# Economic Evaluation of Viral Disease Prevention Programs in Tree Fruits

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**Abstract**

The risk of viral diseases spreading makes government officials and tree fruit producers interested in the adoption of prevention programs. Benefits of prevention programs, however, are not well defined. This paper presents a procedure that can be used to evaluate prevention programs for viral diseases in agriculture. Consumer and producer surplus are used as measures of the welfare impacts from a prevention program.

A theoretical framework is developed to calculate the welfare or economic impacts to nurseries, producers, and consumers resulting from the adoption of a virus prevention program. A conditional probability approach is presented to calculate the expected losses from viral diseases. An application of the framework is presented and can be adopted to evaluate any prevention program of plant diseases.

**Résumé**

*Le risque d'épidémies de maladies virales suscite un grand intérêt de la part des gouvernements et des producteurs d'arbres fruitiers dans l'adoption et l'application de programmes préventifs. Cependant, les avantages de ces programmes de prévention restent encore à définir. Dans cet article, nous proposons un procédé qui peut être employé pour évaluer les programmes de lutte préventive contre les maladies virales dans le secteur agricole. Le surplus du consommateur et du producteur sont employés comme mesures de l'efficacité sociale d'un programme de lutte préventive.*

*Un cadre théorique est proposé pour évaluer les retombées sociales ou économiques de l' adoption de ces programmes pour les producteurs et les consommateurs, et d'une manière plus spécifique, l'impact économique dans le cadre de la gestion des pépinières. En utilisant une approche de probabilité conditionnelle, nous présentons une méthode permettant de quantifier les pertes causées par les maladies à virus. On illustre également une application du modèle qui peut être adopté pour l'évaluation de l'efficacité de différents programmes de prévention des maladies des plantes.*

## 1. Introduction

Frequent shipments of fruit tree planting stock material and seed promote the diffusion of infected material among growing regions (Agrios, 1997). The introduction of exotic pests and the spread of endemic viral diseases represent a threat to any fruit industry. For example, in the last decade the viral diseases that have been introduced in the Mediterranean region include the Citrus tristeza for citrus trees and the Sharka for the stone fruits (AgNIC, 2004). Therefore, measures need to be taken to avoid or reduce such hazards. Prevention has been the preferred method to control the diffusion and spread of viral diseases on fruit trees.

The risk of spread of exotic and endemic plant diseases makes government officials, as well as producers, interested in the adoption of prevention programs. Benefits of prevention programs, however, are not well defined. Producers and nurseries benefit directly from a prevention program because it averts production losses. On the other hand, consumers benefit indirectly from a prevention program because, without the spread of viral diseases, prices will be lower. Other individuals and firms, such as packinghouses, wholesalers, importers, exporters, and retailers, have an interest in viral disease prevention to forestall diseases and reduced quantity and quality of fruit for economic reasons. In general, if the economic benefits of virus prevention program were measured to these different stakeholders, a better understanding of the cumulative value of the program and, therefore the extent to which such a program should be supported is gained.

Consider the economic impact of viruses on the production sector more closely. If viral diseases spread, producers and nurseries will be affected because of lower production levels and increased production costs (Nemeth, 1986). Without prevention of viral diseases, producers and nurseries must practice eradication techniques or other procedures that can be very costly. Overall, viruses decrease producers and nurseries efficiencies and increase marginal costs. Producers are affected because prices of the propagation material increase if viral diseases spread. The impacts of viruses on producers and nurseries are usually passed on to consumers, who then face higher fruit prices.

The nature of viral diseases and the fruit industry is such that individual actions are not enough to guarantee the absence of viral diseases. Viral diseases may be present in an orchard or in a nursery at a latent phase, so no symptoms are visible. If that material is propagated, viral diseases are spread. To avoid this, it is necessary to screen planting stock material with sophisticated equipment to detect viral diseases, and generally neither the seller of the material nor the buyer have the necessary equipment nor sufficient incentive to screen the material. Note that it is necessary to screen both imported planting-stocks and the planting stock

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material used by nurseries to control the spread of viral diseases in fruit trees (NRSP-5, 1997).

In most cases, the government will be the most likely organization to adopt any prevention program since it has resources to support such efforts. Such a program represents a considerable investment and enforcement. With budget constraints that policy makers face, the economic impact of the program needs to be calculated and the benefits from the program need to be identified. There are two reasons to estimate such benefits: one is to help justify the public investment, the other may be to eventually transfer part of the costs of the program to the segments of the society that most benefit. It can be safely assumed that the decision to support the implementation and/or the continuation of a prevention program depends on the economic benefits that the program generates in relation to its costs for the government agencies as well as for each individual stakeholder or economic agent.

