

DALYs, dollars and dogs: how best to analyse the economics of controlling zoonoses

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Summary

Decision-makers increasingly require comprehensive economic metrics summarising and comparing the benefits and costs of controlling zoonotic diseases. The impact of disease in people is conventionally quantified in non-monetary terms, usually a disability-adjusted life year (DALY), whereas the losses due to disease in animals, particularly livestock, are quantified in monetary terms. The potential for the development of a non-monetary metric for ill health in animals, based on life years lost and disability, is discussed and rejected. Within and across animal species and livestock production systems, maximising life spans is not a consistent goal and morbidity/disabilities have very different weights and often lead to culling. By relating livestock losses to a measure of national income forgone, the recently developed alternative of converting monetary losses due to livestock illness into an animal loss equivalent (ALE) provides a viable solution. Based on this, the literature on the economics of controlling zoonoses is revisited and four options for quantifying and comparing benefits and costs are examined and illustrated using numerical examples. These are *i)* the simplistic grouping of all monetary elements and their comparison to DALYs averted (described as the aggregate net cost method), *ii)* the separable costs method, *iii)* the use of ALEs to convert all benefits to a non-monetary equivalent, termed the zoonotic DALY (zDALY), or *iv)* the use of a full monetary cost-benefit analysis, based on converting DALYs to a monetary equivalent. The strengths and weaknesses of each are discussed. For effective prioritisation and decision-making, it is vital that an analytical approach is widely adopted which yields consistent results and which supports the control of zoonoses.

Keywords

ALE – Animal loss equivalent – Cost-benefit analysis – DALY – Disability-adjusted life year – Economics – Separable costs – zDALY – Zoonotic disability-adjusted life year – Zoonoses control.

Background

The quest for data and analysis of the economics of zoonoses control is now in its fifth decade: the 45th World Health Organization (WHO) Executive Board having passed a resolution in 1970 recommending that a group of experts meet and discuss the subject and commission some pilot studies (1). By this time, health economics was already recognised as a sub-discipline of economics (2), cost-benefit analysis had been an established notion for long enough to

merit the writing of a survey article (3) and the difficulties of putting a monetary value on human life were being discussed (4) while alternative non-monetary approaches were being developed (5, 6). The early 1970s also saw the development of veterinary or animal health economics, partly spurred on by the gathering of experts initiated by that same WHO resolution, as described in (7). In 1976 the International Society for Veterinary Epidemiology and Economics held its first meeting (8), marking the formal launching of the subject.

However, these two sub-disciplines were, until recently, mostly pursued separately, with individual practitioners by and large being relatively unfamiliar with the work done by the other group. The rapid growth of the One Health movement over the last decade, along with a greater awareness of zoonoses in general and of the risks posed by potentially pandemic zoonoses in particular, has intensified the need for a practical, 'joined-up' methodology for quantifying the economic impact of zoonotic diseases and for evaluating their control from a societal rather than a single sector viewpoint (9, 10, 11).

This paper examines the options using examples from the neglected zoonotic diseases, which mostly impact on poorer communities (12). This cluster of endemic diseases is useful for analysing the economics of zoonoses control because there are a range of possible interventions, different breakdowns of disease impact between the human and animal sector and varying levels of disease control being implemented in different settings.

The economic impact of zoonotic disease

The costs imposed by a disease on society consist of the money that needs to be spent treating or preventing it plus the effect it has on diseased individuals – which, for a zoonosis, will include both humans and animals, as laid out in the four boxes at the top of Fig. 1. The objective of new

disease control initiatives is to reduce one or all of these four categories. With the growing interest in One Health approaches, papers on endemic zoonotic diseases have reported on the costs of disease to both human health and animal health sectors at local and global levels (e.g. 13, 14, 15, 16, 17). A smaller number of papers have also reported on the economics of controlling specific diseases (e.g. 18, 19, 20, 21, 22).

Health-adjusted life year (HALY) measures to quantify the impact of disease in people

A range of health-adjusted life year (HALY) measures have been developed, of which the two currently most commonly used are the quality-adjusted life year (QALY) and the disability-adjusted life year (DALY) (23). The differences between the DALY and the QALY are explained in the context of a zoonotic disease in (13). The DALY measures burden of disease, and disease control 'averts' DALYs. A DALY value of 0 is equivalent to a perfectly healthy life year and 1 to death, with values in between representing different levels of disability. The DALY has two components: years of life lost (YLL – measuring the impact of premature death) and years of life lived with disability (YLD – measuring time spent living with health problems to which a range of disability weights are applied). The DALY has been widely adopted, notably by WHO, as an international measure of the impact of disease and as a basis for assessing the global burden of disease. In the context of One Health, the DALY has become the preferred measure for expressing the impact of zoonoses on human health. The DALY, in its

