# Economics and the Adoption of Livestock Vaccination: Analysis and New Insights

Clement A. Tisdell*

School of Economics, The University of Queensland, St Lucia, 4072, Australia

**Abstract:** This article uses economic principles and theory and draws on the available scholarly literature to examine the economics of vaccinating livestock. After providing relevant information about the nature of livestock vaccines, the implications of economic principles for private decisions and the gains from livestock vaccination are specified. Empirical findings on this topic are assessed and it is demonstrated that the overhead (fixed) costs involved in vaccinating livestock are an important profitability influence on the willingness of livestock owners to vaccinate their livestock. In considering the economics of livestock, it is necessary to go beyond decision making by individual livestock owners. For example, the externality or spillover effects of livestock vaccination can be of economic importance and can justify the adoption of public policies which result in more livestock vaccination regionally or nationally than otherwise would occur. Furthermore, in market economies, the distribution of economic gains between livestock producers and consumers of livestock products depends on the nature of market adjustments. As demonstrated, this can result in livestock owners only receiving a small share of the economic benefits from vaccination. Moreover, in some cases, their economic surplus can decline. Desirable areas of future research involving economics and animal health are identified. The importance of combining natural and social science in further studies is identified.

**Keywords:** Animal health, Decision-making, Economics, Externalities, Livestock vaccination, Market adjustments.

## INTRODUCTION

Vaccines play an important role in the maintenance of animal health. Vaccines now exist for the prevention or alleviation of a wide range of livestock diseases [see for example, 1]. Their use, however, is often less than can be justified from an economics point of view, especially from a social or collective perspective. The purpose of this article is to apply economic theory to explain and analyse why this is so and to outline and discuss policies which could be adopted to rectify this situation. In addition, attention will be given to how the economic benefits of livestock vaccination are likely to be shared between owners of livestock and buyers of livestock products in market economies. Depending on the nature of market supply and demand schedules, the distribution of economic gains from livestock vaccination between livestock owners and consumers of livestock products varies. For example, in some cases, due to the operation of the market mechanism, all economic gains from livestock vaccination are obtained by consumers alone. This result is not always immediately obvious.

This article provides some background information on the nature of vaccines, and then focusses on the economics and the decisions of individual livestock owners with regard to vaccinating their livestock. Private decisions to vaccinate livestock are liable (in the case of contagious diseases) to result in less vaccination than is desirable from a collective or social point of view for reasons which are outlined. Policy measures are outlined that could be used to rectify this situation. Subsequently, differences between livestock owners and consumers of livestock products in the economic gains from vaccination are examined. This article concentrates only on livestock that are kept for sale of physical products, such as meat, eggs and milk. Animals may be kept for purposes other than this, e.g. as pets.

*Address correspondence to this author at the School of Economics, The University of Queensland, St Lucia, 4072, Australia; Tel: +617 73365 6570; Fax: +617 3265 7299; E-mail: c.tisdell@uq.edu.au

## MATERIALS AND METHODS

Economic theory is applied to analyse the issues mentioned above and reference is made to previous relevant findings reported in the literature with regard to the economics of livestock vaccination. In particular, the economic theories of private decision-making are applied in order to predict economic influences on the decisions of livestock owners about the vaccination of their livestock, and this analysis is related to findings reported in the literature.

The economic theory of external effects (externalities) is also applied to examine the collective effects of livestock vaccination, their social and economic consequences and the desirability of government intervention to increase the extent of livestock vaccination by individual owners.

Standard economic market analysis is utilized to investigate the ways in which the economic benefits from livestock vaccination are shared between

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livestock owners and consumers of such products when they are marketed. Specifically, comparative static market analysis is used for this purpose. This provides findings which appear to have been recieved inadequate attention in the available literature.