Historically, the benefits of prevention programs have been evaluated as the avoided losses that the program generates (Abo et al., 1998; Carroll, 1980; Damsteegt et al., 1990; Taylor et al., 2001; Yudin et al., 1990). This is a good approach in that it recognizes the fundamental importance of a prevention program in preventing losses and it allows quick estimation of some of the direct monetary benefits obtainable from a prevention program. However, this method does not consider the total impacts of the program on society. According to the economic theory, there exist other, more comprehensive approaches, which can be used to evaluate prevention programs more exactly. One of these is the economic surplus approach (Alston et al., 1995).

The objective of this article is to present a procedure that can be used to evaluate prevention programs for viral diseases in agriculture. This method is based on measuring changes in economic surplus. Economic surplus is the amount that an economic agent realizes, above costs (including opportunity costs), from a particular situation. Economic surplus can beapplied to both producers and consumers. Both cases are defined below. The economic surplus method can be used to evaluate any plant disease prevention program. In this paper the economic surplus method is combined with a probability approach to evaluate expected losses from plant diseases.

The paper is divided into five parts. In the first part, economic surplus measures are defined analytically and graphically. The second and third parts present the theoretical model and the conditional probability approach used to calculate the welfare impact respectively. An example of how to use the procedures is reported. The paper ends with conclusions for this case and a discussion of the more general issue of evaluating prevention programs for agricultural diseases.

## 2. Consumer and Producer Surplus as a Measure of Social Welfare

Consumer surplus is defined as the difference between what consumers actually pay for a good and what they are willing to pay for that good rather than give it up all together. Producer surplus is defined as the excess of actual earnings by all producers from a given quantity of output over and above the costs incurred in producing that level of output. The seminal article on the use of consumer (and producer) surplus to measure social welfare for social evaluation is found in Harberger (1971). This method has been widely used in studies of government investment, in many practical policy studies and in theoretical analyses of individual and societal welfare. Although this method has been criticized, it remains the choice for applied analysis because it is easy to use, it has a transparent interpretation, and the data needs for implementation of the technique are low (Slesnick, 1998).

Now consider use of the consumer surplus approach to rigorously define the consumer component of social welfare associated with the introduction of a virus prevention program. First, the consumer demand d(t) needs to be defined as a function of price (P). The change in consumer surplus (DCS) associated with a price change from $P_0$ to $P_1$ can be defined as (Varian, 1992):

$$\Delta CS = \int_{P_0}^{P_1} d(t)dt \qquad 1)$$

Graphically, equation 1 represents the area to the left and below a negative sloping demand curve between the initial equilibrium price $P_0$ and the equilibrium price derived after a change in price ($P_1$). Intuitively, the area under the demand curve represents the total amount that a consumer would pay for the good. The rectangle defined by price times quantity represents the cost paid by the consumer. By the definition of consumer surplus, subtracting the cost to the consumer from the total amount the consumer would be willing to pay is consumer surplus, represented by the triangle $aE_0P_0$ at the equilibrium $E_0$, or $aE_1P_1$ at the equilibrium $E_1$ (Figure 1). For policy, it is often useful to investigate the change in consumer surplus induced by the policy change - in this case by the introduction or elimination of a virus protection program. The shadow area in figure 1 identifies the change in consumer surplus (loss) due to a shift in the supply.

Similarly the change in producer surplus (DPS) is defined using the producers supply s(t) by the following equation (Varian, 1992):

$$\Delta PS = \int_{P_0}^{P_1} s(t)dt \qquad 2)$$

The change in producer surplus described in equation 2 is the area to the left and above a positive sloping supply curve between the prices $P_0$ and $P_1$. Figure 2 shows the change in producer surplus due to the downward shift in the