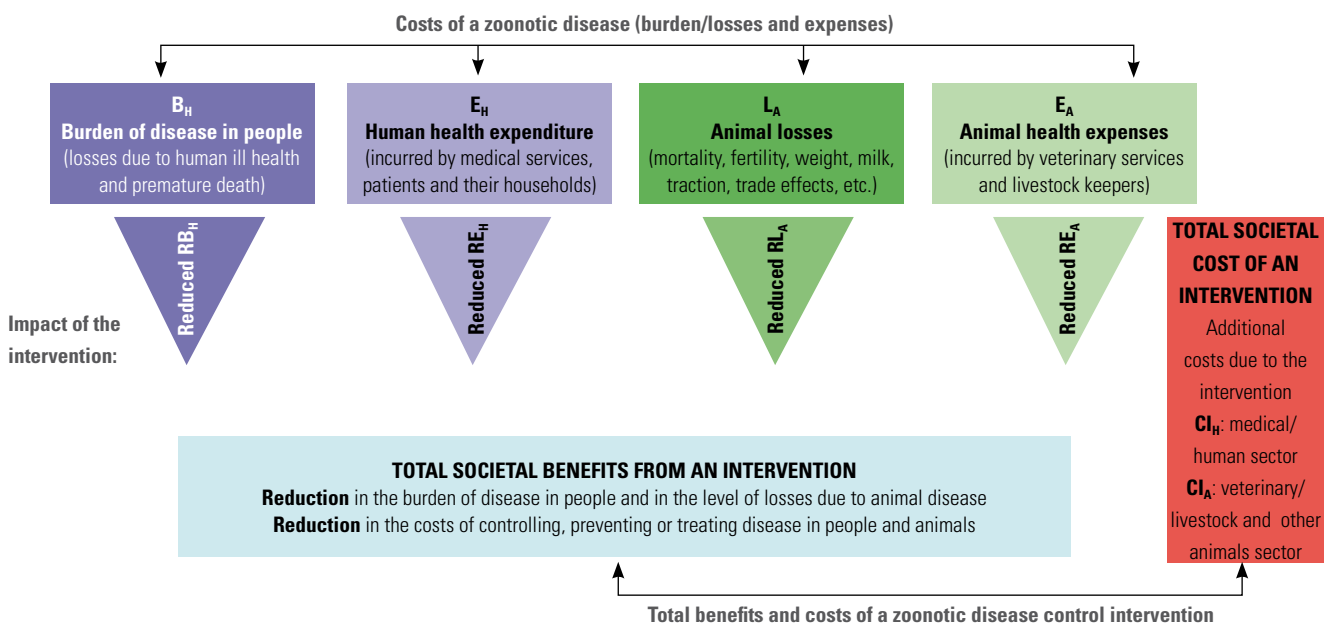


Fig. 1
Components of the costs and benefits of controlling a zoonotic disease

global application also packs a moral punch – it implies that across the world a life is a life, no matter whose it is nor where that person lives or what they earn.

Expenses on treatment and prevention in the human sector

In human health economics, costs are divided into direct medical and non-medical costs (the latter including health-sector overheads and costs that patients necessarily incur, such as transport and hired care-giving) and indirect costs (patient costs while ill: time off from work, seeking treatment, hired household help). The different direct and indirect costs may or may not be taken into account depending on whether the analysis is from the viewpoint of an individual stakeholder or of society as a whole (24).

Animal health losses

Losses due to illness in livestock are valued in terms of their monetary impact on livestock output. This is defined as the total goods produced whether for home consumption or sale (meat, milk, skins, wool, animal traction, manure etc.), minus animals purchased or brought in, plus any change in herd value (7). A range of time periods, methods and scales are used: one-year farm budgets, herd models using production parameters such as death and fertility rates to calculate output, and analyses of the impact of large-scale changes in the health status of livestock populations on supply, demand and prices (producer and consumer surplus estimates). Wider impacts may also need to be quantified. The possible impacts on trade include a fall in prices and a reduction in the number of market outlets as a result of movement controls or import bans. Endemic diseases such as trypanosomiasis or tick-borne diseases in Africa can restrict the livestock breeds farmed and the type of production systems used (25).

Within the livestock sector animals have clear commercial values; however, when considering companion animals and wildlife, estimation is more complex – involving techniques that are also familiar in the human health economics sector, such as willingness to pay (26, 27).

Expenditure on treatment and prevention in the animal sector

As well as suffering losses as a result of their animals' illness, livestock keepers and the local/national Veterinary Services incur expenses as they attempt to mitigate or prevent these losses. The trade-off between accepting losses in livestock and spending money privately or publicly on improving their health has been termed the 'loss–expenditure' frontier and analysed using the tools of economic theory (28).

The analytical dilemma: comparing DALYs and dollars

Thus, the societal cost of zoonotic diseases comprises four categories, three of which are easily expressed in monetary terms, but arguably the most important one: human suffering and premature death, is conventionally expressed using a HALY.

Do we need an animal 'DALY'?

As the One Health movement has gained traction, within the human health field some have expressed surprise that there is no DALY equivalent for animals, while some in the veterinary field have observed what an efficient tool the DALY is for prioritising and for attracting funding. Thus, it has been suggested that an animal 'DALY' – reflecting the productivity impacts of diseases on livestock – would be a useful tool.

If the DALY model were used, then a mortality (YLL) component and a morbidity (YLD) component would need to be considered.

The length of animals' lives is not just determined by a desire to maximise life, but by other considerations – mostly linked to human behaviour and decision-making. These include the following.

- Wildlife generally live longer in captivity, but this may not be the optimal life for them.
- For many production animals, a longer life is not what the livestock producer wants. Animals are fattened to a certain weight and then sent for slaughter. If they do not reach that weight in a certain time the livestock keeper loses money, either by selling them at a lower weight or having to keep and feed them for longer. So, ironically, disease can prolong an animal's life.
- Again, for livestock, life expectancy is not governed by the natural lifespan of the species, but by human decision-making. So, in some societies, a sheep's life could be shortened because the family had a wedding and decided to slaughter it to celebrate. Cows in extensive production systems in Africa are often kept longer (12 or more years) than cows in Europe (5–6 years). Livestock are usually only kept till they are quite old in more traditional production systems where farmers become quite attached to their animals, and, as in Africa, there is a limited supply of replacement breeding stock.
- It is only for companion animals (pets) that humans try to maximise lifespan. So dogs' life expectancies range from