## Background Information about the Nature of Livestock Vaccines

Livestock vaccines have diverse characteristics. The most commonly used vaccines are killed or inactivated vaccines which stimulate the production of antibodies. Live vaccines are those which contain living viruses or bacteria that have been weakened [2]. Vaccines have also been develop which contain only viral or bacterial antigens that trigger immune responses to diseases such as foot and mouth disease [3]. Live vaccines can stimulate life-long immunity to some diseases when livestock are given a single dose. However, they can have harmful effects on pregnant livestock, e.g. cause abortions, and they lose their potency quickly after being mixed on farm [2]. They may also have negative side effects on livestock production, e.g. reduce milk production. These are often temporary.

Killed vaccines are more benign but usually require more than one dose to raise the level of protection of livestock against targeted diseases. The first dose may give little immunity and result in the production of only a low level of antibodies. The second dose (given at a later stage) raises the level of immunity. However, boosters are usually required (for example, annually) to sustain immunity [2]. Therefore, this form of disease prevention involves ongoing expenditures by livestock owners.

Some vaccines provide protection against multiple livestock diseases. These may be more costly to purchase but reduce the number of injections or occasions vaccines have to be administered and therefore can reduce the cost of a vaccination program. Vaccines have been developed for both non-contagious diseases (e.g., botulism) and for contagious diseases (e.g., foot and mouth disease). Vaccinations against the latter types of diseases have positive environmental externality or spillover effects. In these cases, the more widespread the vaccination programs against these diseases are, the lower the risk of the disease occurring among livestock that are not vaccinated or are poorly vaccinated. On the other hand, this spillover effect is absent in the case of non-contagious diseases for which vaccines are available.

Because the nature of livestock vaccines are quite varied as are the attributes of the diseases that they are designed to protect against, evaluating the economics of their use can be quite complicated. Nevertheless, simple economic models can be applied to provide significant insights into the private and social optimality of vaccinating livestock.

## Private Decisions about Economic Gains from Livestock Vaccination

### *Applications of Economic Models*

Livestock owners vary in their economic aims. Let us consider the decisions of individual owners who aim to maximize their profit by deciding whether or not to vaccinate their livestock. The expected change in profit of a livestock owner vaccinating his/her livestock can be expressed as

$$B = V - N, \qquad (1)$$

where

*B* is the owner's expected net gain (or loss) in profit as a result of the vaccination;

*V* is the owner's expected profit after vaccination and after deducting vaccination costs; and

*N* is the owners expected profit in the absence of vaccination.

Formula (1) can be made more specific. Let *p* equal the probability or risk of the occurrence of relevant diseases outbreak among the livestock of an owner. When the livestock are vaccinated let $\hat{V}_1$ represent the owners' predicted profit from his/her livestock if there is a disease outbreak and $\hat{V}_2$ represent this if there is not an outbreak. When the owner's livestock are not vaccinated, let $\hat{N}_1$ indicate the owner's predicted profit in the absence of a disease outbreak and $\hat{N}_2$ indicate that if there is an outbreak among the owners' livestock. Then expression (1) can be rewritten as

$$B = [\hat{V}_1(1-p) + \hat{V}_2(p)] - [\hat{N}_1(1-p) + \hat{N}_2(p)] \qquad (2)$$

Other things being held constant, the economic gain from vaccination (*B*) will be higher, the greater is the risk *(p)* of the owners' livestock being exposed to the focal disease, the greater is the economic reduction in profit in the absence of vaccination, and the more effective the vaccine is in maintaining the profit obtained from the livestock.