Figure 1. *Change in Consumer Surplus after an upward shift in supply*

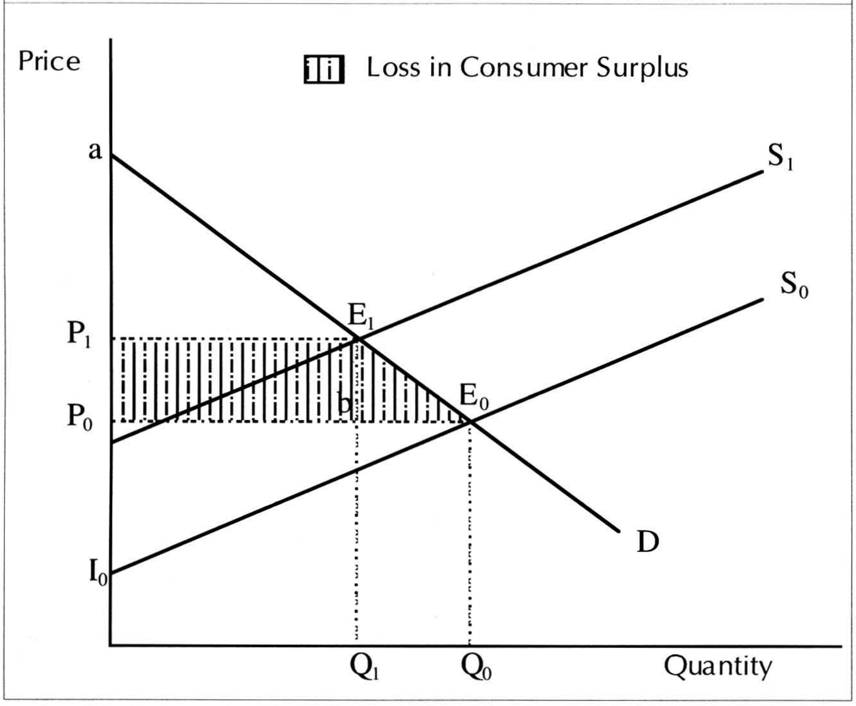
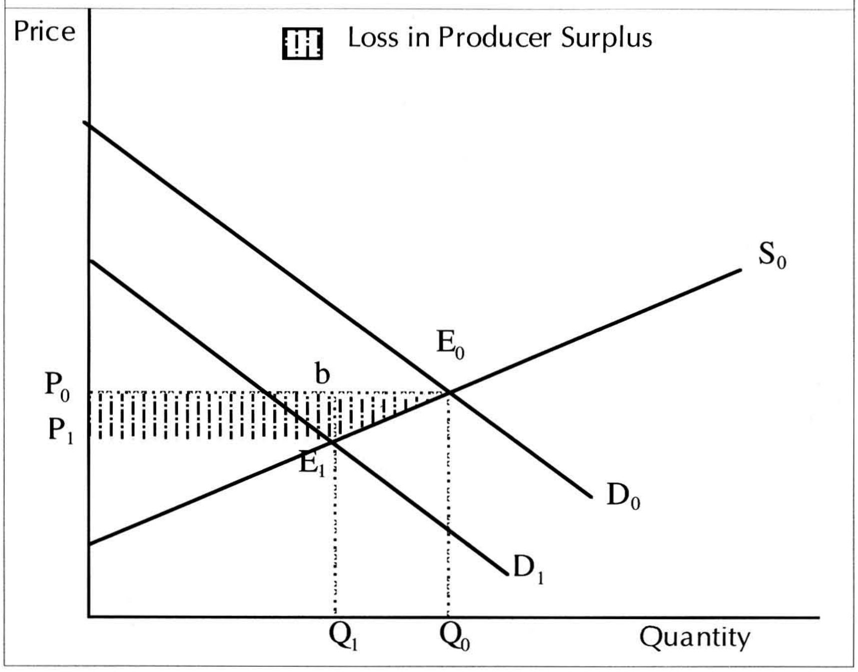



Figure 2. *Change in Producer Surplus after a downward shift in supply*




demand. The shadowed area represents the loss in producer surplus.

For completeness, it should be noted that the use of the consumer and producer surplus as measures of social welfare is an approximation. It is equal to more exact measures of social welfare only under certain restricted conditions, for instance, when the utility function is quasi-linear. However, even when these conditions are not met, it can be shown that consumer surplus is a reasonable approximation to the more exact measures (Varian, 1992).

