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Factors Influencing Rates of Adoption of Trichomoniasis Vaccine by Nevada Range Cattle Producers

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Tritrichomonas foetus vaccine has been marketed since 1989 to combat the Trichomoniasis disease that causes reproductive failure and considerable economic loss to Nevada ranchers. An ex post technology adoption model is estimated to examine the possible adoption rate, to identify the factors that may influence the adoption behavior, and to test how the probability of adoption for five possible adopter groups would change due to changes in various ranch specific factors. Results indicate that use of computers, veterinary checkup of herd, and herd size influence the probability of adoption. Model results show that cooperative extension programs enhance the rate of adoption.

Key words: biotechnology, multinomial logit, ranching, rates of adoption, trichomoniasis

Introduction

Land grant universities have long championed investment and development in agricultural technology. With the success of hybrid corn in the 1930s, development of technology and biotechnology have played an important role in putting programs into priority and funding by agricultural experiment stations within the land grant system. Recently, land grant universities have encouraged development of programs to improve "technological literacy" of agricultural producers,[1] these producers are constantly being bombarded with informational and biological technologies, which require technological literacy to effectively select and use these products.

In this article, the rate of adoption of a new biotechnological product, *Tritrichomonas foetus* (*T. foetus*) vaccine is discussed, and the factors which may enhance its adoption are identified. Trichomoniasis is a venereal disease of beef herds caused by the protozoan *Tritrichomoniasis foetus.* It causes reproductive failure or abortion and thereby considerable economic loss in areas of the world where natural breeding is used (Rae;

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[1] "Technological literacy" is an understanding of new technology and its dynamics, the opportunities it provides, and its impacts on production, market organization, and people (Drueker).

BonDurant et al.).[2] This disease is one of the common infectious diseases in beef cattle operations of the western United States and Florida (BonDurant; Abbitt and Meyerholz).[3] Kvasnicka et al. (1989) reported that Trichomoniasis has been diagnosed in 46% of Nevada cattle herds.[4] It has been estimated that approximately 80% of Nevada range herds have experienced reproduction problems. Some cows develop a natural immunity and conceive and carry a calf to term after three to five heat cycles following an abortion. However, the immunity is not permanent and the cow is subject to reinfection in subsequent breeding periods (Parsonson, Clark, and Duffy 1976)

Awareness of Trichomoniasis has increased in the past few years because of its profound economic impact.[5] Producers and veterinarians have employed a variety of measures to control or eliminate Trichomoniasis.[6] However, the increasing incidence of Trichomoniasis, especially in the western United States, indicates that these practices are not uniformly successful (BonDurant), and proper management programs to prevent the disease are essential.[7]

A *T. foetus* vaccine was developed in a cooperative venture between Fort Dodge Laboratories and the University of Nevada. The U.S. Department of Agriculture (USDA) granted Fort Dodge a conditional license to market the vaccine in 1989. Research at the University of Nevada has demonstrated the efficiency of the vaccine and its impact on reproductive efficiency (Hall et al.).[8] With the recent commercial availability of *T. foetus* vaccine, identification of the factors influencing its adoption or diffusion would be of interest not only to the extension or outreach educators but also to the western livestock producers and commercial business distributors, which will enhance its adoption.

In pursuance of this objective a survey was conducted to collect the necessary data, and an econometric adoption model is estimated to measure the probabilities of adoption of the vaccine. The rest of the article is divided into five sections. First, a brief overview of the survey results of Nevada ranchers is presented to provide the baseline information regarding the potential factors in the adoption of the *T. foetus* vaccine. Second, the estimation procedure is explained. Third, a brief discussion of the factors that may influence adoption of this vaccine is presented. Fourth, results of the estimated model are

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[2] Bovine trichomoniasis is reported worldwide. In some regions of North America, South America, and Australia, where open range beef operations are common, as many as 50% of the herds can be infected (Kvasnicka et al. 1996). A recent study indicates that total economic losses can result in 5% to 35% decrease in economic returns per cow in herds infected with Trichomoniasis (Rae).

[3] A recent report from Missouri, where beef cattle operation is different from typical western range-grazing practice, indicated the prevalence of Trichomoniasis infection in a herd cattle (Peter et al.)

[4] Johnson reported in 1964 that 26% of beef herds and 7.6% of all bulls examined in the western United States were infected by Trichomoniasis. Slaughterhouse surveys in Florida and Oklahoma revealed an infection prevalence of 7.3% and 7.8%, respectively (Abbitt and Meyerholz; Wilson, Kocan, and Baudy). A survey on Nevada from data collected at the veterinary diagnostic laboratory found 27% to 44% of ranches to have at least one infected bull.