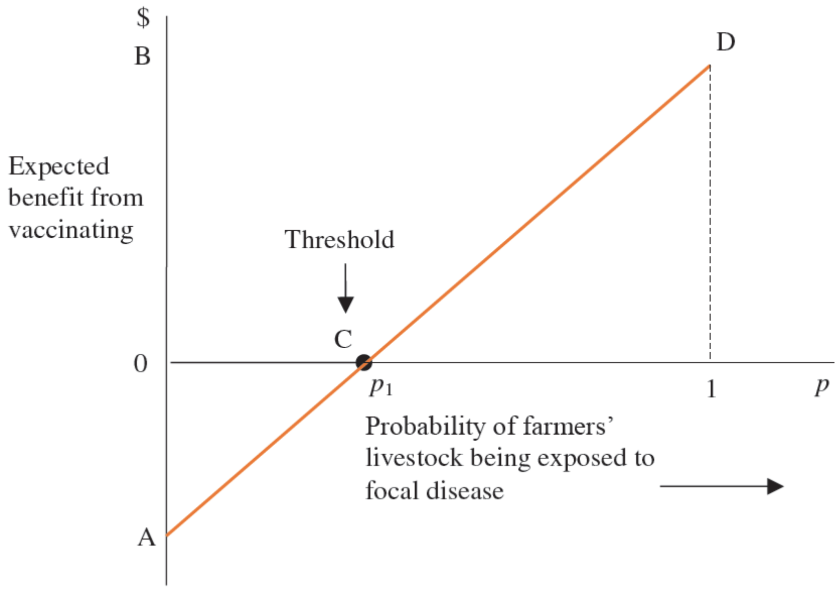


**Figure 1:** An illustration of the expected profitability of a farmer vaccinating his/her livestock as a function of the likelihood of their exposure to a focal disease, other factors being constant.

B is the reduction in expected profit avoided as a result of vaccination where it was profitable to vaccinate. However, it is possible for B to be negative in which case it is unprofitable for an individual livestock owner to vaccinate his or her livestock.

Relationships of the type illustrated in Figure **1** are relevant and these will vary from case to case. In Figure **1**, the expected benefit to a farmer of vaccinating his/her livestock (B) as a function of the probability (p) of his/her livestock being exposed to a focal disease is shown by the line ACD supposing that all the other variables in expression (2) are held constant.In this case, point C (corresponding to a probability of disease exposure of $p_1$) is a threshold value. If the risk of exposure of the livestock to this focal disease exceeds $p_1$, it pays to vaccinate, and if it is below $p_1$, vaccination is unprofitable. The relationship might not be linear.

For some purposes, a more advanced model of 'profit maximization' can be useful. This model can be used to take account of the difference which a program of livestock vaccination makes to the capitalized value of the livestock of a farmer. If this approach is adopted, the expected economic profitability of a farmer vaccinating his/her livestock is equal to the expected net present value of his/her livestock if vaccinated, less their expected net present value if they are not vaccinated. This is equivalent to their change in capitalized value as a result of vaccination. It applies the profit maximization rule proposed by Hicks [4]. It can be especially useful when a disease results in mortalities. In theory, the change in capitalized value can be separated into that due to mortality and that arising from morbidity. Net present value analysis has been used to estimate the economic benefit of vaccination to control bovine brucellosis in Brazil on a state-wide basis [5]. They considered net economic values and the estimated minimum and maximum effects of the disease on livestock production taking into account the different mortality rates in the cattle involved.

### *Comments on Empirical Findings*

Although Heffernan *et al.* [6] found that poorer farmers in Bolivia were less likely to vaccinate their livestock than richer farmers, they concluded that the reasons might be more of a sociological than an economic nature. As a result of an additional study of a sample of 601 livestock kept by poorer households in Tamil Nadu State in India, this viewpoint was reinforced [7]. They concluded that "contrary to conventional wisdom, the ability to pay for vaccination did not appear to be the primary inhibitor to vaccination coverage" [7, p. 116]. While this may be so, further evidence is required before concluding that this is generally so.

Conventionally, one would expect poorer owners to have little or no surplus income to invest in livestock vaccination. They can find it difficult or impossible to forgo income to vaccinate their livestock, even where this might be profitable. These benefits in most cases are not immediately appreciated. Borrowing can also be a problem for poor livestock holders in developing countries when interest rates are high and when they are also often already in debt.

The findings of Suresh *et al*. [8] seem to be at odds with those of Heffernan *et al*. They sampled 998 livestock owners in Rajasthan and analysed the data using logit analysis. They found that the likelihood of a farmer vaccinating his/her bovines (buffalo and cattle) compared to not vaccinating these increased with the value of the farmers' fixed assets associated with livestock production and that this was statistically significant at the 1% level. This was the most statistically significant variable.

