Economic and Epidemiologic Policy Implications of Alternative Bovine Brucellosis Programs

Stephen H. Amosson, Raymond A. Dietrich, Hovav Talpaz and John A. Hopkin

This paper analyzes policy implications arising from the National Brucellosis Technical Commission Study. A systems simulation model was designed to estimate physical losses resulting from alternative bovine brucellosis programs. Changes in benefits, costs, level of infection and net benefits were calculated by program alternatives for determining economic and epidemiologic implications. Results indicate all alternative programs considered yield positive net benefits and reduce the prevalence of the disease. The results imply a need for further research to determine a program that is both epidemiologically and economically optimal.

Bovine brucellosis is a reproductive disease that causes abortions, light weight calves, extended calving intervals and reduced milk production in beef and dairy cows. In 1976, estimated losses from bovine brucellosis exceeded 65 million pounds of beef and 35 million pounds of milk [Amosson, et al]. During that year 75 million dollars were spent by producers, state and federal authorities to control the spread of brucellosis. Thus, the selection of a government program to control and/or eradicate bovine brucellosis has a major economic impact on cattle producers, consumers and taxpayers.

This paper will analyze and present the economic and epidemiologic results of alternative brucellosis programs developed by the National Brucellosis Technical Commission.[1] A systems simulation model was used to analyze the effects of the alternative programs on the spread of brucellosis and to estimate the associated physical losses of beef and milk. Physical losses will then be employed as shift parameters for the respective supply curves from which consequent changes in consumers' and producers' surpluses will be calculated for each alternative program.

Methodology

This study is comprised of two primary components. First, an epidemiologic model was designed to simulate the biological effects of brucellosis through the cattle population and to calculate physical losses resulting from reductions in weaning weights and milk production for each program. Secondly, an econometric model was employed to measure the economic impacts of the changes in physical losses to consumers and producers.

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[1] On the recommendation of the U.S. Animal Health Association (USAHA), the Animal and Plant Health Inspection Service (APHIS), U.S. Department of Agriculture (USDA) appointed a 5-member team, designated as the National Brucellosis Technical Commission (NBTC) to make an impartial study of the national brucellosis eradication program. The NBTC consisted of two epidemiologists, a medical doctor, an animal scientist and an economist.

Epidemiological Model

A simulation model was designed to measure the impact of various brucellosis policy alternatives upon the spread, control and/or eradication of brucellosis among beef and dairy herds in the United States over a 18-year time horizon. Development of the model was based on earlier work by Beal and Kryder.

In this epidemiologic model, the U.S. was divided into eight regions, (Figure 1) on the basis of similarity with respect to such selected criteria relating to brucellosis as level of infection, herdsize distribution, method of operation, trading patterns, and effectiveness of brucellosis surveillance and control. The model was designed to determine simultaneously the effect of various policy alternatives upon both the beef and dairy sectors. The disease could be transmitted, in the model, among and between beef and dairy herds in approximately the same manner as occurred within the cattle industry. In addition, it was designed such that infected and detected herds could be placed in a "quarantined" status while undetected infected herds remained in a non-quarantined status. The subdivision of infected herds into quarantined and non-quarantined herds has a major impact upon physical losses, disease spread, and clean-up rates in the model.

Benefits from investments in bovine brucellosis control programs were based on reduction in physical losses caused by infection. Physical losses due to infection are represented by decreased production of meat and milk. Losses were estimated on a per-infected beef and dairy cow basis, and varied by region, year of infection (1 to 3 years), quarantine (identification) status and vaccination status.

Methods of Disease Transmission

Brucellosis can be transmitted to clean herds by purchasing an infected replacement or through contact with a neighboring infected herd. A double binomial [Beal] was used to simulate the spread of the disease through the purchase of infected replacements. Due to the nature of the cattle industry, parameters p, s, q, m and n, defined below, were necessary for calculating the double binomial which is defined as:

$$1 - [(q + ps^m)^n] \tag{1}$$

where

$$p = \frac{\text{Number of cows in infected herds in the region}}{\text{Total number of cows in the region}}$$

$$q = \frac{\text{Number of cows in brucellosis free herds in the region}}{\text{Total number of cows in the region}}$$

$$s = 1 - \left(\frac{\text{Total number of infected cows in region}}{\text{Total number of cows in infected herds in region}}\right)$$

n = Number of sources from which replacements were purchased

$$m = \frac{\text{Number of replacements purchased annually}}{\text{Number of sources}}$$

Parameters p, s, and q are dependent on the number of undetected infected cows and herds in the region. Therefore, p, s, and q change from year to year as the undetected population expands or contracts.

