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Ex-ante economic analysis of animal disease surveillance

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Summary

This paper provides an *ex-ante* economic analysis comparing four alternative intervention strategies for the control and eradication of rinderpest against a scenario of no intervention in a cattle population similar in size to that of Ethiopia. The interventions were three different coverage levels of mass vaccination and one surveillance-based programme where vaccination targeted infected sub-populations. For each scenario, the disease impact was estimated using an open-population, state-transition SEIR ('susceptible', 'exposed', 'infectious', 'recovered') disease transmission model with parameter estimates developed for lineage 1 rinderpest virus. Projected economic surplus gains and costs estimated from the rinderpest eradication programme in Ethiopia were analysed using benefit-cost methods. Social net present values (NPVs) and benefit-cost ratios (BCRs) were calculated. Although the economic model found that BCRs were greater than one for all interventions examined, the scenarios of intensive mass vaccination (75% vaccination coverage) and surveillance with targeted vaccination were economically preferable. The BCRs for these strategies were 5.08 and 3.68, respectively. Sensitivity analysis revealed that an increase in market prices for beef and milk increased the value of economic loss, the economic surplus and returns to investments in terms of NPVs and BCRs. An increase in demand and supply elasticities for beef and milk decreased the value of economic losses. This also had a negative effect on economic surplus and NPVs. The effect of an increase in the discount rate reduced returns to investments, with lower NPVs and BCRs.

The authors note that 75% mass vaccination coverage was attempted in Ethiopia in the early 1990s, but failed to eradicate rinderpest because the approach was logistically too difficult to implement in practice. Subsequently, an effective surveillance and epidemiologically targeted vaccination programme was developed and has apparently resulted in the eradication of rinderpest from Ethiopia (the last case was recorded in 1996). The authors conclude that epidemio-surveillance with targeted vaccination is both an economically viable and realistic strategy and offers benefits that extend beyond rinderpest eradication.

Keywords

Animal disease surveillance – Benefit-cost analysis – Consumer and producer surplus – Epidemiological modelling – Ex-ante economic analysis – Rinderpest vaccination.

Introduction

In Africa, in the past, national governments and international programmes have used mass vaccination campaigns to control rinderpest (e.g. the Joint Project 15 [JP-15] and the Pan African Rinderpest Campaign [PARC]). However, such campaigns not only resulted in a low level of coverage (30% on average), but were also relatively costly (21). They monopolised limited financial and human resources to manage a single disease, the initial prevalence and distribution of which was often unclear, to the total neglect of other important animal diseases (27). The development of a cost-effective animal disease eradication programme requires reliable disease intelligence (12). A good epidemio-surveillance system provides information that allows for selective vaccination as opposed to blind mass vaccination interventions.

The Pan African Control of Epizootics (PACE) programme was established under the auspices of the Inter-African Bureau for Animal Resources of the Organization of African Unity. The objectives of the programme were as follows:

– to strengthen national and regional capacities in epidemio-surveillance for effective animal disease control

– to eradicate rinderpest from Africa

– to privatise the majority of animal health services

– to improve the control of other epizootic animal diseases.

The PACE strategy is based on the establishment of epidemio-surveillance networks that provide accurate information on disease prevalence and distribution, making it possible to eradicate disease in a cost-effective manner.

In contrast to the mass-vaccination campaigns against rinderpest, whose costs and benefits have been formally assessed (26), the cost-effectiveness of an epidemio-surveillance system as an eradication tool has not been assessed. This *ex-ante* analysis quantifies the potential costs and benefits of using such a system to eradicate rinderpest and plan the control of other epizootic animal diseases in Africa. Epidemiological and economic modelling of rinderpest in Ethiopia is used to compare the likely costs and benefits of an epidemio-surveillance system with those of other options involving no intervention; institutionalised mass vaccination, i.e. a stable and homogenous pattern of sub-optimal immunisation; and hypothetical intensive mass vaccination.

Related cost-benefit analysis studies

Since 1962, when international attention was focused on rinderpest in Africa at the start of the JP-15 vaccination campaign, only a few rinderpest-related economic studies have been carried out. In 1971, Lepissier (9) estimated that the JP-15 campaign cost US$ 16.4 million (€12.4 million) with US$ 7.2 million (€5.4 million) (44%) contributed by national governments and the remaining portion by international donor institutions. An economic analysis of the JP-15 campaign in Cameroon, Chad, Niger and Nigeria (10) showed that for 33 million vaccinations, the programme spent an average of US$ 0.32 (€0.24) per vaccination. In 1978, Felton and Ellis (5) used mortality losses avoided, improved reproductive rate and improved productivity in meat and milk as benefits to evaluate the economic impact of the rinderpest campaign in Nigeria. The authors found the benefit-cost ratio (BCR) to be 2.48 and the internal rate of return to be 48%. They concluded that the campaign was not only economically viable, but also succeeded in reducing mortality during outbreaks and in enhancing the capacity of Veterinary Services to control other major diseases.

In a recent study of the economic impact of rinderpest control in a sample of ten sub-Saharan African countries, Tambi *et al.* (26) estimated the average cost of vaccination to be €0.42 per head of cattle. For the 123 million cattle vaccinated in these countries, unit cost varied from €0.27 for Ethiopia to €1.71 for Côte d'Ivoire. Net benefits per cattle head vaccinated averaged €0.38, varying from €0.07 for Benin to €0.88 for Tanzania. Calculated BCRs varied from 1:1.06 for Côte d'Ivoire to 1:3.84 for Tanzania, with an estimated average return over the ten countries of €1.8 for each euro invested in the campaign. The internal rate of return ranged from 11% for Côte d'Ivoire to 118% for Burkina Faso. Based on these indicators, the study concluded that the PARC generated reasonable returns in each of the ten countries, producing sufficient benefits to at least pay back the initial investment. Benefits exceeded costs by 50% in half of the countries. In terms of large-scale disease control interventions, PARC was thus a viable public investment.

The studies reviewed above have generally been based on *ex-post* analysis of rinderpest control. The results, promising as they are, do not necessarily suggest that the eradication of rinderpest would also be a viable investment venture. The scope and magnitude of the social benefits that will be derived when rinderpest is eventually eradicated are still unknown. These depend on the length of time before an outbreak is reported, how long epidemio-surveillance activities will continue and above all, the costs of all these activities. This *ex-ante* social benefit-cost analysis (SBCA) of rinderpest eradication is necessary for the identification and evaluation of the costs and benefits that will accrue in the future. This information is essential to the decisions of the following:

– national governments in Africa to commit financial and human resources to the PACE programme

– the European Union, which is the major funding institution of the PACE programme

– other stakeholders, such as non-governmental organisations involved in animal disease control in Africa.