They suggested that 'by adopting vaccination, the farmers realised a higher rate of returns from their fixed assets' [8]. In addition, given that these farmers have higher overhead costs, than farmers with fewer fixed assets, they would suffer larger losses in the event of their livestock not being vaccinated and a disease outbreak occurring.

Suresh *et al*. [8] also found that crossbred cattle were more likely to be vaccinated than local breeds of cattle. This was ascribed to crossbred cattle being more susceptible to disease than local cattle [8]. They also reported that the number of bovines that a farmer owned was not a statistically significant determinant as to whether they were vaccinated.

On the other hand, Battacharya *et al*. [9] undertook a study of factors influencing the adoption of *Trichomoniasis* vaccine by Nevada Range cattle producers in the United States, and applied a multinominal logit model to their data. They found that the probability of not using the vaccine fell with herd size. They do not indicate why. One possible reason could be that there are economies of scale in administering the vaccine. That is the cost per animal declines as the number of cattle vaccinated on a property increases. The cost of administering a vaccine usually involves both overhead (fixed) costs and variable costs.

The influence of the fixed or overhead cost on the profitability of vaccinating herds or flocks of animals varies with the herd or flock size. This is illustrated by Figure **2**. In this figure, the line ABC represents the average variable cost of vaccinating animals (cost) as a function of the number of animals needing to be vaccinated on a property, and the curve marked HJFK is the total cost per animal vaccinated. The distance between lines HJFK and ABC indicates the overhead (fixed) cost per animal vaccinated. It forms a rectangular hyperbole. The line marked DEFG is assumed to represent the average economic benefit of vaccinating each animal in the herd or flock. It is shown as being constant, but it need not be. The difference between line DEFG and the curve HJFK is the net benefit of vaccinating the number of livestock requiring vaccination on a property.

In the case illustrated in Figure **2**, it is uneconomic for farmers with fewer than $x_2$ animals on their property

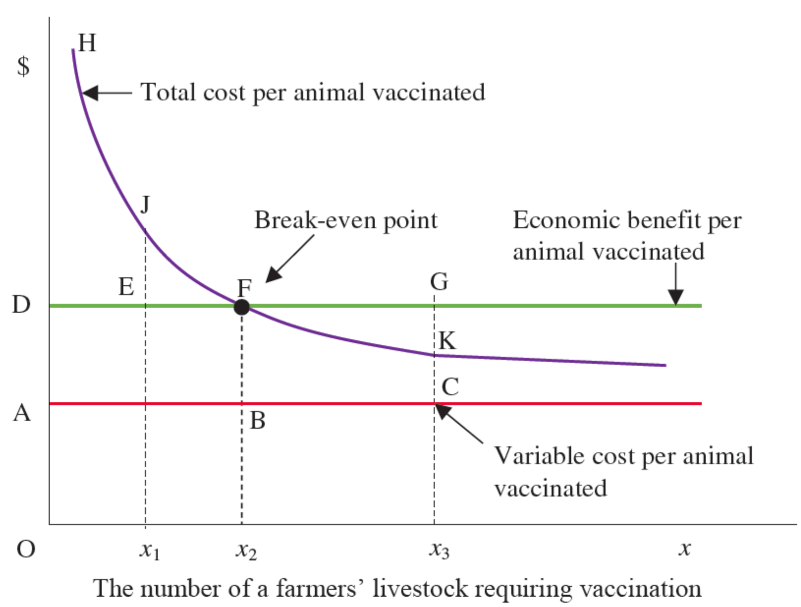


**Figure 2:** An illustration showing the overhead costs of vaccinating livestock on a property which demonstrates that it can be uneconomic for farmers with fewer livestock to vaccinate their animals.

to vaccinate where as it is profitable for farmers with more than $x_2$ animals to do so. Point F represents a break-even point as far as the profitability of vaccination is concerned. A farmer having $x_1$ animals to be vaccinated would lose an average of JE dollars per head by vaccinating whereas one vaccinating $x_3$ animals would gain KG dollars per animal by vaccinating these.