[5] The calf crop in beef herds, and even in dairies, can be reduced 14% to 50% depending on the percentage of bulls infected and the susceptibility of the cows in the herd.

[6] These include using young bulls, culling open cows after a short breeding season, not sharing bulls, buying only virgin breeding stock, and having fences in good repair to keep animals out.

[7] The failure of preventive measures may be attributable to lack of compliance in testing, lack of nutritional resources, animal movement throughout the United States, lack of reliable and sensitive diagnostic tests, and the practice of grazing beef herds in common public lands (Speer and White). The state of Idaho in an attempt to control Trichomoniasis initiated a mandatory bull testing program in 1990. The result indicates that the program has considerably reduced the incidence of Trichomoniasis, but failed to eliminate the disease from the population. The Idaho experience, however, indicated that economic losses can be reduced by a strict management regime.

[8] In a study by Kvasnicka et al. (1992), a control and vaccinated group of heifers were bred to Trich infected bulls. Of the vaccinated heifers, 62.5% produced calves while only 31.5% of control heifers bore calves.

Table 1. Characteristics of Respondents by Group Category

Variables	Units	User	Waiter	Nonuser	Do-Not -Know	Have-Not -Heard
Survey responses utilized	Numbers	21	35	5	17	6
Herd size	100 heads	11.79	7.45	12.03	6.38	4.14
Age	Year	52.18	53.61	53.40	53.86	55.65
Education	Years	13.65	12.72	14.20	13.71	12.90
Experience	Years	29.82	35.11	32.80	30.43	32.20
PC user	%	50.00	22.22	20.00	14.28	10.00
Land size	1,000 acres	134.91	59.41	87.80	114.46	37.37
Ranch income	% of total income	90.44	93.22	96.00	100.00	78.37

discussed. In the concluding section, the main findings of the study are summarized and various policy options are highlighted.

Survey Results

To identify the factors which may influence adoption of the vaccine by range cattle producers, a sample of 125 Nevada ranchers was drawn randomly from a list of 774 ranchers.[9] A questionnaire was mailed to each member and the survey was completed by telephone. Out of 125 mailed, 95 questionnaires were completed—a 76% response rate.[10] The survey was conducted by the Nevada Agricultural Statistical Service (NASS).

Farm specific information that reflect the production and human endowments of the ranchers are obtained. These include years of education, years of experience as a rancher, use of personal computers, size of operation, age of the operator, and so forth. These variables are considered important factors influencing the acceptance of a new technology. In table 1 the main characteristics of different respondent groups are reported. In this section, we will elaborate on the salient features of the sampled ranchers to provide some baseline information regarding the potential adopters.

Average age of the respondents was 53.9, and average years of education was 13.2. Thirty-four percent of the respondents had some sort of specialized education, for example, agribusiness, agricultural economics, animal science, or animal husbandry. Sixteen percent of the respondents used professional advice from paid consultants regarding their ranch management. Twenty-eight percent used a personal computer in their ranch operation and the average duration of computer use was 5–11 years. The range of years of experience of ranchers in this operation was 31–75 years. Average land-holding size, including deeded and allotment holdings of the respondent ranchers, was 92.8 thousand acres. Average herd size was 860 heads. Ninety-four percent of the sample ranchers had been aware of the Trichomoniasis for at least eight years. Forty-five percent of the re-

[9] The sample size is approximately 16% of total (listed) population and 8% of total state beef cattle operations from the 1987 Census of Agriculture (U.S. Department of Commerce 1987).

[10] Out of 30 nonrespondents, 5 selected ranchers were not contacted due to prior agreements with the operators to limit contacts or demise of the operation since sample selection. Eighteen sample ranchers refused to provide information. Five were not accessible after several attempts. Two of the selected ranchers were screened out as they no longer have beef-cow operations.

spondents who were aware of Trichomoniasis did not have their herd checked by a veterinarian. Seventy-two percent of the respondents were aware of at least one of the Trichomoniasis vaccines. Almost 40% of the respondents had already used Trichomoniasis vaccines on their cattle. Seventy-eight percent of them have indicated improvement in their herd condition.