Methods

Of the several *ex-ante* assessment approaches (e.g. scoring models, mathematical programming models, a production function and systems approach, benefit-cost methods), benefit-cost analysis is considered to be the most practicable and is, therefore, the most widely used method of evaluating long-term public disease control programmes (2, 6, 22, 23). In benefit-cost analysis, the economic viability of an animal disease control programme is assessed from a societal point of view. Martin *et al.* (17) note that in deciding whether to invest in a public animal disease control programme, consideration is given to whether society as a whole will benefit, whether there will be transfers of benefits between sectors of the economy, whether the programme should receive priority over other programmes and how heavily the economic and social achievements of the programme should be weighted. In benefit-cost analysis, the most appropriate measure to capture these considerations is economic surplus analysis. Models that incorporate benefit-cost and economic surplus analyses assume that disease eradication would increase production, which, under certain conditions, can be translated into benefits that can be distributed between producers and consumers. When the costs of eradication are taken into account, the estimated benefits can be projected over time and discounted to present-day values to yield the social net present values (NPVs), BCRs and internal rates of return.

Epidemiological and economic modelling

This *ex-ante* benefit-cost analysis is largely based on an economic spreadsheet model that utilises inputs from an epidemiological model to determine the productivity effects of rinderpest eradication. The epidemiological model produces average estimates of annual disease prevalence, incidence and herd immunity. The model calculates annual morbidity and mortality as output parameters and estimates the number of epidemics over a twelve-year period. The economic spreadsheet model was developed to use the parameter values simulated by the epidemiological model, together with other zoo-technical and economic data, as inputs for the SBCA.

The epidemiological model

As a part of the benefit-cost analysis, an open-population, state-transition model of the transmission of rinderpest was developed in @Risk® (14). The data used for model parameter estimation were collected in rinderpest-endemic areas of East Africa and have been reported previously (13, 15). Only key elements of the model are summarised here, as a complete description of model structure, parameter estimates, sensitivity analysis and epidemiological predictions will be published elsewhere (16). The states modelled are 'susceptible', 'exposed', 'infectious' and 'recovered'. The model was developed to simulate the transmission of rinderpest over a twelve-year period under various control scenarios: no control, random mass vaccination and an epidemio-surveillance programme with targeted vaccination. The model utilises the mass action formulation of the SIR model of de Jong (in which 3 groups of animals are defined, namely, 'susceptible', 'infected' and 'recovered/removed') (3) and incorporates stochasticity where less than ten or fractional transitions are predicted. As a simplifying assumption, the model tracks 100 internally homogeneous sub-populations that constitute an overall heterogeneous population of 30 million cattle in Ethiopia.

Inputs to the model largely utilise pert distributions and include birth rate, non-specific mortality rate, rinderpest mortality rate, the basic reproductive number (R_0), the rate at which exposed animals become infectious, the recovery rate of infectious animals and the annual immunisation rate (successful vaccination rate). The estimates for input parameters are for lineage 1 rinderpest virus. The rinderpest mortality rate was estimated from proportional piling exercises with livestock owners, and the basic reproductive number (12, 13) was estimated from serological data on lineage 1 rinderpest published by Majok *et al.* (11). The rate at which exposed animals became infectious and the recovery rate of infectious animals were derived from published laboratory work (8).

The immunisation rate applied is a result of human decision and not a feature of the disease. The immunisation rate is a user-defined input to the model (ρ) and is determined by the type of strategy used in each of the three scenarios. The model then determines how effective the strategy is at interrupting transmission or reducing the frequency of outbreaks. The model calculates the number of vaccinations performed based on the strategy option chosen and the impact of the strategy on population size.

The daily rate of vaccination is calculated by dividing the annual rate by 365 days. A sine function is used to distribute the vaccinations throughout the year. This results in a gentle cycle of immunisation alternating between annual peaks and troughs that reach zero. This mimics the largely seasonal pattern of vaccination campaigns practiced in most countries. A simplifying assumption in this scenario is that vaccination is equally applied in all the one hundred sub-populations modelled.

The model identifies how each control scenario affects the numbers of rinderpest-infected sub-populations, the number of outbreaks, prevalence, incidence and mortality, which then drives the estimation of changing intervention costs and benefits. These outputs are defined as follows:

– annual average of daily prevalence calculated as the annual average of the total number of infectious cattle on a given day divided by the population size on that day. The results are expressed as cases per cow

– annual incidence calculated as the total number of new cases occurring in a year divided by the average population size and expressed as cases per cow-year

– annual average of daily herd immunity calculated as the annual average of the total number of immune cattle on a given day divided by the population size on that day. The results are expressed as the fraction of the population that was immune

– annual mortality calculated as the number of deaths due to rinderpest that occurred in the year

– annual morbidity expressed as the number of cases of rinderpest that occurred in a year minus the number of deaths that occurred due to rinderpest

– annual number of immunisations calculated as the number of vaccinations that were administered based on the user-defined strategy, a field-level vaccination success rate of 80% and the population size

– an outbreak defined as a peak in the epidemic curve and the number of outbreaks defined as the number of peaks in the curve.

Economic analysis

The SBCA is used to determine the economic feasibility of alternative strategies to eradicate rinderpest. The analysis involves the identification and quantification of economic benefits and costs occurring over the lifespan of a programme. The economic benefits and costs are based on social prices and so involve changes in both producer and consumer welfare. These welfare changes are denoted as producer and consumer surplus. Producer surplus is the excess of the total revenues earned by producers over the total costs of supplying the product. Consumer surplus on the other hand, is the excess that consumers are prepared to pay for a product over and above the amount they actually pay. Both producers and consumers benefit as they share the economic surplus from reduced disease risk. Producers gain from lower production losses and less need to continue vaccinating against disease. Consumers gain from market price reductions due to increased market supply. Lower production costs from reduced disease risk encourage increased production, which in turn applies a downward pressure on prices. As prices decline, consumers are able to purchase more.

For each of the eradication strategies adopted, producer and consumer welfare gains are assumed to increase because of increased gains in productivity. The increase in welfare gains is reflected in a rightward shift in the supply and demand schedules of the products made available as disease is eradicated. The distribution of these gains between producers and consumers depends, however, on the manner in which the shifts occur and is sensitive to the functional form, the type of supply curve shift and the relative slopes at equilibrium of the supply and demand curves (7, 18). Taking this into account, a linear and parallel shift in the supply curve for cattle products is assumed. Furthermore, the cattle sub-sector, being a sub-system of the economy, is assumed to remain neutral to the other sectors of the economy and competitive price behaviour is considered to exist.

