Economic assessment of African horse sickness vaccine impact

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Abstract

Background: African horse sickness (AHS) is endemic in sub-Saharan Africa posing a threat to equine populations in non-endemic regions. Available vaccine technologies have limitations, creating barriers to horse movement, AHS control and, in non-endemic areas or countries, rapid elimination of virus after incursion. The literature lacks an economic assessment of the benefits of bringing a new, more effective AHS vaccine to market.

Objectives: The study assesses the economic impact of AHS and tests the hypothesis that investment in a safer, more effective AHS vaccine would give an economic return.

Study design: Cost-benefit analysis.

Methods: Primary and secondary data were collected to populate the cost-benefit analysis model. A literature review was followed by a questionnaire survey and interviews to gather primary data. At-risk populations were defined and qualitative assessment completed to narrow the target populations for quantitative assessment. A deterministic cost-benefit model was developed in Excel and different scenarios tested. Break-even and sensitivity analysis were conducted on key parameters.

Results: The economic impact of AHS was estimated to be US$95 million per annum, and this was mainly in endemic regions with domestic equine industries and involved in international trade. Investment required to bring a new AHS vaccine to market was estimated to be up to US$3.5 million, which was very small relative to the benefits estimated in this study. The economic return on investment in bringing a new AHS vaccine to market was predicted to be positive and the analysis demonstrates this result was robust.

Main limitations: Data for the analysis were scarce, requiring expert opinion and extrapolation by the authors. Sensitivity analysis with the deterministic modelling structure indicated there was no justification for stochastic modelling, given the robustness of the return on investment.

Conclusions: The analysis predicts a strong and robust economic return on the investment in bringing a new AHS vaccine to market. Main economic beneficiaries would be the high value horse sectors, specifically the equine industries in Republic of South Africa (RSA) and in non-endemic countries. In addition, major benefits would...
be captured in poor communities in sub-Saharan Africa where working equids are of high economic and social importance.

**KEYWORDS**

horse, animal health economics, cost benefit analysis

1 | **INTRODUCTION**

African horse sickness (AHS) is a viral disease caused by an Orbivirus (AHSV) which affects equids and is transmitted by biting midges of the genus *Culicoides*. It causes high mortality in horses and is carried by other equids including wild equids (zebras). It is endemic in many parts of sub-Saharan Africa and periodic incursions into non-endemic countries have occurred, threatening immunologically naïve horse populations in previously AHSV-free countries.\(^2\)\(^3\) A recent incursion of the virus into Thailand, confirmed in March 2020, highlights the ongoing threat and the potential for serious disruption and damage to the economy and livelihoods in non-endemic countries.\(^2\)\(^3\)

AHS is one of the diseases listed by the OIE (World Organisation for Animal Health) for its negative impact on animal welfare, its capacity to inflict severe economic losses on the equine industries and its significance for international trade. AHS is the only equine infectious disease for which the OIE issues an official status of disease freedom.

The presence of AHSV is the main barrier to international trade in horses between sub-Saharan Africa and the rest of the world, largely due to the lengthy and expensive quarantine requirements which make rapid or large scale horse movements unviable. Exporting a horse from the Republic of South Africa (RSA) to a European Union destination requires 6 weeks of quarantine and costs around US$30,000. This impacts greatly on the ability of horses from this region to participate in equestrian events internationally and is also a barrier to the hosting of such events in endemic countries. Movement of horses for breeding between endemic and AHSV-free countries is also greatly restricted.

Currently available vaccines have technical limitations, being dependent on live attenuated virus which can itself cause disease through reversion to virulence or reassortment.\(^4\) The development of a vaccine which allows infected and vaccinated horses to be differentiated (a DIVA vaccine, Differentiating Infected from Vaccinated Animals) has also been identified as a key control measure.\(^5\) DIVA technology could protect horses from AHS without compromising surveillance, thereby facilitating freer international movement of horses for sport, racing and breeding. Such a vaccine would also facilitate more rapid eradication when AHSV incursions into disease-free areas occur, as serology could continue to be used to investigate virus spread even after vaccination.

Although there are a number of new AHS vaccines being researched, none of the potential vaccine candidates has yet been brought to market and no studies have previously been published estimating the economic benefits of a new AHS vaccine with superior technical qualities. There are also very few studies which examine the economic impacts of AHS.

