Using the Economic Surplus Model to Measure Potential Returns to International Livestock Research

The case of trypanosomosis vaccine research

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Executive summary

This report addresses issues surrounding measurement of the potential productivity gains from new livestock technologies and the returns to international livestock research. The approach, applicable to many livestock production constraints and technologies, integrates a herd simulation model to measure the potential size of impact of a new technology, geographic information systems (GIS) to predict where this impact is likely to be felt, and an economic surplus model to value it. The particular problem examined is trypanosomosis in cattle in Africa, and the potential research product is a multi-component vaccine. The results suggest that the potential benefits of trypanosomosis control, in terms of meat and milk productivity alone, are worth over US$ 700 million per year in Africa. The disease is costing livestock producers and consumers an estimated US$ 1.3 billion annually, without including productivity losses associated with less manure and traction due to the presence or risk of the disease. Given an adoption period of 12 years, a maximum adoption rate of 30%, a discount rate of 5%, and a 30% probability of the research being successful within 10 years, the net present value of the vaccine research is estimated at US$ 288 million, with an internal rate of return of 33%, and a benefit:cost ratio of 34:1. The results of this study will assist in research priority setting and have highlighted the need for further research aimed at better understanding who the beneficiaries of the vaccine will be, and how it will reach them.

1 Introduction

As resources for agricultural research and development become increasingly scarce worldwide (Anderson et al 1994), *ex ante* impact assessments of the potential benefits and costs of research investments are being used by more national and international research centres to aid in priority setting and resource allocation (Norton and Pardey 1987; Anderson 1992). The economic surplus model has been used to measure the benefits of crop research in inducing changes in supply (e.g. Norton et al 1987; Walker and Collion 1997). Relatively little work has been done on the economic returns to livestock research, particularly research applicable to different production systems and countries. The nature of livestock enterprises raises issues that do not apply to crop research, where the measurement of increases in productivity per hectare resulting from successful research is relatively straightforward.

The objectives of this study are to illustrate how:

- productivity impacts resulting from livestock research can be measured using a herd simulation model
- the results of this model can be extended spatially using geographic information systems (GIS) to determine the potential increase in livestock production that would result from adoption of a new technology
- an economic surplus model can be used to value the estimated productivity impacts.

The methodology developed in this study can be used to measure the benefits of alleviating constraints to livestock production and the potential returns to research and development approaches addressing those constraints. Here we use it to measure the potential benefits to control of African animal trypanosomosis and the benefits to one particular area of research, the development of a trypanosomosis vaccine.[1]

1. This report draws heavily on Kristjanson et al (1999).

2 Background

Trypanosomosis is an important constraint, if not the most important constraint, to livestock and mixed crop–livestock farming in tropical Africa. More than a third of the land area across Africa (8.7 million km^2) is infested with tsetse flies, where at least 46 million cattle are exposed to the risk of contracting tsetse-borne trypanosomosis, as are millions of sheep, goats, donkeys, camels and horses (Reid et al 1999). Ten years ago, African livestock producers and governments were spending US$ 30 million annually to treat animals exposed to this disease, administering 25–30 million curative and preventive treatments (Borne 1996). If one assumes an average of one annual treatment per animal at risk (at a cost of around US$ 1), this figure is now conceivably closer to US$ 46 million. By generally constraining farmers from the overall benefits of livestock to farming—efficient nutrient cycling, access to animal traction, income from milk and meat sales, access to liquid capital—trypanosomosis reduces both crop yields and areas cultivated. Taking into account the lower density of cattle found in tsetse-infested as compared to tsetse-free areas of Africa, and empirical estimates of the relationship between a country's stock of livestock and total agricultural output, Swallow (1997) estimated annual losses in income (i.e. gross domestic product) for the 10 African countries completely infested by tsetse to be in the range of US$ 192 to US$ 960 million.

Around 300 million out of 670 million people in Africa will be living in tsetse-infested areas by the year 2000 (R. Kruska, ILRI, unpublished data). The costs of human trypanosomosis (sleeping sickness) are extremely difficult to quantify. However, it has been estimated that at least 50 million people are at risk of contracting this killer disease (Kuzoe 1991).

The International Livestock Research Institute (ILRI) has devoted a considerable part of its past and current research budget to the development, refinement and application of technologies to aid livestock producers in controlling trypanosomosis. These technologies include the use of livestock breeds that tolerate the disease, control of tsetse fly numbers and use of curative or prophylactic trypanocidal drugs. Recent research results on the development and application of an anti-trypanosomosis vaccine by ILRI scientists and collaborators indicate that the problems associated with antigenic variation of the parasite surface coat can be overcome. The goal now is a multi-component vaccine with components aimed at both the parasite and the disease (ILRI 1997; ILRI 1998). Good progress has been made with the identification of antigens aimed at parasite control. In addition, parasite components that are involved in pathology such as anaemia and immunosuppression are being pursued as vaccine candidates. Some parasite components currently under consideration appear to be shared by different trypanosome species. What this means is that a vaccine based on these common parasite components would be effective against livestock trypanosomosis transmitted by tsetse flies in sub-Saharan Africa (the focus of this study) and livestock trypanosomosis transmitted by biting flies in North Africa, Asia and Latin America. Furthermore, development of an effective livestock vaccine would have major spillover benefits for the development of a vaccine for human trypanosomosis.

Direct losses from trypanosomosis in livestock include mortality, morbidity and impaired fertility, and the costs of implementing and maintaining tsetse fly and

trypanosomosis control operations. Indirect losses stem from farmers' responses to the perceived risk of the disease, including the reduction and, in some cases, the exclusion of livestock from tsetse-infested grazing lands, and reduced crop production due to insufficient animal draft power (ILRAD 1993). Previous attempts to quantify these indirect losses have been based on the assumption that marked differences in the density of cattle in similar agro-ecological zones are due to the presence of tsetse flies. Such estimates of the potential increases in cattle numbers range from 33 million head (Jahnke et al 1988) to 95 million head (FAO, cited in Hoste (1987)).

This study provides new evidence regarding the direct impact of trypanosomosis on the productivity of cattle in tsetse-infested areas of Africa and extrapolates using GIS to capture some of the indirect impacts as well. The approach integrates models of the biophysical, economic and spatial aspects of livestock disease in Africa.

3 Methodology

There are four stages to the analysis: 1) use of a herd simulation model to measure the impact of trypanosomosis control on productivity of cattle in terms of meat and milk output at a case study site in Ethiopia where tsetse control was applied; 2) linking data on tsetse distribution and livestock populations using GIS to determine the 'recommendation domain' for trypanosomosis interventions and extrapolate from the case study to all of sub-Saharan Africa (SSA); 3) use of an economic surplus model to measure the potential benefits of trypanosomosis control and to estimate the costs of the disease in terms of meat and milk productivity; and 4) use of these results to measure the potential economic returns to ILRI's trypanosomosis vaccine research.

Measuring the impact of trypanosomosis control on livestock productivity

Measures of livestock productivity such as reproduction and mortality provide a starting point for comparing the performance of herds exposed to differing levels of disease risk. However, to determine the economic value of productivity effects and to compare them across systems, productivity should be expressed in terms of outputs of meat and milk (Upton 1989). An updated version of a 10-year herd simulation model (von Kaufmann et al 1990; Itty 1995) was used to capture the dynamics of cattle production and to develop annual projections of herd growth and milk and liveweight offtake.

