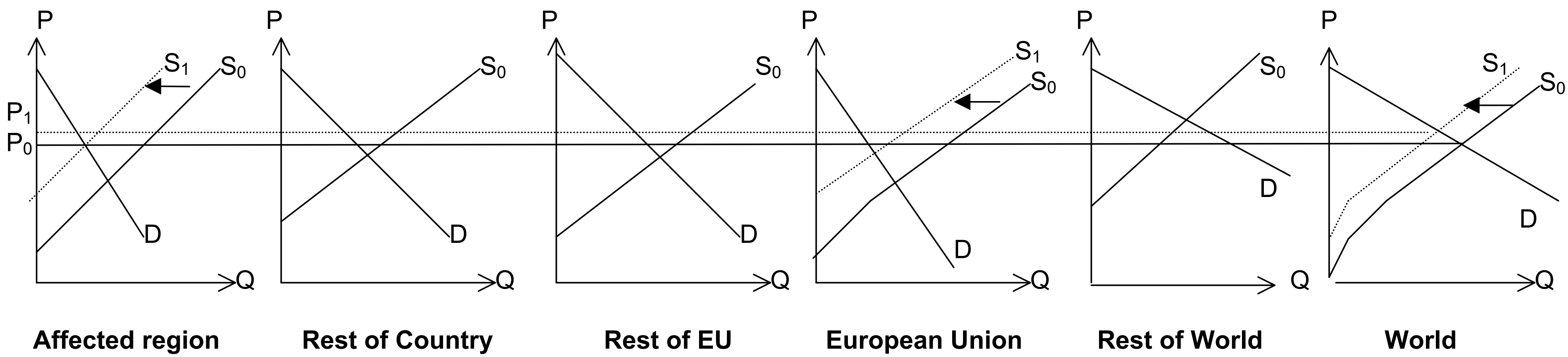
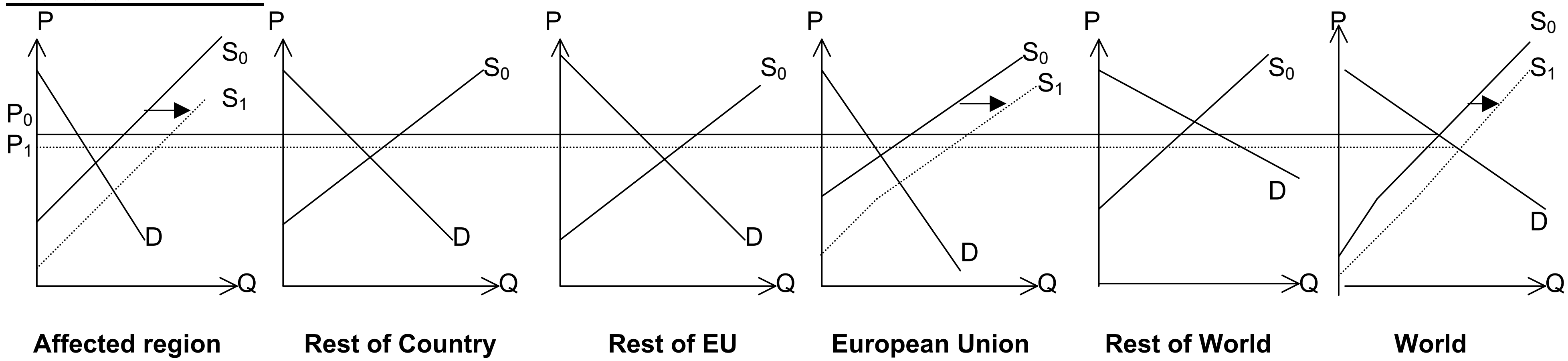


Figure 4: Framework Used to Determine Price and Welfare Effects

Milling Wheat Market



Feed Wheat Market



The resultant welfare gains are measured as changes in PS and CS for each of the regions. Regions such as the Rest of the World, in which supply does not shift, still face the price effect of the supply shifts in the affected region, and can have a change in producer or consumer surplus for both types of wheat. In effect, a price change induced by a supply shift in the affected region can transfer welfare between producers and consumers.

The analysis was carried out for the three classes of wheat:

- Bread wheat
- Durum wheat
- Feed wheat

Bread and durum wheat affected with KB were assumed to be down-graded to feed, so that the bread and durum wheat supply curves shifted to the left, while the down-graded wheat induced a shift in the feed wheat supply curve to the right.