Since the *T. foetus* vaccine had only been available for four years when the survey was initiated, the survey participants were divided into five categories: (*a*) those who have used the vaccine, Users; (*b*) those who will probably use the vaccine but prefer to wait, Waiters; (*c*) those who will not use the vaccine in the future, Nonusers; (*d*) those who are unsure of their future actions regarding use of the vaccine, Do-not-know; and (*e*) those who are not aware of the vaccine availability, Have-not-heard.

Approximately 42% responded as current or future users of the vaccine, while 20% of the respondents belonged to the Waiter group. Seven percent belonged to the Do-not-know group, and 6% classified as the Nonusers. Respondents of the Nonuser and Do-not-know categories justified their actions because their herd was free from Trichomoniasis, their herd was closed or fenced, and/or they always use virgin bulls.[11] Twenty-five percent of the respondents indicated that they had not heard of any vaccine.

Special education and use of personal computers were found to be the two factors most highly related to acceptance of the vaccine. For the User category, 50% of the respondents used personal computers and 41% had some type of special agricultural education. Of the specialized education, 79% had degrees either in agricultural economics or in animal science. Average land holdings for the User group were the highest, and the average age of a User respondent was the youngest for all the categories. Average herd size for Users was second to Waiters. On average, respondents in the User category have the least experience (29.8 years). Percentage of total earnings attributable to ranch operation was lowest for the User category when compared with others. For Users, most important source of information pertaining to the *T. foetus* vaccines is found to be the local veterinarians (68%), followed by state extension specialists (44%).

Waiters have, on average, smaller ranches both in terms of herd size and land size, but their dependence on ranch earnings as a proportionate share of their total income was higher than that of the User category. However, an average member of the Waiter group was found to be the most experienced and least educated of all five respondent categories. Waiters ranked next to Users in computer use, but were lowest in extended education. For the Waiter category, again the veterinarian was the most important source of information regarding the *T. foetus* vaccine. Sixty-one percent of Waiters obtained this information from veterinarians, while 45% from the state extension specialists.

Nonusers had the highest years of education, and 60% had specialty education which was the highest of all five respondent categories. Nonusers ranked third in both herd and land size. Nonusers and Waiters on average had similar durations of experience in the industry, but only 20% of Nonusers use personal computers in their range cattle operations. For the Nonuser category, veterinarians were the most important source of information regarding the availability of the vaccine. Eighty percent of Nonusers obtained

[11] Investigators and practitioners have found yearling bulls and even so-called virgin bulls with positive culture results for *T. foetus*. Trichomoniasis usually has an insidious onset and will be well established by the time a veterinarian is consulted. With cows, ranchers could notice onset usually after 60 days of a breeding season (Berry and Norman). The infected bulls rarely show any sign of the infection (Parsonson, Clark, and Duffy 1974).

information from their veterinarian and only 20% indicated extension specialists were a source of information.

All of the respondents who were not sure about adopting the vaccine, Do-not-know category, derived 100% of their total earnings from range cattle operations. On average, members of the Do-not-know category had more than average levels of education, but less than average years of experience. As to operation size, respondents of this category had the smallest herd size, but were second to the User group in average land size. Seventy-one percent of the respondents of the Do-not-know category received information of *T. foetus* vaccine from a veterinarian, while 43% received the information from a state extension specialist.

The last exclusive group of interest was Have-not-heard. They were the smallest in relation to acreage and herd size, and ranked the lowest in computer use and extended education. They had below average education and ranked lowest in their dependence on ranch revenues. Experiencewise, this category ranked third, but the average age of these respondents was the highest.

All respondents were asked if they perceived any possible risk in the use of the vaccine. Only four respondents indicated that there was no risk involved, but the rest of the respondents indicated that it was too early to make a judgment. The potential users were also asked how they would choose animals to inoculate—whether they would inoculate their herd randomly or follow a scheme. None of the respondents indicated that they would use random selection. They also indicated that they are not going to inoculate their entire herd in the future. Many of the respondents in the Waiter category indicated they would not inoculate their herds before cattle became infected.

It appears from the survey result that the fast adopters of *T. foetus* vaccine tend to be younger, are better-than-average educated, use modern technology, and operate large herds and land size. Other potential adopters are those who relied more on ranch operations as their source of income and they tended to be more experienced. Those who have not heard of Trichomoniasis vaccine tended to have less than average education, less extended education, very small herds, and were the least likely users of personal computers. The factors considered in the econometric model are discussed further in the data section.