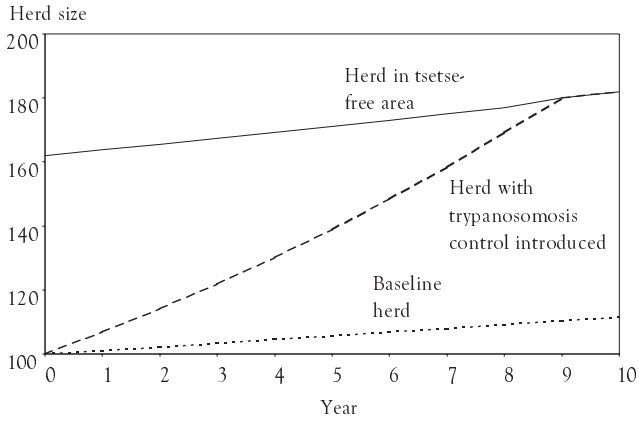
Data on livestock productivity and herd structure from field studies (described below) in Ghibe valley, Ethiopia, were used as inputs for the herd model. The model predicted annual herd milk and liveweight offtake both before and after tsetse control was introduced. Trypanocidal drugs were routinely applied to animals detected with trypanosomal parasitaemia for four years before the introduction of tsetse control, and over this period annual growth in herd size was 7.6%. The impact on productivity measured by the model thus represented the impact of tsetse control in a situation where farmers were already benefiting from routine chemotherapy. To simulate the impact of introducing tsetse control to a herd that may be more representative of the continental average, offtake was artificially increased to reduce the herd growth from 7.6% to 1.1% (estimated average herd growth for SSA (Winrock 1992)). To achieve this, a constant percentage offtake was added to each age group in year 1, with that for males (7.2%) double that for females (3.6%), (Table 1); thereafter, offtake rates were kept at these levels for the next 9 years for cattle up to 48 months of age, with the extra offtakes needed to maintain constant herd growth applied to the cattle above this age range. Following tsetse control the herd in Ghibe grew at 13.3% per year. The growth rate of this herd was likewise reduced by the same amount (6.5%) to 6.8% to measure the likely impact of tsetse control on the baseline herd. The herd was allowed to grow at this rate until year 9 when it was predicted that cattle numbers had reached a level consistent with the relative carrying capacity for a tsetse-free area (Figure 1).

Table 1. *Input values obtained from a survey of the effect of tsetse control on the productivity of a herd of cattle in Ghibe, south-west Ethiopia, and adapted for use in the herd model.*

		Baseline			Trypanosomosis control		
Age class (months)	Starting herd structure[a]	Mortality (%)[b]	Average disposal offtake[c] (%)	Body weight (kg)	Mortality (%)[b]	Average disposal offtake[c] (%)	Body weight (kg)
Females							
0–12	10.2	21[d]	3.6 (0)	75	9[d]	3.3 (0)	75
13–24	8.8	5	3.6 (0)	130	5	3.3 (0)	133
25–36	7.7	5	3.6 (0)	162	5	3.3 (0)	178
37–48	6.8	4	3.6 (0)	181	4	3.3 (0)	187
49–60	6.2	4	6.2 (0)	189	4	5.7 (0)	195
61–84	9.0	10	6.2 (0)	198	2.5	5.7 (0)	204
85–120	7.1	10	14.5 (10)	209	2.5	14.0 (10)	215
>120	5.8	15	16.2 (10)	209	15	15.7 (10)	215
Males							
0–12	9.9	21	9.7 (2.5)	84	9	9.1 (2.5)	85
13–24	8.3	5	9.7 (2.5)	136	5	11.6 (5)	139
25–36	7.3	5	7.2 (0)	167	5	11.6 (5)	184
37–48	6.3	4	10.7 (3.5)	206	4	12.6 (6)	226
49–60	5.3	4	19.2 (7)	223	4	18.4 (7)	242
61–84	1.1	10	89(4)	254	2.5	88(11)	273
85–120	0	10	100(4)	265	2.5	100(11)	285
>120	0	15	100(4)	265	15	100(11)	285

Female production	Baseline	Trypanosomosis control
Age at 1st calving (months)	38	37.5
Calving rate (%)[e]		
1st calving	65.2	68.0
< 9 years	73.3	76.8
≥ 9 years	81.6	86.5
Calving interval (days)		
1st calving	560	537
< 9 years	498	475
≥ 9 years	446	422
Lactation offtake (litres)[f]		
1st lactation	298	298
Other lactations	290	290
Lactation length (days)[f]		
1st lactation	310	310
Other lactations	277	277

a. Estimate of average population herd structure derived by running the baseline model for 10 years. The model was then re-run for 10 years for both baseline and trypanosomosis control models with this herd structure used as input to the model in year 0.
b. Same values assumed for males and females.
c. Observed disposal offtakes, given in parentheses, increased to those shown, averaged over 10 years, necessary to restrict annual growth of baseline herd to 1.1% and herd under trypanosomosis control to 6.8%. In addition, offtakes of 88–100% were substituted to remove from the herd males over 5 years of age for traction.
d. Includes values of 7.5% and 4.4%, for still births for baseline and control herds, respectively.
e. Calculated as 365/calving interval × 100.
f. For cows in neighbouring herds raising a calf that survived until the end of lactation.



Baseline herd growing at 1.1% per year; herd with trypanosomosis control introduced in year 0 growing at 6.8% per year until year 9; herd in tsetse-free area growing at 1.1% per year and starting with herd size of 162, equivalent to the estimated carrying capacity in tsetse-free areas.

Figure 1. *Simulated herds used in herd model.*

The difference in average herd live weight and annual milk and liveweight offtakes predicted by the model between the 'baseline' and the 'trypanosomosis control' cases, estimates the potential benefits over 10 years following introduction of trypanosomosis control to a representative herd in SSA. Thus, this measures the impact of an intervention applied in year 0 with benefits accruing over a 10-year period, and is not an estimate of the cost of trypanosomosis *per se*. To do this it was necessary to simulate a herd of a size that matched the carrying capacity of a tsetse-free area in year 0, growing at a rate of 1.1% per year (Figure 1), and to compare this herd with the baseline herd. Productivity levels achieved in Ghibe following introduction of tsetse control (Table 1) were also used in the simulation of this herd.

Additional outputs such as animal traction, manure and increased crop production were not valued and males (oxen) were excluded from the analysis when they reached 5 years of age.[2] This was achieved by setting offtake rates to 100% (Table 1).

Field data

A sentinel village herd of 90 Highland zebu cattle exposed to high levels of drug-resistant trypanosomes in the Ghibe valley, south-west Ethiopia, was monitored from March 1986 until February 1997 (Leak et al 1995). Cattle were weighed monthly and blood samples collected for the estimation of packed red cell volume (PCV) and detection of trypanosomes using the phase contrast/buffy-coat technique (Murray et al 1977). Throughout the period

2. The magnitude of the benefits from animal traction and manure can be substantial in many production systems in Africa. For example, ILCA (1987) estimated that, on average, traction and manure are worth 34% of the total value of livestock production.

animals with a PCV below 26% and found to be parasitaemic, or animals showing clinical signs of trypanosomosis were treated with diaminazene acetate (Berenil, Hoechst®, Germany) at 3.5 mg/kg body weight. At the time of sampling owners provided details of births, deaths and disposals during the previous month.