Parameters m and n are calculated in the initial year of the model by region and herdsize group. M and n are held constant for the rest of the years of the simulation.

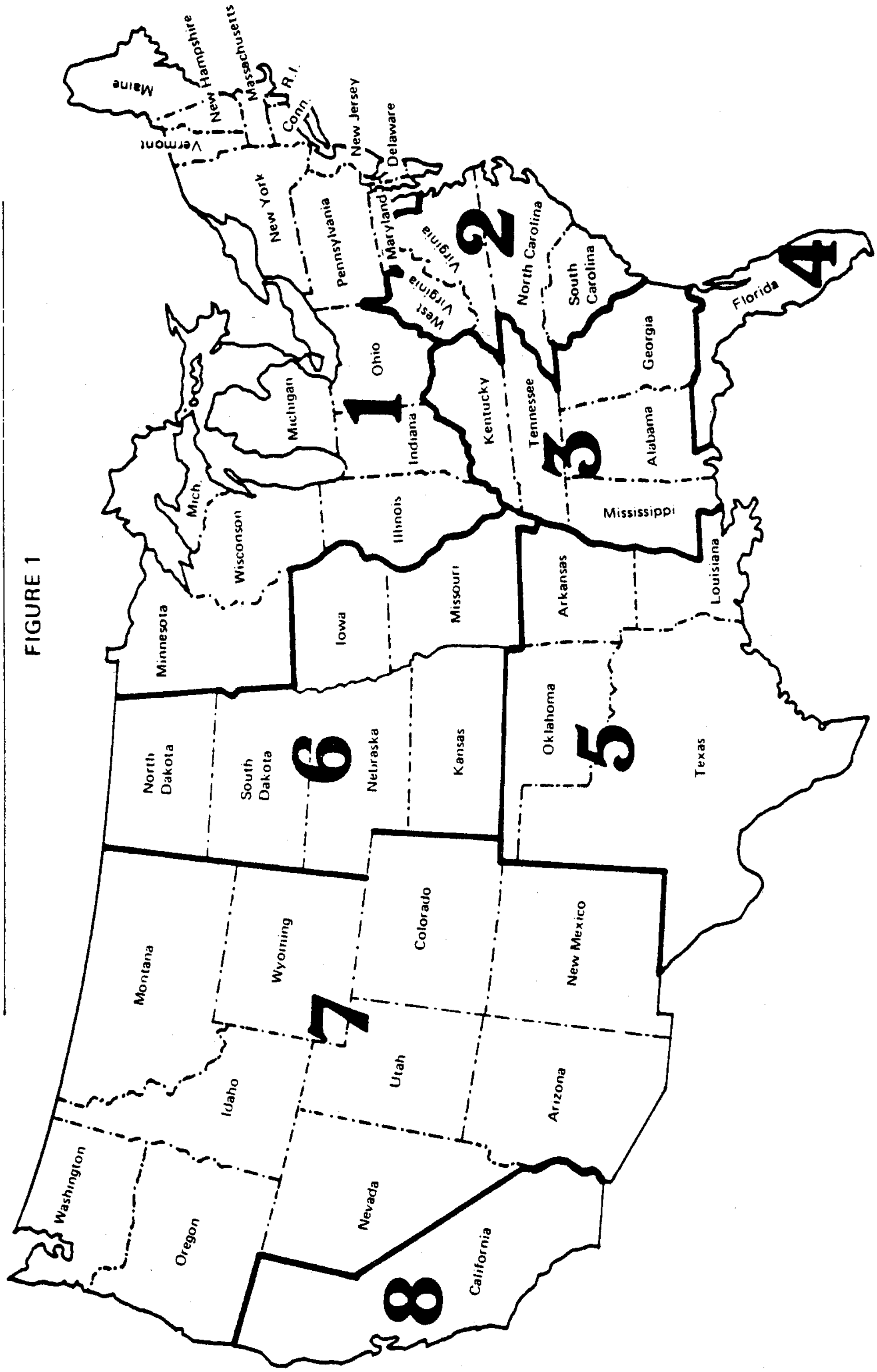
The double binomial was modified to allow for interregional movement of breeding stock. Each region has a certain probability of purchasing from within their own region and each of the other regions. These probabilities always sum to 1 for any given purchasing region and are held constant throughout the simulation (equation 2).

To arrive at the number of newly infected herds, the probability of purchasing one or more infected replacements by herdsize and region is multiplied by the number of clean herds in that herdsize group and region.

$$PP_{hij} = \sum_{LL=1}^{8} \left[\left(\begin{matrix}\text{Regional}\\ \text{Purchase}\\ \text{Probability}\end{matrix}\right)_{hiLL} \times (1 - ((q + PS^m)^n)_{hij}\right] \tag{2}$$

REGIONAL DEMARCATION, BRUCELLOSIS STUDY, UNITED STATES, 1978.