Figure 1 illustrates the producer and consumer surplus changes with an assumed parallel shift in the supply curve of a particular livestock product caused by disease. Before disease eradication, supply (S_0) of cattle products equates demand (D) at point E_0, where price is P_0 and quantity Q_0. Consumer surplus from market purchases is equal to area $P_0E_0P_d$, i.e. total benefits ($OP_dE_0Q_0$) less the cost of consumption ($OP_0E_0Q_0$). Producer surplus from market supply equals $P_0E_0I_0$, i.e. total gains ($OP_0E_0Q_0$) less total costs of production ($OI_0E_0Q_0$). Total economic surplus is the triangular area $P_dE_0I_0$ equal to the total value of consumption ($OP_dE_0Q_0$) less the total cost of production ($OI_0E_0Q_0$).

With the eradication of disease, supply increases, shifting S_0 to S_1 and producing a new equilibrium, but a lower price (P_1) and a larger quantity (Q_1) at E_1. Increased supply

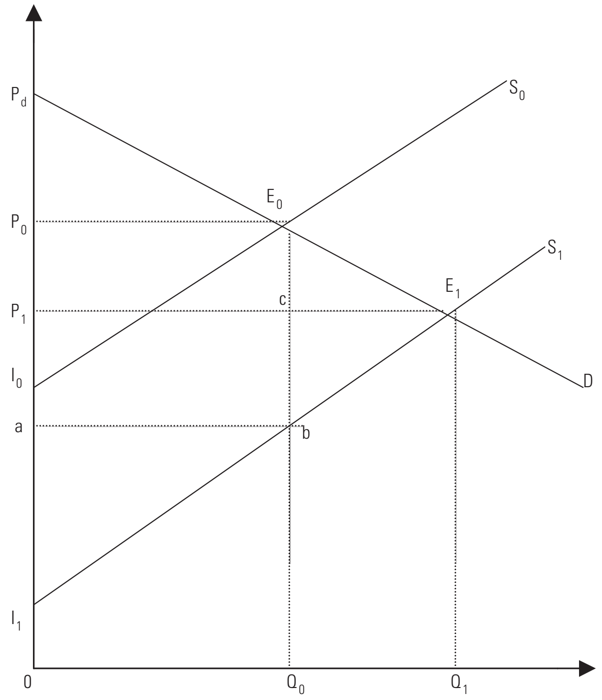

Fig. 1
Distribution of welfare gains from rinderpest eradication

and reduction in price both increase consumer surplus from $P_0P_dE_0$ to $P_1P_dE_1$, a gain equivalent to $P_1P_0E_0E_1$. The change in producer surplus attributed to eradication of disease is represented by the area $I_1P_1E_1$ less $I_0P_0E_0$. Total economic surplus is thus equal to the area below the demand curve and between the two supply curves, i.e. $\Delta TS = I_0E_0E_1I_1$. This area is made up of two components, as follows:

a) economic surplus due to the increase in supply and demand, i.e. area bE_0E_1, which is the total increase in consumption (area $Q_0E_0E_1Q_1$) less the total cost of the increase in production (area $Q_0bE_1Q_1$)

b) cost savings on the original quantity, i.e. area $I_0E_0bI_1$. Without the eradication of rinderpest, society incurs a social welfare loss equivalent to area $I_0E_0E_1I_1$.

Following Alston *et al.* (1), the changes in consumer, producer and total welfare are derived as follows:

Change in consumer surplus:

$$\Delta CS = P_0 * Q_0 * Z\,(1 + 0.5Z\eta)$$

Change in producer surplus:

$$\Delta PS = P_0 * Q_0 * (K - Z) * (1 + 0.5Z\eta)$$

Change in total surplus:

$$\Delta TS = \Delta CS + \Delta PS$$

$$\Delta TS = P_0 * Q_0 * K\,(1 + 0.5Z\eta)$$

where P_0 and Q_0 are the initial equilibrium market-clearing price and quantity respectively, Z is the percentage reduction in price from the supply shift defined as $Z = K\varepsilon / (\varepsilon + \eta)$, K is the vertical supply shift defined as the unit cost difference before and after the eradication of disease expressed as a proportion of price and ε and η are the price elasticities of supply and demand.

An economic spreadsheet model designed in Excel 5.0 for Windows was used to estimate the economic surplus. This was performed in two steps. In the first step, the data simulated by the epidemiological model were entered into the spreadsheet along with other data (e.g. calving rates, cattle herd structure and composition, off-take, meat and milk yield per cattle head, market prices, etc.) to calculate the production losses incurred under each scenario. These production losses were used to approximate the changes in economic surplus caused by the disease. The direct costs or economic losses incurred comprised the sum of the production losses and the control costs incurred under each scenario. These were compared with the baseline situation of no intervention to establish the incremental benefits and costs. The incremental costs are of two types as follows:

a) new costs incurred that would not have been incurred under the existing situation

b) any livestock revenues foregone that are no longer earned as a result of the intervention.

For the scenarios considered, no production losses are sacrificed, so incremental costs are limited to the new costs of each scenario. Incremental benefits, defined as the change in total value of production losses between scenarios, are also of two types as follows:

a) increased revenues from improved productivity

b) savings in costs avoided.

In the second step, the incremental or economic surplus changes were used as inputs into the spreadsheet to re-estimate the net benefits. The annual costs and benefits were then projected over time and discounted at 12% over a twelve year time period to compute the BCR and NPV as follows:

$$BCR = \sum_{t=1}^{n} [B^t / (1 + i)^t] \,/\, [C^t / (1 + i)^t] \quad (\text{for } t = 1, 2, \ldots, n)$$

$$NPV = \sum_{t=1}^{n} B_t - C_t / (1 + i)^t \quad (\text{for } t = 1, 2, \ldots, n)$$

where B_t is benefits in year t, C_t is costs in year t, i is discount rate and n is the number of years in the future. The BCR measures the economic efficiency of each scenario whereas the NPV measures the economic feasibility of the programme. The larger the BCR and NPV, the more efficient and feasible the scenario.

Scenarios

The four scenarios considered are described below.

No intervention

No intervention is defined as no vaccination, no movement control and no slaughter. Thus, there is no effort to reduce the number of susceptible animals, contact rates or the number of animals shedding infectious material.

Institutionalised mass vaccination

In this scenario, a stable and homogenous pattern of sub-optimal immunisation is practiced. Observations show that on average, countries practicing institutionalised vaccination cover about 30% of the national herd per year (21). In the first run of this scenario, a 24% immunisation rate is used. This is equivalent to 30% vaccination coverage when an 80% success rate is assumed. A second run of this scenario was completed using a 30% immunisation rate equivalent to a 37.5% vaccination rate.

Intensive mass vaccination

Vaccination activity is assumed to be maintained at a high level and equally applied across populations in a homogeneous manner. This massive mobilisation of resources allows for higher coverage. In the model, a 60%

annual immunisation rate is used. This is equivalent to 75% vaccination coverage when an 80% success rate is assumed.