Evidence from the United States indicates that beef operators with a smaller number of cattle are less likely to vaccinate their herd than those with a larger herd size. The United States Department of Agriculture [10] undertook a survey of the extent to which (depending on the size of herds) beef cattle and calves were vaccinated in 2007 in 24 states. The results are illustrated in Figure **3** and indicate that small herds are much less likely to be vaccinated than larger ones. As was illustrated, in Figure **2**, the importance of overheads might be an important factor contributing to this result.

Further discussion of the significant fixed costs for the economics of animal health systems can be found in Tisdell and Adamson [11].

## Economics and Externalities (Spillovers) from Livestock Vaccination

### *Economic Theory and the Failure to Sufficiently Control Contagious Diseases from a Social Point of View*

In the case of contagious livestock diseases, individual owners of livestock are liable to engage in insufficient vaccination of their livestock from a social or collective point of view. These spillovers can be of two types (1) a reduction in the likelihood of livestock being infected on individual properties by a contagious disease as the national or regional proportion of livestock vaccinated increases (this is a positive environmental spillover), and (2) increased access of livestock or livestock products to export markets as a consequence of this coverage. The latter aspect is a pecuniary externality (an economic benefit) to individual owners of livestock which depends on the extent to which a disease is collectively controlled. These factors have been discussed by Knight-Jones and Rushton [12] in relation to foot and mouth disease. Here the externalities of the first type will be discussed [see for example, 13, Ch. 3]. When externalities of this type occur, private decisions often do not result in the socially optimal proportion of livestock being vaccinated and thus there is insufficient vaccination of livestock from a collective point of view as has been pointed out by McLeod and Rushton [14] and Knight-Jones and Rushton [12].

Figure **4** illustrates this problem for an theoretical case. The line ABC represents the marginal private willingness of livestock owners to vaccinate their livestock, and line FBDG is the assumed marginal cost of vaccinating livestock. This may be but need not be constant. If $x$ represents the proportion of the national or the regional number of livestock vaccinated as a result of private decision making, the result would be that $x_1$ of these animals would be vaccinated. At this level, the private marginal economic benefit from vaccination equals its marginal cost.

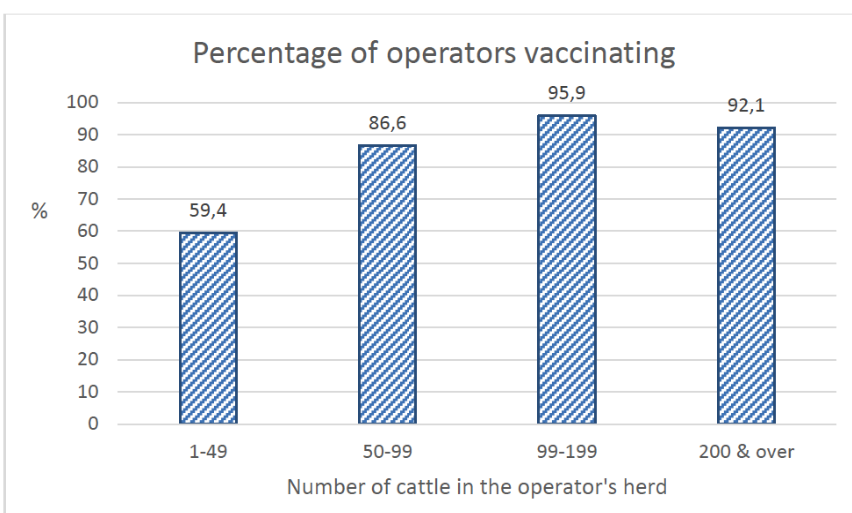


**Figure 3:** Vaccination coverage of beef cattle in the United States in 2007 by number of cattle in the herds of operators. *Source*: Based on Table 1. United States Department of Agriculture [10].