The economic welfare analysis undertaken through shifts in supply and demand curves incorporates all of the components of disease impacts, reactions and control costs that affect the quantity of wheat available within each class of wheat. Thus, the welfare effects include the economic impacts of: (a) yield losses; (b) destruction of growing crops; (c) destruction of harvested grain; (d) down-grading from food to feed wheat; (e) export bans; and (f) price effects. Some of these components [(a) to (d)] can be estimated directly, and simply estimating the total welfare effects would involve some double-counting. As a consequence, the residual of the total welfare effects, after the direct estimates have been deducted, is the "price and export effects" shown in the results tables below.

3.5 Price Effects in Affected Region's Feed Wheat Market

The ban on exports of grain from the affected region mean that the feed wheat market is isolated from the world market, and must determine its own price to clear the market. Thus, while the Rest of the Country, Rest of EU and Rest of the World sectors operate as if the affected region's supply were removed from the market, the affected region itself behaves like a closed market for feed wheat (as illustrated in Figure 3). The price (P_{F1}) to clear the region's feed wheat market after an horizontal shift H is determined as follows:

$$P_{F1} = P_{F0}\,[(Q_{FD0}\,(1 - e_D) - (Q_{FS0}\,(1 - e_S) - H] \,/\, [Q_{FS0}\, e_S - Q_{FD0}\, e_D\,], \qquad (4)$$

where P_{F0} is the initial feed wheat price, Q_{FS0} and Q_{FD0} are the initial quantities of feed wheat supplied and demanded, respectively, in the region, and e_S and e_D are the supply and demand elasticities for feed wheat in the region, respectively. To address the case where a small feed wheat market is overwhelmed by huge quantities of down-graded wheat so that prices could become negative to clear the market, prices for feed wheat have a lower limit of zero in the analysis.

3.6 Qualifications of Empirical Results

In the empirical analysis, the following assumptions are made for the analysis of the impact of price effects:

- Elasticities of demand and supply are the same throughout the EU;
- The cross-price elasticity between milling and feed wheat is zero.

One of the consequences of a static analysis such as this one is that a number of simplifications are made. One such simplification is the lack of dynamic aspects such as second-round impacts on demand or supply of other commodities as a result of a change in surplus, and therefore income. A further simplification is that demand is assumed to remain static in the face of KB outbreak. If demand for wheat products was changed, as was the demand for beef in the face of foot and mouth diseases, further impacts could occur through shifts in demand. In this analysis, such impacts are expected to be small, because there are no human health issues relating to the use of wheat associated with KB.

In reporting the results, figures for the Rest of the World are provided in this report for completeness, but they do not reflect the impact on individual countries. As the focus of this report is on the EU, all other countries are grouped together in the analysis. In some countries, there will be impacts significantly different from the overall aggregate for the Rest of the World, so the results of this study should not imply any particular impact for countries other than the EU.

3.7 Evaluation Model

The analysis was carried out using a spreadsheet model designed to take the impacts of KB into account. The conceptual model is based on that used in the DREAM (Dynamic Research Evaluation Model) evaluation model (Alston *et al.* 1995, Appendix A5.1.2), which has been developed by the International Food Policy Research Institute (IFPRI). However, DREAM was not able to accommodate horizontal shifts in supply, since it is designed to be driven by vertical shifts or cost reductions. Therefore it had to be adapted to accommodate the shifts in supply that are associated with a re-classification of wheat from milling to feed quality. A copy of the spreadsheet model, based on Excel®, is available from the authors.

4. Empirical Analysis

4.1 Outbreak Scenario

The costs of a KB outbreak will depend on a number of factors, including:

- The size of the outbreak;
- The region in which the outbreak occurs;
- The country in which the outbreak occurs;
- The time of detection of the outbreak;
- The mix of milling, durum and feed wheat in the affected region.

Because these factors will all determine the costs involved, the costs can only be determined for different outbreak and detection scenarios. In this analysis, the scenario analysed is a "large" outbreak in the UK affecting 50,000 ha of wheat. In this scenario, the outbreak is detected in mid-harvest, with the pathogen being found in grain being delivered to a silo. This means that in the first year, the only impact is on the harvesting, processing and storage of the existing grain. In subsequent years, farmers can alter their varieties and crop choices, can apply fungicides, controls can be placed on crops that can be grown in the affected areas, etc, but in the first year the only controls are those that can be imposed with detection at harvest.