Epidemio-surveillance and targeted vaccination

Epidemio-surveillance alone will not eradicate disease. However, this may be achieved by targeting problem areas with intensive interventions comprising surveillance and effective disease detection. This scenario combines a surveillance programme with a period of two years of mass vaccination (37.5% diffuse national coverage) to suppress disease followed by a four-year period of targeted vaccination (75% coverage of selected populations) that only covers sub-populations identified by the surveillance activity as infected after the mass vaccination phase.

Data and assumptions

The data used in the economic spreadsheet model originated from several sources. Data on disease prevalence, incidence, mortality, vaccinations and herd immunity were simulated using the epidemiological model. Data on calving rates, cattle herd composition and structure, off-take, meat and milk yield per cattle head, market prices, demand and supply elasticities, discount rates, etc. were obtained from secondary sources (25).

Annual costs of vaccination and surveillance were obtained from the consolidated PACE Ethiopia annual work plan and cost estimate (WPCE). The WPCE covers costs for the first five years, e.g. vehicles, laboratory and field equipment, office materials and utilities, personnel salaries, allowances and administrative overheads, and vaccine supplies. Costs for subsequent years were projected from the average of these costs at an increase of 5% per year up to year 12 for the 30% vaccination scenario. For the 37.5% and 75% vaccination rates, the 30% costs were assumed to continue, but increased by 7.5% and 15% respectively, to reflect the additional costs that would be incurred at higher levels of vaccination. The surveillance scenario combined the costs of the 37.5% mass vaccination for the first two years and the cost of the 75% targeted vaccination for the next four years. Annual costs for subsequent years were calculated as the mean of these years and then projected to increase at 5% per year.

Due to the paucity of data available, a deliberately conservative approach was taken to limit benefits or economic surplus to beef and milk only and to exclude animal traction and manure. Milk losses were estimated from the number of reproductive females in the cattle herd. The proportion of breeding females and the calving rate were assumed to be 34% and 55%, respectively (25). Milk yield per cow per year was assumed to be 209 kg (Food and Agriculture Organization production statistics as of January 2003 [http://www.fao.org/waicent/]). The rate of milk reduction due to morbidity was assumed to be 90%, while the rate of milk reduction due to dead cows was 100%. Beef losses were estimated for each of the age classes of cattle, i.e. adult, immature and calves. The rate of beef loss due to morbidity was estimated by the epidemiological model to be 34%. A mortality rate of 15% was assumed for calves while the mortality rate for immature and adult cattle was 4% (24). Beef yield per cattle head per year was 130 kg with an off-take rate of 12%. Market prices, demand and supply elasticities for cattle products and discount rates (Table I) were obtained from secondary sources (4, 19). Sensitivity analyses were conducted to determine how changes in these variables affect the benefits from rinderpest surveillance and vaccination. Market prices, elasticities and the discount rate were assumed to rise by 10% and 20% from the original values used in the model.

Results

The epidemiological model was designed to generate the data required by the economic model. The model simulated data on morbidity, mortality, incidence, prevalence and immunity levels. A morbidity rate of between 4% and 17% and a mortality rate of between 2% and 8% was generated for the no intervention scenario. Morbidity and mortality rates for the other scenarios are between 0% and 9% and 0% and 4%, respectively. These data together with outbreaks, incidence and prevalence rates are presented in Table II. The total number of cases per day is plotted in Figure 2 for typical outcomes under the first three scenarios. If the disease faded out or was eradicated from a sub-population, this took place within the first two years (i.e. by day 685). In the scenarios modelled, if the disease survived beyond two years in a sub-population, endemic persistence was observed as long as the vaccination rate was not increased. Note that in the case of a 37.5% annual vaccination rate, two example

Table I
Market prices, elasticities and discount rates used in the economic spreadsheet model

Variable	Original situation	10% increase	20% increase
Market prices (€/kg)			
Beef	1.740	1.910	2.090
Milk	0.250	0.280	0.300
Elasticities			
Supply			
Beef	0.104	0.114	0.125
Milk	0.220	0.242	0.264
Demand			
Beef	– 0.500	– 0.550	– 0.600
Milk	– 0.050	– 0.055	– 0.060
Discount rate	12.000	13.200	14.400

Table II
Epidemiological data used in the economic spreadsheet model

Year	Total outbreaks	Morbidity (%)	Mortality (%)	Average incidence	Average prevalence	Average herd immunity
No intervention						
1	100	16.51	8.14	0.24656	0.00222	0.65614
2	0	4.22	2.11	0.06325	0.00056	0.64101
3	71	8.36	4.32	0.12675	0.00114	0.61994
4	71	7.67	3.83	0.11503	0.00103	0.57959
5	0	5.71	2.93	0.08638	0.00077	0.56532
6	71	7.81	3.79	0.11783	0.00106	0.54601
7	71	6.94	3.50	0.10441	0.00093	0.52809
8	0	6.72	3.42	0.10141	0.00091	0.51868
9	71	7.26	3.68	0.10935	0.00098	0.50772
10	71	6.97	3.53	0.10496	0.00094	0.49882
11	0	6.91	3.50	0.10415	0.00093	0.49287
12	71	7.11	3.61	0.10722	0.00096	0.48709
30% mass vaccination						
1	100	8.74	4.26	0.12997	0.00119	0.66110
2	3	1.55	0.79	0.02342	0.00021	0.66380
3	57	2.14	1.06	0.03201	0.00029	0.63829
4	57	2.47	1.26	0.03729	0.00034	0.63356
5	57	1.75	0.88	0.02623	0.00024	0.62090
6	57	2.50	1.27	0.03768	0.00034	0.61842
7	57	1.93	0.97	0.02904	0.00026	0.61431
8	57	2.28	1.15	0.03432	0.00031	0.61250
9	57	2.10	1.06	0.03157	0.00028	0.61127
10	57	2.17	1.09	0.03263	0.00029	0.61033
11	57	2.14	1.09	0.03231	0.00029	0.60968
12	57	2.16	1.09	0.03251	0.00029	0.60955
37.5% mass vaccination						
1	100	7.30	3.56	0.10861	0.00099	0.66455
2	2	0.92	0.47	0.01395	0.00013	0.67078
3	36	0.78	0.38	0.01158	0.00010	0.64980
4	36	1.09	0.53	0.01626	0.00015	0.64033
5	36	0.84	0.42	0.01260	0.00011	0.63341
6	36	0.92	0.45	0.01363	0.00012	0.62890
7	36	0.92	0.45	0.01371	0.00012	0.62639
8	36	0.94	0.46	0.01405	0.00013	0.62525
9	36	0.90	0.44	0.01343	0.00012	0.62417
10	36	0.91	0.45	0.01360	0.00012	0.62357
11	36	0.92	0.45	0.01366	0.00012	0.62314
12	36	0.92	0.45	0.01378	0.00013	0.62313
Intensive mass vaccination						
1	43	0.01	0.03	0.04652	0.00043	0.69277
2	2	0.00	0.00	0.00017	0.00000	0.72994
3	0	0.00	0.00	0.00000	0.00000	0.74005
4	0	0.00	0.00	0.00000	0.00000	0.74458
5	0	0.00	0.00	0.00000	0.00000	0.74661
6	0	0.00	0.00	0.00000	0.00000	0.74752
7	0	0.00	0.00	0.00000	0.00000	0.74794
8	0	0.00	0.00	0.00000	0.00000	0.74812
9	0	0.00	0.00	0.00000	0.00000	0.74820
10	0	0.00	0.00	0.00000	0.00000	0.74824
11	0	0.00	0.00	0.00000	0.00000	0.74826
12	0	0.00	0.00	0.00000	0.00000	0.74827
Epidemio-surveillance and targeted vaccination						
1	71	7.30	3.56	0.10861	0.00099	0.66455
2	0	0.92	0.47	0.01395	0.00013	0.67078
3	43	0.00	0.00	0.00043	0.00043	0.69277
4	2	0.00	0.00	0.00000	0.00000	0.72994
5	0	0.00	0.00	0.00000	0.00000	0.74005
6	0	0.00	0.00	0.00000	0.00000	0.74458
7	0	0.00	0.00	0.00000	0.00000	0.67497
8	0	0.00	0.00	0.00000	0.00000	0.55213
9	0	0.00	0.00	0.00000	0.00000	0.45165
10	0	0.00	0.00	0.00000	0.00000	0.36945
11	0	0.00	0.00	0.00000	0.00000	0.30222
12	0	0.00	0.00	0.00000	0.00000	0.24722