## 3. Theoretical Framework

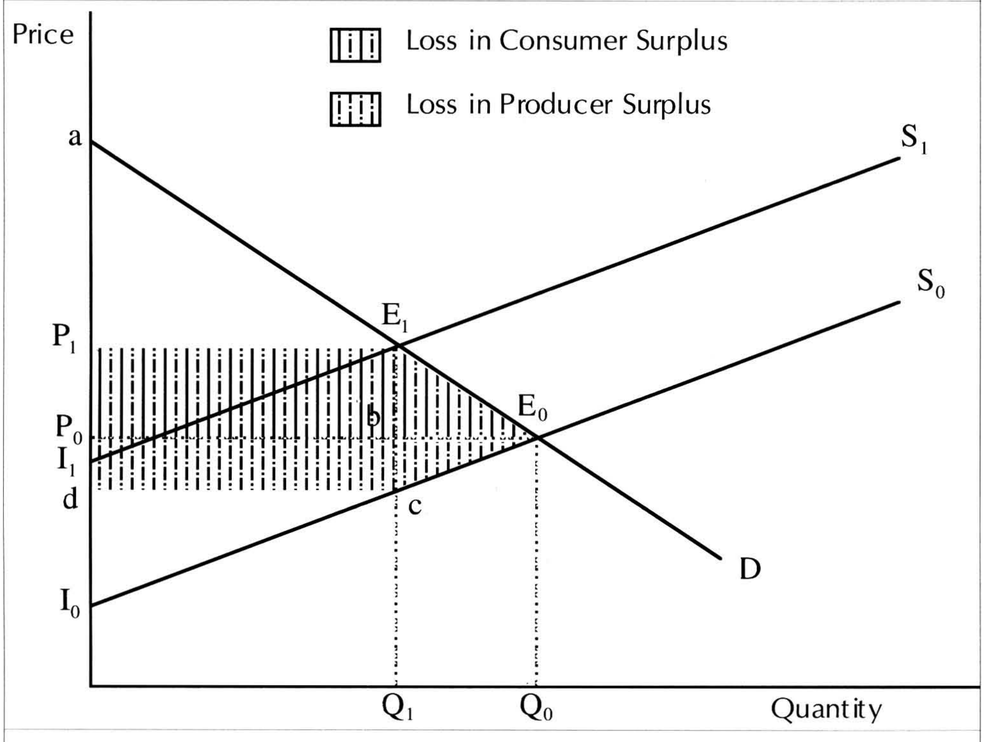
In applying the theoretical economic surplus framework to the current case, some simplifying assumptions were necessary. Supply and demand curves were assumed to be linear. Dynamic issues were not considered - a static model was used to calculate the economic consequence of a protection program. The market was assumed to be competitive. The shift in the supply due to the viral disease spread was assumed to be parallel. The supply and demand curves were defined as annual curves (Alston, et al., 1995). Also, it was assumed that the market structure was a closed competitive economy where one homogenous product was exchanged (fruit) and no substitutes were available. Note that this analysis identifies two different markets: 1) the fruit market that involves consumers and producers; and 2) the planting stock market that involves producers and nurseries.

If viral diseases spread, both producers and nurseries are negatively affected. Both groups will be affected because of the reduced quantity (sales) and the increased production costs. These changes are due to the use of eradication practices necessary to control the spread of the viral diseases in the orchard. Production efficiency is decreased and marginal production costs increased. In addition, fruit producers will face higher prices for planting stock.

In the fruit market, producers supply fruits to the consumers, while in the planting stock market producers represent the demand for planting stock from nurseries that supply the stock. In this paper only the primary categories of the fruit marketing chain including the fruit producers, consumers, and nurseries are considered. While other segments of the economy (such as suppliers of other production and marketing inputs and services) could be included in the analysis, only the impacts of prevention program for the primary entities are included.

In the model it is assumed that there will be a shift in the aggregate supply curve in each market because of the increase in the marginal costs. This shift was assumed to be parallel and lead to a higher equilibrium price. To simplify calculations and to make the best use of the data available, it is assumed that consumers would not have

Figure 3. *Graphical Analysis of the Change in Consumer and Producer Surplus in one Market*




*Source: Cembali et al, 2003*

access to substitutes because the market is closed. With more data on consumer demand (including substitutes and complements) more refined estimates might be made, but the calculations presented here should approximate the more complex case.

The shift in the supply curve leads to a higher equilibrium price (Figure 3). This results in a change in producer and consumer surplus. Figure 3 illustrates the changes in consumer and producer surplus in the case of a virus disease which causes losses in fruit production. At the initial equilibrium the consumer surplus is represented by the triangle $aE_0P_0$, while the producer surplus is defined by the triangle $P_0E_0I_0$. After the shift in the supply due to the viral diseases, the new consumer and producer surplus are represented by the triangles $aE_1P$ and $E_1P_I$, respectively.