FIGURE 1



where

NI = number of newly infected herds
PP = probability of purchasing one or more infected replacements
NCLEAN = number of clean herds in the region
h = 1,2 species
i = 1, . . . ,8 regions
j = 1, . . . ,7 herdsizes
LL = probability of purchasing a replacement from a given region

The second avenue in which a clean herd could become infected is through contact with a neighboring infected herd. A quarantined herd was assumed to have one-half the spread of a first year undetected infected herd (equation 3). The adjusted newly undetected infected herds were then weighted by their year of infection and totaled over herdsize, year of infection and species for the region (equation 4).

$$(3) \quad INF_{hijl} = \sum_{L=1}^{3} \sum_{k=1}^{3} QUAR_{hijkl}$$

$$(4) \quad T_i = \sum_{h=1}^{2} \sum_{j=1}^{7} \sum_{k=1}^{3} (INF_{hijk} \times WINF_{hik})$$

where

INF = undetected infected herds
QUAR = quarantined infected herds
T = total weighted infected herds
WINF = weighted infection rate

$$\text{where } WINF_{hik} = \frac{INFR_{hik}}{INFR_{hi2}}$$

INFR = within herd infection rate
i = 1, . . . ,4 regions
j = 1, . . . ,7 herdsizes
k = 1,2,3 years of within herd infection
L = 1,2,3 years of quarantine
n = 1,2 species

Newly infected herds (INF) due to neighborhood spread were then calculated by multiplying the weighted total infected herds (T) by the probability of a herd becoming infected (NS) which varies by region and species. These newly infected herds are distributed to the herdsize groups on the basis of their weighted population proportions (WPP), where the weighted population proportion equals the number of herds by herdsize group, and species within the region divided by total number of herds in the region.

$$(5) \quad INF_{hijl} = T_i \times NS_{hi} \times WPP_{hij}$$

Disease Surveillance Programs

The two primary methods of disease surveillance are the market cattle identification program (MCI) and the brucellosis ring test (BRT). The MCI tests cattle moving through marketing channels and at the slaughter level. The BRT analyzes milk from dairy herds three to six times annually for possible brucellosis infection.

The probability of undetected infected herds being detected through the MCI surveillance system had to be estimated in order to determine the number of newly quarantined herds in the beef population. The detection probabilities were calculated by an approximation of a hypergeometric distribution. (For detailed discussion of a hypergeometric distribution consult *Regulatory Statistics* or Cochran, W. G.) Detection probabilities varied by region, herdsize, year of infection, cull rate cycle, MCI rate and level of vaccination:

$$(6) \quad DP = 1 - \left(\frac{A - I - S/2 + .5}{A - S/2 + .5} \right) S$$

where

DP = detection probability

A = number of cows culled

I = number of infected cows culled

S = number of cows culled under surveillance system

Detection probabilities were used in combination with the quality control factor and program test efficiency ratings for that region in determining the number of newly quarantined herds each year.

The number of quarantined herds resulting from the BRT is estimated in the equation below. Due to the nature of the BRT, it was assumed that the BRT surveillance system would quarantine a percentage of the total infected herds subjected to the BRT. The effectiveness of the BRT is dependent on frequency of which milk samples are collected and properly analyzed and can vary by region.

$$(7) \qquad QUAR_{ijkl} = BRT \times INF_{ijk}$$

where

QUAR = quarantined herd

BRT = brucellosis ring test efficiency rating

INF = undetected infected dairy herds

Economic Models

For purposes of economic analysis, costs were defined as those expenditures relating to brucellosis incurred by federal and state governments plus estimates of costs incurred by private operators as a result of bovine brucellosis. Producer costs could also be classified as an indirect associated cost and netted out of the benefit stream [Beattie, et al.]. Since accounting procedures of some states include part of producer costs in their state costs, producer costs were considered as direct program costs. Total federal, state and producer expenditures during 1976 totaled about $75 million. Program costs for the various alternative programs analyzed varied annually by type of program and were based on information supplied by APHIS, USDA and a cost-management questionnaire mailed to a random sample of producers. APHIS estimates of program costs include all anticipated indemnities to producers for reactor cattle and possible herd depopulations.