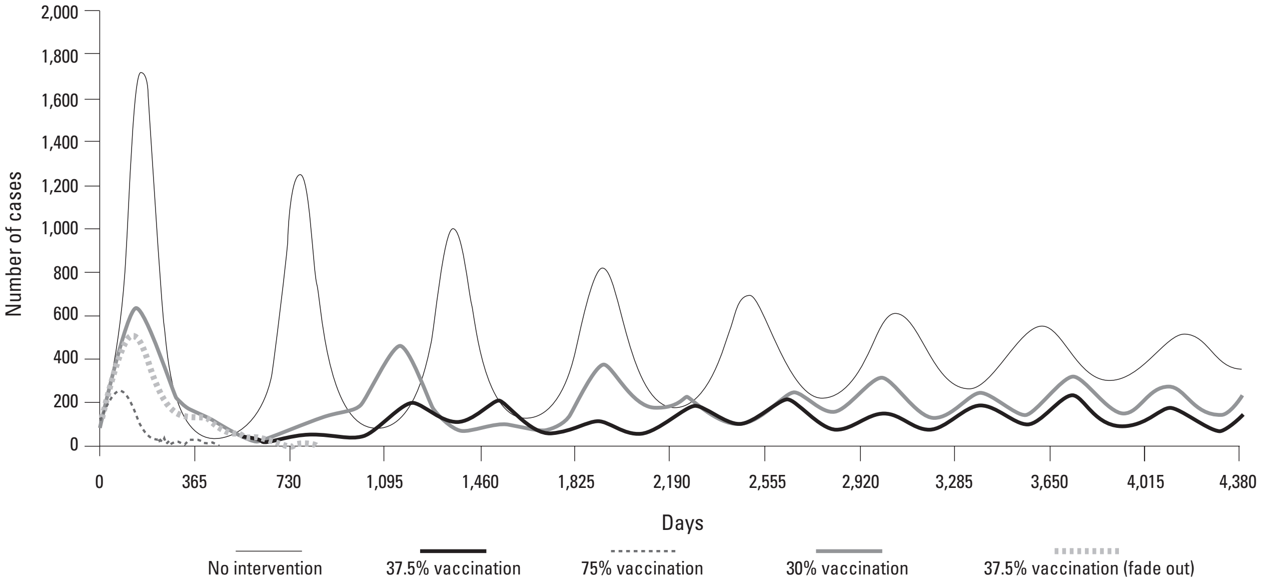

Fig. 2
Plot of common outcomes of the no intervention strategy and the three immunisation rates used (30%, 37.5% and 75% annual vaccination coverage)

curves are presented. The first is an example of persistence and the second is an example of a stochastic fade-out. Both of these curves nearly overlay each other in the first 600 days. Disease either fades out at about 600 days or survives this critical trough to persist endemically. Increasing vaccination depresses the height of the curves and reduces the inter-epidemic period. After year two, the inter-epidemic period is 1.56 and 0.99 years for the no vaccination and 37.5% vaccination scenarios, respectively. Incorporating moderate levels of vaccination using the seasonal sine model disrupted the smooth oscillation evident in the no intervention scenario. When vaccination rates above 37.5%, but less than 50% were entered, intermediate periods of disease persistence between three and five years were observed.

Without intervention, the disease persists in 71 of the 100 sub-populations (Table II) for the length of the model (twelve years), but fades out in 29 sub-populations within two years. With 30% mass vaccination (24% immunisation rate), the disease persists in 57 of the 100 affected sub-populations and fades out in 43 sub-populations within two years. Increasing vaccination coverage to 37.5% reduces the number of endemic communities to 36, or about half the number of endemic foci present in the no intervention model. With intensive mass vaccination, the disease is eradicated from all sub-populations within two years. In the epidemio-surveillance and targeted vaccination scenario, the first two years of the 37.5% vaccination scenario is combined with a second phase of four years of targeted vaccination restricted to the remaining infected communities. The disease is still present in 36 sub-populations after two years of 37.5% vaccination coverage, but is fully eradicated from these communities by the four-year phase of targeted vaccination. By the end of year four, there are no reports and vaccination ceases at the end of year six when provisional freedom can be declared to the World Organisation for Animal Health (OIE).