The demand for fruits is assumed not to change with the spread of viral diseases since the quality and appearance will not be affected. Therefore, the consumer surplus decreases due to the shift in the supply function and the increase in the equilibrium price. Producer surplus is subject to countervailing influences so that, a priori, the change in producer surplus cannot be determined. However, it is likely that the increase in production costs that the producers will incur will be greater than the benefits that they gain from the higher equilibrium price. In addition, the spread of viral diseases will cause a reduced quantity produced and supplied to the market because orchards will not be as productive as in the absence of viral diseases. If the increase in costs per unit results in unprofitable situations, some producers may exit the industry because of the viral disease.

The same supply and demand considerations also apply to the planting stock market, where the fruit producers represent the demand side and the nurseries the supply side of the market. If viral diseases spread, nurseries will face higher losses in planting stock material because of the losses due to reduced graft taking and a higher rate of discard of diseased plants that do not reach standards necessary for sale. Nurseries will face higher production costs due to the lower production efficiency. The increase in marginal costs will have an impact on the supply curve of the planting stock material by causing a parallel shift in the supply curve upward. It was assumed that the demand curve for planting stock material remains the same and no substitution will occur because the market is closed. There could be an increase in the demand of planting stock material because some fruit producers will have to replace diseased plants to continue efficient production. Also, the average life of orchards may decrease because producers may choose to replace entire orchards earlier instead of replacing only a few trees at a time. The demand for planting stock may decrease because some growers might exit the industry because of reduced profits. The assumption used in the analysis presented in this paper is that the demand for planting stock will not change, i.e. producers will not exit the industry. The consumer and producer surplus analysis for the planting stock material will be similar to the one for the fruit market.

The total benefit from the program that prevents the spread of viral diseases is the avoidance of losses in consumer and producer surplus in both markets. The change in consumer surplus is identified with the difference between the triangle $aE_0P_0$ and the triangle $aE_1P_I$ (Figure 3). This can be identified graphically in the summing of the rectangles $P_IE_1bP_0$ and $E_1E_0b$. Similarly the difference in producer surplus is represented by the difference between the triangles $P_0E_0I_0$ and $P_IE_1I_1$. Because of the assumption of a parallel shift of the supply curve this difference is equal to the sum of the rectangles $P_0bcd$ and $bE_0c$.

The arc elasticity of demand ($\varepsilon_d$), and supply elasticity ($\varepsilon_d$) were used (Cembali et al., 2003). Consider the percent of fruit losses caused by the viral disease spread defined as $\alpha$, where $\alpha \geq 0$. Recall that $Q_0$ is the quantity of fruit produced in the absence of viral diseases, while the quantity $Q_1$ is the quantity produced when viral diseases are present. $Q_1$ can also be written as $Q_1 = (1 - \alpha) Q_0$, and the difference between $Q_1$ and $Q_0$ (also defined as $\Delta Q$) is represented by _ $Q_0$. The change in price is defined as $\Delta P = P_0 - P_1$. Then, using the arc elasticity formula (equation 3), the new equilibrium price ($P_1$) in case of the presence of viral diseases (equation 4) can be calculated.

$$\varepsilon_d = \frac{\Delta Q}{\Delta P}\frac{P_0}{Q_0} \quad 3)$$

$$P_1 = P_0\left(1 - \frac{\alpha}{\varepsilon_d}\right) \quad 4)$$

Suppose that an upward shift of the supply curve as a consequence of the virus losses equals $m = P_1 - d$. The value of the shift in the supply can be calculated using the arc elasticity of supply (equation 5).

$$\varepsilon_s = \frac{\Delta Q}{\Delta P}\frac{P_0}{Q_0} \quad 5)$$

$$m = P_1 - d = \alpha P_0\left(\frac{1}{\varepsilon_s} - \frac{1}{\varepsilon_d}\right) \quad 6)$$

The change in consumer surplus and producer surplus can be calculated using equations 7 and 8, respectively.

$$\Delta CS = \frac{\alpha P_0 Q_0}{\varepsilon_d}\left(1 - \frac{\alpha}{2}\right) \quad 7)$$

$$\Delta PS = \frac{\alpha P_0 Q_0}{\varepsilon_s}\left(1 - \frac{\alpha}{2}\right) \quad 8)$$

Equations 7 and 8 estimate the losses in economic surplus, therefore the sign of the evaluation will be negative. Detailed derivations of equations 7 and 8 are presented in the Appendix.