The key elements of the scenario analysed are taken as:

- 20% of crops in the area are affected in year 1, increasing to 30% in year 2, then falling to 20% in year 3, 5% in year 4 and then to zero in year 5;
- On the basis that 50,000 ha of crop was affected in Year 1 and those crops represent 20% of the region's wheat, total wheat area in the affected region is 250,000 ha;
- On detection, unharvested crops identified as affected will be destroyed, amounting to 20% of the total crops affected;
- Once the grain is harvested, a further 10% of affected grain is destroyed directly;

- 80% of the remaining affected grain is subjected to heat treatment to kill KB spores;
- The remainder of the affected wheat is fed to livestock;
- No wheat from the affected region is milled;
- An export ban is imposed on all wheat from the affected region, whether directly affected or not;
- All wheat produced in the region is down-graded to feed wheat, even where no KB spores are detected;
- In subsequent years, farmers in the affected region plant a more tolerant variety, which suffers a yield reduction from the best non-tolerant variety of 4%. In year 2 60%, year 3 70% and subsequent years 80% of the area is sown to tolerant varieties;
- All wheat crops in the region in Years 2 to 10 receive an additional fungicide spray;
- In the UK, road is the principal means of transport for wheat;
- The affected region has the same mix of milling, durum and feed wheat as the UK;
- The affected region has the same average wheat yields as the UK;
- The affected region has the same proportion of national wheat consumption as it has of national wheat production.

4.2 Supply and Demand Elasticities

The extent of price changes is determined by the interaction of supply and demand elasticities. No authoritative sources of short-run elasticities were identified that could be used in this analysis. Therefore, synthesised elasticities were used to cover the likely responses and range of elasticities. In the short-run, after an outbreak of KB is detected, supply is fixed, with no possibility of supply response, since the scenario being analysed is one in which KB is detected at or after harvest. In this case, the supply elasticity is zero (Table 2). Only if the outbreak is detected in time for farmers to make decisions not to produce or harvest wheat will there be any supply response. Consequently, for the purposes of the current scenario, the elasticity of supply in Year 1 is assumed to be zero.

Table 2: Demand and Supply Elasticities Used in Analysis

	Region	Rest of Country	Rest of EU	Rest of World
Elasticities: Short term (Year 1)				
Elasticity of supply - Milling	0.00	0.00	0.00	0.00
Elasticity of demand - Milling	-0.60	-0.60	-0.60	-0.60
Elasticity of supply - Feed	0.00	0.00	0.00	0.00
Elasticity of demand - Feed	-10.00	-10.00	-10.00	-10.00
Elasticity of supply - Durum	0.00	0.00	0.00	0.00
Elasticity of demand - Durum	-0.60	-0.60	-0.60	-0.60
Elasticities: Medium term (Years 2-5)				
Elasticity of supply - Milling	0.50	0.50	0.50	0.50
Elasticity of demand - Milling	-0.60	-0.60	-0.60	-0.60
Elasticity of supply - Feed	0.50	0.50	0.50	0.50
Elasticity of demand - Feed	-10.00	-10.00	-10.00	-10.00
Elasticity of supply - Durum	0.50	0.50	0.50	0.50
Elasticity of demand - Durum	-0.60	-0.60	-0.60	-0.60

However, the impacts of an outbreak of KB will be felt for several years afterwards. There may be planting restrictions on crops for five years after the initial outbreak. There will also be trade implications for several years after an outbreak, until the markets are satisfied that KB is no longer a problem in that area. Thus, after Year 1, the elasticity required relates to the annual cropping decisions and annual supply response. The elasticity of supply is likely to be low, approximately 0.5 in that case, for both milling and feed wheat.

For demand, the demand elasticities for milling wheat and durum wheat are likely to be low (less than 1.0) because there are few substitutes for wheat in food production and –0.6 was the assumed rate for the analysis. However, in feed, there is high substitutability between feed ingredients (Brennan and Singh 2000). Consequently, wheat demand elasticities are assumed to be greater than -1.0. After consultation, the demand elasticities for feed wheat chosen for this analysis were assumed to be –10.0 for all regions. The rationale for using -10.0 is that there is a high degree of substitutability in the feed grain market, as people who had not previously used wheat will re-think their usage if feed wheat becomes more abundant following an outbreak of KB.

4.3 Data Used

For area, yield and production data, the five-year average to 2001, which was the latest data available, was used for the analysis (see Brennan, Thorne and Kelly 2004 for further information on data sources). However, the general basis for wheat statistics is for "common wheat" and durum wheat. Given that it was important to identify feed wheat separately from milling wheat in this analysis, estimates were made of the likely breakdown within "common wheat" between milling and feed wheat.