In estimating economic benefits for alternative programs, differences in annual physical losses associated with each program alternative were measured from levels of losses projected for the base program. These annual differences in losses were then used to represent changes in the total supply of beef and milk in calculating new equilibrium prices. This was accomplished with a modified version of the USDA "Cross-Class-Commodity Feed Grain-Livestock-Wheat Model" [Teigen and Carman]. This is an econometric model with 165 endogenous variables representing livestock sectors (beef, dairy, swine, chickens, turkeys and eggs), interrelated with the feed grain sectors (wheat, barley, oats, sorghum, corn and soybeans). There are 120 exogenous variables representing demand and supply shifters. The equations in the USDA model provide an impact response as a function of supply and price of all the above sectors and not only the corresponding supply curves themselves.

Benefits from program alternatives were measured in terms of reduction in the physical losses of meat and milk thus increasing their supply. Biological innovations tend to create divergent shifts in supply curves [Lindner and Jarrett]. In the case of brucellosis it is assumed that the supply shift will be pivotal in nature i.e. control and/or eradication of brucellosis will have a greater impact on the average cost structure of marginal producers than inframarginal producers. This leads to the variation between S-S and S-S_1 in Figure 2. For example, an increase in the supply of beef changes the equilibrium price and quantity bundle from E to E_1 in Figure 2. Assuming that the intercept (S) remains unchanged for linear supply and demand curves, producer and consumer benefits can be readily calculated.

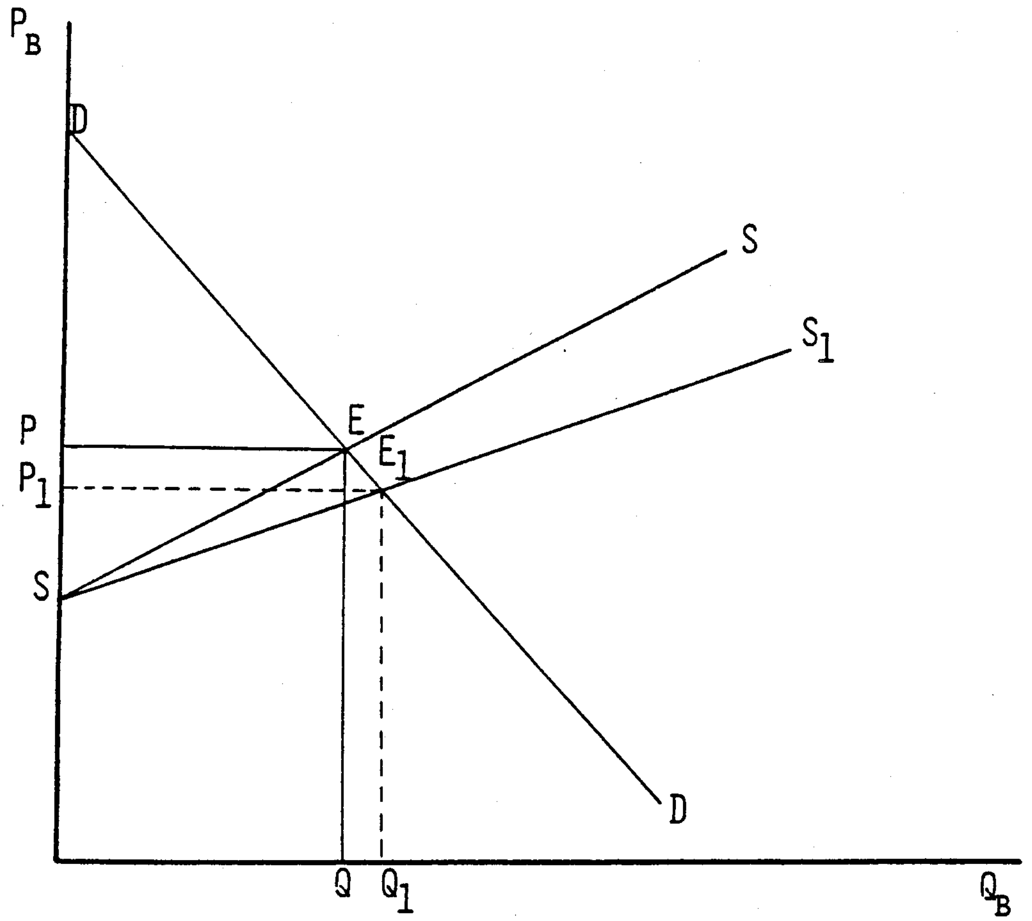


Figure 2. A Graphic Illustration of Consumers' and Producers' Surplus.

Where:
DD: Demand curve for beef
SS: Supply curve for beef under "Base Program" for brucellosis control
SS_1: Supply curve for beef under "Accelerated Brucellosis Eradication Program"
The change in Consumer surplus = area PEE_1P_1.
The change in Producer surplus = difference between areas PSE and P_1SE_1.

The change in consumers' surplus ($\triangle CS$) is given by the trapezoid PP_1E_1E (Figure 2) and calculated by equation 8 [Anderson].