A tsetse control trial was started in January 1991 using a synthetic pyrethrod cypermethrin 'pour-on' (ECTOPOR®, Ciba-Geigy, Switzerland) applied monthly to cattle as described by Leak et al (1995). This resulted in a 95% reduction in the relative density of tsetse flies and less nuisance from biting flies. Treatments were given free of charge until November 1992 when a cost recovery scheme was introduced and farmers paid for each animal treated (Leak et al 1995). Monthly records were kept of the numbers of treated cattle.

Mean annual values of productivity variables (body weights, calving intervals etc) were calculated for the period before (1987–90) and after introduction of tsetse control (1992–96) as described by Rowlands et al (1999) (Table 1). Milk offtake was recorded monthly from 1989 to 1996 for cows in herds close to the area of control, and these were used to estimate milk offtake from the sentinel herd. The same average milk offtakes were assumed before and after tsetse control since there were no significant increases in calf body weight associated with tsetse control (Rowlands et al 1999), and trypanosomosis in individual cows did not significantly affect lactation offtake for human consumption (G.J. Rowlands, ILRI, unpublished data).

Annual rates of mortality and disposal were calculated for different age groups over 12-month periods. Separate rates of disposal were calculated for males and females and, in view of the small numbers in each age group, consecutive age groups were pooled as appropriate. As described above, these offtake rates were subsequently modified to restrict herd growth (Table 1).

The herd structure in 1990, the year before tsetse control began, was used to define the initial herd structure and the herd model was used to predict how the herd structure would change over the following 10 years. By year 10, the structure of the herd had reached an equilibrium; this was used to represent the structure of a 'population average' herd. This population average structure was used as the starting point for the different runs of the model reported in this study.

Extrapolating impact on livestock production spatially using GIS

In Africa, the likelihood of tsetse flies being present largely defines the risk of trypanosomosis in cattle. GIS was used to overlay data layers for the distribution of tsetse (Lessard et al 1990) and the density of cattle (Figure 2). The cattle density data layer was compiled from national census data reported for administrative units that varied widely in resolution (province, district, division etc) (Kruska et al 1995). A digital administrative boundary layer for the continent of Africa was acquired from FAO,[3] and the best available cattle population information for each country was attached. Cattle densities were then calculated for each administrative unit in the GIS (ESRI 1996). Areas with no cattle, such as protected areas and water bodies, were excluded.

3. Soil Resources Management and Conservation Service (AGLS), Land and Water Development Division.

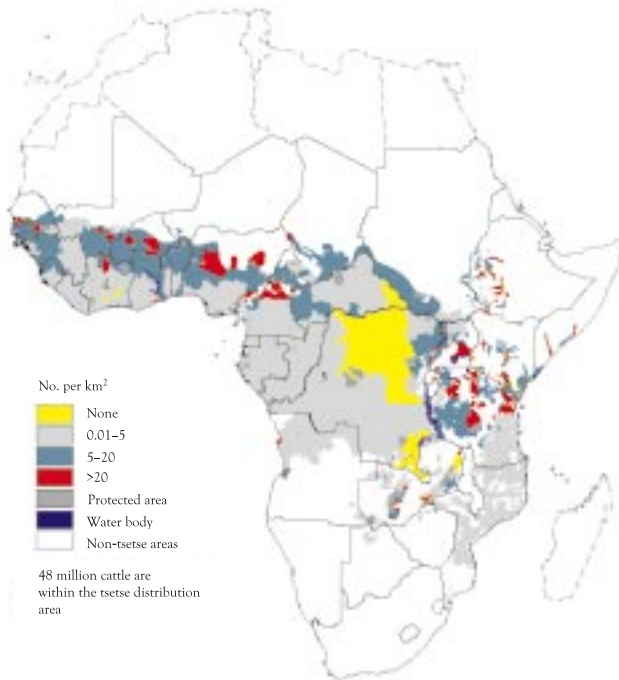


Figure 2. *Cattle density in tsetse areas in Africa.*

The results give a rough approximation of the 'recommendation domain', or target zone, for a potential trypanosomosis vaccine. An overlay of human population shows the number of people living within this recommendation domain and potentially affected by trypanosomosis (Figure 3).

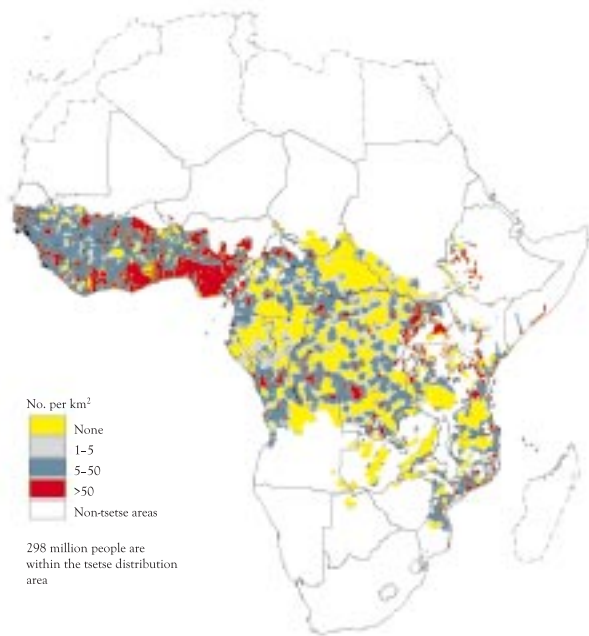


Figure 3. *Human population density in tsetse areas in Africa.*

Assessing potential benefits from trypanosomosis control using an economic surplus model

An economic surplus model (Alston et al 1995) can be used to measure the potential benefits of trypanosomosis control itself, as well as the potential benefits of and returns to research or development efforts aimed at alleviating the constraint. A partial-equilibrium,

comparative static model of a closed economy was used in the analysis, undertaken at a regional level. Assuming a closed economy implies that the adoption of a cost-reducing or yield-enhancing technology increases the supply of a commodity such as meat or milk. Because there is little or no international trade (an appropriate assumption for our regional as opposed to country-level analysis), the increase in supply reduces both the price of the commodity to consumers and the cost to producers. The simple case of linear supply and demand curves with parallel shifts was chosen. A review of studies of research benefits by Alston et al (1995) reveals that the majority of such studies use similar assumptions. Alston and Wohlgenant (1990) argue that when a parallel shift is used, as suggested by Rose (1980), the functional form is largely irrelevant, and that a linear model provides a good approximation to the true (unknown) functional form of supply and demand.

In Figure 4, D is the demand function for the product (meat or milk) and S_0 is the supply function for the product before the research-induced technical change (e.g. trypanosomosis control). The initial equilibrium price and quantity are P_0 and Q_0, respectively. Adoption of the new technology shifts the supply curve of meat or milk to S_1, resulting in a new equilibrium price and quantity of P_1 and Q_1, respectively. Gross annual research benefits are measured by the area between the two supply curves and beneath the demand curve.