This study presents an economic assessment estimating the impact of a new, safe and effective AHS vaccine. The work presents: the current economic impact of AHS; the predicted main beneficiaries of a new vaccine technology; and an assessment of the net economic benefit of a new vaccine. It tests the hypothesis that investment in a safer, more effective vaccine would be economically justified. The analysis also examines where benefits will accrue to owners of the at-risk equine populations, and considers the impact of a new vaccine on communities in low and middle income countries (LMICs) with important working equid populations that contribute to the livelihoods of poor and vulnerable people.

2 | **MATERIALS AND METHODS**

The equine populations at risk of, or already affected by, AHS were first defined. The focus was primarily on African countries, not officially free from AHSV, and domestic equine populations at risk in AHSV-free regions due to geographical or trading factors. The framework for describing the domestic equine population and sub-populations is illustrated in Figure 1 and this informed the design of subsequent primary data collection.

A review of the literature and other sources was completed (Data S1, including full reference list). Informed by the data gaps identified in the literature, a structured questionnaire survey for government veterinary services in African countries was designed and distributed through OIE Representatives to OIE Delegates in these countries (Data S2A). A similar questionnaire was designed and distributed to equine non-government organisations (NGOs) working in African countries (Data S2B) and to the FEI Group IX (sub-Saharan Africa region) veterinarians (Data S2C). The questionnaire was developed in English and French.

Information was also obtained through face-to-face meetings, interviews and detailed discussions with the International Federation of Horseracing Authorities (IFHA), the Fédération Equestre Internationale (FEI), high value equine industries in the Republic of South Africa (RSA), the UK and Ireland and the European Commission.

The information obtained allowed a thorough understanding of the AHS context and a more precise definition of the at-risk populations. A general framework for economic assessment was developed and, based on this, a set of data and assumptions were
assembled. Cost and benefit streams for each at-risk population group were described. Qualitative data were used to both inform the subsequent analysis and nuance the interpretation of quantitative results.

A deterministic cost-benefit analysis (CBA) model was developed in Excel to assess the economic case for the investment needed to bring a new, safe and effective AHS vaccine to market. The additional costs, additional benefits and net benefits associated with a new vaccine were assessed for the key at-risk population groups. The model facilitated transparent discussion with the industry. Stochastic modelling was considered but dismissed given the uncertainty of parameters and lack of information on their ranges. It was also deemed unnecessary due to the robustness of the results.

The cost-benefit analysis was run over a 15-year period. A discount rate of 10% was used, in line with the higher rates of return generally expected from commercial investments. Scenarios were tested for robustness across different discount rates. Sensitivity and breakeven analysis were performed on the prices of key inputs, outputs and other parameters in order to test the assumptions and the robustness of the investment.6

A quantitative assessment was run for each population group in turn, with the cost of the whole investment required to bring a new vaccine to market attributed to each population group alone, to test the hypothesis that the benefits accruing to any one of these population groups would be sufficient to justify the investment.

3 | RESULTS

3.1 | Literature review, questionnaire survey, interviews

The literature review revealed underlying problems with determining the equine populations, their current use and economic value to societies. Information on AHS prevalence and the economic impact of the disease was also lacking.7 No studies have systematically quantified the economic burden of AHS in endemic countries. Information that exists focuses on direct costs associated with the disease and its treatment.8 Hypothetical studies on the potential cost implications of outbreaks in non-endemic countries have tended to estimate a burden based on the overall size of the equine-related economy.
particularly horse racing) and assumptions about the potential scale and duration of disruption caused by actions that might be taken to deal with an outbreak. The questionnaire survey conducted in African countries addressed some of the literature data gaps, in particular the market value of equids and data on the availability and price of existing AHS vaccines which were subsequently used in the quantitative analysis. There is currently significant AHS vaccine production in Ethiopia, Senegal and RSA, which are also the countries with the highest reported cases of AHS. This may well reflect the importance of equids in these economies and the number of animals.