Estimation Procedure

The adoption of new technology, especially in agriculture, has received considerable attention in economics research since the publication of Griliches' seminal paper. Research in this area mainly followed two distinct trends. On the one hand, some studies mainly concentrated on exploring the adoption paths, growth rates, ceiling levels, and potential for further expansion. On the other hand, numerous cross-sectional, micro-level studies have focused on the effects of various firm- and/or institution-specific factors on the individual's adoption behavior. The first approach follows the "epidemic" models of Griliches and Mansfield where diffusion is considered as a process of imitation and the speed of adoption is influenced by profitability and other economic considerations alone. The second approach requires an identification of the various dimensions of heterogeneity in the population that are relevant for the adoption of the specific technology and incorporate them in an analytical study. Our study attempts to explain the adoption process of the *T. foetus* vaccine using the latter approach.

To analyze the adoption of *T. foetus* vaccine by the cattle ranchers of Nevada, a multinomial logit model is estimated following the work of McFadden and Domencich and McFadden who used Thurstone's random utility formulation. It is assumed, with respect to the adoption of the *T. foetus* vaccine, that each rancher attempts to maximize the expected utility of the present value of profit through a process of choice among n discrete technologies. We assume that a choice set C with J number of alternatives is available for some population. The perceived profit of the ith rancher from the jth choice, π_{ij}, is assumed to be composed of two independent elements: a systematic component and a random component. Thus π_{ij} can be expressed as:

$$(1) \qquad \pi_{ij} = V_{ij} + \epsilon_{ij}, \qquad i = 1, \ldots, N, \quad \text{and} \quad j = 1, \ldots, J,$$

where V_{ij} is a nonstochastic function of parameters to be estimated and the observed variables associated with the ith decision maker for the jth technology. The unobserved characteristics are represented by ϵ_{ij}, and if the sample is a randomly drawn sample, the variable is a random variable. Given (1), the ith rancher chooses the technology, say the jth, that maximizes the expected utility of the present value of profit. Let the choice of the ith rancher for the jth technology be represented by a binary variable as:

$$(2) \qquad T_{ij} = \begin{cases} 1, & \text{if } \pi_{ij} \geq \pi_{ik};\ k = 1, \ldots, J,\ k \neq j, \\ 0, & \text{otherwise;} \end{cases}$$

that is, when $T_{ij} = 1$, technology j is chosen. The probability that the ith individual chooses alternative j is

$$(3) \qquad P_i(j) = \text{Prob}(T_{ij} = 1) = \text{Prob}(\pi_{ij} \geq \pi_{ik}) = \text{Prob}(\epsilon_{ik} - \epsilon_{ij} \leq V_{ij} - V_{ik}); \quad \forall\, j \in C_i, j \neq k.$$

Following Domencich and McFadden, we assume ϵ_{ij} to be independent random variables with a Weibull distribution. The ϵ_{ij} is nonnegative, its mean is the Euler constant divided by the parameter β (= $0.57722/\beta$), and the variance is $\pi/6\beta^2$. Through β the contribution of the stochastic elements to perceived profit can be varied. The parameter β can also be interpreted as estimated coefficients of some exogenous variables. The Weibull distribution is stable under maximization, that is, the maximum of any number of independent Weibull-distributed random variables has a Weibull distribution; and the difference between two independent Weibull random variables has a logistic distribution. When ϵ_{ij}s are *i.i.d.* Weibull random variables, the probability of using the jth technology by the ith rancher can be expressed, following Domencich and McFadden, as:

$$(4) \qquad P_i(j) = \frac{\exp(\beta V_{ij})}{\sum_{j=1}^{J} \exp(\beta V_{ij})}.$$

Following Maddala, we normalize $\beta_J = 0$. The equation (4) then can be expressed as:

(5) $$P_i(j) = \frac{\exp(\beta V_{ij})}{1 + \sum_{j=1}^{J-1} \exp(\beta V_{ij})} \qquad j = 1, \ldots, J - 1,$$

and

(6) $$P_i(j) = \frac{1}{1 + \sum_{j=1}^{J-1} \exp(\beta V_{ij})},$$

where the Ps are conditional probabilities of adoption given the specification of the systematic component V_{ij}.

Next, we specify $V_{ij} = \phi(X)$, where for the ith rancher any choice alternative, say the jth, is characterized by a $(k \times 1)$ vector of attributes X, reflecting his personal and production endowments influencing his/her choice of a particular technology. Given this specification, the conditional probabilities can be estimated by the maximum likelihood estimation (MLE) method. The likelihood function, Ł, can be expressed as:

(7) $$Ł = \prod_{i=1}^{N} P_i^{T_{i1}}(1) P_i^{T_{i2}}(2) \ldots P_i^{T_{iJ}}(J),$$

and the log of the likelihood function is estimated.