The total economic loss (valued in terms of beef and milk only) incurred without intervention is estimated at €3.46 million compared to €1.37 and €0.95 million with 30% and 37.5% vaccination coverage, respectively (Table III). Total losses increase with lower levels of vaccination coverage. Increasing vaccination coverage from 0% to 30% would reduce total losses by €2.20 million. This is equivalent to an economic gain. A further 7.5% increase in vaccination coverage reduces the losses incurred when there is no intervention by €2.62 million. Adopting a surveillance and epidemiologically targeted vaccination strategy where the vaccination activity is restricted to infected sub-populations narrows the losses significantly, suggesting that this is the optimal vaccination coverage required for rinderpest eradication. However, some losses, equivalent to €0.74 million, would be incurred under the surveillance scenario, because of the initial disease incidence, the continuous efforts to search for disease and the additional costs associated with this. Note that most of the economic losses occur during the first year. Without intervention and with 30% and 37.5% vaccination rates, the losses are associated with disease persistence and endemicity, consistent with the fact that rinderpest would remain in 36 to 71 of the 100 sub-populations modelled. Annual vaccination rates in excess of 37.5% are associated with a significant decline in losses. For targeted vaccination and surveillance, the annual losses decline significantly to zero after the first two to three years.

Reducing the incidence of rinderpest through vaccination and/or surveillance increases the total benefit to society. These benefits go to producers as increased products and reduced production costs (higher profit margins) and to consumers as reduced market prices due to increased supply. The producer and consumer surplus derived from each scenario is presented in Table IV. The change in total surplus is the sum of the changes in consumer and producer surplus and equals €2.19 million for the 30% vaccination scenario. A 37.5% vaccination coverage would increase total societal gains to €2.61 million. Adopting a more intensive vaccination strategy with coverage of 75% would contribute a total gain to society of €3.42 million. Producers would be the beneficiaries of 52% of this gain while consumers would have a 48% benefit. The estimated societal gains resulting from an epidemio-surveillance strategy of €2.82 million would be shared equally between producers and consumers.

The NPVs and BCRs are presented in Table V. All the scenarios are economically viable with positive NPVs and BCRs greater than one. Intensive vaccination at 75% and surveillance are however preferable to the other two scenarios. The BCRs are 5.08 and 3.68 respectively compared to 1.74 for 30% vaccination and 2.63 for 37.5% vaccination. Net benefits range from €0.57 million for the 30% vaccination scenario to €2.47 million for the intensive mass vaccination scenario. The discounted NPVs range from €0.56 million to €1.70 million. Note that doubling the

Table III
Economic losses incurred under various rinderpest surveillance and vaccination scenarios in Ethiopia (in thousands of euros)

Year	Scenarios No intervention	Mass vaccination (30% coverage)	(37.5% coverage)	Intensive mass vaccination (75% coverage)	Epidemio-surveillance and vaccination
1	1,370	691	636	145	718
2	69	32	21	0	24
3	234	57	20	0	1
4	146	74	33	0	0
5	170	60	30	0	0
6	247	78	28	0	0
7	222	62	30	0	0
8	181	64	27	0	0
9	217	62	29	0	0
10	215	68	32	0	0
11	195	64	31	0	0
12	198	62	30	0	0
Total	**3,464**	**1,374**	**947**	**145**	**743**

Table IV
Economic surplus from rinderpest surveillance and vaccination in Ethiopia (in thousands of euros)

Economic surplus	Scenarios Mass vaccination (30% coverage)	(37.5% coverage)	Intensive mass vaccination (75% coverage)	Epidemio-surveillance
ΔPS	937	1,245	1,789	1,419
Percentage	42.86	47.63	52.00	50.40
ΔCS	1,249	1,369	1,627	1,397
Percentage	57.14	52.37	48.00	49.60
ΔTS	2,186	2,614	3,417	2,816
Percentage	100.00	100.00	100.00	100.00

ΔPS: change in producer surplus
ΔCS: change in consumer surplus
ΔTS: change in total surplus

Table V
Net present values and benefit cost ratios from rinderpest surveillance and vaccination in Ethiopia (in thousands of euros)

Economic surplus	Scenarios Mass vaccination (30% coverage)	(37.5% coverage)	Intensive mass vaccination (75% coverage)	Epidemio-surveillance
Undiscounted benefits	2,187	2,613	3,417	2,818
Undiscounted costs	1,617	1,278	943	886
Net benefits	570	1,335	2,474	1,932
Discounted benefits	1,313	1,537	2,119	1,589
Discounted costs	755	585	416	432
Net present value	558	952	1,703	1,156
Benefit-cost ratio	**1.74**	**2.63**	**5.08**	**3.68**

vaccination coverage from 37.5% to 75% results in a two-fold increase in both the NPVs and the BCRs. Vaccination at a rate of 37.5% for the first two years and at 75% for the next four years, followed by surveillance, would yield a four-fold return to the investment with a NPV of €1.2 million. The implementation of a rinderpest surveillance programme is thus an economically viable activity.

Sensitivity analysis

Results of sensitivity analyses of changes in market prices, demand and supply elasticities on economic losses are presented in Table VI. A 10% and 20% rise in the market prices of beef and milk resulted in similar proportional increases in economic losses for all scenarios. However, when the demand and supply elasticities increased by 10% and 20%, economic losses declined insignificantly for all scenarios. As shown in Table VII, the value of the economic surplus increased at a similar proportion as the increase in market prices of beef and milk. Total economic surplus increased from €2.2 million (original situation) to €2.4 million and €2.6 million with a 10% and 20% increase in price, respectively, for 30% vaccination coverage. For the epidemio-surveillance scenario, economic surplus increased from €2.8 million to €3.1 million and €3.4 million for a 10% and 20% increase in price, respectively (Table IV). A 10% and 20% increase in demand and supply elasticities reduced economic surplus by 1.5% to 4.0% respectively for all scenarios (Table VII).

Increased market prices of beef and milk had a very positive effect on returns to investment. The NPV increased by 25% to 45% for all scenarios except the 75% vaccination coverage, which increased by 7% (Table VIII). The BCR increased for all scenarios with a 10% increase in beef and milk prices. With a 20% increase in the prices of beef and milk however, the increase in BCR was not as high (Table VIII). For all scenarios, an increase in the demand and supply elasticities resulted in a decrease in NPVs and BCRs (Table IX). When the discount rate was increased by 10% and 20%, NPV declined for all scenarios (Table X). However, an increase in the discount rate resulted in an increase in BCR.

Briefly, this sensitivity analysis reveals that an increase in market prices for beef and milk would increase the value of economic loss, the economic surplus and returns to investments in terms of NPVs and BCRs. An increase in demand and supply elasticities for beef and milk would decrease the value of economic losses. This would also have a negative effect on economic surplus and NPVs. The effect of an increase in the discount rate is to reduce returns to investments with lower NPVs and BCRs.