Interviews provided a detailed understanding of the costs and barriers to international movement of horses from sub-Saharan Africa and the impact of existing AHS vaccines on disease control in both endemic and virus-free countries. DIVA attributes are valuable for facilitating rapid return to disease-free status and international movements following outbreaks in previously AHSV-free areas, as well as for allowing pre-emptive vaccination. However, interviews indicated that the complete safety of AHS vaccine was the overwhelming requirement and this alone would deliver the bulk of the benefits: (a) by reducing the current level of disruption and high cost of international horse movements caused by vaccine-related outbreaks in the Controlled area (AHSV-free zone and buffer zone) in the case of RSA; and (b) by facilitating the establishment of robust contingency vaccine supplies in the case of non-endemic areas with high value horse sectors, such as those in Europe. The current study therefore did not attempt to differentiate between DIVA and non-DIVA vaccine technologies in economic terms, although the authors acknowledge that a vaccine with DIVA qualities would be the most versatile and acceptable internationally.

3.2 | General economic framework

A general economic framework, presented in Table 1, was adapted to enable a systematic assessment of the impact of the disease and of the introduction of a new, safe and effective vaccine.

3.3 | At-risk equine populations

Equine population groups of greatest relevance across endemic and AHSV-free countries were defined as the horse populations of the continent of Africa, with special focus on RSA, and the continent of Europe. The analysis focused on horses, since this species is most susceptible to clinical disease and death when exposed to AHSV. Although mules are also susceptible, their numbers are relatively small.

Four clearly distinguishable at-risk equine populations were delineated:

- Population 1: Endemic Countries – working equids used in agriculture and for transport;
- Population 2: Endemic Countries – domestic equine industries, with RSA as an example;
- Population 3: Endemic Countries – horses moving in and out of endemic countries, with RSA as an example;
- Population 4: Non-Endemic Countries – domestic equine industries at risk from AHS incursion, requiring contingency measures to support eradication, with an AHS outbreak in the European horse population as an example.

### Table 1: General economic framework – additional costs and additional benefits of a new vaccine

| **Additional costs** | **Additional benefits** |
|----------------------|-------------------------|
| **New Costs**        | **Costs Saved**         |
| **Capital costs**    | **Treatment costs avoided** |
| Vaccine development and testing, authorisation process and initial vaccine marketing. Investment in manufacturing and cold chain facilities. Training of staff and equine owners. | Costs of treating animals that would have been sick without the new vaccine, albeit it is recognised there is no curative medicine available. |
| **Recurrent Costs – Vaccine and its application** | Costs of application of existing vaccines |
| Coordination and monitoring of vaccination programmes. Vaccine production, maintenance of manufacturing and storage facilities. Vaccine delivery. Vaccine price at point of application and application costs for routine, outbreak and emergency vaccination. | Other costs avoided |
| **Other Recurrent Costs** | A change in the level of disease surveillance and related costs. Animal movement control costs. Depopulation, and welfare slaughter costs. |
| Diagnostic tests. Quality assurance processes. Ongoing marketing, estimation of vaccine demand in the different populations. | Costs incurred from additional measures taken to enable events to take place. |
| **Lost revenue** | **New Revenue** |
| No significant items of lost revenue with the adoption of an improved vaccine were identified. | **Mortality and morbidity reduced** |
| Reduced numbers of equids that die. Reduced level of animals sick. | Reduced disruption of horse race meetings, FEI events, other equestrian activities or cultural events. |
| **Economic activity increased** | Trade facilitation either national or international (import or export) |

No significant items of lost revenue with the adoption of an improved vaccine were identified.
Within endemic countries (populations 1, 2 and 3), there would be considerable differences between the impact of a new vaccine on the large numbers of working equids versus that on other parts of the domestic equine industries such as horse racing, sport and leisure sectors. Impacts on the equine economy in non-endemic countries at risk of AHSV incursion were addressed separately, population 4. Europe was selected as an illustrative example due to the geographical proximity to endemic regions, the risk of contact through trade, movement of equids and climate change, the history of incursions and the existence of very high value horse populations.

3.4 | Qualitative assessment

The qualitative assessment identified the most important additional benefits from a new vaccine for each of the at-risk populations. This analysis did not consider costs of vaccine development and bringing a new vaccine to market as these were assumed to be similar across all population groups. The general framework was used to qualitatively assess, for each population, which of the benefit streams were most likely to be significant and to weight their relative importance.

A summary of the qualitative assessment is shown in Figure 2.

The analysis identified the importance of estimating direct savings in animal mortality in working equids, population 1, since these animals are the most numerous but unlikely to be moving over great distances. A large number of these animals are currently not vaccinated at all.