The expected yield losses in affected crops of 0.1% assumed for the analysis were derived from Brennan and Warham (1990). The price data used in the analysis were obtained from different national sources (see Brennan *et al.* 2004 for further information on data sources). The weighted average EU price for each wheat type was then calculated using production as weights. The final set of prices across the EU for use in the analysis was:

- Bread wheat €130 /t
- Feed wheat €118 /t
- Durum wheat €149 /t

One of the key impacts of KB is the disruption to trade, because so many countries refuse to accept wheat from areas where KB is present. The international movement of cereal grain and seed is regulated by individual countries' plant health import regulations. Many countries are keen to avoid importing *T. indica* and legislate accordingly. The legislative measures that are imposed by various countries to prevent *T. indica* crossing international borders are outlined in Smith (2001). Of the 81 countries listed, 35 of them (43%) have specific restrictions on the importation of wheat from countries with KB. After consultation, the break-down of exports into wheat types was estimated for each country (S. Thornhill, Personal communication). From those calculations, an average of 43% of milling wheat produced in each EU country is exported, and an average of 15% of feed wheat is exported.

The costs associated with cropping restrictions require the following data items:

- Gross margin associated with wheat production;
- Gross margins for alternative crops to be grown under a crop restriction policy.

The best alternative gross margin under a cropping restriction scenario was assumed to be the highest gross margin for the alternative crops. The data used for the analysis to calculate this information is available in Brennan *et al.* (2004).

4.4 Results from Analysis of Large Outbreak Detected at Harvest

4.4.1 Costs in Year 1

The components of the costs in the first year resulting from an outbreak at harvest are outlined in Table 3. With 50,000 ha of affected crop and expected average disease-free yields of 7.63 t/ha, the value of the 0.1% yield loss is estimated as €46, 000. Outside the region, there are no yield losses.

The economic effects of down-grading milling and durum wheat to feed grade and the effects of export bans were analysed in the market framework outlined above. These components cannot be directly separated in that analysis, since the net effects of shifts in quality between market sectors and the reduction in production because of crop destruction, disease-based yield losses and export bans are all integrated into the one analysis. Care has been taken to ensure that there has been no double-counting in estimating the components of the losses in welfare involved by estimating some components separately and determining the "price and export effects" as the balancing item. (see Brennan *et al.* 2004 for further details). The economic losses for farmers when milling and durum wheat is down-graded to feed wheat depend on the quantity of each type of wheat down-graded and the price premium for milling and durum wheats over feed wheat. Given the prices determined above, the 502,000 tonnes of milling wheat and 1,000 tonnes of durum wheat down-graded in Year 1 have a loss in value of €3.50 million. Of that grain, only 15% was affected with KB, so the majority (€2.96 million) of those losses are reaction costs rather than direct costs. The costs of the price and export ban effects, in addition to the quality down-grading, are estimated at €1.19 million in the first year.

In terms of containment and control, the total costs within the region for collecting grain samples, laboratory analysis to extract teliospores and for molecular identification of the teliospores in the first year are estimated as €0.17 million. The costs of surveying and analysis in the remainder of the EU to ensure freedom from the pathogen are estimated at a further €0.18 million. There will be considerable bureaucratic and administrative activity in the event of a KB outbreak, with costs estimated at €200,000 for the affected region, and a further €80,000 in the rest of the EU and €10,000 in the rest of the world.

Because the outbreak was detected at harvest, there were no additional management costs in Year 1 for the growing crop, and no costs in Year 1 associated with restrictions in the area that could be planted to wheat. In the year the outbreak is detected, 20% of affected crops were assumed to be destroyed before harvesting, with a total cost of €9.57 million. Similarly, in the year the outbreak is detected, 10% of harvested affected grain is assumed to be destroyed, with the value of the wheat destroyed and the cost of the destruction process estimated at €4.71 million in that year.