(8) $\triangle CS = (P - P_1)(Q + Q_1)/2$

The change in producers' surplus ($\triangle PS$) is given by the difference between the triangles P_1E_1S and PES or

(9) $\triangle PS = [(P_1 - S)Q_1/2] - [(P - S)Q/2]$

Economic benefits were then calculated in terms of benefit to society as a whole, including both consumer and producer surpluses. In order to place the benefits and costs on a common time pattern, the projected annual data were converted to present value using a 4 percent real discount rate.[2]

The program alternatives which were modeled and some of the basic assumptions were:

1. *Base Model.* The base model was designed to simulate existing conditions within the industry during 1975-1976. Included in this model were 1975-76 levels of infection, surveillance efficiency rates, levels of vaccination, levels of management and prevailing Uniform Methods and Rules (UMR). The other program alternatives were then designed to measure single modifications from this base program.

2. *Base Model Plus Accelerated Programs.* This model was designed to simulate conditions which might prevail under the APHIS "10-year Accelerated Eradication Program." The accelerated program involved down-the-road or area testing of about one-third of the herds, and also first-point of concentration (FPC) testing in addition to the MCI and BRT surveillance systems. In those areas or regions where area testing and FPC testing is scheduled to take place, program efficiency (level of detection) is assumed to increase sharply and the level of infection is reduced. However, the level of program efficiency after area testing is affected by the duration of FPC testing and follow-up testing in those areas which were previously area tested. Consequently, two accelerated alternatives were modeled. In accelerated program 1, it was assumed that program quality would remain at the high level reached during area testing and FPC testing for the duration of the program. Accelerated program 2 assumed that program efficiency would drop back after area testing to the same level that prevailed in the region prior to area testing.

3. *Base Model Plus Calfhood Vaccination.* This model assumed that incentives would be established for increased calfhood vaccination in Regions 3, 4, 5, 6 and 7 (South, Southeast and Plains states). It was assumed that Regions 1, 2 and 8 were already proceeding to local eradication within these regions. Three levels of calfhood vaccination were modeled: 90 percent or higher (high), 60-89 percent (medium) and 20-59 percent (low).

4. *Base Model Plus Whole Herd Vaccination.* This model was designed for use in high prevalence Regions 3, 4 and 5 (South and Southeast). The base program was applied in all other areas. This program assumed that promising research in progress will demonstrate that adult cattle may be vaccinated successfully with reduced dosages and that distinction can be made between field strain and strain 19 titers. Vaccination could occur under two plans: (1) herds known to be infected but reactors would be removed prior to vaccination, and (2) high risk, non-infected herds — that is, no reactors revealed by a complete herd test at the time of vaccination and the herd has not been under quarantine during the last 6 months. Whole herd vaccination levels were also programmed at 3 levels: 90 percent or higher (high), 60-89 percent (medium) and 20-59 percent (low).

Simulation Projections

Baseline projections reflect the belief of the NBTC epidemiologists that the government program in effect during 1975-76 was holding the disease in steady state to slightly decreasing in incidence, Table 1. Major variances in statistics from year to year reflect changes in the cattle cycle. Weaner calf losses range from 64 to 91 million pounds per year, while the range on milk losses is 25.96 to 29.5 million pounds. The number of

[2]The NBTC used a 4 percent discount rate as a conservative estimate of the real discount rate. The real discount rate in this study is the nominal interest rate for non-real estate loans (Melichar and Sayre) minus the consumer price index for all items (U.S. Department of Commerce). Using this definition and the average rate charged on non-real estate farm debt by banks, the real discount rate varied between -1.8 and 4.5 percent during 1970-76.

TABLE 1. Epidemiological Baseline Projections, Physical Losses, Infected Detected and Undetected Herds, Dairy and Beef Sector, United States, 1976-93.

	Dairy Sector				Beef Sector		
Year	Quarantined Herds	Undetected Infected Herds	Milk Losses (mil. lbs.)	Weaner Calf Losses (mil. lbs.)	Quarantined Herds	Undetected Infected Herds	Weaner Calf Losses (mil. lbs.)
1976	773	153	28.75	0.30	14909	20106	64.18
1977	732	147	26.77	0.28	14922	20194	66.65
1978	719	145	26.03	0.27	13669	21821	67.04
1979	729	149	25.96	0.27	15405	22265	74.08
1980	750	154	26.43	0.28	14986	24067	75.52
1981	784	162	27.31	0.30	15963	25740	81.77
1982	830	172	28.55	0.31	20461	24183	91.96
1983	846	174	29.43	0.31	21211	22453	88.96
1984	827	168	29.50	0.30	18043	22955	79.88
1985	813	165	29.27	0.30	17459	23327	79.76
1986	812	166	29.18	0.30	17920	23292	81.18
1987	812	166	29.19	0.30	19564	21708	82.94
1988	794	161	28.90	0.30	17076	22138	75.66
1989	781	159	28.56	0.30	17067	22076	76.59
1990	775	158	28.31	0.29	17901	21182	77.40
1991	763	155	28.01	0.29	17246	20703	74.44
1992	747	151	27.62	0.29	18438	18553	74.79
1993	710	143	26.80	0.28	15762	18196	66.37

quarantined and undetected infected herds remained relatively stable.