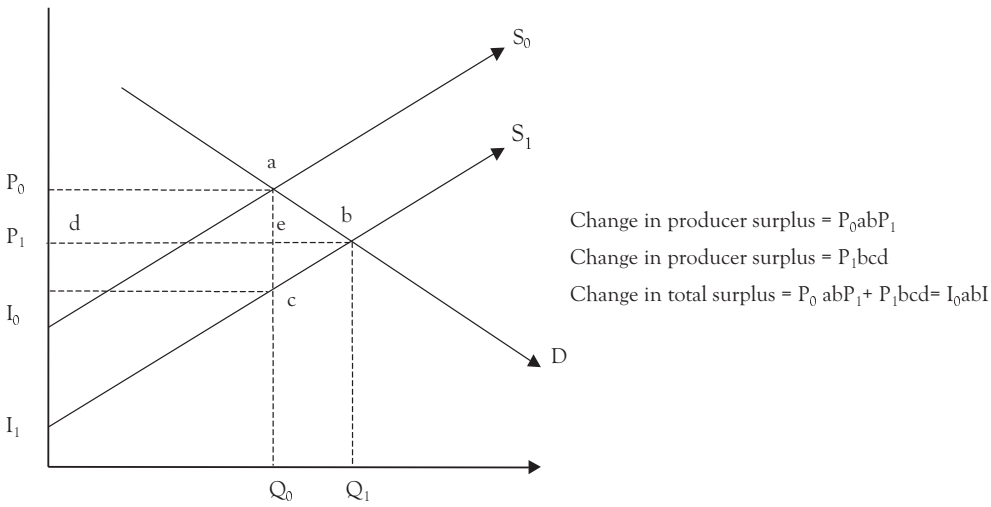


Figure 4. *Measuring gross annual research benefits (change in total surplus).*

This area represents the total increase in economic welfare (change in total surplus), and comprises both the changes in producer and consumer surplus resulting from the shift in supply. Consumers are better off because they consume more at a lower price. Although producers are receiving a lower price for their milk or meat, they are able to sell more, so their benefits increase (unless supply is perfectly elastic or demand is perfectly inelastic, in

which case their revenues remain the same). These effects are shown in Figure 4. The algebraic derivations of these surpluses are shown in Table 2. The change in total surplus can be thought of as the maximum potential benefits to a technology (trypanosomosis control); they would be actual benefits if the research was successful and fully adopted.

Table 2. *Calculation of change in total surplus due to trypanosomosis control.*

Parameter	Formula
Elasticity of supply	$\varepsilon = \partial Qs / Qs / \partial Ps / Ps$
Elasticity of demand	$\eta = \lvert \partial Qd / Qd / \partial Pd / Pd \rvert$
Gross proportionate productivity gain per head (%)	$E(Y) = (Q_1 - Q_0) / Q_0$
Gross cost change per tonne (%)	$C = E(Y)/\varepsilon$
Input cost change per head (%)	E(c)
Input cost change per tonne (%)	$i = E(c)/1 + E(Y)$
Net proportionate reduction in cost per tonne output (%)	$k = C - i$
Relative reduction in price	$Z = K \times \varepsilon / (\varepsilon + \eta)$
Price (US$/t)	P
Quantity (t)	Q_0
Change in total surplus (US$)	$k \times P \times Q_0 \times (1 + (0.5 \times k \times \eta))$
Change in consumer surplus (US$)	$Z \times P \times Q_0 \times (1 + (0.5 \times Z \times \eta))$
Change in producer surplus (US$)	$(k - Z) \times P \times Q_0 \times (1 + (0.5 \times Z \times \eta))$

Source: Adapted from Alston et al (1995).

The output from the herd simulation model provided the estimate of the proportionate increase in productivity per head, E(Y). E(Y) was thus measured empirically in terms of quantity (i.e. the horizontal shift in the supply curve, or distance eb in Figure 4), and translated into a common currency (US$) by calculating the distance ac in Figure 4, i.e. the vertical shift in the supply curve. Productivity gains were then converted to gross proportional reductions in cost per tonne of output (C) by dividing the estimated productivity gain by the elasticity of supply (Table 2). This is a gross reduction in output cost, because the changes in input costs (E(c)) associated with the introduction of trypanosomosis control also have to be considered. These include the cost of the control technology itself and, in some cases, the corresponding reduction in the use of other inputs (e.g. trypanocidal drugs). The net proportionate change in marginal cost per tonne of output (k) is derived by subtracting the effect of variable input cost changes associated with the use of the technology.

The technology or control measure is assumed, in this analysis, to be a vaccine. That is, we have assumed that a trypanosomosis vaccine will have the same effect on productivity that the pour-on technology had on productivity of cattle in the Ethiopian study. The main difference between the two technologies lies in their costs. We have also assumed that the vaccine will be available at a relatively low cost to the producer and that he or she, as in the case of the pour-on, will be able to reduce the amount of trypanocidal drugs used for

treatment of the disease because of the vaccine.[4] Estimates of the change in input costs associated with the vaccine came from scientists' estimates of the probable production cost and likely number of doses needed for successful application of a vaccine, and from observed reductions in the use of trypanocidal drugs following tsetse control in the Ethiopian study (Rowlands et al 1999).

A weighted average price of meat and milk was derived for different regions from recent farm-gate price data from various sources (Table 3). The meat and milk price for each country was weighted by its contribution to the total regional output of the product. The pre-research quantities (Q_0) of meat and milk produced in tsetse-infested areas of Africa came from the GIS analysis (Table 4). By overlaying the spatial distribution of tsetse flies with cattle densities, we were able to estimate the amount of meat and milk currently being produced in areas under trypanosomosis risk. The percentage increase in meat and milk production made possible with trypanosomosis control (k), was applied to this initial quantity. Elasticities of supply and demand were taken from regional empirical studies (Table 3).

Table 3. *Economic surplus input data and sources.*

Closed economy model	Western and central Africa		Eastern and southern Africa	
Parameter	Milk	Meat	Milk	Meat
Elasticity of supply [a]	1	1.7	1	1.4
Elasticity of demand [a]	0.5	1.8	0.5	1.8
Price per unit (US$/t) [b]	404	2,019	248	1,384
Quantity (t) [c]	759,000	398,000	2,113,000	374,000

Information sources:

a. Elasticity of supply of milk (Alston et al 1995); elasticity of demand for milk for SSA (ERS/USD (Economic Review Service/United States Department of Agriculture), unpublished data); elasticity of demand for meat (Tambi 1996); elasticity of supply of meat (ACIAR, unpublished data).

b. Prices: Eastern and southern Africa—weighted average 1997 farm-gate meat and milk prices for Zimbabwe and Uganda (Williams 1997), Kenya (Peeler and Omore 1997), and Ethiopia (B. Swallow, unpublished data); western and central Africa—weighted average 1997 farm-level meat and milk prices for Ghana, Nigeria and Niger (Elbasha et al 1999).

c. Quantities: Authors' calculation, using ILRI/GIS (Kruska et al 1995, Table 7) and FAO data to calculate meat and milk production in tsetse areas (Table 8).

Estimating the cost of trypanosomosis

The same methods were applied in the estimation of the costs of trypanosomosis. Potential annual benefits (i.e. change in total surplus) were calculated in a similar manner, using percentage increases in milk and meat output demonstrated when comparing tsetse-free and

4. A reduction in input costs with the introduction of a vaccine was only assumed to occur in eastern and southern Africa, where the use of trypanocidal drugs is common and a reduction in use corresponding to successful trypansomosis control has been observed. For western and central Africa, it was assumed that input costs would increase slightly with the introduction of a vaccine (Table 3).