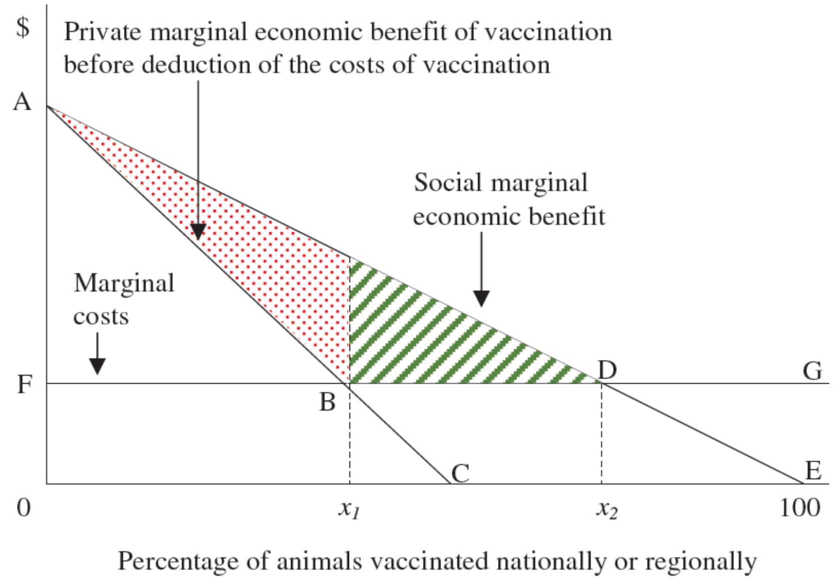


**Figure 4:** As is illustrated, in the case of contagious livestock disease, private decisions about vaccination of livestock are liable to result in the proportion of animals vaccinated being less than is economically optimal collectively. See the text for the explanation.

Given that the probability following infection of livestock held by owners is likely to fall as the percentage of animals vaccinated regionally or nationally rises, the social marginal economic benefit from vaccinating livestock exceeds the private marginal economic benefit. The size of the marginal spillover benefit in dollar terms is equal in this illustrative case to the difference between line ABC and DEF. The net social benefit from vaccinating livestock nationally or regionally reaches a maximum when the percentage, $x_2$, of these livestock are vaccinated. At $x_2$, the social marginal cost of vaccinating livestock equals the marginal case of doing so. The social economic gain from the increase in vaccination covering from $x_1$ to $x_2$ is equal to the area of the hatched triangle. Other factors being constant, this gain will be larger the greater the spillover effect. The dotted area is equal to the spillover of economic benefits generated by private decision making.

Note that the slope of line ABC is likely not to be independent of the number of animals vaccinated regionally or nationally. As infection rates decline due to more widespread vaccination, this line will be steeper than if it were independent of $x$. In expression (2) for example, $p$ will decline as more animals are vaccinated regionally or nationally.

### *Policies to Increase Vaccination Coverage*

When externalities or spillovers for vaccinating livestock are important, there can be a case for the adoption of public policies to increase the extent to which livestock are privately vaccinated [14]. For example, the government may provide free vaccinations or subsidize its use. The former is more likely to occur when vaccination against a particular livestock disease is compulsory. Free vaccination is available in some developing countries for the control of priority livestock diseases. However, the extent to which livestock are vaccinated as a result of such schemes depends on the availability of veterinary services and vaccines.

It is also possible to make vaccination for the control of certain diseases compulsory with penalties for non-compliance. However, this may not be practical in some developing countries, because poor owners of livestock may find it difficult (if not impossible) to comply with regulations of this type.

## Who Gains Economically from the Vaccination of Livestock?

The use of effective vaccines to control livestock diseases usually results in a reduction in the cost of production of livestock products and increases their supply. The question arises as to what extent do individual livestock producers benefit economically (if at all) as a result of this adoption? The predominant view presented in the economic literature has been that suppliers of livestock products will have an increase in the amount of their producers' economic surplus, except in the special case where the demand for livestock products is perfectly inelastic. In the latter case, the predominant economic view is that the amount of their producers' surplus remains constant after the market adjusts to the increased supply. In virtually all cases, the increased supply results in a reduction in the price of livestock products and the economic surplus obtained by consumers of these products rises. In every case, consumers' surplus plus producers' surplus increases when the cost of production of livestock products fall. Consequently, there is an overall net social economic benefit. However, when both producers and consumers gain economically, the distribution of the overall gain is likely to be uneven. For example, for a given market supply curve, the relative gain to producers declines when the market demand curve for livestock products is more inelastic [15, p. 8].