Comparing model estimates of total quarantined herds with data obtained from APHIS, USDA forms 433 and 435 yielded results given in Table 2. The simulation model underestimated the total number of quarantined herds in both 1976 and 1978 by 8.6 and 2.9 percent, respectively, when compared to APHIS form 433 totals. The APHIS form 435 yielded 20.18 and 18.65 percent *less* quarantined herds during 1976 and 1978. Data availability and implementation of portions of the accelerated and vaccination programs in 1979 make further validation difficult.

Comparison of alternative programs to the baseline projections yielded consistent results, Table 3. All alternative programs lead to a reduction in weaner calf losses, milk losses, quarantined herds and undetected infected herds. The accelerated programs showed a greater decrease in undetected infected herds than did the vaccination programs. This reflects the results of down-the-road testing and higher within-herd infection. Down-the-road testing in the adult vaccination programs led to fewer undetected infected herds than did the calfhood vaccination programs. The vaccination programs showed their greatest strength in reducing the magnitude of weaner calf and milk losses via reduction in the number of infected animals and loss per animal.

The decrease in physical losses caused by all the alternative program caused minimal supply shifts. The supply shifts for both beef and milk production were less than 0.4 percent of total production in any one year and/or program. The supply changes resulted in a maximum decrease in price of beef of 40 cents per hundredweight and a maximum increase of 8 cents per hundredweight for any given year of the analysis. Further, the retail price of beef varied only 2 cents per pound between the alternative programs and the baseline. The price of milk per hundredweight varied less than a penny a hundredweight among programs primarily due to the small magnitude of the shift and the government price support system for milk.

Results[3]

Table 4 provides a ranking of the various program alternatives according to four criteria: (1) the present value of the *program costs*, (2) the present value of *net benefits*, (3) reduction in *infection* and (4) *change in benefits* (total welfare).

When programs were ranked according to program costs, the high-level calfhood vaccination program ranked lowest with the highest total cost. The second highest program cost was medium-level calfhood vaccination followed by accelerated-1 and accelerated-2 programs, since whole-herd vaccination programs were applied to only 3 regions compared to 5 regions for the calfhood programs.

[3]The extreme differences in the definitions of alternative programs and underlying assumptions make comparisons of the NBTC study with the preceding APHIS study by Beal and Kryder and consequent economic analysis by Liu of questionable value.

TABLE 2. Total and Change in Total Quarantined Herds Between Simulation Model and Published Sources, United States, 1976 and 1978.

	Quarantined Herds in 1976 (herds)	Change in Total Quarantined Herds in 1976 (percentage)	Quarantined Herds in 1978 (herds)	Change in Total Quarantined Herds in 1978 (percentage)
APHIS 433	17,036	+8.63	14,808	+2.92
APHIS 435	12,518	−20.18	13,143	−8.65
Model	15,682	--	14,388	--

TABLE 3. Changes in Weaner Calf Losses, Milk Losses, Quarantined Herds and Undetected Infected Herds From Baseline Projections to Alternative Programs, United States, 1980, 1985 and 1990.

Program/Year/ Unit	Change In Weaner Calf Losses (mil. lbs.)	Change In Milk Losses (mil. lbs.)	Change In Quarantined Herds (Percentage)	Change In Undetected Infected Herds (Percentage)
Accelerated-1				
1980	−23.39	−3.03	−14.19	−41.02
1985	−53.89	−12.57	−59.26	−67.58
1990	−63.26	−17.48	−76.63	−81.64
Accelerated-2				
1980	−23.39	−3.03	−14.19	−41.02
1985	−54.36	−12.57	−63.69	−62.59
1990	−49.42	−14.85	−63.17	−62.29
Calfhood Vaccination-Low				
1980	−38.01	−13.23	−39.29	−3.99
1985	−47.74	−17.31	−50.02	−19.10
1990	−52.37	−18.11	−58.89	−32.10
Calfhood Vaccination-Medium				
1980	−60.17	−19.08	−71.05	−3.36
1985	−67.10	−23.27	−76.68	−5.09
1990	−66.93	−22.87	−79.34	−14.70
Calfhood Vaccination-High				
1980	−66.08	−19.83	−81.11	14.66
1985	−74.26	−24.36	−84.71	4.52
1990	−72.47	−23.84	−87.40	−3.13
Whole Herd Vaccination-Low				
1980	−44.98	−13.98	−50.23	−22.09
1985	−52.45	−17.93	−57.91	−33.91
1990	−55.94	−18.62	−65.16	−44.41
Whole Herd Vaccination-Medium				
1980	−58.78	−17.71	−70.02	−23.85
1985	−64.65	−21.77	−75.29	−36.67
1990	−64.58	−21.72	−78.17	−42.98
Whole Herd Vaccination-High				
1980	−64.98	−18.97	−76.96	−28.22
1985	−70.63	−23.12	−81.91	−37.40
1990	−69.67	−22.90	−85.11	−43.81