Table VII
Sensitivity analysis: economic surplus from rinderpest surveillance and vaccination in Ethiopia (changes in prices and elasticities) (in thousands of euros)

Scenarios	Change in prices of beef and milk 10% increase	 20% increase	Change in demand and supply elasticities 10% increase	 20% increase
Mass vaccination				
30% coverage				
ΔPS	1,032	1,125	884	831
ΔCS	1,376	1,501	1,257	1,256
ΔTS	2,408	2,626	2,141	2,087
37.5% coverage				
ΔPS	1,369	1,493	1,189	1,134
ΔCS	1,507	1,644	1,377	1,377
ΔTS	2,876	3,137	2,566	2,511
Intensive mass vaccination (75% coverage)				
ΔPS	1,968	2,147	1,701	1,640
ΔCS	1,791	1,954	1,635	1,635
ΔTC	3,759	4,101	3,336	3,275
Epidemio-surveillance				
ΔPS	1,563	1,706	1,366	1,312
ΔCS	1,538	1,678	1,407	1,407
ΔTC	3,101	3,383	2,773	2,719

ΔPS: change in producer surplus
ΔCS: change in consumer surplus
ΔTS: change in total surplus

Table VI
Sensitivity analysis: economic losses incurred under various rinderpest surveillance and vaccination scenarios with changes in market prices and elasticities (in thousands of euros)

Scenarios	Changes in market prices 10% increase	 20% increase	Changes in demand and supply elasticities 10% increase	 20% increase
No intervention	3,919	4,276	3,512	3,453
Mass vaccination				
30% coverage	1,511	1,649	1,370	1,365
37.5% coverage	1,043	1,138	946	942
Intensive mass vaccination (75% coverage)	160	174	176	177
Epidemio-surveillance	817	892	739	734

Table VIII
Sensitivity analysis: net present values and benefit-cost ratios with changes in market prices (in thousands of euros)

Economic surplus	Scenarios Mass vaccination (30% coverage)	 (37.5% coverage)	 Intensive mass vaccination (75% coverage)	 Epidemio- surveillance
10% increase in prices of beef and milk				
Undiscounted benefits	2,408	2,876	3,760	3,102
Undiscounted costs	1,289	953	1,827	1,009
Net benefits	1,119	1,923	1,933	2,092
Discounted benefits	1,445	1,690	2,332	1,748
Discounted costs	655	485	509	288
Net present value	790	1,205	1,823	1,459
Benefit-cost ratio	**2.21**	**3.49**	**4.58**	**6.06**
20% increase in prices of beef and milk				
Undiscounted benefits	2,627	3,137	4,101	3,383
Undiscounted costs	1,617	1,281	945	874
Net benefits	1,010	1,856	3,156	2,509
Discounted benefits	1,577	1,844	2,545	1,907
Discounted costs	757	587	417	433
Net present value	819	1,257	2,128	1,474
Benefit-cost ratio	**2.08**	**3.14**	**6.10**	**4.41**

Table IX
Sensitivity analysis: net present values and benefit-cost ratios with changes in demand and supply elasticities (in thousands of euros)

Economic surplus	Scenarios Mass vaccination (30% coverage)	 (37.5% coverage)	 Intensive mass vaccination (75% coverage)	 Epidemio- surveillance
10% increase demand and supply elasticities				
Undiscounted benefits	2,141	2,566	3,336	2,772
Undiscounted costs	1,617	1,281	945	874
Net benefits	524	1,285	2,391	1,898
Discounted benefits	1,283	1,515	2,058	1,558
Discounted costs	757	587	417	433
Net present value	526	918	1,641	1,125
Benefit-cost ratio	**1.69**	**2.56**	**4.94**	**3.60**
20% increase in demand and supply elasticities				
Undiscounted benefits	2,088	2,511	3,275	2,719
Undiscounted costs	1,617	1,281	945	874
Net benefits	471	1,230	2,330	1,845
Discounted benefits	1,249	1,469	2,017	1,523
Discounted costs	757	587	417	433
Net present value	492	882	1,600	1,090
Benefit-cost ratio	**1.65**	**2.50**	**4.84**	**3.52**

Table X
Sensitivity analysis: net present values and benefit-cost ratios with changes in the discount rate (in thousands of euros)

	Scenarios			
Economic surplus	**Mass vaccination**		**Intensive mass vaccination**	**Epidemio**
	(30% coverage)	**(37.5% coverage)**	**(75% coverage)**	**-surveillance**
10% increase in discount in rate				
Discounted benefits	1,262	1,473	2,043	1,518
Discounted costs	709	548	387	406
Net present value	553	925	1,656	1,112
Benefit-cost ratio	**1.78**	**2.69**	**5.28**	**3.74**
20% increase in discount rate				
Discounted benefits	1,215	1,415	1,972	1,452
Discounted costs	665	512	360	382
Net present value	550	903	1,612	1,070
Benefit-cost ratio	**1.83**	**2.76**	**5.48**	**3.80**

Conclusion and implications

Disease intelligence information is essential for developing a cost-effective animal disease eradication programme. A good epidemio-surveillance system can provide such information and make it possible to plan a selective low-cost intervention as opposed to a blind intervention using mass vaccination. This *ex-ante* economic study used epidemiological and economic modelling to establish the economic feasibility of several rinderpest eradication scenarios in Ethiopia.

The results show that either surveillance or intensive mass vaccination against rinderpest are economically preferable to institutionalised sub-optimal mass vaccination. Although vaccination levels below 37.5% are also economically viable, from an epidemiological standpoint, they are inadequate to eradicate disease. The 30% vaccination rate had such a limited impact that it is unlikely that such vaccination levels would contribute to the benefit of disease eradication. This is why the mass vaccination scenario was also run using 37.5% annual vaccination. At this level, mass vaccination eliminated about half of the endemic foci expected to occur in the absence of any vaccination and contributed an additional €394,000 to the NPV. When a 75% vaccination rate was used, an additional €1.15 million in NPV was added to the benefits. This primarily resulted from increased benefits in the first year as a result of the predicted rapid eradication of rinderpest.

Institutionalised mass vaccination was attempted in Ethiopia in the early 1990s and failed to eradicate the disease. In one 15-month period, an estimated 27 million cattle were vaccinated. The reason for the failure was that intensive mass vaccination was logistically too complex to manage in an effective manner to ensure that all sub-populations were equally covered. As a result, disease persisted in selected locations, mainly remote pastoral areas. In the absence of a comprehensive surveillance programme, these foci were poorly characterised. A decision was taken to enhance surveillance and target vaccination in 1994. This strategy proved to be realistic. The last case of rinderpest in Ethiopia was recorded in 1996. Although either intensive mass vaccination or surveillance with targeted vaccination are theoretically economically comparable, surveillance with targeted vaccination has proved to be a much more achievable strategy.

An epidemiological surveillance system has additional advantages, beyond economic superiority, over indiscriminate mass vaccination campaigns in eradication programmes. An active surveillance system improves the performance and image of the veterinary department by maintaining a continuous link between farmers, field workers and veterinarians. Improved and regular communication between stockowners and veterinary staff is essential for promptly identifying other key animal health problems and responding to them appropriately.