Table I
Selected disability impacts in people and livestock

Condition or disease	Disability weight for humans*	How would it be for livestock?
Infertility (result of disease)	0.011 (new) 0.180 (old)	In female cattle, infertility results in culling. In the UK between 6% and 8% of dairy cows are culled each year because of infertility (29)
Blindness (various causes)**	0.195 (new) 0.510–0.600 (old)	In livestock, blindness usually results in culling
Leg amputation	0.021–0.164 (new) 0.300 (old)	In livestock, amputation usually results in culling. In the UK about 3% of dairy cows are culled annually because of lameness in the leg or foot (29). Some farmers treat and retain lame cows, but lame work oxen or bulls are usually culled
Tuberculosis (cases)	0.331 (new) 0.271 (old)	Possibly less disabling in cattle than in humans, as cattle are often retained by extensive livestock producers despite being infected, with reductions of 5–10% applying to key productivity parameters (30). Carcasses may be totally or partially condemned

* Each condition was weighted on a scale ranging from 0 (perfect health) to 1 (death). The 'old' disability weights are those from Murray & Lopez (31) and the 'new' weights those from the 2010 Global Burden of Disease study (32)

** Of all the conditions, blindness had the widest range of disability weights

two years or less in many parts of Africa to about 12 years in Europe.

Turning to disability, as Table I illustrates, the outcomes for people and animals are very different. Lameness or infertility tends to lead to culling in many production animals. The presence of diseases such as endemic brucellosis and tuberculosis are tolerated by livestock keepers, who are often unaware that their animals are infected unless a test-and-slaughter programme identifies them and marks them for removal.

Within species there are huge differences in value. Taking the example of dogs, probably the species with the biggest range of function and worth to humans, the following apply:

- Dogs can be companion animals, virtually regarded as family members.
- Working dogs play an important role in helping humans in the pursuit of their livelihoods in many situations.
- The commercial value of dogs varies greatly: from zero, for non-pedigree puppies given free to neighbours or friends, to amounts as high as US \$1.5 million, a sum paid for a Tibetan mastiff dog in 2014. In general, in Europe and North America, a pedigree puppy costs US \$500–3,000. In court cases involving injuries or death of pets, judges in the United States typically award sums which reflect the cost of keeping the animal for the duration of its life, for example around US \$30,000 for a dog.
- Dogs can be eaten; in the past they were eaten in almost all parts of the world and still are in some places.
- Dogs can be considered as vermin that must be destroyed, for example feral dogs which pose a risk to cattle or sheep or are feared as carriers of disease, especially rabies.

Then, there is the issue of combining different species. The DALY relates to our own species and translates a deeply held moral conviction about the value of human life. For animals this is very different. This is where the idea of an animal DALY runs into its biggest problem. Many zoonotic diseases and many livestock diseases affect more than one species. In the absence of a monetary metric, it becomes very difficult to compare the death of a sheep to the death of a cow, for example. This would become even more impossible if somehow an animal 'DALY' were to be integrated with a human DALY. Many zoonotic diseases are particularly important in wildlife, so how would individuals of a critically endangered species, such as the mountain gorilla, be ranked in relation to people or other animals? Is a cow more or less valuable than a much-loved family pet dog? Lastly, where does a (possibly disease-carrying) wild rat or mouse fit in?

For these reasons, and the ease of comparisons across species and production systems, the standard practice of valuing animal health impacts in monetary terms does seem to be the most practical and consistent. This allows each animal's life or ill health to be valued in the context of its purpose and production system.

What about putting a monetary value on human life?

Conversely, if the objective is to have all human and animal health benefits valued using a single metric, then it is possible to turn to the cost–benefit analysis methodology used in health economics. Since Mishan's (4) original discussion, standardised methodologies have evolved (33). The basic approaches are as follows.

- Human capital: people's lives are valued in relation to their contribution to society and thus implicitly it is the

economic impact, not the wider social impact, of ill health and premature death that is measured.

– Observed or revealed preferences: the implied values which either society or individuals place on human life are estimated on the basis of the financial choices made. For example, decision-makers' investments in safety measures to prevent known levels of injury or death would provide a guideline, as would purchases of health insurance or judges' awards for injury. The notion of the value of a statistical life (VSL) falls within this category and has been applied in many instances, but it is often considered to apply more to wealthy societies and, by some, as having a tendency to produce exaggerated values (34).

– Stated preference: people are canvassed as to their willingness to pay to avoid certain health risks or enhance certain health outcomes. Discrete choice experiments involve a more complex approach where those questioned are asked about a selection of options, each of which has several attributes (cost, service provider, type of intervention). These approaches rely on a robust sampling strategy and it has been observed that responses can be highly subjective and may vary over time, even for the same individual.

In contrast to these more formal approaches with a solid theoretical underpinning, a more simplistic approach is to use measures of average national income per capita as a monetary proxy for the value of a year's human life. This valuation reflects the 'human capital' approach, but by using an 'average' figure, it does not discriminate between high earners and low earners, rich and poor, rural and urban, young and old. Thus, while not reflecting within-country income differences and hence ability and willingness to pay, by distinguishing between poor and wealthy countries, the use of national income measures does nevertheless depart from the DALY ideal.

The animal loss equivalent (ALE) – a solution to the conundrum

With the debate about the need for an animal DALY ongoing for the best part of a decade, a new approach has now been proposed (35). Reflecting on the different values of livestock in different societies and production systems, in relation to human income, it points out that, in parts of Africa, a bovine might be worth US \$500, which is nearly half of the average per capita annual income. By contrast, in Europe or North America, a bovine might be worth US \$1,500, say a twentieth of an annual income of US \$30,000. Using these fundamental differences as a basis, the adoption of a non-monetary 'animal loss equivalent' (ALE) is suggested. This would be calculated by quantifying livestock losses, as usually done in animal health economics, by estimating their monetary value as accurately as possible. This figure

would then be divided by the value of national income to produce an ALE. This would reflect both the contribution of livestock to the human economy and, more immediately, how much time an average income earner would have to work in order to obtain the funds to replace that animal. This could also be seen as 'labour time lost' due to animal ill health. Thus, a dead bovine in Africa would be worth 0.5 ALEs and in Europe or North America, 0.05 ALEs.