However, it is not always appreciated that the level of producers' surplus can actually fall as a result of reduced costs, for example, due to the more widespread adoption of vaccination of livestock. On the other hand, a reduction in consumers' surplus never occurs – it usually rises as a result of the reduced costs of production.

Otte and Chilonda [15] analysed the economic gains to consumers and producers resulting from increased vaccination of livestock by assuming that the market supply curve of livestock product shifts down by a constant. However, it may not shift by a constant. When it shifts down, it is also possible for its slope either to increase or decrease. In the former case, producers' surplus may actually fall, as was pointed out by Duncan and Tisdell [16]. The more inelastic the demand for the market supply of the livestock product, the more likely producers' surplus will decline.

If it does, it may be considered to be unfair for livestock producers to either have to pay for research and development of a vaccine or to be mandated to use a vaccine without being financially compensated for doing so.

Figure **5** provides an example of the effects on the level of producers' surplus of different types of shifts in industry supply curves of a livestock product as a result of vaccination. For illustrative purposes, the industry demand curve is shown as being perfectly inelastic and is indicated by the vertical line BEM. It is supposed that in the absence of vaccination, the industry supply curve is as indicated by the line $ABS_1$. Market equilibrium is established at point B and the price of the livestock product is equal to OC. Producers' surplus is equal to the area of triangle ABC.

Now suppose that the supply curve moves downwards by a constant amount so that after vaccination the new industry supply curve becomes $DES_2$. The amount of producers' surplus then remains unchanged. After this shift, the amount of producers' surplus equals the area of triangle DEF. This is the same as initially because both the bases and heights of triangle ABC and DEF have the same length. However, the amount of this surplus rises if the supply curve shifts to $GES_3$, which is a case in where the supply

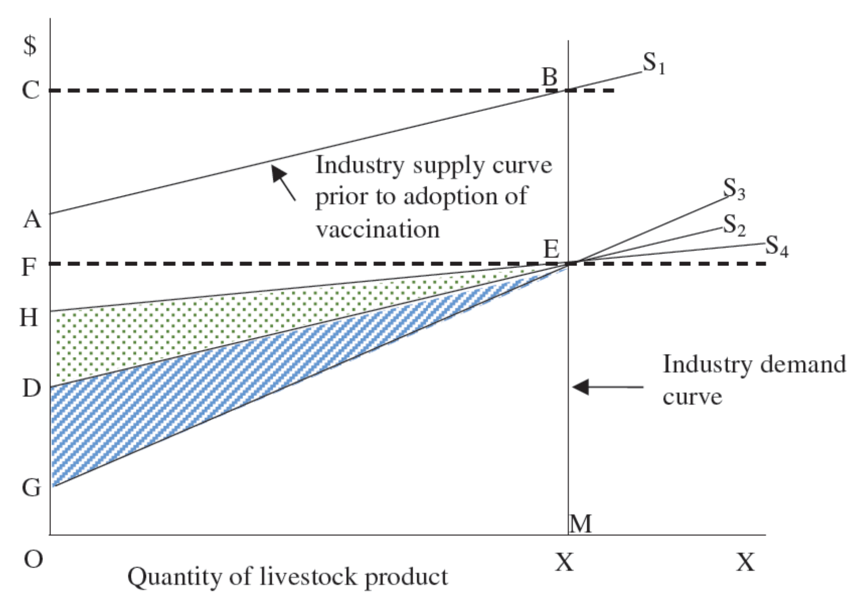


**Figure 5:** An illustration of the possible impacts of livestock vaccination on the level of producers' surplus. See explanation in the text.

curve becomes steeper. The area of triangle DEF exceeds that of triangle ABC because the length of the base of triangle GEF exceeds that of triangle ABC whilst their heights are the same. The surplus is larger by an amount equivalent to the hatched area. On the other hand, if the supply curve shifts to $DES_4$, a case in which the industry supply curve becomes less steep, producers' surplus falls. This is because the length of the base of triangle HEF is less than that of triangle ABC but the height of both triangles are the same. The reduction is equivalent to the area of the dotted triangle.