## 4. Expected Losses from Viral Diseases: a Conditional Probability Approach

In this section an approach that uses conditional probability theory to calculate the expected losses to producers if viral diseases spread is presented. The key components of this approach are the severity of losses, the extent of spread of viral diseases, and the conditional probability of the event with the severity of loss subject to the extent of spread (Cembali et al, 2003). Several scenarios of severity of losses from viral disease and the extent of spread need to be identified according to the characteristics of fruit trees, the structure of the fruit industry, and the planting stock provenance. There are several requirements which must be imposed on this approach to be consistent with probability theory. First, the sum of the conditional probabilities for each extent of spread considered must be equal to 100%. Second, the sum of the extent of spread must equal 100%. If those two conditions are satisfied, the calculated expected losses are consistent with conditional probability theory and can be used as a proxy to substitute the real value that may be impossible to calculate. Each conditional probability value indicates the probability that growers have to face certain levels of losses in a certain percentage of the fruit region. Loss events are assumed independent but not mutually exclusive. Therefore, different infections and different levels of crop losses can affect the same area simultaneously.

Using this approach, the expected losses from a viral disease can be calculated with the sum of the product of the severity of losses, the proportion of spread, and the conditional probability of the severity of losses subject to the extent of spread. Analytically, the expected losses are derived using the following formula:

$$\alpha = \sum_{i,j} d_i s_j x_{ij} \quad 9)$$

where di represent the crop losses or severity of the viral diseases (percent of losses in infected areas), sj the extent of spread (percent of the area interested by viral diseases), and xij is the conditional probability on the extent of spread.

This approach was first applied to viral disease prevention program in the U.S. (Cembali et al., 2003). The following classes of the extent-of-spread were used: no losses (0%), low (5%), medium-low (10%), medium-high (15%), and high (20%). The following classes of extent of spread were used: low (1%), medium-low (10%), medium (20%), medium-high (29%), and high (40%). The complete framework with the conditional probability values is shown in Table 1.

## 5. A Practical Application: the Case of a Virus Protection Program in the U.S.

The proposed method was used to calculate the economic implication of a Virus Prevention Program (VPP) for deciduous fruit trees in the U.S. The evaluation was made applying equations 7 and 8 to obtain measures of welfare changes for the participants in the two markets affected by the program: the planting stock and the fresh fruit market. The analysis was made for apples, sweet cherries, and Clingstone peaches.

The demand elasticities used were published in previous research and were: – 0.374 for apples (Roosen, 1999), – 0.48 for Clingstone peaches (George and King, 1971), – 0.558 for California sweet cherries, and – 0.381 for the other sweet cherries (Schotzko et al., 1989). The supply elasticity value available for apples was 0.713 (Roosen, 1999). This value was also used for the other fruits. Conditional probability frameworks were developed to calculate the ex-

Tab. 1. *Conditional Probabilities of Virus's Crop Losses on the Extent of Spread in Deciduous Fruit in the US*

| Crop Losses ($d_i$) | Extent of Spread ($s_j$) (Scope Level) | | | | | |
|---|---|---|---|---|---|---|
| | Low 1% | Medium – Low 10% | Medium 20% | Medium – High 29% | High 40% | |
| No Losses 0% | 0% | 12% | 32.95% | 47.99% | 79.9898% | |
| Low 5% | 48% | 47% | 35% | 32% | 15% | |
| Medium – Low 10% | 40% | 32% | 25% | 15% | 5% | |
| Medium – High 15% | 10% | 8% | 7% | 5% | 0.01% | |
| High 20% | 2% | 1% | 0.05% | 0.01% | 0.0002% | |
| Conditional Probability on the Extent of Spread | 100% | 100% | 100% | 100% | 100% | Total Expected Losses $\sum d_i s_j x_{ij}$= =3.46% |

*Source: Cembali et al, 2003*

Tab. 2. *Avoidable Losses to Growers, Nurseries, and Consumers from a Viral Disease Reduction of Apple, Sweet Cherry, and Clingstone Peach, ($1,000).*

| Industry | Avoidable Losses to Growers | Avoidable Costs to Nurseries | Consumer Surplus Reduction |
|---|---|---|---|
| Apple | 63,406.7 | 417.7 | 119,361.6 |
| Sweet Cherry | 11,191.5 | 48.2 | 19,138.1 |
| Clingstone Peach | 5,580.9 | 22.5 | 8,240.3 |
| Total for Selected Sectors | 80,179.1 | 488.4 | 146,740.0 |

*Source: Cembali et al, 2003*

pected losses from viral diseases in the fruit industry and the planting stock industry. Economic implications for fruit producers, nurseries, and consumers are presented in Table 2.