When evaluating the losses due to a zoonosis, these ALEs could then be added to the conventionally calculated DALYs from human health impacts to produce a combined metric, the zoonotic DALY, or zDALY.

Analysing the economics of interventions to control zoonoses

Figure 1 sets out how the costs of disease provide the basis for estimating the impact of a particular disease control intervention in terms of reductions in some or all of the four categories. Adding up all of these benefits, from both the human and animal health sectors, yields the total societal benefit from controlling the disease using that intervention (36). These benefits are then compared to the costs, which for a zoonotic disease often depend on interventions being implemented jointly by the human sector and the veterinary sector; for example, in the case of rabies, the former provides post-exposure prophylaxis for people and the latter vaccinates dogs.

Basic conventions in human and animal health economics

In human health economics the three main approaches used for assessing interventions are cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and cost-utility analysis (CUA) (24). CBA compares costs to monetary benefits and CEA compares costs to a measure of effectiveness – which can range from number of patients successfully treated through to lives saved. Increasingly, CEA refers to the cost of an intervention per DALY averted, whereas CUA refers to the cost per unit of utility, a measure of welfare as defined in economy theory, and thus usually per QALY gained. In the international field and in zoonoses control, the most frequently cited measure is a cost-effectiveness ratio (CER) based on cost per DALY averted. In all cases, costs are the numerator, so that strategies yielding smaller results (lower cost-benefit, cost-effectiveness or cost-utility ratios) are to be preferred.

When comparing benefits and costs, in human health the convention is to analyse the costs and impacts of a range of

interventions to tackle a particular health problem. In each case, the extra benefits from an additional intervention are compared to the extra costs, thus yielding an incremental cost-effectiveness ratio (ICER). At an international level, until recently, interventions costing less than US \$25 per DALY were regarded as highly attractive and US \$25–150 as attractive (37). Current WHO cost-effectiveness thresholds define interventions costing less than one year's gross domestic product (GDP) per person as being very cost-effective, those costing between one and three years' GDP per person as cost-effective, and those costing more than three years' GDP per person as not cost-effective (38). A graph illustrating a wide range of CERs for different conditions can be found in (39) and the practicalities of applying the new thresholds are discussed in (40).

Animal health economics also uses CBA. Relating costs to measures of effectiveness, such as a reduction in disease prevalence or the number of animals vaccinated, is less standard, although it has been recommended that veterinary economics make more use of CEA (41). Both at the farm level and at the veterinary service level, break-even analysis fulfils a useful role when outcomes are uncertain, as it indicates what minimum level of benefit or return is required to cover costs.

In animal health economics, the basic outline for identifying costs and benefits is the 'partial analysis' framework. Costs are divided into the 'extra costs' (of the intervention and any extra inputs required for a healthier or more numerous livestock population) plus any 'revenue forgone' (such as negative side-effects of the intervention). Benefits consist of 'extra revenue' (reflecting a reduction in disease losses) and 'costs saved'. This framework is most commonly applied at a farm level, but provides a basis for identifying benefits and costs of interventions on any scale. The emphasis on extra revenue/extra costs and revenue forgone/costs saved identifies it as an incremental calculation analogous to the ICER, in which the benefit unit is monetary rather than a measure of effectiveness.

These differences in analytical focus and method are a clear reflection of the ways in which the human and animal health sectors operate. Human health and the control of disease in people is overwhelmingly considered a public good, both for communicable and non-communicable diseases, with the possible exception of more personal, elective interventions such as cosmetic surgery or prolonged fertility treatments. In animal health, the control of highly contagious and transboundary diseases and zoonoses is considered a public good, whereas endemic diseases which affect animal productivity and farmers' incomes – for example, mastitis or non-zoonotic worm infestations – is the responsibility of livestock keepers (7). Thus, much of animal health economics focuses on farm-level decision-making and on financial benefits. In human health, the

focus is on spending public-sector funds in such a way as to achieve maximum health impact, so a wide range of options is costed out and their effects compared.

Four options for zoonoses

To assess the economics of interventions to control zoonotic diseases, the impacts on the human and animal health sectors need to be integrated so that decision-makers in both sectors can assess and interpret outcomes in a way which is meaningful both to their sector and to society. Four options are investigated here, taking three neglected zoonoses as examples: one at national, one at county and one at city level (Table II). The first, brucellosis in Mongolia (18), has been widely used as a template for economic analyses of zoonoses control using the separable costs method (36, 42). The second is echinococcosis (19) in Shiqu County, Sichuan, in the People's Republic of China. In these examples, monetary benefits from improved livestock productivity are substantial, in contrast to the third example, rabies in Colombo, Sri Lanka (21), an instance where no livestock benefits were quantified. The intervention consisted of increased investments in activities which were already ongoing, so the additional investments are considered as incremental costs, but the previous investments are not categorised as costs saved or reduced expenses. Thus, the only benefit category represented is DALYs averted.

Throughout, prices are in current US\$, applicable at the time the study was undertaken, so as to retain the original ratios between the animal losses, disease control costs and GDP.

Aggregate net cost per DALY averted

The simplest and most obvious way to compare benefits and costs would be to combine all the monetary components (intervention costs, reductions in health expenditure and livestock losses) and compare them to the single non-monetary unit, the reduced burden of human disease expressed in DALYs averted. In order to obtain a net cost (NC) per DALY averted, the benefits are subtracted from the costs, and divided by the DALYs.

