

U-6016: Cost-benefit Analysis

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Assignment #3

Scenario: a risk analysis of a cattle vaccination program in Botswana

Introduction: The Ministry of Animal Husbandry in Botswana is considering a vaccination program for livestock (cattle), which, if approved, would be funded by the World Bank and the Food and Agriculture Organization of the UN. The program calls for a nationwide campaign to vaccinate cattle against a particularly virulent form of *bovinus kookius*. You've been called in as a consultant to carry out a risk-analysis of the program.

Bovinus kookius is a fatal disease for which there are no known cures. The disease is currently not found in Botswana. However, there have been a few reported cases in neighboring countries, and there is thus a probability that the disease may be introduced into the country in the near future. Given that cattle are a primary source of income for a majority of households in Botswana, the government wishes to take pre-emptive steps to protect the national herd and the proposed vaccination program is one way of doing so.

Epidemiological details: Though fatal once contracted, *bovinus kookius* is not transmitted simply through exposure. Studies in other countries have shown that only a fraction of uninfected cattle that are exposed to the disease (through contact with infected cattle) actually become infected. Prior immunization (i.e., administration of the vaccine) lowers the infection rate dramatically. However the vaccine has two shortcomings. First, a tiny fraction of the uninfected cattle that receive the vaccine become infected as a result. And second, even among the cattle that do not become infected from the vaccine, the vaccine is not 100% effective in preventing future infection—i.e., there is a small chance that immunized cattle will nevertheless acquire the infection from subsequent exposure.

Scope of the analysis: Your task is to undertake a cost-benefit analysis of the proposed vaccination program. The main benefit of the program is the value of the cattle that are saved as a result of the program. To calculate this benefit, you need to estimate the difference between the number of cattle that are likely to be lost to the disease if the program is not implemented, and the number that will be lost with the program in place. Doing this requires a fully-specified epidemiological model which describes the spread of the disease within the population. Rather than work with a complicated dynamic model, you choose to work with a simple model with the following assumptions:

- (1) the spread of the disease is *limited to two stages*: in the first stage, a number of cattle (the first generation) are infected from external sources or from the vaccine; this first stage is followed by a second generation of infections stemming from the exposure of uninfected cattle to the first-generation of infected cattle. The key simplifying assumption is that the spread of the disease is limited to these two stages, i.e., that there are no third, fourth, etc. generations of infection.
- (2) the probability of exposure in the second stage is given by the fraction of cattle that were infected in the first stage.
- (3) the possibility of infection from external sources is independent of the possibility of infection from the vaccine

The main costs of the program are its fixed administrative costs and the cost of the vaccine itself. Exhibit A shows the point estimates and ranges that you have been provided with, for the key parameters of the program.

Exhibit A

Parameter		Point estimate	Range
Number of cattle:	N	1,000,000	
Per head price of cattle:	V	1,000.00	
Per dose price of vaccine:	p	100.00	[75,125]
Administrative costs:	C	10,000,000	$\pm 5,000,000$
Infection rate from external sources:	α	0.15	[0.05,0.25]
Infection rate from vaccine:	β	0.03	[0.01,0.05]
Effectiveness rate of vaccine:	e	0.85	[0.75,0.95]
Probability of infection if exposed:	γ	0.25	[0.20,0.30]

Assignment #3

Scenario: a risk analysis of a cattle vaccination program in Botswana

A. Base simulations: Based on the point estimates shown in Exhibit A:

- (a) derive, through simulations, the probability distribution as well as the *expected* number of first-generation infections in the absence of a vaccination program—i.e., when the only source of primary infection is external
- (b) derive, through simulations, the probability distribution and the *expected* number of second-generation infections in the absence of a vaccination program
- (c) derive, through simulations, the probability distribution and the *expected* number of first-generation infections if the vaccination program were implemented—i.e., when there are two sources of primary infection, external and from the vaccine itself
- (d) derive, through simulations, the probability distribution and the *expected* number of second-generation infections if the vaccination program were implemented
- (e) provide an estimate of the expected net benefit of the vaccination program

B. Partial sensitivity analysis Under the law of large numbers (and subject to a few technical details), if the underlying population is large enough, the actual number of infections should equal the “theoretically-derived” expected number of infections. What this means is that with a population of 1,000,000 cattle (which is large) you do not need to rely on simulations to estimate the number of infections—you can instead proceed using the theoretically derived expressions for the number of first and second generation infections. These are:

Expected number of infections	
Without a vaccination program	
first-generation:	αN
second-generation:	$\alpha\gamma(1 - \alpha)N$
With a vaccination program	
first-generation:	$[\beta + \alpha(1 - e)(1 - \beta)]N$
second-generation:	$[\beta + \alpha(1 - e)(1 - \beta)]\gamma[(1 - \beta)(1 - \alpha)(1 - e)]N$

Using these expressions and the point estimates provided in Exhibit A, carry out a partial sensitivity analysis of the expected net benefits of the program to different assumptions about:

- (a) the probability of infection from the vaccine: β
- (b) the effectiveness rate of the vaccine: e
- (c) the probability of infection from external sources: α
- (d) the administrative costs of the vaccination program: C
- (e) the probability of infection from exposure: γ
- (f) the per dose price of the vaccine: p

Summarize the results from *all* of the partial sensitivity analyses in a *single* table.

C. Risk analysis/Monte-Carlo sensitivity analysis You have thus far worked with the point estimates of the key parameters shown in Exhibit A. As noted in the previous section, with a large enough population, the law of large numbers implies that the actual number of infections should equal (or be very close to) the expected number of infections. What this means is that if there is no uncertainty about the underlying parameters, there will not be any uncertainty about the net benefit of the vaccination program. That is obviously somewhat unrealistic. So suppose instead that there is some uncertainty about the values of the key parameters. Specifically, assuming that the parameters are each *uniformly* and *independently* distributed in the ranges specified in Exhibit A, derive, through simulations:

- (a) the histogram of net benefits
- (b) the cumulative distribution of net benefits
- (c) an estimate of the probability that the net benefits will be below zero
- (d) an estimate of the probability that the net benefits will be above 10,000,000
- (e) an estimate of the expected net benefit

Repeat the exercise under the assumption that e and α are *perfectly negatively correlated*. Provide an explanation for why these two parameters might be negatively correlated.