Table 4. *Number and density of cattle in tsetse areas of Africa by region and agro-ecological zone (AEZ).*

Region and AEZ	Total number of cattle (head × 10^6)	No. of cattle in tsetse-infested areas (head × 10^6)	Per cent of total	Tsetse-infested area (cattle/km^2)	Non-tsetse area (cattle/km^2)
Southern Africa					
Arid	4.9	0.08	2	3.4	2.8
Semi-arid	10.1	1.28	13	2.4	8
Subhumid	7.1	0.76	11	1.1	6
Humid	0.1	0.03	19	0.3	3.1
Highlands	6.1	0.05	1	6.5	8.6
Total/mean	28.4	2.2	8	2.7	5.7
Eastern Africa					
Arid	15.5	1.5	10	13.7	5.4
Semi-arid	17.9	5.09	28	23.7	16.9
Subhumid	10.2	6.19	61	9.9	13.7
Humid	0.9	0.59	66	7.9	8.6
Highlands	31.7	7.96	25	21.5	34.5
Total/mean	76.2	21.32	28	15.3	15.8
Mean—Eastern and southern less arid				8.9	14.4
Western Africa					
Arid	6.2	0.01	0	9.7	1.6
Semi-arid	18.1	6.93	38	11.3	13.3
Subhumid	11.6	9.97	86	9.2	18.5
Humid	1.1	1.07	94	1.5	6.9
Highlands	0.001	0	100	13.2	0
Total/mean	37.1	17.98	48	9	8.1
Central Africa					
Arid	0	0	0	0	13.6
Semi-arid	1.1	0.18	15	4.3	27.3
Subhumid	2.9	2.35	82	3	8.3
Humid	3.6	3.46	96	1.1	4.9
Highlands	0.5	0.28	55	3.2	14.5
Total/mean	8.2	6.26	77	2.3	13.7
Total—All SSA	149.8	47.75	32	5.3	7.2

Sources: ILRI/GIS calculations, using most recent available country-level livestock population data, usually by district, as described in Kruska et al (1995). Tsetse distribution data is from Lessard et al (1990). For some countries, information at district level data or recent cattle census data was not available, thus the total number of cattle may be underestimated. The data continue to be updated.

baseline herds (Figure 1). In this case, the change in total surplus represents the estimated cost of trypanosomosis associated with reduced milk and meat output.

Assessing the returns to trypanosomosis vaccine research

Gross annual research benefits, measured by the change in total surplus, represent the maximum potential benefits to society from a new technology. To estimate the likely potential net benefits accruing to current research, however, some uncertainties must be considered: the uncertainty surrounding if and when the research may be successful, the uncertainty in the proportion of farmers adopting the vaccine and the rate at which they adopt. The economic surplus model accounts for such uncertainties by the use of probabilities. The challenge in using the economic surplus model to measure the potential returns to research, therefore, was how to estimate research and adoption lags, probability of research success, and the ceiling level of adoption.

Probability and length of time to research success

A survey of ILRI and non-ILRI researchers (both laboratory-based and those doing field-level research) was undertaken. Scientists were asked to give their pessimistic, most likely and optimistic estimates of the probability of research success. The probability of research success is jointly determined with the definition of a successful research outcome and the length of time until success is achieved; it depends on the assumed value for research costs. In this case research success was defined as a multi-component vaccine with components aimed at both the parasite and the disease (ILRI 1997; ILRI 1998). The research period was assumed to be 10 years, costing US$ 1 million per year starting in 1998, increasing at 3% per year.

The results of this survey are summarised in Table 5. The average of ILRI researchers' pessimistic estimates was used as the baseline to enhance the credibility of the conclusions. A sensitivity analysis was conducted to evaluate the effects of changes in these assumptions. This included an analysis using the mean lowest estimate of probability of research success from non-ILRI scientists as well.

Table 5. *Results of scientist survey regarding probability of developing a vaccine that will control the productivity losses due to trypanosomosis within the next 10 years (%).*

Number/location of scientists	Low estimate	Most likely estimate	High estimate
n=12 / ILRI			
Mean	33	44	56
Standard deviation	19	23	26
n= 9 / Outside ILRI			
Mean	16	23	35
Standard deviation	22	20	18

Adoption rates and lags

Figure 4 represents research benefits for one product for one year. A successful research investment will yield benefits over a number of years. As the level of adoption increases there will be further shifts in the supply curve, and corresponding changes in benefits. This adoption process was assumed to follow a typical S-shaped curve approximated by a discrete time distribution (Jacobsen and Norton 1996).

Since the results of research are likely to depreciate over time (e.g. due to availability of newer technologies), a depreciation factor also needs to be taken into account in the calculation of net benefits. The authors of this report assumed, based on information from the scientist survey, that a vaccine would be a relatively sustainable technology (compared to drugs against which the trypanosomes can develop resistance, for example). Thus it was assumed that the benefits would not depreciate substantially (1% per year), and that this depreciation would not begin until 10 years after the vaccine became available (Table 6).

Table 6. *Summary of assumptions for baseline analysis of potential returns to ILRI/collaborator's trypanosomosis vaccine research.*

Research period (starting from 1998)	10 years
Research costs	US$ 1 million/year, increasing at 3% per year until 2006 (Total: US$ 11.46 million; NPV: US$ 8.75 million)
Probability of research success	30%
Adoption period	12 years
Ceiling level of adoption	30%
Depreciation of benefits factor	1% per year, starting in 2018
Long-term discount rate	5%

NPV = net present value.

Interpretation and use of the results of the economic analysis

The benefits and costs of the research were arrayed on a yearly basis over a 30-year period, and a discount rate of 5% was applied to calculate the net present value (NPV) of vaccine research: the sum of total discounted returns minus total discounted costs. A positive NPV implies a research programme that is profitable. The internal rate of return (IRR), or the discount rate at which the NPV is zero, was also calculated. Using this criterion, research programmes are profitable if the IRR is greater than the opportunity cost of funds. The benefit:cost ratio, or total discounted returns divided by total discounted costs, was also calculated. Since many of the baseline assumptions are debatable (including the decision to start with the pessimistic, rather than most likely estimates as is often done), sensitivity analyses were undertaken to assess the effect of different discount rates, adoption levels and probability of research success on the NPV, IRR and benefit:cost ratio.

4 Results

The impact of trypanosomosis control on livestock productivity

The major impacts of tsetse control on the productivity of cattle in Ghibe valley, south-west Ethiopia, were shown to be a reduction in calf mortality (including still births) and increases in adult body weight, particularly in males (Table 1) (Rowlands et al 1999). Trypanosome prevalence in adult cattle was reduced from 41% to 16% during years of tsetse control (an absolute reduction of 25%) and the percentage of cattle requiring treatments with the trypanocidal drug diminazene aceturate declined from 42% to 21%. Annual growth of the herd increased from 7.6% to 13.3% per year.

Applying the herd model to simulated herds growing at reduced rates of 1.1% and 6.8%, respectively, showed that milk offtake increased by 51% as a result of tsetse control (Table 7). Milk offtake for a herd of 100 cattle increased from 64,375 to 97,293 litres over the 10-year period. Overall herd live weight plus live weight/meat offtake increased by an average of 50%.[5] The increase in liveweight offtake (41%) was associated with an increased offtake rate of 17% under trypanosomosis control compared with 13% for the baseline herd. This baseline offtake rate was equivalent to the continental average (Winrock 1992).

Table 7. *Productivity gains over 10 years estimated from simulated herd model applying results obtained from tsetse control study in Ghibe valley, south-west Ethiopia.*

Herd outputs	Baseline herd without trypanosomosis control (1)	Herd with trypanosomosis control introduced (2)	Herd in tsetse-free area (3)	Percentage increase in productivity (2) – (1)	(3) – (1)
Milk offtake (litres)	64,375	97,293	117,747	51[1]	83
Herd live weight (kg)	16,039	26,724	26,246	67	64
Liveweight offtake (kg)	26,469	37,291	57,580	41	117
Total meat/live weight (kg)	42,508	64,015	83,826	50[1]	97
Average annual growth rate (%)	1.1	6.8: years 1-9[2]; 1.1: year 10	1.1	–	–
Average annual offtake rate (%)	13	13: years 1-9; 17: year 10	19	–	–
Starting herd size	100	100	162	–	–

1. These estimates are used in the economic surplus model as the proportionate productivity gain, E(Y), obtainable from a trypanosomosis vaccine.
2. In year 9, herd size was predicted to reach that found in tsetse-free areas (Table 4); this was assumed to be the carrying capacity of the land, and herd growth thereafter was assumed to be at the same rate as for the baseline herd.