Using the convention of human health economics, this method does provide a series of costs per DALY averted, which can be ranked, with rabies control being the most expensive, and brucellosis the least. However, disconcertingly, for all the examples except rabies, the cost per DALY averted is negative. This is because the substantial monetary benefits from costs saved and from the livestock sector outweigh the costs before even considering the reduction in the human health burden of the disease.

For exclusively human health sector interventions, the implicit approach is often this type of net cost, since the

Table II
Four methods for analysing the benefits and costs of controlling zoonotic diseases illustrated for three contrasting interventions
 For an explanation of the formula abbreviations, see Figure 1

	Formula	Brucellosis control at national level	Echinococcosis control at county level	Rabies control at city level
Baseline parameters				
Location		Mongolia	Shiqu County, Sichuan, People's Republic of China	Colombo, Sri Lanka
Source		Roth <i>et al.</i> , 2003 (18)	Budke <i>et al.</i> , 2005 (19)	Häsler <i>et al.</i> , 2014 (21)
Year to which prices apply		2001	2002	2011
GDP (per capita, current US\$, year above)		410	238	2,860
Intervention				
		Vaccinate yaks, cattle, sheep and goats	Deworm dogs, vaccinate sheep and goats*	Better care for people bitten: post-exposure prophylaxis, dog bite follow-up; increased dog vaccination coverage
Total cost (US\$ '000)	CI	8,300.0	56.5	1,033.9
% in animal intervention		100	100	79.2
Project benefits				
DALYs averted ('000)	RB_H	49.0	0.53	0.74
Reduced human health expenditure (US\$ '000)	RE_H	11,200.0	14.8	–
Reduced animal health losses and expenditure (US\$ '000)	$RL_A + RE_A$	15,400.0	141.3	–
Aggregate net cost calculation				
Net cost (NC) (US\$ '000)	$NC = CI - RE_H - RL_A - RE_A$	–18,300.0	–99.7	1,033.9
Net cost/DALY	$NC / DALY$	–373.3	–188.8	1,401.0
Separable costs parameters				
Monetary benefits (MB) (US\$ '000)	$MB = RE_H + RL_A + RE_A$	26,600.0	156.1	0
Monetary benefit–cost ratio	MB / CI	3.2	2.8	0
% monetary benefits HH	$100 \times RE_H / MB$	42.1	9.5	100
% monetary benefits AH	$100 \times (RL_A + RE_A) / MB$	57.9	90.5	0
Cost share HH sector (US\$ '000)	$\% HH \times CI / 100$	3,494.7	5.4	1,033.9
CER (US\$)	Cost share HH / DALY	71.3	10.2	1,401.0
Cost–benefit analysis parameters				
DALYs as \$ (US\$ '000)	$DALY \times GDP$	20,101.1	125.7	2,110.7
Total benefits (TB) (US\$ '000)	$TB = (DALY \times GDP) + RE_H + RL_A + RE_A$	46,701.1	281.8	2,110.7
% benefits HH	$100 \times (DALY \times GDP + RE_H) / TB$	67.0	49.9	100
% benefits AH	$100 \times (RL_A + RE_A) / TB$	33.0	50.1	0
Benefit–cost ratio	TB / CI	5.6	5.0	2.0
Net benefit	$TB - CI$	38,401.1	225.3	1,076.8
zDALY parameters				
DALYs averted ('000)		49.0	0.53	0.74
Animal loss equivalents (ALE) averted ('000)	$ALE = (RL_A + RE_A) / GDP$	37.6	0.6	0
Health expenditure equivalents (HLE) averted ('000)	$HLE = RE_H / GDP$	27.3	0.1	0
zDALY ('000)	$DALY + ALE + HLE$	113.9	1.2	0.74
% benefits HH	$100 \times (DALY + HLE) / zDALY$	67.0	49.9	100
% benefits AH	$100 \times ALE / zDALY$	33.0	50.1	0
CER (US\$)	$CI / zDALY$	72.9	47.7	1,401.0
% of per capita GDP	$100 \times (CI/zDALY) / GDP$	17.8	20.0	49.0

*The authors analysed several scenarios, the one illustrated here is based on the assumption that *E. multilocularis* has a five-month lifespan
 AH: animal health; CER: cost-effectiveness ratio; CI: cost of the intervention; DALY: disability-adjusted life year; GDP: gross domestic product; HH: human health; NC: net cost; zDALY: zoonotic disability-adjusted life year

overall increase in expenditure is compared to the additional DALYs averted.

Separable costs method

The separable costs method aims to apportion costs for controlling the disease in proportion to the monetary benefits obtained from its control. This type of cost allocation is the classic approach used for interventions involving several sectors (43). Although it is usually applied to fully monetised calculations of benefits and costs, it has been adapted for zoonoses control (18).

Having quantified all the component elements, the first step is to work out the share of monetary benefits accruing to the human health sector and the share accruing to the animal health sector. Next, these percentages are applied to the costs, to derive the share of costs which should be attributed to each sector, where CS stands for 'cost share'. The cost-effectiveness ratio (CER) for human health is then calculated as its share of costs divided by the DALYs averted. For the animal sector the monetary benefits are divided by the sector's share of costs. This yields a benefit–cost ratio (BCR) which is identical to that which would be obtained for the human sector if the expenditure saved were divided by its cost share, so without considering the DALYs. For the examples given, it gives a CER which ranges from US \$10–1,400 per DALY averted, well within current thresholds of good value for money for each example. These are credible figures which make good sense to health service providers. This method has been widely adopted for zoonoses control interventions (18, 19, 20). By emphasising that a substantial share of monetary benefits accrues to the human health sector in terms of savings in treating people, it seeks to promote greater human health sector funding for disease control, even when the control (vaccinating reservoir animals as for rabies or brucellosis) is mainly undertaken by the animal health sector.