Table 3: Economic Costs of Karnal Bunt Outbreak, Baseline Scenario, Year 1

		Region	*Rest of Country*	*Rest of EU*	*Rest of World*	*World*	*Country (UK)*	*EU*
Direct Costs								
Yield losses	(€'000)	46	0	0	0	46	46	46
Down-grading affected milling wheat to feed	(€'000)	533	0	0	0	533	533	533
- Total Direct Costs	*(€'000)*	**579**	**0**	**0**	**0**	**579**	**579**	**579**
Reaction Costs								
Down-grading unaffected milling wheat to feed	(€'000)	2,964	0	0	0	2,964	2,964	2,964
Price and export effects	(€'000)	1,190	-84	-2,941	3,021	1,186	1,106	-1,835
Seed industry costs	*(€'000)*	184	-184	0	0	0	0	0
Quality assurance costs	*(€'000)*	0	0	0	0	0	0	0
- Total Reaction Costs	*(€'000)*	**4,338**	**-268**	**-2,941**	**3,021**	**4,150**	**4,070**	**1,129**
Control Costs								
Survey and identification costs	*(€'000)*	170	114	69	0	352	283	352
Administrative - Compliance costs	*(€'000)*	200	60	20	10	290	260	280
Cropping restrictions	*(€'000)*	0	0	0	0	0	0	0
Yield reduction from tolerant variety	*(€'000)*	0	0	0	0	0	0	0
Additional fungicide costs	*(€'000)*	0	0	0	0	0	0	0
Value of standing crop destroyed	(€'000)	9,118	0	0	0	9,118	9,118	9,118
Costs of destroying growing crop	*(€'000)*	450	0	0	0	450	450	450
Value of affected grain destroyed	(€'000)	3,647	0	0	0	3,647	3,647	3,647
Costs of destroying affected grain	*(€'000)*	1,066	0	0	0	1,066	1,066	1,066
Treatment of mill by-products	*(€'000)*	0	0	0	0	0	0	0
Grain processing costs (heat treatment)	*(€'000)*	2,194	0	0	0	2,194	2,194	2,194
Livestock industry costs	*(€'000)*	1,536	0	0	0	1,536	1,536	1,536
Machinery cleaning costs	*(€'000)*	18	0	0	0	18	18	18
Facility cleaning costs	*(€'000)*	7	0	0	0	7	7	7
- Total Control Costs	*(€'000)*	**18,405**	**174**	**89**	**10**	**18,678**	**18,579**	**18,668**
Total Economic Costs	*(€'000)*	**23,322**	**-94**	**-2,852**	**3,031**	**23,407**	**23,228**	**20,376**

Cleaning to remove spores from all machinery, equipment and facilities coming into contact with affected grain, costs approximately €25,000 each year. Given the need to plant pathogen-free seed, seed producers in the affected region will lose their ability to market clean wheat seed, incurring estimated losses of €0.18 million per year. The seed normally produced in that region will need to be sourced elsewhere in the country, so that there will be equivalent gains in the rest of the affected country. On the basis that all UK production is subject to quality assurance (QA) in relation to KB, there are no specific costs associated with QA, since they would be included in the market reaction to the presence of the pathogen.

Since no affected grain is milled in Year 1, costs for treating mill by-products are zero in that year. An estimated 219,000 tonnes of affected grain are subjected to heat treatment in Year 1, costing a total of €2.19 million. A total of 55,000 tonnes of affected grain is fed to livestock in Year 1, resulting in manure destruction costs of €1.54 million.

Within the affected region, the total economic costs in Year 1 for an outbreak of KB detected at harvest are €23.32 million (Table 3). Of that total, direct costs are only €0.58 million, reaction costs are €4.34 million and control costs are €18.41 million. In addition, there are welfare gains of €0.09 million and €2.85 million in the rest of the country and the rest of the EU, respectively, in Year 1. Within the affected region, there are significant price falls for feed wheat and small price rises for milling and durum wheat. In all sectors outside the affected region, there are offsetting losses for consumers and gains for producers (with higher prices), with the net welfare effects being small in relation to the size of the changes for each of those groups.

4.4.2 Costs in Years 2 to 10

In the subsequent years, the costs resulting from an outbreak varied from those in Year 1 because some other control measures and responses could be implemented, and also because the level of affected crops was assumed to vary over time. Initially, the proportion of crops in the region affected by *T. indica* increased in Year 2 to 30%, then fell to 20% in Year 3, 5% in Year 4, and was assumed to be reduced to zero by Year 5.

The total costs of surveying and analysis within the affected region (€170,000) for collecting grain samples and laboratory analysis and in the remainder of the EU (€182,000) to ensure freedom from the pathogen remain the same each year. The costs associated with various meetings and administration each year are estimated at €200,000 for the affected region, and a further €80,000 in the rest of the EU and €10,000 in the rest of the world each year.

In Year 2, the area of affected crop increases, and then declines to zero over the following three years. The value of the yield loss remains relatively small, reaching a peak of €63,000 in Year 2. In Years 2 to 10, after the outbreak, farmers planted the tolerant variety, incurring a 4% yield reduction from the highest-yielding, valued at €5.04 million in Year 2, and increasing in each subsequent year to €9.13 million in Year 10. The additional fungicide costs in years 2 to 10 were €8.33 million across the region on average. After the outbreak, farmers with affected crops in the previous five years were restricted in the area that could be planted to wheat. These costs in terms of income foregone increased to a maximum of €12.94 million in Years 5 and 6 across the region, declining to zero by Year 10 as the area of affected crops also declined. In Year 2, the loss of production from destruction of standing crops declines, as other less destructive policies are implemented over time. The losses are estimated at €6.60 million in Year 2, declining to zero by Year 5. Similarly, the amount of affected grain destroyed is reduced over time as other policies are introduced. The value of the wheat destroyed in Year 2 and the costs of the destruction process are estimated at €7.32 million, with those costs declining to zero over the following three years.