In the absence of a priori information on βV_{ij}, for estimation we approximate the relationship as a linear function $X_i' \beta_j$, where β_j is a $(k \times 1)$ vector of unknown parameters. In this study, we are interested in the dynamics of adoption of the vaccine; we have $j >$ 1 adoption decision under different adoption schemes ($j = 1, \ldots, J$). The conditional probabilities of various adoption schemes are represented by $P_0, P_1, \ldots, P_{J-1}$, as defined by (4).[12] The logarithm of the odds of choosing the jth technology over the technology J by the ith individual can be obtained from:

(8) $$\ln(P_{ij}/P_{iJ}) = X_i' \beta_j, \qquad \forall j = 1, \ldots, J - 1.$$

The coefficient vector β_j represents the marginal effects of elements of the regressor vector, X, on the odds ratio. It can be shown that the likelihood function is globally concave, so that a solution to the first-order condition exists, and it is unique. The log-likelihood function can be estimated using some iterative procedures. The parameter estimates thus obtained are consistent, asymptotically efficient, asymptotically normal, and the asymptotic variance-covariance matrix can be obtained from the inverse of the information matrix.

Model Specification

The choice of regressors is very crucial for explaining the dynamics of adoption. In our study this choice is guided by two sets of factors: human endowment and production endowment. The human endowment factors enable a potential adaptor to understand and decode information (Schultz 1964, 1975) and thereby help the diffusion of new technology. The production (physical) endowment affects the choice and/or desirability of a

[12] Note, P_0 is the probability of the Jth choice, and β_J is normalized to zero.

particular technology. Three variables are included in the model to capture the human endowment of a rancher. These are years of education, E; years of experience in ranching operations, G; and a binary variable H that represents computer use by the rancher.

Nelson and Phelps and Lin, among others, have hypothesized that education facilitates the diffusion of new technology. That is, a rancher with a relatively higher level of education is likely to have higher probability of adopting an appropriate technology, compared to those with lower education. The education variable, E, is the number of years of schooling. For estimation we scale E by 10.

The accumulation of knowledge and information regarding alternative technologies that come through experience is another key element in the adoption process. Feder and Slade, among others, argue that the production function associated with the new technology incorporates an efficiency factor which is positively related to the level of knowledge. Increased knowledge improves productive efficiency and helps appropriate decision making regarding the adoption of new technology, thus reducing uncertainty associated with new technology. Ranching experience could influence the adoption decision to a large extent, as it captures the accumulated knowledge. A continuous variable, G, measuring the years of involvement in the ranching operation is included to represent the knowledge factor in our model.

Putler and Zilberman and Zepeda highlighted the importance of the role of personal computers in the diffusion of new technology. Potentially, computers can be used in a wide variety of farm-level activities at the production, clerical, and planning levels. Putler and Zilberman found that the livestock producers are much more likely to use computers than crop producers; and well-educated farmers with large farms adopt computers more often than their smaller counterpart. Zepeda, in her study, also found a positive and significant influence of PC use on the rate of adoption. In this study, the binary variable H captures the effect of PC use on the rate of adoption of the vaccine. $H = 1$ if the rancher uses PC in his ranching operations; it is 0 otherwise. From the policy point of view, it is a very important tool, especially because much information and education can be provided through the computer network at a very moderate cost.

The production endowment of a rancher is captured by two sets of factors—physical endowment and industry involvement. Prior research emphasized the importance of physical endowment in technology diffusion (see Globerman; Rogers; Feder and Slade; Rahm and Huffman). We recognized two factors to capture this effect—numbers of animal, A (sum of bulls and cows), and the total acreage under ranch operation, L.

Concerted efforts on the part of the potential adopters to accumulate information on the new technology, especially when they expect positive economic returns, play an important role in the diffusion of the technology. Rogers and Stanfield highlighted the importance of industry involvement in the diffusion process. In this study, the industry involvement of a rancher is captured by two binary variables: (*a*) the variable B represents the presence (or absence) of extension services as a source of information on *T. foetus* vaccine; and (*b*) the variable R indicates whether the information was obtained from other ranchers ("ranch club effect"). The dummy variable, $B = 1$ if extension, is one of the sources of information, and 0 otherwise. Similarly, $R = 1$ if other ranchers are one of the information sources, and 0 otherwise. Two more firm-specific variables are introduced in the model to capture the production environment. These are the number of times the herd is being checked (annually) by a veterinarian, D; and a binary variable M representing whether (or not) a rancher hires consultant for his/her ranching operations.