## DISCUSSION

The economic modelling applied in this article is as pointed out previously, based on the assumption that the main aim of owners of livestock is to maximize their profit from their husbandry. It was also supposed that they are reasonably well informed about the profitability or otherwise of vaccine use. In practice, imperfect knowledge can be a major problem and in particular in some societies not all livestock owners are motivated to maximize their profit [6, 7]. Nevertheless, profit maximization is likely to be a dominant motivator in the management of livestock in countries and regions where the market system is well established. This is especially likely to be so in higher income countries and possibly less so in Third World countries. Therefore, socioeconomic models need to be revised to reflect different regional circumstances. Models that are applicable in developing countries may not, for example, be appropriate to the circumstances prevailing in more developed countries.

Surprisingly there appear to be many more scholarly articles available that take into account the social and economic influences on the adoption of livestock vaccination in developing countries than exist for more developed countries. This topic needs more attention in the case of higher income countries. In addition, future studies should consider the role which the indebtedness of livestock enterprises play in their willingness to adopt vaccines and the relevance of their financial liquidity. Furthermore, many livestock owners may prefer to earn a steady stream of income (profit) rather than maximize the net present value of their enterprises. In this case, if the use of vaccines provide improvement in everyday income then they are more likely to be adopted; but if vaccination puts the steadiness of this stream at risk, they may be less inclined to use them. Also those livestock enterprises in higher income countries which depend more heavily on loans (that is, are highly geared financially) may be more likely to vaccinate their livestock if this improves the prospect of them meeting their obligations to lenders. This would be a precautionary strategy. There appear to have been no studies into the influence of these factors on the adoption of livestock vaccination programs.

Empirical studies of differences in the perceptions of scientists and livestock owners about the value of livestock vaccination are also useful. A study of this kind was completed in India by Rathod *et al*. [17]. They found that only 61.4% of the 390 dairy farmers surveyed considered vaccination of their livestock to be profitable whereas 100% of the scientists surveyed believed that this vaccination was profitable. They listed the major problems mentioned by farmers in relation to vaccinating dairy cattle. These included possible side effects of some vaccines (e.g. reduced milk production, and vaccinated animals becoming disease affected). Other problems included poor infrastructure to store vaccines, non-availability of veterinarians or skilled staff to administer vaccines and lack of knowledge about vaccines.

However, we do not know why this lack of knowledge existed. In some cases, it can be unprofitable for livestock owners to vaccinate. To seek a lot of knowledge about this particular vaccine then makes no sense to them. Battacharya *et al*. [9] found for example, that cattle ranchers with smaller herds were less well informed about the *Trichomoniasis* vaccine than were those with larger herds and stated that this should be a matter for further investigation. In some cases, the estimated economic value of providing additional information about a vaccine exceeds the extra costs of obtaining it. This would be so be the case where limited information was sufficient to conclude that vaccination would be uneconomic [see for example, 18, Ch. 1].

It also needs to be understood that vaccination is not the only possible response to many livestock diseases. Other than vaccination, possibilities can include the adoption of measures to reduce the likelihood of an animal being subjected to disease and and also medical treatments if an animal should become infected. The economic value of all these possibilities should be considered when making decisions with regard to the control of livestock diseases.

Zoonoses also add an extra dimension to the economic and social evaluation of the control of animal diseases. They raise difficult questions about how the economic value of reducing human mortality and morbidity resulting from animal diseases should be calculated. Public policies surrounding these issues were not covered in this article. In addition, this article has not considered how the economic value of sustaining the health of pets could be evaluated and issues associated with the healthiness of wildlife.

## CONCLUSION

This discussion has indicated that the economics of vaccinating livestock can be complex and that there is a need for more research into this subject and the topic of animal health economics generally. From a policy point of view, it is important that the studies of natural scientists about animal health (including those involving the vaccination of animals) be supplemented by economic and social studies.

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