The effects of the quality down-grading, export bans and production losses become higher in the years immediately following the outbreak. The economic losses for farmers when milling and durum wheat is down-graded to feed wheat are estimated to range from €4.00 million in Year 2 to approximately €2.0 million per year in subsequent years. However, the welfare costs of the export bans and consequent price impacts are estimated to increase rapidly to €12.27 in Year 2, reaching a peak of €38.55 million in Year 5, and then declining rapidly over the next five years.

With the production of affected grain reaching a peak in Year 2, the costs of heat treatment is €3.41 million in Year 2, declining to zero over the following three years. Again with the production of affected grain reaching a peak in Year 2, the total affected grain fed to livestock reaches a peak in that year, resulting in manure destruction costs of €2.38 million. This cost declines to zero over the following three years as affected grain is removed from livestock feed. The cost of cleaning all machinery, equipment and facilities coming into contact with affected grain is estimated to be €22,000 each year. The estimated income losses for seed producers in the affected region are €0.18 million each year that they are prevented from marketing their seed. There are equivalent gains in the rest of the affected country as the seed is sourced from outside the affected region. As in Year 1, there are no specific costs associated with quality assurance, since they would be included in the market reaction to the presence of the pathogen.

As the area of affected crop increases in the early years of the outbreak, the total welfare losses for the affected region increase to €54.30 million in Year 2 and €67.37 million in Year 4. While the export bans remain in place, the welfare losses for the affected region then decline slowly to €29.81 million in Year 10. There are some welfare gains of over €2.0 million each year in the rest of the EU, and a slightly smaller gain for the rest of the world, from the higher prices outside the affected region.

The pattern of costs in the affected region over the ten years after the outbreak is shown in Table 4. Total costs in the affected region reach a peak of €67.4 million in Year 4. Direct costs reach a peak of €1.1 million in Year 2 and then decline to zero. Reaction costs reach a peak of €40.3 million in Years 5 and 6, and remain high in subsequent years (until the export ban is lifted). Control costs rise rapidly to reach €37.8 million in Year 2, but are still over €19 million in Years 5 and beyond.

4.4.3 Total Economic Costs

In the affected region, the present value of the costs of a 10-year strategy to control and eradicate *T. indica* from the EU, following an initial outbreak affecting 50,000 ha of wheat in the UK, is estimated at €418 million (Table 4). Less than 1% of those costs are the direct costs resulting from the disease itself. A further 48% of the costs are the result of the market reactions to the disease, and 51% of the total costs are the economic costs of controls established to contain and eradicate the disease. On average, the costs of *T. indica* are equivalent to an average of €167 per hectare over the ten years following the outbreak.

Table 4: Components of Costs in Affected Region, Large Outbreak, Years 1 to 10

		Direct Costs	*Reaction Costs*	*Control Costs*	*Total Costs*
Total Costs					
Year 1	*(€ m)*	0.6	4.3	18.4	**23.3**
Year 2	*(€ m)*	1.1	15.4	37.8	**54.3**
Year 3	*(€ m)*	0.5	29.9	34.3	**64.7**
Year 4	*(€ m)*	0.1	38.5	28.8	**67.4**
Year 5	*(€ m)*	0.0	40.3	26.7	**67.0**
Year 6	*(€ m)*	0.0	40.3	26.7	**67.0**
Year 7	*(€ m)*	0.0	35.0	24.8	**59.8**
Year 8	*(€ m)*	0.0	23.3	21.9	**45.3**
Year 9	*(€ m)*	0.0	13.1	20.0	**33.1**
Year 10	*(€ m)*	0.0	10.3	19.5	**29.8**
Present Value[a]	***(€ m)***	**2.2**	**202.3**	**213.5**	**418.0**
Total Costs per Hectare					
Year 1	*(€/ha)*	2	17	74	**93**
Year 2	*(€/ha)*	4	62	151	**217**
Year 3	*(€/ha)*	2	120	137	**259**
Year 4	*(€/ha)*	0	154	115	**269**
Year 5	*(€/ha)*	0	161	107	**268**
Year 6	*(€/ha)*	0	161	107	**268**
Year 7	*(€/ha)*	0	140	99	**239**
Year 8	*(€/ha)*	0	93	88	**181**
Year 9	*(€/ha)*	0	53	80	**133**
Year 10	*(€/ha)*	0	41	78	**119**
Present Value[a]	***(€/ha)***	**9**	**809**	**854**	**1,672**