In terms of net benefits whole herd vaccination at the medium level ranked the highest with 768.9 million followed by whole-herd at the high and low levels. Calfhood vaccination at the medium, high and low levels ranked fourth through sixth, respectively. The accelerated 1 and 2 programs ranked lowest but still yielded positive

TABLE 4. Change in Infected Cattle, Discounted Benefits and Costs of Various Program Alternatives Relative to the Base Program.[a]

Program	Infected[b] Cattle	Change In[c] Benefits	Alternative Program Costs	Base Program Costs	Marginal Program Costs[d]	Net Benefits[e]
Accelerated - 1	−87.5	615.4	1,598.0	1,356.6	241.4	374.0
Accelerated - 2	−69.1	535.8	1,597.6	1,356.6	240.0	294.9
Calfhood Vaccination — Low	−76.3	651.9	1,515.4	1,356.6	158.8	493.1
Calfhood Vaccination — Medium	−89.2	980.2	1,733.1	1,356.6	376.5	603.7
Calfhood Vaccination — High	−93.1	1,064.2	1,896.2	1,356.6	539.4	524.7
Whole Herd Vaccination — Low	−79.2	636.0	1,274.7	1,356.6	−81.9	718.0
Whole Herd Vaccination — Medium	−87.1	802.2	1,390.0	1,356.6	33.4	768.9
Whole Herd Vaccination — High	−91.5	894.3	1,504.6	1,356.6	148.0	746.3

[a]Computed for 19 years or from 1977 to 1995 and represent discounted present values.
[b]Percentage change in infected cattle from year 1 of base program to year 20 of alternative program.
[c]Total change in benefits of the program alternatives over the basic program.
[d]Total program costs minus the base program costs.
[e]Change in benefits (column 1) minus marginal program costs (column 4).

net benefits of 374.0 and 294.9 million, respectively.

Ranking among programs on the criteria of reduction in infection showed that calfhood vaccination at the high level ranked first followed by whole-herd vaccination-high level, calfhood vaccination-medium level, whole-herd vaccination-low level, calfhood vaccination-low level and accelerated program option 2.

Total welfare equals the summation of the change in consumer surplus and producer surplus [Chavas and Collins or Just and Hueth] for the program alternative considered (change in benefits column 2, Table 1). All programs had positive changes in total welfare with calfhood vaccination and the high and medium levels showing the greatest increases. Changes in producers' and consumers' surplus resulting from the implementation of alternative programs are presented in Table 5.[4]

Implications

Program alternatives analyzed suggest that investment of funds in epidemiologically sound modifications of the present program which are specifically targeted to varying requirements of herds, states and regions will produce a favorable return. Further, results revealed that vaccination programs, both calfhood and whole-herd, would be highly effective in reducing infection in the high prevalence regions. Some specific implications are as follows:

1. Whole-herd vaccination shows promise as a tool to combat brucellosis in high prevalence regions. Whole-herd vaccinations at the three vaccination levels analyzed, revealed the highest net benefits and were lowest in program costs of all alternative programs evaluated. However, whole-herd vaccinations programs in the model were implemented only in the three highest prevalence regions while calfhood vaccination programs were implemented in five regions. Whole-herd vaccination at the high level ranked no lower than third on any one decision criteria. While whole-herd vaccination looks promising, it is not an epidemiologically accepted program practice presently due to problems with false positive reactors (Anderson, et al.).

2. If eradication is the prime criterion, the high calfhood vaccination level reduced infection more than any other program alternative, but ranked lowest and highest in total program costs. This program cost was influenced by higher producer costs associated with additional round-ups, cattle handling costs, and vaccination expenditures.

[4]The production of meat and milk can be classified as intermediate goods. "Consumer surplus" in this context also includes intermediate processing, handling, etc. This surplus would be shared by these producers and the ultimate consumers.