Avoidable losses for producers represent the producers' surplus losses in the fruit market and the consumer surplus losses in the planting stock market under the no virus prevention program (virus spread) scenario. On the other hand avoidable costs for nurseries are the producer surplus losses from the shift in the demand curve in the planting stock market if viral diseases spread. Similarly, a benefit to the consumers from the VPP is the consumer surplus reduction that they would face if viral diseases expand.

Results of these calculations indicate that the overall benefit of the VPP is approximately $227 million. These benefits are considerably higher than the cost of the program, which was $541,142 in 2000. Using this estimate, the VPP has a ratio of benefits to costs greater than 420 to 1 (Cembali et al., 2003). In this case, the decidedly favorable benefit-cost ratio attests to the economic importance of the virus prevention program and supports continued government sponsorship.

## 6. Conclusion

This research presents a practical approach to evaluating the economic implications of a virus prevention program. The framework uses economic surplus to measure economic value and conditional probability theory to estimate the expected losses from a viral disease. The conditional probability approach can be used to infer losses when more direct information is not available. Data requirements of this approach are limited. Its accuracy in evaluating the social welfare impact is greater than the method used by non specialists to evaluate prevention programs. An application has been presented on a VPP in the US. The methods proposed can be used to evaluate any prevention program whether or not it is funded by a government agency.

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# APPENDIX

This Appendix provides the algebraic steps necessary to derive the expressions for the change in consumers and producers surplus (equations 7 and 8 respectively).

Recall that the losses caused by viral diseases are indicated with $\alpha$ and it is assumed that $\alpha \geq 0$, also, the change in quantity due to viral diseases spread is expressed as follows $\Delta Q = Q_0 - Q_1 = \alpha Q_0$, where $Q_0$ indicates the production before, and $Q_1$ after the spread.

The new equilibrium price $P_1$ is calculated using the arc elasticity of demand,

$$\varepsilon_d = \frac{\Delta Q}{\Delta P}\frac{P_0}{Q_0}$$

$$\Delta P = \frac{\Delta Q}{\varepsilon_d}\frac{P_0}{Q_0}$$

$$P_1 = P_0\left(1 - \frac{\alpha}{\varepsilon_d}\right)$$

Assuming a parallel shift of the supply curve, the value of d can be calculated using the arc elasticity of supply,

$$\varepsilon_s = \frac{\Delta Q}{\Delta P}\frac{P_0}{Q_0}$$

The correspondent price on the supply curve in case the quantity supplied is reduced (from $Q_0$ to $Q_1$) and it is equal to $\Delta P = P_0 - i$.

$$i = P_0\left(1 - \frac{\alpha}{\varepsilon_s}\right)$$

The loss in consumer surplus ($\Delta CS$) is equal to the sum of the areas of the rectangle $P_1E_1bP_0$ and the triangle $E_1E_0b$ as follows:

$$\Delta CS = (P_0 - P_1)Q_1 + \frac{(P_0 - P_1)(Q_1 - Q_0)}{2} = \frac{\alpha}{\varepsilon_d}(1-\alpha)Q_0 + \frac{\alpha P_0}{\varepsilon_d}\alpha Q_0 = \frac{\alpha P_0 Q_0}{\varepsilon_d}\left(1 - \frac{\alpha}{2}\right)$$

In the same way, the loss in producer surplus ($\Delta PS$) is equal to the difference between the triangle $aE_0P_0$ and the triangle a $E_1P_1$. As a result of the parallel shift of the supply curve, the change in producer surplus is negative. Algebraically the change in producer surplus is sum of the areas of the rectangle $P_0bcd$ and the triangle $bE_0c$ that is equal to:

$$\Delta PS = (P_0 - d)Q_1 + \frac{(P_0 - d)(Q_0 - Q_1)}{2} = \frac{\alpha P_0}{\varepsilon_s}(1-\alpha)Q_0 + \frac{\alpha P_0}{\varepsilon_s}\alpha Q_0 = \frac{\alpha P_0 Q_0}{\varepsilon_s}\left(1 - \frac{\alpha}{2}\right)$$