Additional benefits of a new vaccine for population 2 alone, other equids moving domestically in endemic countries, are likely to be relatively low and difficult to estimate. The impact of control measures on movement and consequential losses, for example cancelled events, are potentially important if AHS outbreaks occur, and impacts could be very severe for horse owners caught in an outbreak control zone, but overall numbers will be small and impacts very localised. The animals are likely to be of greater, though varied, economic value than the working equids. However, due to vaccination requirements for movement and participation in events, these animals are more likely to be vaccinated and therefore the impact of a new vaccine would potentially be less. Information obtained from interviews suggests that the regime of movement controls domestically in RSA will continue to be necessary to support exports even with a new vaccine and so the cost of domestic movements is unlikely to change much – the biggest difference will be that there would be expected to be fewer, if any, disruptive outbreaks in the Controlled area.

For population 3, the costs associated with international movement restrictions imposed on RSA, as the result of outbreaks in the Controlled area, were identified as very significant. In particular, reducing these costs through the availability of a new, safe and effective vaccine is key to unlocking future growth potential and the significant economy-wide benefits that would flow from this.

Outbreaks in non-endemic countries, affecting population 4, would impact across the whole equine economy and consequently the wider economy. Informed by the literature search and interviews,

| Costs Saved                                                                 | Endemic                      |
|----------------------------------------------------------------------------|------------------------------|
| Treatment costs avoided (e.g. vet fees, medicines)                         | +++                          |
| Direct impact of control measures (e.g. depopulation, welfare slaughter, breeding controls) | +                            |
| Other potential direct savings (e.g. blood tests, disease surveillance and related costs) | +++                          |

| New revenue                                                                | Endemic                      |
|---------------------------------------------------------------------------|------------------------------|
| Animals saved-mortality (loss of expected future profitability/value added by animal) | +++                          |
| Animals saved -morbidity (diseased animals not able to work, resulting in higher production costs or reduced crop yield) | +++                          |
| Improved movement and marketing structures                                | N                            |
| Lower disruption of events (direct)                                       | +                            |
| Lower disruption of service related activities                            | +                            |
| Exports facilitated                                                       | +                            |
| Imports facilitated                                                       | +                            |

+++ most substantial additional benefits; ++ substantial; + potentially substantial; N negligible
this assessment assumes an outbreak will occur at some point in future and that direct impacts without a new vaccine would be very high, with very high mortality in immunologically naïve populations and severe economic losses. A new vaccine would significantly enhance the ability of these countries to prepare for a future incursion of AHSV, would greatly reduce the likelihood of infection spreading and would allow a much more rapid return to disease-free status when an outbreak occurs.

The qualitative assessment was used to guide the quantitative assessment. Given the additional benefits of a new vaccine for population 2 alone are likely to be relatively low and difficult to estimate, this population was combined with population 3 – the horses of RSA that are involved in domestic and international equine industries and which are not working equids. This combined group is termed the “non-working horses of RSA” in the quantitative assessment.

3.5 | Quantitative assessment

The quantitative analysis estimated, for populations 1, 2 and 3 combined, and 4 described above, the potential additional costs, additional benefits and net benefits arising from a new, safe and effective AHS vaccine. Key data on equine numbers, current AHS deaths and current vaccine production, as well as assumptions on the likely demand for a new AHS vaccine and production costs, are described in Data S3. Parameters used in the cost benefit analysis are provided in Data S4.

3.6 | Cost-benefit analysis by population group

The entire investment required to bring a new vaccine to market was attributed first to each population group alone, to test the hypothesis that the benefits accruing to any one of these population groups would be sufficient to justify the investment. A more detailed description of these analyses is presented in Data S5.

3.7 | CBA population 1: endemic countries – working equids

The analysis found that even if the vaccine was brought to market at a minimal cost of US$70,000 per serotype, total investment US$490,000, the cost-benefit analysis for the working equid population would not be positive. Changing the discount rate between 5% and 10% made no difference to the result, it remained negative. Break-even analysis indicated that the number of AHS-related deaths per year would need to be more than 150,000 to justify the investment, equivalent to an approximately 150 fold underreporting of deaths due to AHS (on average 1,000 per year are officially reported). Alternatively, the price of a vaccine dose (not including costs of application) would need to be less than US$1.33 per dose, which is in line with the cost of vaccine reported by African countries in the survey.