Table 2. Estimated Coefficients of the Multinomial Logit Model

Parameter							
User $\ln(P_1/P_0)$		Nonuser $\ln(P_2/P_0)$		Waiter $\ln(P_3/P_0)$		Do-Not-Know $\ln(P_4/P_0)$	
β_{O10}	−2.3626 (−1.6154)	β_{O20}	−6.3656 (−1.8220)	β_{O30}	−3.7482 (−2.7881)	β_{O40}	−15.0448 (−1.8062)
β_{G10}	0.0113 (0.5758)	β_{G20}	0.0338 (1.0091)	β_{G30}	0.0271 (1.2129)	β_{G40}	0.0029 (0.0764)
β_{A10}	0.0713 (1.2907)	β_{A20}	0.1643 (2.0712)	β_{A30}	0.0314 (0.4493)	β_{A40}	−1.8027 (−2.2217)
β_{E10}	0.2658 (0.2882)	β_{E20}	1.5801 (0.7543)	β_{E30}	0.4699 (0.5477)	β_{E40}	8.7221 (1.7228)
β_{B10}	2.5514 (2.7595)	β_{B20}	1.2152 (1.0397)	β_{B30}	2.3937 (2.4042)	β_{B40}	2.8584 (1.7517)
β_{L10}	0.0013 (0.3503)	β_{L20}	−0.0033 (−0.5296)	β_{L30}	0.0020 (0.6298)	β_{L40}	0.0354 (2.2925)
β_{D10}	0.6316 (1.8840)	β_{D20}	0.3132 (0.5504)	β_{D30}	0.6956 (1.9155)	β_{D40}	−3.0690 (−1.6769)
β_{H10}	1.1691 (1.4655)	β_{H20}	−1.3386 (−0.9647)	β_{H30}	0.4379 (0.4590)	β_{H40}	−18.7395 (−2.1271)
β_{M10}	0.0213 (0.0191)	β_{M20}	0.9427 (0.5958)	β_{M30}	−1.1944 (−0.8847)	β_{M40}	14.3688 (2.5313)
β_{R10}	0.3347 (0.3416)	β_{R20}	1.6452 (1.3782)	β_{R30}	2.6138 (2.8746)	β_{R40}	12.8187 (2.7345)

Note: t-Statistics are in parentheses. Glossary: O intercept, G experience, A herd size, E eduction, B extension, L land size, D vet. checkup, H computer, M consultant, and R other rancher.

As mentioned earlier, five different adoption schemes are examined. Potential adopters can be divided into two broad categories: those who have not heard of any vaccine for Trichomoniasis and those who have. The first group is called Have-not-heard. The second group contains four categories: User, Waiter, Nonuser, and Do-not-know. In our econometric estimation, out of 95 observations, 84 were used. This was because all required information was not available in the initial set.

Results

The probabilities of five categories of responses—Have-not-heard, User, Waiter, Nonuser, and Do-not-know—are represented by P_0, P_1, P_2, P_3, and P_4, respectively. The maximum likelihood parameter estimates of the multinomial logit model and their asymptotic t-statistics are reported in table 2. The predicted probability of each category were estimated as:

$$\hat{P}(j) = \sum_{i=1}^{N} \hat{P}_i(j)/N, \tag{9}$$

which are reported in table 3. The model predicts the conditional probability of each category within 1% of the unconditional (actual) probabilities, which are reported in table 3. The User and the Waiter groups are considered to be potential adopters in our

Table 3. Predicted and Actual Probabilities of Adoption

Category	Predicted $\hat{P}_j$	Actual
Have-not-heard	0.2508 (0.2507)	0.2500
User	0.4163 (0.2632)	0.4167
Nonuser	0.0592 (0.0624)	0.0595
Waiter	0.2022 (0.1891)	0.2024
Do-not-know	0.0714 (0.2186)	0.0714

Note: Standard deviations are in parentheses.