TABLE 5. Impact of Alternative Programs on Producers and Consumers.

Program	Discounted Change in Economic Surplus Over 19 Year Planning Horizon (Million Dollars)	
	Consumers	Producers
Accelerated 1	1,418.7	−803.3
Accelerated 2	1,249.0	−713.1
Calfhood Vaccination — Low	1,476.6	−824.7
Calfhood Vaccination — Medium	2,159.7	−1,179.5
Calfhood Vaccination — High	2,353.1	−1,288.9
Wholeherd Vaccination — Low	1,583.4	−947.4
Wholeherd Vaccination — Medium	1,974.1	−1,171.9
Wholeherd Vaccination — High	2,170.9	−1,276.6

3. The MCI and FPC as defined in the APHIS "10-year eradication program" and represented by the accelerated 1 and 2 programs in this study, are not sufficient tools to achieve eradication. The accelerated programs did not attain eradication within the model planning horizon and rated fourth or lower among the various decision criteria.

4. Vaccination is effective in reducing infection and individual producer losses but will not eradicate the disease. Vaccination has a "masking effect" on brucellosis detection. That is, as the vaccination level increases, the number of infected animals culled decreases, lowering the probability of the infected herd being detected through the MCI system.

5. An increase in expenditures on control and/or eradication of bovine brucellosis is justified. All alternative programs which increased program activity yielded positive net benefits.

6. Effective control leading to local eradication of bovine brucellosis is biologically feasible. However, eradication on a national basis will be considerably more difficult to obtain in the absence of increased research efforts and increased incentives for producer cooperation. For example, in 1975 federal expenditures on brucellosis research was equivalent to .8 percent of the total federal brucellosis program expenditures. Program goals will be difficult to accomplish in the absence of substantial increases in research effort and expenditures in such areas as the effect of the cattle cycle on surveillance systems, producer management strategies for combating brucellosis, movement and marketing patterns, and other economic and epidemiologic factors which influence disease control. Such research must be used to systematically review brucellosis program policy, its implementation and evaluation.

References

Amosson, Stephen H., Raymond A. Dietrich, John A. Hopkin, Report-National Brucellosis Technical Commission, Appendix B, Benefit-Cost Analysis Prepared for APHIS, USDA, 1978.

Anderson, J. E., "A Note on Welfare Surplus and Gains from Trade in General Equilibrium." *American Economic Review*, 64(1974):758-762.

Anderson, Robert K., David T. Berman, W. T. Berry, John A. Hopkin and Robert Wise, (1968). *Report-National Brucellosis Technical Commission*, prepared for APHIS, USDA.

Beal, Victor J., "The Use of the Double Binomial in Animal Disease Work," APHIS Working Paper, U.S. Department of Agriculture, October, 1971.

Beal, Victor and Harvey Kryder, (1977). *Brucellosis Program Analysis*, APHIS, USDA, Hyattesville, Maryland.

Beattie, B. R., E. N. Castle, W. G. Brown and W. Griffin, *Economic Consequences of Interbasin Water Transfer*. Ag. Exp. Sta., Tech. Bull. 116, Oregon State University, pp. 63-66, June 1971.

Chavas, J-P and Glenn S. Collins, "Multimarket Welfare Implications at a Non-Price Distortion." Mimeograph. College Station, Tx., Texas A&M Univerity, 1979.

Cochran, W. G. (1963). *Sampling Techniques*, 2nd edition, John Wiley & Sons, Inc., New York, pp. 55-57.

Just, Richard E. and D. L. Hueth, "Welfare Measures in Multi-Market Framework." *American Economic Review*, 69(1979):947-54.

Lindner, R. K., and F. G. Jarrett, "Supply Shifts and the Size of Reseach Benefits." *American Journal of Agricultural Economics*, 60(1978):48-58.

Liu, Chun-Ian, "An Economic Impact Evaluation of Government Programs: The Case of Brucellosis Control in the United States." *Southern Journal of Agricultural Economics*, 11(July, 1979):163-168.

Melichar, Emanual and Marian Sayre. *Agricultural Finance Databook* — Annual Series. Board of Governors of the Federal Reserve System, Division of Research and Statistics, Washington, D.C., November, 1977.

Regulatory Statistics, 5th edition, APHIS Veterinary Services, Animal Science Dept. of Agriculture, June, 1975, Part III.

Teigen, L. D., and L. M. Carman. "The 10-Year Brucellosis Eradication Program: A Short-Term Analysis." CED/Forecast Support Group, USDA Working Paper, 1978.

U.S. Department of Commerce. Bureau of The Census, Statistical Abstract of the United States, 100th edition, Washington, D.C., 1979.