As the rabies example demonstrates, if there are no monetary benefits to either sector from the intervention, but DALYs are averted, all costs are attributed to the human health sector, so the result will be the same as for the aggregate net cost method.

Cost–benefit analysis

As discussed above, within human health economics, a monetary CBA is sometimes undertaken, using various methods to value human life and suffering. In Table II, this is done by valuing a DALY at a year's per capita GDP. Thus, RB_H is expressed in monetary terms as $GDP \times DALYs$ and a BCR calculated.

A net benefit (sum of benefits less sum of costs) can also be calculated. For a multi-year project, where figures are

discounted to their present value, this would be in the form of a net present value (NPV), and an internal rate of return (IRR) could usually also be calculated.

Two things are noticeable from this fully monetised analysis. First, including the value of the human health benefits in the BCRs makes these much larger than they were before: increasing from 3.2 to 5.6 for brucellosis and from 2.8 to 5.0 for echinococcosis. Second, their inclusion increases the share of benefits attributed to human health, from 42% to 67% for brucellosis and from 10% to 50% for echinococcosis. For the rabies example, which consists of increasing investment in both sectors, the only measured benefit is in DALYs, so only a fully monetised CBA allows for a BCR to be calculated, yielding a value of 2.0.

zDALY analysis: incorporating the ALE

Lastly, the ALE, as a non-monetary metric representing the cost of animal disease to society using a measure of national income as a numeraire, allows for the CBA process above to be undertaken in reverse, by converting monetary units into non-monetary units.

Thus, all monetary benefits are converted to income equivalents by dividing their monetary amount by the monetary value of one year's per capita GDP. For livestock losses, this yields an ALE. For human health monetary costs saved, a similar process yields a human expenditure loss equivalent or HLE.

Looking at Table II, this yields CERs with higher costs than the separable costs method (up from US \$71 to US \$73 for brucellosis, from US \$10 to US \$48 for echinococcosis, with the rabies figure staying constant at US \$1,401, as no animal benefits were quantified). The difference increases as the share of human benefits increases (a function of including the DALYs averted in the equation). As the same value of one year's GDP was used in this calculation as for the BCR calculation, the shares of each sector in total benefits are identical for these two approaches, but as noted above, higher for human health than when using the separable costs method. The CERs produced can be ranked and, as shown in the last line of the table, expressed as a proportion of one year's per capita GDP, ranging from 18% to 49% for the examples given, thus falling well within WHO's threshold of very cost-effective interventions.

Each of these four methods has its strengths and weaknesses, which are set out in Table III.

Discussion

In this paper the focus has been on trying to find practical metrics that can be applied and understood by both the

Table III
Comparison between methods for analysing benefits and costs of zoonotic disease control interventions

Method	Strengths	Weaknesses	Conclusion
Aggregate net cost	Maintains the separation of monetary and non-monetary components of benefits and costs. By pooling all monetary elements, provides a single consistent net monetary cost figure which can be compared to the number of DALYs averted.	Difficult to interpret because it becomes negative if there are substantial monetary benefits, usually from within the animal sector. Such negative 'costs per DALY averted' give the impression that controlling the disease can almost be done for free. Where animal sector benefits are high it could lead to disease control being considered exclusively or mainly a veterinary responsibility.	Best suited to situations where there are low monetary animal benefits so that there is a positive net cost per DALY.
Separable costs	Provides a consistent result without the need to try to convert monetary into non-monetary costs or vice versa. Provides a credible cost per DALY figure. Focuses attention on all four components of societal costs. Highlights the distribution of benefits and costs between the two sectors. Where the control measure is implemented largely through the animal sector, emphasises that there is a gain to human health and that funding from the human/public health sector should be allocated to that control measure.	Because the proportion of total costs allocated to the health sector is reduced where there are monetary benefits from the animal health sector, the cost/DALY averted cannot be compared to the cost/DALY averted from non-zoonotic interventions. Effectively, the DALYs are not included in the cost-allocation equation. Thus, it is questionable whether the standards of 'good value for money' (either in monetary or GDP terms) can be applied. Suffers from the classic BCR dilemma: if some costs are netted out from the benefits the CER will be altered.	Has been widely adopted and is well understood by the health sector, though less by the animal health sector. In practice, has not often led to costs being allocated to each sector in proportion to expected monetary benefits. Public sector budgets are usually allocated to each sector in proportion to their actual responsibility for achieving control. The challenge is to allocate sufficient total funding for controlling these diseases.
Cost–benefit analysis	Provides a single metric by expressing all figures in monetary terms. Results (NPV, BCR and IRR) are well accepted and widely understood by decision-makers. Provides an equitable analysis of how benefits are distributed between the human and animal health sectors. By allowing for a net benefit or NPV to be calculated, can avoid the classic BCR dilemma.	Departs from the DALY ideal, in assigning different monetary values to a DALY in different national-level economic contexts. However, does not differentiate between poor and rich individuals within a country or reflect their different levels of 'willingness to pay'. Does not provide either a CER or ICER so is not easily compared to other human health sector interventions. There are decisions to be made about which value of national income per capita to use to best represent a DALY	Suitable for decision-makers preferring to evaluate benefits in terms of monetary amounts. Best used alongside the zDALY method as these are both consistent and complement each other by providing both a DALY-based and a fully monetised analysis.
zDALY analysis	Provides a single metric by expressing all figures in zDALY terms. Results (CER/ICER) are well accepted and widely understood by decision-makers and can be ranked in relation to currently accepted thresholds of good value for money. Provides an equitable analysis of how benefits are distributed between the human and animal health sectors.	There are decisions to be made about which value and what proportion of national income per capita best represent an ALE. Does not provide a full NPV/BCR or IRR so not easily compared to other animal health interventions. Suffers from the classic BCR dilemma: if some costs are netted out from the benefits, the CER will be altered.	Suitable for decision-makers preferring to evaluate benefits in terms of DALYs. Best used alongside the CBA method, as these are both consistent and complement each other by providing both a DALY-based and a fully monetised analysis.