model. The estimated probabilities indicate that the potential for adoption of the vaccine by a Nevada rancher is 62%. The goodness of fit of the estimated model is examined by testing a hypothesis that all slope coefficients are zero simultaneously. This has been done using the log-likelihood ratio (*LR*) test. The *LR* test statistic is defined as $LR = -2[\mathcal{L}(0) - \mathcal{L}(\hat{\beta})] \sim \chi^2_\nu$, where ν is the numbers of restrictions, $\mathcal{L}(\hat{\beta})$ is the value of the estimated log-likelihood function; and $\mathcal{L}(0)$ is the value of the log-likelihood function when all slope coefficients are restricted to zero. The $\mathcal{L}(0)$ can be calculated as $\mathcal{L}(0) = \Sigma_j^J n_j \ln P(j)$, where n_j is the number of observations in the jth choice category, and $P(j)$ is the sample proportion of the observations that makes choice j. In our model $\mathcal{L}(\hat{\beta}) = -77.05$ and $\mathcal{L}(0) = -116.87$, therefore, the estimated *LR* statistic is 79.64. This clearly rejects the null hypothesis at even 0.005% level of significance, indicating a good fit of the estimated model.

Since there are five categories of adopters, the model yields ten sets of parameter estimates. The parameter set $\hat{\beta}$ enters the probability expression in a nonlinear way, but the estimated coefficients can be interpreted using equation (8). Since the relation is linear, the estimated coefficients measure the marginal effect of the regressor on the logarithm of the odds of being in one of the adoption categories versus another. P_1 through P_4 are compared with P_0. P_2 through P_4 are compared with P_1; P_3 and P_4 are compared with P_2. P_4 is compared with P_3. The multinomial logit model only estimates the first four sets of parameters given in table 2; the remaining six sets can be obtained from:

$$\ln\left(\frac{P_{im}}{P_{ik}}\right) = \ln\left(\frac{P_{im}}{P_{il}}\right) - \ln\left(\frac{P_{ik}}{P_{il}}\right) = X_i'(\hat{\beta}_m - \hat{\beta}_k), \tag{10}$$

where $k = 1, 2, 3$; $m = 2, 3, 4$; and $m > k$.[13] Since the relationship is linear, a positive $\hat{\beta}$ implies that the associated explanatory variable affects the probability of being in an adoption category, listed at the top of the table 2, in a positive way, and the *t*-statistic of the parameter indicates the statistical significance of that effect. Thus, the test of significance of each parameter explains the probability of each adoption category. For example, a positive value of $\hat{\beta}_{G10}$ for User relative to Have-not-heard indicates that years

[13] The recovered parameters and their t-statistics are reported in table A1 in the appendix.

of experience, G, has a positive but insignificant effect on the probability of being a User relative to being a Have-not-heard. Thus, the parameters and their respective t-statistics explain the probability of being a User, Nonuser, Waiter, Do-not-know, or Have-not-heard, relative to the probability of being in another group.

Education, extension services, personal computers, veterinarian checkup, and herd size have profound influence on increasing the probability of being an immediate User relative to being in the Have-not-heard category. However, the impact of other factors, that is, experience, land size, use of hired consultant, and information from other ranchers, is statistically insignificant. The probability of User relative to Nonuser increases with respect to personal computer use, information from other ranchers, and land size, but decreases with herd size and extension information. The probability of being an immediate User with respect to being a Waiter decreases with respect to extension information, but improves with veterinarian checkup of herd. Finally, the probability of User relative to Do-not-know decreases with education, extension information, consultant, and conversations with other ranchers, but increases with herd size.

The probability of Nonuser versus User increases with herd size and extension information, but decreases with land size and conversations with other ranchers. The impact of land size on the probability of Nonuser with respect to all other categories is insignificant. On the one hand, the impact of herd size and veterinarian checkup on the probability of Nonuser with respect to Waiter is positive; on the other hand, the impact of education, extension, veterinarian checkup, and computer use are negative with respect to the Do-not-know category. The impact of consultants and conversations with other ranchers are positive with respect to the Do-not-know category. Conversations with other ranchers and herd size positively affect the probability of Nonuser relative to Have-not-heard, but the effect is negative with computer use.

Relative to the Have-not-heard category, the probability of the Waiter category is positively related to extension programs, veterinarian checkup, and conversations with other ranchers, and the effect is negative with respect to use of consultant service. Relative to the User category, the probability of the Waiter category is positively affected by extension programs and negatively affected by the number of veterinarian checkups. Both herd size and the number of veterinarian checkups are negatively related to the probability of Waiter relative to Nonuser. Finally, with respect to Do-not-know, the probability of Waiter is negatively affected by extension programs, veterinarian checkup, and computer use and positively affected by consultant, conversations with other ranchers, and herd size.