3.8 | CBA populations 2 and 3: endemic countries – non-working horses of South Africa

Attributing the entire cost of investment to the population of non-working horses in RSA alone, the result was strongly positive. With a scenario of 5 years to market and a cost of US$500,000 per serotype, totalling US$3.5 million, the investment is predicted to have a cost benefit ratio of 2.23 over 15 years, indicating that every US$1 invested will return US$2.23. The analysis also showed that the payback period was only 5 years. Discount rates of lower than 10% increase the value of the benefits even further and strengthen the case for investment, as the rate of return is well above 10%. The result was found to be sufficiently robust to generate a positive economic return even if each serotype cost US$1 million to bring to market, total investment US$7 million.

A sensitivity analysis was performed setting the benefit streams to zero for the growth in exports, growth in events, and savings on outbreaks and emergencies. The cost saved per horse for international transport was then varied to give a break-even point. Transport cost savings could drop as low as US$6,698 per horse exported and would still give a return on the investment needed for a new vaccine, even if no other major benefit streams are included and the cost per serotype was US$500,000. This compares to a transport cost saving of US$15,000 per horse predicted by the industry.

Another way of expressing this is to look at the total estimated saving on transport costs (US$15,000 per horse) for 350 horses currently exported per year, an annual total of US$5.25 million assuming all continue to the EU. In one year alone this saving would pay for the investment required to produce a new vaccine (US$3.5 million), without considering any of the other benefits from increased economic activity such as stimulus to host international events, greater demand for RSA horses, growth of domestic industries, growth of exports and so on.

This modelling, using very conservative estimates, indicated the benefits accruing from growth in the horse industries of RSA would alone justify the investment in bringing a new vaccine to market.

3.9 | CBA population 4: non-endemic countries at risk of AHS incursion – Europe

The cost benefit analysis of impacts of a new vaccine for population 4, non-endemic areas at risk of incursion of AHSV, modelled a single outbreak in a European context with wide economic damage. The analysis assumed that, if a new vaccine were available, the costs of an emergency outbreak would be reduced from an estimated US$500 million to US$300 million per year per outbreak, a saving of US$200 million per year per emergency. These assumptions were conservative when compared with predicted costs to the UK equine sector in the
order of US$6 billion per year per outbreak. It was also assumed that an EU vaccine bank would be set up if a new vaccine were available.

With a scenario of 5 years to market and a cost of US$500,000 per serotype, totalling US$3.5M, the investment is predicted to have a cost benefit ratio of 4.45 over 15 years, indicating that every US$1 invested will return US$4.45 and with a payback period of 10 years. The latter simply coincides with the year in which an outbreak is predicted to occur in the model, as an outbreak occurring at any time will immediately justify the investment. As with the horse industries of RSA, discount rates of lower than 10% strengthen the case for investment and the rate of return for this population was found to be significantly higher than this.

Break-even analysis was used to estimate the level of savings needed to off-set the vaccine investment for the European horse population alone. The savings could drop as low as US$45 million per emergency and still justify the investment in a European regulatory environment where the cost per serotype is assumed to be high.

Even if an outbreak occurred every 15 years, at the end of the analysis period the investment in a new vaccine returned a net benefit in all scenarios and suggested a robust investment. Some may argue that wider time periods should be tested, as the last AHS outbreak in Europe occurred in 1987–1991. However, the recent incursion and spread of Bluetongue and Schmallenberg in Europe indicate the risk of vector-borne viruses is increasing.

Although this analysis models the benefits based on the predicted costs of an outbreak in a single country with high value equine industries such as the UK, it is likely that any outbreak in Europe would spread to multiple countries, due to their geographical proximity and strong commercial and cultural links which promote movement of equids throughout the region. In such circumstances the benefits of a new vaccine, particularly one with DIVA and which could be used pre-emptively, would be many times greater.

### 3.10 Analysis of three population groups combined

The summary below brings together the analyses for the three population groups, addressing firstly the impact of AHS and secondly the economic return on investment in a new vaccine for each population and across all populations combined.