An effective epidemiological surveillance system is also a requirement of the OIE for the verification of rinderpest eradication (20). Countries that cannot demonstrate that an effective surveillance system is in place that would be capable of detecting rinderpest if the disease were present will not be granted rinderpest infection-free status for the purposes of international trade. As a result, epidemio-surveillance systems are a requirement for countries wishing to reap the full economic benefit of rinderpest eradication regardless of the intervention strategy used to eradicate the disease.

Analyse économique *ex-ante* de la surveillance des maladies animales

N.E. Tambi, W.O. Maina & J.C. Mariner

Résumé

Une analyse économique *ex-ante* a été réalisée pour évaluer quatre stratégies possibles de contrôle et d'éradication de la peste bovine et un scénario de non-intervention, dans une population bovine comparable par sa taille au cheptel éthiopien. Les trois premières stratégies envisagent une vaccination de masse, à différents niveaux de couverture, tandis que la quatrième est un programme combinant la surveillance et la vaccination ciblée des sous-populations infectées. L'impact de chaque scénario sur la maladie a été estimé à partir d'un modèle mesurant le passage d'un état de transmissibilité de la maladie à un autre (susceptible, exposé, infecté et guéri) dans une population ouverte, en fonction de paramètres estimés pour la lignée 1 du virus de la peste bovine. Les méthodes d'analyse bénéfice-coût ont servi à évaluer les bénéfices escomptés ainsi que les dépenses supplémentaires entraînées par le programme d'éradication de la peste bovine en Éthiopie. La valeur sociétale actualisée nette et le ratio bénéfice-coût ont été calculés. Si les quatre stratégies d'intervention présentent un ratio bénéfice-coût supérieur à un, le scénario de vaccination massive et intensive (assurant une couverture vaccinale de 75 % du cheptel) et celui associant la surveillance et la vaccination ciblée s'avèrent les plus intéressants du point de vue économique. Ils présentent respectivement un ratio bénéfice-coût de 5,08 et de 3,68. L'analyse de sensibilité a révélé qu'une augmentation des cours du marché de la viande bovine et du lait se traduit par des pertes économiques plus élevées et par une augmentation des excédents et de la rentabilité de l'investissement en termes de valeur actualisée nette et de ratio bénéfice-coût. Une élasticité accrue de l'offre et de la demande de viande bovine et de lait réduit au contraire les pertes économiques, tout en ayant un impact négatif sur les excédents et sur la valeur actualisée nette. Un taux d'escompte en hausse réduit la rentabilité des investissements ayant une faible valeur actualisée nette et un ratio bénéfice-coût bas.

Les auteurs rappellent qu'une vaccination de masse couvrant 75% de la population bovine a été tentée en Éthiopie au début des années 1990, sans réussir à éradiquer la peste bovine en raison des difficultés logistiques ayant empêché la mise en œuvre concrète du dispositif. Le programme mis en place par la suite, combinant la surveillance épidémiologique et la vaccination ciblée, a sans doute permis d'éradiquer la peste bovine en Éthiopie. Les auteurs en concluent que la surveillance épidémiologique associée à la vaccination ciblée est une stratégie à la fois rationnelle au plan économique, réaliste dans la pratique et rentable, dans la mesure où ses bénéfices vont au-delà de la simple éradication de la peste bovine.

Mots-clés

Analyse bénéfice-coût – Analyse économique ex-ante – Excédent pour le consommateur et pour le producteur – Modélisation épidémiologique – Surveillance des maladies animales – Vaccination contre la peste bovine.

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Análisis económico *ex-ante* de la vigilancia zoosanitaria

N.E. Tambi, W.O. Maina & J.C. Mariner

Resumen

Los autores presentan un análisis económico realizado *ex-ante* en el que, suponiendo una población bovina de tamaño similar a la cabaña etíope, evalúan cuatro estrategias alternativas de intervención para controlar y erradicar la peste bovina y las comparan también con la hipótesis de no intervención. Dichas estrategias consistían en tres niveles distintos de cobertura con vacunaciones masivas y un cuarto programa de vigilancia en el que sólo se vacunaba a subpoblaciones infectadas. Utilizando un modelo de transmisión de la enfermedad que presuponía una población abierta y la transición entre los sucesivos estados «sensible», «expuesto», «infeccioso» y «convaleciente» de los animales, y estimando el valor de los parámetros a tenor de las características del linaje 1 del virus de la peste bovina, se cifraron los eventuales efectos de la enfermedad en cada uno de los cuatro supuestos considerados. Aplicando métodos de cálculo de la rentabilidad (cociente beneficios-costos), se analizaron las proyecciones de ganancias de plusvalía y costos estimadas a partir del programa de erradicación de la peste bovina en Etiopía. Se calcularon así el valor neto actualizado para la sociedad y el cociente entre beneficios y costos. Aunque el modelo económico indicaba que esos cocientes eran superiores a uno en todas las intervenciones contempladas, las hipótesis de vacunación masiva (con una cobertura del 75%) y de vigilancia con vacunación selectiva resultaban preferibles desde el punto de vista económico. Esas estrategias arrojaban cocientes de rentabilidad de 5,08 y 3,68 respectivamente. El análisis de sensibilidad reveló que un aumento en los precios de mercado de la carne y la leche bovinas incrementaba el valor de las pérdidas económicas, de la plusvalía y del rendimiento de las inversiones en términos de valor neto actualizado y de rentabilidad. Un aumento en la magnitud de la elasticidad de la demanda y la oferta de carne y leche bovinas resultaba en pérdidas económicas de inferior cuantía, y a la vez afectaba negativamente a la plusvalía y al valor neto actualizado. Por otro lado, un alza en el tipo de descuento deparaba un menor rendimiento de las inversiones, con cifras más bajas de valor neto actualizado y rentabilidad.

Los autores recuerdan que a principios de los noventa se intentó lograr en Etiopía una cobertura de vacunaciones masivas del 75%, aunque esa tentativa no culminó con la erradicación de la peste bovina porque la aplicación práctica del método presentaba demasiadas dificultades logísticas. Posteriormente se elaboró un programa eficaz de vigilancia y vacunas epidemiológicamente selectivas, que en apariencia sirvió para erradicar la enfermedad del país. Los autores concluyen que la vigilancia epidemiológica con vacunación selectiva constituye una estrategia realista y económicamente viable, cuyos beneficios trascienden además el ámbito de la erradicación de la peste bovina.

Palabras clave

Análisis económico ex-ante – Análisis de la rentabilidad – Elaboración de modelos epidemiológicos – Plusvalía del consumidor y el productor – Vacunación contra la peste bovina – Vigilancia zoosanitaria.

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