5. The herd simulation model measured the percentage increase in the weight of the overall herd plus the liveweight offtake for the herd before and after tsetse control. The same percentage change applies to meat, valued in the economic surplus model.

In the economic surplus model, these estimates of productivity gain were assumed to apply to quantities of milk and meat currently produced in tsetse-infested areas of eastern and southern Africa, but they were halved for western and central Africa. A recent review of the literature suggests that productivity gains from trypanosomosis control in trypanotolerant cattle breeds in western and central Africa may be somewhat lower than those found in breeds more susceptible to the disease (Swallow 1997).

Extrapolating impact on livestock production spatially using GIS

The results of the GIS cross-tabulation of cattle populations in tsetse-infested areas of Africa are found in Table 4. The results show that of a total of 150 million cattle in SSA, there are at least 48 million cattle raised in tsetse-infested areas. The quantities of meat and milk produced in each region (averaged over the 5-year period 1989–93) were multiplied by the percentages of animals found in tsetse areas of each region to estimate the amount of meat and milk produced in areas of trypanosomosis risk (Table 8). These 48 million cattle produce approximately 772,000 t of meat and 2.9 million tonnes of milk. Valued at the same farm-level prices used in the analysis (Table 3), this implies meat production worth US$ 1321 million and milk production worth US$ 830 million.

Table 8. *Annual meat and milk production in tsetse-infested areas of Africa.*

Region	Meat production ($t \times 10^3$)	Meat produced in tsetse-infested areas ($t \times 10^3$)	Milk production ($t \times 10^3$)	Milk produced in tsetse-infested areas ($t \times 10^3$)
Southern Africa	1,068	83	3,514	273
Eastern Africa	1,041	291	6,577	1,840
Western Africa	590	286	1,203	583
Central Africa	146	112	230	176
Total SSA	2,845	772	11,524	2,872

SSA = sub-Saharan Africa.
Source: Average 1989–1993 meat and milk production for each region (FAOSTAT 1996) multiplied by the percentage of animals found in tsetse-infested areas of each region (Table 4).

Sixty-nine per cent of Africa's cattle are found in eastern and southern Africa, the majority of which are zebus susceptible to trypanosomosis. The density of cattle found in tsetse-infested areas of this region (excluding the arid zone since tsetse flies are only found along water sources) is 8.9 cattle/km^2, much lower than the 14.4 cattle/km^2 found in non-tsetse areas (Table 4). This implies that with successful trypanosomosis control, a herd of 100 head would be able to increase to 162 head to reach the density level found in the non-tsetse area and this value was used as a measure of the relative carrying capacity of a tsetse-free to a tsetse-infested area (Figure 1).

There will be an estimated 300 million people living in tsetse-infested areas of Africa in the year 2000 (Figure 3). With 65% living in rural areas (World Bank 1996), and if we assume 7 people per household, the recommendation domain for a trypanosomosis vaccine (or other trypanosomosis control measures) includes some 28 million rural households (not all of whom own livestock).

The potential economic benefits of controlling trypanosomosis

The calculation of total economic surplus (i.e. gross annual benefits) from trypanosomosis control is shown in Table 9. Averaging over both regions, the estimated potential gains in productivity result in a 38% reduction in the cost per tonne of producing milk. Similarly, the cost per tonne of live weight produced decreases by 25%. Since the percentage change in the live weight of the herd plus offtake from before to after trypanosomosis control is accounted for (and will be the same for meat as live weight), the potential increase in the value of livestock capital with disease control is included in the estimate of potential benefits in terms of live weight/meat.

The lower cost of production results in an increase in the amount of meat and milk supplied by farmers and a lower price to consumers. The change in total economic surplus, or potential gains from trypanosomosis control to farmers and consumers across Africa is estimated to be US$ 702 million per year (Table 9).

Table 9. *Results of the economic surplus model: Change in total surplus and cost of production reductions with trypanosomosis control and distribution of the benefits.*

Change in total surplus/benefits	US$ 702 million
Estimated average reduction in cost per tonne output (both regions)	
Milk (%)	38
Live weight/meat (%)	25
Distribution of benefits	
Milk	
Change in consumer surplus (US$ × 10^6)	252
Change in producer surplus (US$ × 10^6)	126
Meat	
Change in consumer surplus (US$ × 10^6)	146
Change in producer surplus (US$×$10^6$)	178
Eastern and southern SSA[1] (US$×$10^6$)	543
Western and central SSA[1] (US$ × 10^6)	158

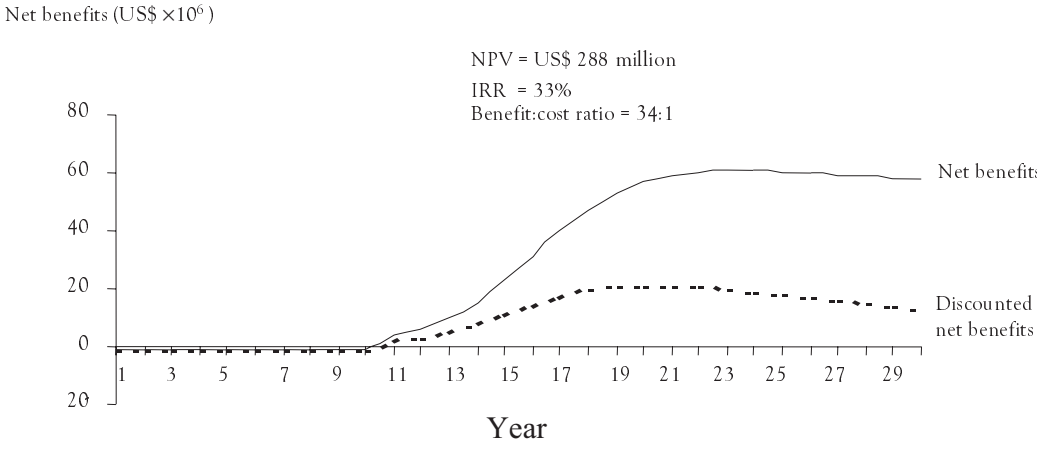
1. Change in total surplus.

Estimating the cost of trypanosomosis

Simulation of a herd in a tsetse-free area produced estimated increases of 83% and 97% in milk and meat offtakes (Table 7), respectively. The total economic surplus was shown to be US$ 1338 million (Table 9). This is an estimate of the annual cost of trypanosomosis in terms of foregone milk and meat productivity.

Potential returns to a trypanosomosis vaccine

The change in total surplus was adjusted by the levels of adoption, the probability of research success, and a depreciation factor (see Table 6) to estimate the returns to research into a potential new control strategy, a vaccine. These 'uncertainty adjusted' benefits, generated over the next 30 years, were then compared to ILRI's vaccine research costs and discounted (using a discount rate of 5%) to calculate the net present value (NPV) of the research. The net benefit stream (i.e. benefits minus costs over the next 30 years) is shown in Figure 5. The NPV of trypanosomosis vaccine research is estimated to be US$ 288 million, with an IRR of 33%, and a benefit:cost ratio of 34:1.