a Discounted to present values with an discount rate of 5% per annum

5. Implications and Conclusions

The results of the baseline scenario indicate that a large outbreak affecting 50,000 ha of wheat would have very large economic costs for the affected region. The disruption to production, the inability to export wheat from the region and the wide range of control measures introduced would impose costs of €418 million on the region over a ten-year period. While there would be some economic consequences for those outside the affected region, even some gain in economic welfare, those consequences are small compared to those within the region. In the first year, for example, the estimated cost to the region is equivalent to €93 per ha of wheat, while in the rest of the country there would be net gains equivalent to €0.06 per ha, and in the rest of the EU there are net gains of €0.19 per ha. Since the overall costs to a region of an outbreak are likely to be substantial, considerable efforts are warranted to prevent such an outbreak occurring.

The direct yield and quality effects of the disease are small, and on their own do not justify substantial control measures being implemented or substantial efforts to exclude the disease from the EU. However, the reaction costs, where the market's response to the outbreak and the presence of the pathogen is reflected, are substantial. In trying to minimise the direct and reaction costs, and especially in trying to prevent the spread of the pathogen to other parts of the EU, considerable control costs are justified. Nevertheless, on the basis of these estimates of the costs associated with the baseline scenario of a large regional outbreak, control costs constitute the majority of the economic costs borne by the industry within the affected region. If the markets could be induced to react differently, then the economic consequences, and the justification for the proposed levels of control, could be substantially altered.

Thus, the producers in the affected region can pay a high price for the controls that are put in place to prevent it spreading elsewhere. The impacts of an outbreak of KB are likely to be felt unevenly across the wheat industry and the wider economy. Even within the affected region, there can be large differences in outcomes for individuals. Farmers with KB on their farms will suffer considerable economic losses, particularly if crops and/or harvested grain are destroyed. Farmers within the affected region, but not having a crop affected by the pathogen, will also suffer economic losses, albeit to a lesser extent. Farmers outside the affected region will not incur significant costs, and may even gain from the outbreak, as long as it does not spread to their own region.

The issue of compensation payments is not addressed in this economic analysis. However, without any compensation payments, the costs on the affected region are very high, while the costs in the rest of the EU are minimal. Any compensation payments from governments or the EU would alter the burden of those costs falling on different groups.

In addition, there are likely to be significant social consequences if there were to be an outbreak of KB in the EU. There would be social disruption for the farmers, particularly (but not only) those with affected crops, as there are likely to be significant impacts on many aspects of their production, including which crop to grow, the seed that can be used, crop management practices and where and how the grain can be marketed. There will also be social disruption for those involved in supplying inputs and processing the outputs of the grains industry. These social effects are likely to affect the broader community across the region, as multiplier effects occur and quarantine and other control measures are imposed. These impacts could extend beyond the agricultural sector in the event of a major outbreak.

In conclusion, an outbreak of KB could have serious impacts on the affected region. If the outbreak were large and the affected region correspondingly large, the aggregate costs would be very significant. Given the likely response of markets to an outbreak, the costs are likely to be substantial, and considerable efforts are warranted to prevent such an outbreak occurring.

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Appendix A: Calculation of Producer and Consumer Surplus Measures

A.1 Calculation of Producer Surplus

In order to calculate the PS, we first need to estimate the equation for the supply curve from the available data. P_0, the initial price, and Q_0, the initial quantity supplied, are observable data, and the supply elasticity, e_S, can be estimated from other sources. The initial market situation for milling wheat is illustrated in Figure 1.

By definition, $e_S = (\Delta Q/Q) / (\Delta P/P)$, where $e_S \geq 0$, so that

$$\Delta Q/\Delta P = e_S\, Q/P = e_S\, Q_0/P_0 \tag{A1}$$

The supply curve is

$$Q = \alpha + \beta P \tag{A2}$$

The slope of this curve is $\beta = \Delta Q/\Delta P = e_S\, Q_0/P_0$, so that the supply curve equation becomes

$$Q = \alpha + e_S\, (Q_0/P_0)\, P. \tag{A3}$$

At the initial equilibrium, X, $Q = Q_0$ and $P = P_0$. Substituting into equation (A3),

$$\alpha = Q_0\, (1 - e_S) \tag{A4}$$

It follows that where $e_S < 1$, α is positive, and where $e_S > 1$, α is negative.