**TABLE 2** Current economic costs of AHS (US$ per annum, authors’ analysis)

| Population                        | Costs | Losses in economic activity |
|-----------------------------------|-------|-----------------------------|
|                                   | Losses in production | Vaccination | Treatment | Transport | Events | Export/import | Outbreaks | Emergencies |
| Endemic - working                 | 500,000 | 4,125,000 | 10,000 | — | 49,000,000 | 10,000,000 | 12,500 | — |
| Endemic - non-working RSA         | 200,000 | 4,000,000 | 20,000 | 5,250,000 | 49,000,000 | 10,000,000 | 25,000 | 1,800,000 |
| Non-endemic at risk Europe        | —      | —      | —      | —      | —      | —      | 20,000,000 | — |
| Total                             | 700,000 | 8,125,000 | 30,000 | 5,250,000 | 49,000,000 | 10,000,000 | 37,500 | 21,800,000 |

**TABLE 3** Current economic impact of AHS – total and per horse year (US$ per annum, authors’ analysis)

| Population                        | Impact | Per horse year |
|-----------------------------------|--------|----------------|
| Endemic - working                 | 4,647,500 | 0.85 |
| Endemic - non-working RSA         | 70,295,000 | 439.34 |
| Non-endemic at risk Europe        | 20,000,000 | 3.64 |
| Total                             | 94,942,500 | 8.51 |

Table 2 summarises the estimated impacts of AHS in the three at-risk population groups. The losses due to trade impacts are estimated to be large relative to production losses because the current vaccine is unstable and unsuitable for facilitating international movements. In the endemic region of Africa, RSA experiences the largest losses related to the impact of AHS on international horse movements (imports/export), and non-endemic countries can incur very major costs in the event of an outbreak.

Table 3 presents the estimated AHS impact per horse per year in the different populations, assuming that in Europe there would be an outbreak every 10 years with an average net outbreak cost per year of US$20 million (distributing the cost of any one outbreak over 10 years). The table indicates the high level of impact in the non-working RSA population, as the main impact of the disease is felt in endemic areas with trade potential.

Bringing the quantitative analyses for the three populations together, Figure 3 shows the additional undiscounted costs of introducing a new vaccine, split by the populations and distributed over the 15-year period assuming a 5-year implementation period and cost per serotype of US$500,000. Undiscounted data have been used to highlight the ongoing financial investment required to make the vaccine available to the working equid populations in endemic areas. The ongoing costs, following introduction of a new vaccine, are many times higher than the initial capital cost.

Additional undiscounted benefits are presented in Figure 4. These are dominated by the predicted benefit of a new vaccine in
FIGURE 3 Undiscounted costs of new vaccine by population and type of cost

FIGURE 4 Undiscounted benefits of the new vaccine by population

FIGURE 5 Undiscounted benefits minus recurrent costs by population group
tackling a major outbreak of AHS in the non-endemic area at risk. Note that this only accounts for a single outbreak in Europe, based on a predictive study from the UK. It is likely that any outbreak in Europe would spread to multiple countries, hence this is a very conservative estimate.

The undiscounted benefits minus costs by population group are shown in Figure 5, illustrating that the estimated net benefit is only negative for working equids in endemic countries.

The quantitative assessment tested the hypothesis that the benefits accruing to any one of three identified equine population groups alone would be sufficient to justify the investment in bringing a new, safe and effective AHS vaccine to market.

For two out of the three populations studied this hypothesis was confirmed. The assessment has shown a clear and significant net benefit to the equine industries in both RSA and Europe, and it can be concluded that investment in a new vaccine would deliver significant returns for either of these populations alone. The benefits to these two populations combined make the case for investment even more convincing, and sensitivity analyses around the data and assumptions indicated that the case is very robust.

When the population of working equids in endemic countries is taken alone, the benefits were not found to be sufficient to justify the investment in a new vaccine unless the costs could be kept to a very low level, both in terms of regulatory costs and ongoing production costs. It is, however, incredibly difficult to estimate the true economic and social impact of AHS in communities which depend on working equids for their livelihoods, particularly when the level of underreporting of disease is likely to be high and the lifetime contribution to household incomes is difficult to assess. Hence the economic case could be strengthened with a more detailed study of disease impacts in endemic areas.

4 | DISCUSSION

AHS has significant impacts which touch upon owners of equids well beyond the endemic regions in sub-Saharan Africa. The disease impact was predicted to be in the region of US$95M per year across three different equine populations and is largely caused by losses in trade and events in the high value equestrian sport and racing industries and the consequences of AHS outbreaks in non-endemic countries. The 2020 outbreak in Thailand is a sobering reminder of the risk of spread across borders and the potential for significant harm to the livelihoods of individuals and to the wider economy.