Assuming a research lag of 10 years, a 30% probability of research success, an adoption period of 12 years, a ceiling level of adoption of 30% and a discount rate of 5%.

Figure 5. *Distribution of predicted benefits over time from a trypanosomosis vaccine.*

5 Discussion

Estimation of impacts of trypanosomosis control on livestock productivity

Valuing the productivity effects of constraints to livestock production in sub-Saharan Africa is problematic. It depends heavily on assumptions on herd growth and offtake rates. We chose an approach that combined the use of observed productivity traits of a herd in a particular location with simulation of different offtake and growth rates that were judged to be more representative of the situation throughout Africa. This is difficult, because the productivity of a herd depends heavily on breed, management, and uses of the animals (e.g. primarily for milk, meat, traction or as a store of wealth). Ideally this type of analysis would be done for each production system, but this requires more data than exist at present. The aim of our analysis, however, has been to establish a methodology that is conducive to a production systems approach, so that estimates can become more precise as new data become available.

The average reduction in trypanosome prevalence brought about by introduction of tsetse control in Ghibe, Ethiopia, was from 41% to 16%, which may not reflect reductions in trypanosome prevalence resulting from the same control strategy in other areas or through alternative control technologies. In the no tsetse-control situation in Ghibe, animals were being treated with trypanocidal drugs when they were found to have trypanosomes in their blood and were suffering the ill-effects of trypanosomosis. Thus the benefits of tsetse control were additional to those achieved through the chemotherapy that was being applied (Rowlands et al 1999). For this reason, we reduced the growth rate of the baseline herd to reflect the population situation. Another complicating factor may be that the tsetse control technique used in Ghibe, pour-on treatments of cattle, may have had positive impacts on animal health and productivity beyond its effects on trypanosomosis (e.g. reduction of nuisance biting flies) (Leak et al 1995). For farmers in the area the main advantages of the pour-on treatments were less trypanosomosis, fewer problems with biting flies, and fewer problems with ticks (Swallow et al 1995). Where trypanosomosis is one of a number of limiting factors to increased production, other limiting factors may reduce the benefits brought about by trypanosomosis control.[6]

We have used a case study from one site in south-west Ethiopia to estimate the productivity benefits of trypanosomosis control, and we may have underestimated or overestimated productivity benefits that may occur in other regions. The Ghibe valley case study was chosen because it is the most extensive assessment of trypanosomosis control that has been undertaken. By reducing herd growth in our model, we were able to simulate a baseline herd with the average continental herd growth rate of 1.1% and offtake rate of 13% (Winrock 1992), so that our analysis is more representative of the overall situation in sub-Saharan Africa.

6. Separating out the various constraints, or the sequence of limiting constraints, to animal productivity is extremely difficult, and is one of the reasons ILRI's research covers animal health, feed, management, and genetic constraints as well. This analysis does not capture the potential complementary benefits if new technologies or strategies are pursued across these areas, nor the dampening effect on benefits if a vaccine is successful, for example, but poor feed strategies are followed.

Potential benefits of a trypanosomosis vaccine

The results suggest that consumers of milk may have even more to gain from application of a successful trypanosomosis vaccine than producers, due to the lower prices they will pay for milk (Table 9). Given the high urbanisation rates in developing countries, many consumers will be relatively poor families living in cities. Cheaper milk could contribute to significant improvements in nutritional status, an indirect benefit.

Milk sales provide an important source of steady income for many African smallholder producers (particularly women in many areas). Demand and world prices are expected to rise over the coming years due to increasing urbanisation and incomes and changes in dairy policies of the European community and other dairy exporters (Staal and Shapiro 1994). This analysis, which focuses on the supply shift only, suggests that smallholder producers will be able to sell more milk, and, despite lower prices, earn more total revenue.[7]

In the case of meat production, the potential benefits to producers are higher than those to consumers, but again both gain. If the demand curve for livestock products is indeed undergoing an outward shift (Delgado et al (1998) estimate an annual growth rate of meat consumption for SSA of 3.4% from 1993–2020), farm revenues will increase even more than the level predicted here.

The potential benefits to trypanosomosis control are considerably higher in eastern and southern Africa than in western and central Africa (Table 9). This is largely a result of the higher initial quantity of milk produced in tsetse-infested areas in the region (2.1 million tonnes in eastern and southern Africa compared to 0.8 million tonnes in western and central Africa). However, the relative benefits are also influenced by the assumption that the productivity impact is lower in western and central Africa (one-half the productivity impact estimated from the Ghibe data). It is possible that the productivity impact of trypanosomosis is thus being underestimated for western and central Africa, particularly as more susceptible breeds of cattle move into the region (de Leeuw et al 1995; Bassett 1993).

In this analysis, where and how much impact trypanosomosis control is predicted to have is determined by current knowledge about the distribution of tsetse and cattle across Africa. In fact, both are continually changing. Changes in tsetse relative densities are due to the effectiveness of the diverse technologies now available and the steadily increasing requirements for land by a rapidly growing human population (Perry 1988). Future analyses could build in predicted changes in tsetse distribution, for example, as a result of population pressure (Reid et al 1999). Capturing impacts due to the migration of cattle or shifts in breeds (or lack thereof), however, remains a challenge.

7. Producers gain given the baseline assumptions regarding elasticities of supply and demand and the linearity assumption. With a non-linear, constant elasticity specification of supply and demand, for example, the change in producer surplus is negative.

Estimating the cost of trypanosomosis

In similar studies that have measured the returns from application of new technologies arising from crop research, benefits can be determined as soon as the crop is harvested for the first time. The benefits of a new disease-resistant crop variety, for example, also represent a measure of the costs caused by the disease. For the control of livestock diseases, however, this is not the case. The introduction of a vaccine, for example, has benefits that increase over time as the herd increases in size. Thus it would take several years for livestock farmers to reap the full benefits of a new vaccine.

Our cost estimate ignores the value of cattle as suppliers of manure. With respect to traction, we have valued males over five years of age at a farm-level market (meat equivalent) price, which probably underestimates their value as trained oxen. Other costs of trypanosomosis not included in this estimate include:

- inability or reluctance to shift to more productive breeds of cattle due to the high risk (or perceived high risk) of losses associated with trypanosomosis
- cost of human trypanosomosis
- costs of the disease outside of SSA
- cost of trypanosomosis in sheep, goats, camels and horses
- potential costs associated with land use changes resulting from trypanosomosis control.

Returns to vaccine research

The estimated present values (US$ 288 million) of and internal rates of return (33%) to ILRI's trypanosomosis vaccine research indicate a sound investment, even with the cautious assumptions made regarding likely adoption rates and scope of the benefits (i.e. only meat and milk production in cattle). Returns of similar magnitudes have been estimated for international research on crops. An analysis of returns to 15 research themes at the International Potato Center (CIP) yielded estimates of net present value ranging from US$ 1 million to US$ 195 million (average US$ 67 million), with internal rates of return ranging from 13% to 51% (Walker and Collion 1997). CIP used an approach similar to the one in this report, taking scientists' most conservative estimates regarding likelihood of success and levels of adoption. The International Crops Research Centre for the Semi-Arid Tropics (ICRISAT) ranked returns to 110 different research areas. The average NPV, net benefit:cost ratio and IRR for the top 20 of those were US$ 61 million (with a range from US$ 8 million to US$ 265 million), 52:1 and 39%, respectively (Kelley et al 1995). The ICRISAT analysis used scientists' most likely as opposed to lowest estimates for the baseline analysis. Both CIP and ICRISAT included only their own research costs, as in this analysis, excluding costs associated with technology transfer.