Thus, the supply curve is

$$Q = Q_0\, (1 - e_S) + e_S\, (Q_0/P_0)\, P. \tag{A5}$$

The producer surplus (PS) is the triangle P_0 X I_S in Figure 1.

$$PS = ½\, (P_0 - I_S)\, Q_0 \tag{A6}$$

where P_0 is the initial price, I_S is the initial intercept on the price axis, and Q_0 is the initial quantity supplied.

We can estimate I_S from equation (A5). When Q = 0, price equals I_S, so that

$$I_S = - Q_0\, (1 - e_S)/\, e_S\, (Q_0/P_0)$$

or

$$I_S = P_0\, (e_S - 1)/\, e_S \tag{A7}$$

Thus, substituting in equation (A6), the producer surplus is

$$PS = ½\, P_0\, Q_0\, (1 - (e_S - 1)/\, e_S\,),$$

$$PS = ½\, P_0\, Q_0\, (1/\, e_S) \tag{A8}$$

However, when the price intercept I_S is negative, the calculations need to be modified to ensure that only PS above the horizontal axis is calculated since PS cannot be more than P_0Q_0. One means of carrying this out operationally is to calculate the PS as the difference between the maximum possible (ie, the rectangle O P_0 X Q_0 in Figure 1) and the area under the supply curve. Where the price intercept (I_S) is positive (as shown in Figure 1), the area under the supply curve is the trapezoid O I_S X Q_0 , which is calculated as ½ ($P_0 + I_S$) Q_0. On the other hand, where the price intercept (I_S) is negative (as illustrated in Figure 2), the area under the supply curve is the triangle α X Q_0. This area is calculated as ½ P_0 ($Q_0 - \alpha$), since α is the horizontal intercept of the supply curve, as in equation (A2)

Thus, the producer surplus is calculated as:

Where $\alpha < 0$ (that is, if $e_S > 1$), as illustrated in Figure 1, then

$$PS = P_0 Q_0 - \tfrac{1}{2} (P_0 + I_S) Q_0 \quad \text{(A9)}$$

Substituting for I_S from equation (A7) and simplifying,

$$PS = \tfrac{1}{2} P_0 Q_0 (1/e_S) \quad \text{(A10)}$$

Where $\alpha > 0$ (that is, if $e_S < 1$), as illustrated in Figure 2, then

$$PS = P_0 Q_0 - \tfrac{1}{2} P_0 (Q_0 - \alpha) \quad \text{(A11)}$$

Substituting for α from equation (A4) and simplifying,

$$PS = \tfrac{1}{2} P_0 Q_0 (2 - e_S) \quad \text{(A12)}$$

Where $\alpha = 0$ (that is, if $e_S = 1$), then the two equations coincide, giving

$$PS = \tfrac{1}{2} P_0 Q_0 \quad \text{(A13)}$$

Also, where $\alpha = Q_0$ (that is, if $e_S = 0$), as where the supply curve is vertical, then

$$PS = P_0 Q_0 \quad \text{(A14)}$$

A.2 Calculation of Consumer Surplus

In a parallel way to that for producer surplus, the initial consumer surplus can be estimated from the available data on P_0, Q_0 and the demand elasticity, e_D.

By definition, $e_D = (\Delta Q/Q) / (\Delta P/P)$, where $e_D \le 0$, so that

$$\Delta Q/\Delta P = e_D\, Q/P = e_D Q_0/P_0 \quad \text{(A15)}$$

The demand curve is

$$Q = c + dP \quad \text{(A16)}$$

The slope of this curve is $d = \Delta Q/\Delta P = e_D Q_0/P_0$, so that the demand curve equation becomes

$$Q = c + e_D (Q_0/P_0) P. \quad \text{(A17)}$$

At the initial equilibrium, X, $Q = Q_0$ and $P = P_0$. Substituting into equation (A17),

$$c = Q_0 (1 - e_D) \quad \text{(A18)}$$

Thus, the demand curve is

$$Q = Q_0 (1 - e_D) + e_D (Q_0/P_0) P. \quad \text{(A19)}$$

The initial consumer surplus (CS) is the triangle I_D X P_0 in Figure 1 or 2.

$$CS = \tfrac{1}{2} (I_D - P_0) Q_0 \quad \text{(A20)}$$

where P_0 is the initial price, I_D is the initial demand intercept on the price axis, and Q_0 is the initial quantity supplied.

We can estimate I_D from equation (A19): when $Q = 0$, price equals I_D, so that

$$I_D = P_0 (e_D - 1)/ e_D \quad \text{(A21)}$$

Thus, substituting in equation (A20), the initial consumer surplus is

$$CS = - \tfrac{1}{2} P_0 Q_0 (1/ e_D) \quad \text{(A22)}$$