The cost-benefit analysis predicted that investment in bringing a new safe and effective AHS vaccine to market was economically justifiable in either the population of horses in RSA involved in domestic equine industries and international horse movements or the European horse population at risk of AHSV incursion alone. A single year of reduced cost of transporting horses from RSA to the EU, by avoiding the lengthy journey via Mauritius, would be sufficient to justify the investment in a new vaccine, even if there was no growth in exports or any other aspect of the RSA equine-related industries. Similarly, when the horse population of Europe is considered alone, a single outbreak 10 years from now would immediately, and overwhelmingly, justify the investment made in a new vaccine, even if the cost of that outbreak would otherwise be in the order of US$45M which is very low compared with estimates of the potential economic damage an outbreak would cause and experiences of the 1987–1991 outbreak in southern Europe. Sensitivity analysis indicated that even if an outbreak did not occur until 15 years into the future, the return on investment would be very strongly positive.

The economic assessment for working equids in endemic regions of sub-Saharan Africa indicated that while there is a sizable population affected by AHS, the value of the individual animals and their associated economic activities are not sufficient alone to return a benefit on the investment required. It is, however, likely that the analysis has underestimated the benefits which might accrue to the owners of these equids. Although data are scarce, the market values used may not have fully captured the economic and social contribution to a household over the lifetime of an animal. Equids in this category have enormous value in areas of the world where there are high rates of poverty, making major contributions in relative terms to household incomes, and therefore this population should not be ignored.

The study shows that those who have an interest in protecting high value horse sectors and/or in moving horses internationally for breeding and competition will derive the greatest benefit. The challenge is that much of the benefit to non-endemic countries is not immediately apparent and might be difficult for investors to appreciate because an outbreak of AHS in Europe, or any major equine nation outside Africa, has not occurred for nearly 30 years. Yet the risks to these non-endemic areas are greater than in the past, as demonstrated by recent experiences with viruses transmitted by biting insects, with a future outbreak inevitable. Now is therefore an opportune moment to invest in this area. The technologies are already developed to the stage where they could be brought to market with a moderate level of investment to progress them through the trials and authorisation process.

In addition, there is an unquantified social benefit in developing a safer and more effective vaccine for use in the working equid population in endemic countries, with the potential to increase the resilience of communities where equids play a critical role in terms of transport and draught power. This benefit is difficult to quantify and needs further data collection and analysis, in particular analysis of the unreported burden of disease and the wider economic and social benefits of an effective vaccine to those on the margin who are arguably more dependent in relative terms on the health and welfare of equids for their livelihoods. Further work would strengthen the case for equity of vaccine distribution to these regions and communities.

Better protection of equids in endemic areas of Africa may also have benefits for non-endemic countries, in reducing the chances of spread through trade or climatic factors (albeit that donkeys and zebras are likely to continue to be asymptomatic reservoir hosts). There is also a developing interest, and potential for growth, in the
equine sectors in endemic areas outside RSA, indicated in replies to the survey questionnaires. This growth would be facilitated by the availability of a new AHS vaccine, as it would protect nascent domestic industries and support international movement of horses from these regions for breeding and competition.

It is also important to recognize that vaccine alone will not be sufficient to allow the realization of all the potential benefits. There will need to be a major co-ordination of effort, linking national governments, international organizations and NGOs with the high value equine industries worldwide, including consideration of equity of access to any new vaccine technology. To bring an alternative vaccine into use across the endemic areas of sub-Saharan Africa will also require very careful negotiation with Ethiopia and Senegal vaccine production facilities as well as those in RSA, since these facilities currently supply very high numbers of vaccines across these sub-regions and have the potential to reach the largest numbers of working equids on the African continent.

The outbreak of AHS in Thailand, confirmed in March 2020, shines a spotlight on the urgent need to bring an alternative AHS vaccine to market and to ensure it is accessible to owners of horses worldwide, whether they are high value performance horses or working equids on which poorer communities depend.

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All authors contributed to study design, data collection and analysis, editing and approving of the final manuscript.

INFORMED CONSENT
Completion of the questionnaire was taken as participant consent.

CONFLICT OF INTERESTS
No competing interests have been declared.

ETHICAL ANIMAL RESEARCH
Not applicable.

DATA ACCESSIBILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

PEER REVIEW
The peer review history for this article is available at https://pubon ns.com/publon/10.1111/evj.13430.

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SUPPORTING INFORMATION
Additional supporting information may be found online in the Supporting Information section.

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