ALE: animal loss equivalent; BCR: benefit–cost ratio; CER: cost-effectiveness ratio; DALY: disability-adjusted life year; GDP: gross domestic product; ICER: incremental cost-effectiveness ratio; IRR: internal rate of return; NPV: net present value; zDALY: zoonotic disability-adjusted life year

human and animal health sectors, in the context of evaluating and ranking interventions to control zoonotic diseases. On the veterinary side, the focus has been on animal disease losses that are conventionally quantified in monetary terms.

Thus, the implications of valuing companion animals and wildlife (26, 27) and the wider ecosystem impacts which underlie a more holistic One Health vision (44) have not been brought into this analysis (for more information on

the economics of ecosystems and biodiversity, visit www.teebweb.org).

The economic analysis of zoonoses control brings out a number of classic discussion points. In human health, discount rates of 3%–5% are typically used as against rates of 6%–12% in animal health. While recent low interest rates have encouraged the use of lower discount rates, a disparity between human and animal health sector rates remains.

How costs and benefits are defined can affect BCRs. In animal health, comparing project costs to net benefits to livestock keepers will yield a higher BCR than comparing gross benefits to the total costs incurred by both livestock keepers and the project. Since CERs are a ratio, they are susceptible to the same problem. The calculation of incremental costs and their comparison to incremental DALYs avoids this problem, but including animal benefits may tend to reintroduce it.

The choice of which value of national income to use as a numeraire needs more thought and discussion. With respect to value, the calculations here have used the Atlas valuation of GDP at current, nominal US\$, rather than the producer-price parity (PPP) valuation at international US\$. The Atlas and PPP valuations are similar for wealthier countries, but Atlas is usually much lower than PPP for poorer countries (e.g. US \$2,860 rather than US \$8,949 for Sri Lanka in 2011). The Atlas value was used for several reasons. All three studies valued costs and monetary benefits at current US\$. For low-income countries, local salaries, local hospitalisation costs and livestock prices would be higher at international US\$ than at current US\$ values, but the prices of inputs for disease control would probably be similar at international and current US\$ values, because many of these inputs are sourced internationally. Thus, converting to international US\$ would alter the BCRs reported in the studies. Lastly, taking the lower Atlas US\$ GDP valuation and thus setting a lower cost-effectiveness threshold, effectively requires projects to achieve a higher level of economic return. However, a comprehensive economic analysis should use international US\$, as recommended by WHO (38).

The use of GDP also ties in with WHO's new thresholds for value for money which are linked to GDP (38), which in turn reflect the suggestion in the Commission on Macroeconomics and Health report (45) that a DALY be valued at between one and three years' per capita GDP. A comparison of this with the VSL can be found in (46).

Turning to the relation between per capita GDP and a DALY, it could be argued that people do not equate their time working with their whole available time. If people felt that only half their waking time was spent working then

it could be argued that an ALE, representing the working time needed to recoup monetary losses, would only be equivalent to half a DALY, which values a person's whole existence. The same logic would then imply that GDP, as a reflection of earning power, also only represents half a DALY. Thus, the symmetry between the CBA and the zDALY approach would be maintained, with the relative proportion of benefits attributed to animal and human health remaining identical. This is a discussion point for further development.

Conclusion

'If the scientific community was to find an agreement on a standardised approach to measure outcomes of rabies control in an integrated way, the economic efficiency of such control measures could be compared internationally and the best approach chosen' (21).

Accepting the ALE, as a way of converting monetary animal benefits into a non-monetary metric, enables animal health benefits to be integrated into human health economic analyses. This is a much more realistic and viable option than trying to develop a DALY-type metric for ill health in animals, i.e. a metric based on disability and premature death. One great strength of the DALY approach has been in evaluating global health burdens, because deaths from all causes need to add up to total deaths, although there are still unresolved issues around the avoidance of double-counting for co-morbidities. However, in animal health, for many diseases and production systems there is no consensus at all on what overall losses are. Disease losses are assessed one disease at a time, so that the sum of deaths ascribed to various individual causes often greatly exceeds the total number of deaths observed. Thus, there remains a huge gap to fill in terms of providing more coherent data on the impacts of livestock diseases.

Conversely, converting the DALY into monetary terms based on GDP does detract from its appeal as a universal metric. WHO's value-for-money criteria implicitly already accept this and comparisons are made on a country, not an individual, income basis. Similar issues arise when deciding whether to apply regional or global life expectancies for DALY calculations. Such monetary conversions do not diminish the value of being able to calculate and compare the burden of disease across countries in terms of DALYs.

To summarise, this paper argues that all four measures outlined (aggregate net cost, separable costs, CBA and a zoonotic CER based on a non-monetary zDALY metric integrating human and animal health benefits) should be considered. The latter two are essentially mirror images of each other, presenting the same figures: once with monetary

benefits and once with non-monetary benefits. In each case, the shares of benefits reaped by the animal and human sectors are the same. The zDALY-based CER could easily be set alongside human-health-only CERs and compared across diseases. The CBA yields results which decision-makers are used to interpreting. Thus, it is recommended that these two measures be calculated in a standardised way and presented together when assessing the economics of interventions to control a zoonotic disease.