The research costs included in our analysis (US$ 11.5 million over 10 years) do not include past, sunk costs but only current and projected annual variable costs of research specifically related to trypanosomosis vaccine development. Sunk costs would of course be

considered in an *ex post* analysis. In this *ex ante* impact assessment, the NPV measure cannot be attributed solely to the research done by ILRI scientists. Benefits and costs of other inputs into the research and adoption process are also excluded, yet are critical to achieving impact. These include research undertaken at national agricultural research centres; work by government health services and projects, pharmaceutical companies, and agricultural extensionists; and infrastructure development. What has actually been estimated is the benefit of the value of the research at the margin (Kelley et al 1995). In other words, the NPV represents the benefit foregone, or the opportunity cost, of ILRI not carrying out this research.

Sensitivity analysis

Since many of the assumptions underlying the analysis of returns are subject to debate, sensitivity analyses were undertaken to explore the implications of changes in several of these assumptions—namely, the probability of research success, the period of adoption, the ceiling level of adoption and the discount rate (Table 10).

Table 10. *Sensitivity of estimated vaccine research returns to assumptions.*

Scenario		NPV (US$ × 10^6)	IRR (%)	Benefit: cost ratio
1. Baseline/conservative assumptions[1]		288	33	34:1
2. Optimistic research success assumptions[2]				
Probability of research success in 10 years (%)	50	486	38	57:1
Probability of research success in 6 years (%)	50	662	50	77:1
3. Optimistic adoption assumptions[2]				
Adoption period (years)	6			
Ceiling adoption level (%)	40	504	43	59:1
4. Pessimistic research success assumptions[2]				
Probability of research success in 10 years (%)	16	149	27	18:1
5. High discount rate assumption[2]				
Discount rate (%)	10	103	33	16:1

NPV = net present value; IRR = internal rate of return.
1. Baseline assumptions[1]
   Productivity gains: milk—51% eastern and southern SSA; 26% western and central SSA
   meat—50% eastern and southern SSA; 25% western and central SSA
   Adoption period: 12 years
   Ceiling adoption level: 30%
   Probability of research success in 10 years: 30%
   Discount rate: 5%
2. Other assumptions same as baseline.

The baseline analysis deliberately used fairly conservative estimates (derived from an average of researchers' pessimistic rather than most likely estimates) about adoption and probability of research success. First, more optimistic assumptions about the probability of developing a vaccine within the next 10-year period were made. When the probability of

research success increased to 50%, research returns increased from US$ 288 to US$ 486 million with a benefit:cost ratio of 57:1. When the research lag was then lowered from 10 to 6 years, the NPV of the research more than doubled to US$ 662 million and the benefit:cost ratio increased to 77:1 (Table 10).

Sensitivity analysis also demonstrates the benefits of earlier adoption that might be achieved by establishing stronger linkages between research centre and farmer. With an adoption lag of 6 years and 40% of farmers in tsetse areas adopting the vaccine, the NPV increases from US$ 288 million to US$ 504 million.

The choice of appropriate discount rate has a significant impact on the results of this model. The discount rate is a time preference concept. If a 'socially optimum' discount rate actually exists, it is evident that such a rate can never be precisely known because the preferences and circumstances of future generations remain unknown (Goodland and Ledec 1987). Economists disagree as to whether the appropriate social discount rate should reflect the alternative value of public resources being consumed or invested (Alston et al 1995). They do agree, however, that in this type of analysis the rate should be a real rate of interest (adjusted for inflation) and that it should reflect any restrictions placed on alternative uses of the funds. Alston et al (1995) argue that this corresponds to a long-term, risk-free rate of return, such as the real yield from long-term government bonds (typically around 5%, used in the baseline analysis). We assessed the effects of the discount rate on returns by increasing it from 5% to 10% (commonly used in project analysis). High discount rates discourage investments with long-term benefits (which incorporate a relatively long period of research and adoption). Thus, in our case, the NPV of the research fell to US$ 103 million and the benefit:cost ratio decreased from 34:1 to 16:1 (Table 10).

Because of the complexity of the disease, the most controversial assumption in this analysis is the probability of research success. It is jointly determined with the definition of a successful research outcome and the length of time until success is achieved, and it depends on the assumed value for research costs. Our approach was to interview scientists knowledgeable about the challenges trypanosomosis poses, the problems, opportunities and current 'state of the science' in vaccine development. These included those with some stake in the research (within ILRI) and those with no personal involvement in the research (within and outside ILRI). As could be expected, the estimated probabilities of research success were higher for ILRI scientists than non-ILRI scientists (Table 4). This can partly be explained by the fact that those not working on the research on a day-to-day basis are less familiar with the current state of knowledge. The 'pessimistic' scenario using a 16% probability of research success (as suggested by the lowest non-ILRI estimates) resulted in positive returns to research of US$ 149 million, with expected benefits outweighing the costs of the research by a factor of 18.

In cost:benefit analyses of private investments the IRR is typically compared to a market rate of return on alternative investments. However, in this case we are considering returns to investment in research oriented towards the development of a 'public good'. Arguably, the lowest acceptable level of return one might expect is at least 20%. Another approach

that can be taken with the sensitivity analysis is to ask the question, 'What does it take to maintain a 20% rate of return?' Keeping other assumptions constant, the rate of return falls from 28% to the 'break-even' point of 20% as the probability of research success reaches 7%. This suggests that if scientists think that they can solve this research challenge within 10 years, they should be able to give it at least a 7% chance of success to generate reasonable returns. Using the optimistic adoption estimates, this break-even probability of success falls to 3%.

Similarly, a break-even analysis using a 50% probability of research success suggests that if ILRI wants to achieve at least a 20% return on the trypanosomosis vaccine research investment, researchers should be able to reassure donors that the ceiling level of adoption within tsetse areas of Africa will not be less than 3% of cattle producers (with a 12-year adoption lag). With 300 million people living in tsetse-infested areas (R. Kruska, ILRI, personal communication), 65% in rural areas (World Bank 1996), and assuming an average household size of 7 people, the 'recommendation domain' for a trypanosomosis vaccine includes some 28 million rural households (not all of whom own livestock). It will take 3% of these, or 840,000 households, to adopt the vaccine for the research to pay for itself.

6 Summary

This study has developed a methodology that builds on the approach to measuring agricultural research returns suggested by Alston et al (1995). We have integrated a herd model to measure the potential size of impact of a new technology, GIS, to predict where this impact is likely to be felt, and the economic surplus model to estimate some of the costs of trypanosomosis, the potential benefits of controlling it, and potential returns to vaccine research. The advantage of this approach is that it uses field data and GIS analysis to determine where and how much impact research will have on livestock productivity, rather than 'guesstimates' by researchers, as has often been done in previous studies of returns to agricultural research. It is an approach, however, that requires much data and the type of information that is still scarce in many developing countries. This includes evidence of the productivity impacts of a given livestock technology at the herd, rather than individual animal level, and access to GIS data at the lowest administrative level possible (e.g. district). Ideally, household level survey data are used to complement the GIS data and verify the recommendation domain. Thus this approach will be enhanced in future analyses by the availability of a wider range of data collected at the household level from different livestock production systems to examine more closely the question 'Impact on whom?'

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