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Des DALY, des dollars et des chiens : quelle est la meilleure option pour l'analyse économique de la lutte contre les zoonoses ?

A.P.M. Shaw, J. Rushton, F. Roth & P.R. Torgerson

Résumé

Les décideurs politiques sont de plus en plus dépendants de méthodes exhaustives de mesure économique permettant de synthétiser et de comparer les avantages et les coûts de la lutte contre les zoonoses. Par convention, l'impact des maladies humaines est quantifié en des termes non monétaires, à savoir, le plus souvent, en « années de vie corrigées de l'incapacité » (DALY), tandis que les pertes dues aux maladies animales, en particulier celles affectant les animaux d'élevage, sont quantifiées en termes monétaires. Dans cet article, les auteurs envisagent (et réfutent) la possibilité de mettre en œuvre un système de mesure non monétaire des problèmes sanitaires chez les animaux qui soit basé sur les années de vie perdues ou d'incapacité. La longévité n'est pas un objectif uniformément recherché dans tous les systèmes de production, ni pour toutes les espèces animales, voire pour tous les individus au sein d'une même espèce, et la morbidité et l'incapacité représentent des fardeaux très variables, conduisant souvent à l'abattage. Parce qu'elle relie les pertes animales à une mesure de la réduction du revenu intérieur entraînée, la récente proposition de convertir les pertes monétaires dues aux maladies du bétail en un « équivalent pertes animales » (indicateur ALE : *animal loss equivalent*) constitue une solution viable. À partir de ces considérations, les auteurs examinent la littérature dédiée aux aspects économiques de la lutte contre les zoonoses en détaillant quatre méthodes possibles pour en quantifier et comparer les avantages et les coûts, avec des exemples chiffrés. Ces possibilités sont : *i*) le simple regroupement de tous les éléments monétaires et leur comparaison en termes de DALY évitées (méthode dite de la présentation agrégée des coûts nets) ; *ii*) la méthode des coûts séparables ; *iii*) l'utilisation d'un indicateur ALE pour convertir l'ensemble des bénéfices en leur équivalent non monétaire, désigné sous le terme de DALY zoonotique (zDALY) ; *iv*) le recours à une analyse monétaire coûts-avantages exhaustive, après avoir converti les DALY en leur équivalent monétaire. Les auteurs font ressortir les atouts et les faiblesses de chacune de ces méthodes. La priorisation et la prise de décisions gagneront en efficacité si les décideurs

adoptent et appliquent largement une approche analytique permettant d'obtenir des résultats cohérents et de renforcer la lutte contre les zoonoses.

Mots-clés

Analyse coûts-avantages – Année de vie ajustée sur l'incapacité – Année de vie ajustée sur l'incapacité associée aux zoonoses – Coûts séparés – DALY – DALYz – Économie – « Équivalent pertes animales » – Indicateur ALE – Lutte contre les zoonoses.



AVAD, dólares y perros, o cómo analizar idóneamente la economía del control de las zoonosis

A.P.M. Shaw, J. Rushton, F. Roth & P.R. Torgerson

Resumen

Cada vez más, las instancias decisorias necesitan parámetros econométricos integrales, que sirvan para sintetizar y comparar los costos y beneficios de la lucha contra enfermedades zoonóticas. Convencionalmente, los efectos de una enfermedad en las personas se cuantifican en términos no monetarios, por lo general en forma de «años de vida ajustados en función de la discapacidad» (AVAD), mientras que las pérdidas inducidas por las enfermedades en animales, en particular el ganado, se cuantifican en valores monetarios. Los autores examinan y descartan la posible definición de parámetros no monetarios, basados en los años de vida perdidos y en la discapacidad, para cuantificar problemas zoonosarios. Con independencia de la especie animal o el sistema de producción ganadera de que se trate, el de lograr una longevidad máxima no es un objetivo habitual, y los niveles de morbilidad o discapacidad, que suelen desembocar en el sacrificio sanitario, tienen un peso muy variable. En fechas recientes ha aparecido una alternativa que, al establecer una relación entre las pérdidas de ganado y una medida de la renta nacional prevista, ofrece una solución viable: se trata de convertir las pérdidas monetarias causadas por enfermedades del ganado en un «equivalente a las pérdidas animales» (*animal loss equivalent*: ALE). Partiendo de esta idea, los autores repasan la bibliografía sobre la economía de la lucha contra las zoonosis y examinan cuatro opciones para cuantificar y comparar beneficios y costos, ilustrándolas con ejemplos numéricos. Se trata de las siguientes: *i)* el simplificador procedimiento de agrupar todos los elementos monetarios y compararlos con los AVAD evitados (método que describen como del «costo agregado neto»); *ii)* el método de los costos específicos; *iii)* el uso de «equivalentes a las pérdidas animales» para convertir todos los beneficios en un equivalente no monetario que denominan AVAD por zoonosis; y *iv)* el uso de un análisis monetario completo de la relación entre beneficios y costos, basado en la conversión de los AVAD en un equivalente monetario. A continuación examinan los puntos fuertes y débiles de cada uno de esos métodos, y concluyen que para fijar prioridades y adoptar decisiones con eficacia es vital aplicar de forma generalizada un mismo planteamiento analítico, que arroje resultados coherentes y ayude así a combatir las zoonosis.

Palabras clave

ALE – Análisis de la relación beneficio-costos – Años de vida ajustados en función de la discapacidad – Años de vida ajustados en función de la discapacidad por zoonosis – AVAD – AVAD por zoonosis – Control de zoonosis – Costos específicos – Economía – Equivalente a las pérdidas animales.



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