Herd size decreases and education and extension programs improve the probability of the Do-not-know category relative all other categories. While consultant and "ranch club effect" improve the probability of the Do-not-know category relative to the Have-not-heard category, their impact relative to other categories is negative. Computer use and veterinary checkup improve the probability of Do-not-know relative to all other categories except for Have-not-heard. The land-size variable positively influences the probability of Do-not-know significantly only with respect to Have-not-heard.

Estimated parameters alone do not indicate the change in the probability associated with a change in one of the explanatory variables (Capps and Kramer). Rather, the marginal probability associated with a change in an explanatory variable offers additional information. To highlight the impact of marginal change of the probability of being in an adoption category for a small change in each explanatory variable, elasticity of each probability is calculated as:

Table 4. Elasticities and Marginal Effects of the Estimated Probability

Elasticity	User	Waiter	Nonuser	Do-Not-Know	Have-Not-Heard
ε_G	−0.0745	0.4033	0.6701	−0.0322	−0.2697
	(0.1436)	(0.4623)	(0.9219)	(0.0923)	(0.2744)
ε_A	0.1166	−0.1647	1.3803	−0.5620	−0.1699
	(0.1609)	(0.2815)	(0.7811)	(0.5247)	(0.1356)
ε_D	0.0916	0.1946	−0.1698	−0.1469	−0.2172
	(0.0941)	(0.2060)	(0.4203)	(0.1374)	(0.1155)
ε_E	−0.0752	0.1507	1.5352	0.6737	−0.2914
	(0.3329)	(0.7757)	(2.1714)	(0.6225)	(0.5383)
ε_L	0.0183	0.0502	−0.3939	0.2520	−0.0213
	(0.0775)	(0.0679)	(0.4528)	(0.2351)	(0.0715)
MP_B	0.2073	0.0771	−0.0881	0.0489	−0.5941
	(0.1274)	(0.1299)	(0.1261)	(0.0766)	(0.2149)
MP_H	0.2195	−0.0758	−0.2456	−1.0988	−0.1804
	(0.1392)	(0.1675)	(0.1933)	(0.9242)	(0.1848)
MP_M	0.1300	−0.2625	0.1408	0.8489	0.0559
	(0.2148)	(0.2617)	(0.1683)	(0.7498)	(0.2563)
MP_R	−0.2902	0.4657	0.1023	0.6513	−0.2728
	(0.1530)	(0.1877)	(0.1424)	(0.5625)	(0.2185)

Note: Standard errors are in parentheses. Glossary: *G* experience, *A* herd size, *D* vet. checkup, *E* education, *L* land size, *B* extension, *H* computer, *M* consultant, and *R* other rancher.

(11.1) $$\varepsilon_{x_{ij}} = \left(\frac{\partial P_i(j)}{\partial x_{ij}}\right)\left(\frac{x_{ij}}{P_i(j)}\right) = \left[\beta_j - \sum_{j=1}^{J-1} P_j\beta_j\right]x_{ij}; \quad \text{and}$$

(11.2) $$\varepsilon_{x_{iJ}} = \left(\frac{\partial P_i(J)}{\partial x_{iJ}}\right)\left(\frac{x_{iJ}}{P_i(J)}\right) = -\left[\sum_{j=1}^{J-1} P_j\beta_j\right]x_{iJ}.$$

Computed elasticities for each category with respect to the continuous variables, evaluated in the category means of the variables, are reported at the top part of table 4. A 1% increase of the herd size, veterinarian checkup, and land size seems to increase the probability of immediate adoption by 0.12%, 0.09%, and 0.02%, respectively. A marginal increase in experience reduces the probability of immediate adoption by 0.07%. Although, a marginal increase in education seems to reduce the chance of immediate adoption, but the statistical significance of this effect is zero. This may be due to the fact that the User as a group is the second most educated group and an additional year of education does not improve the chance of adoption significantly any further. For other potential adopter group, namely, Waiter, the impact of marginal increase in education, experience, land size, and veterinarian checkup are positive, but the impact of a marginal increase in herd size is negative. This negative effect is due to the fact that administering a vaccine like *T. foetus* to an open range herd beyond a manageable size may not be cost effective.

For the Do-not-know and Have-not-heard groups, marginal increase in education seems to reduce the probability of being a nonadopter. Increase in herd size significantly increases the probability of being a Nonuser, while reduces the probability of Do-not-know and Have-not-heard. Increased veterinary checkups reduce the probabilities of being in the categories of Nonuser, Do-not-know, and Have-not-heard.

For the discrete variables, extension, computer, paid consultant, and other rancher, the marginal probabilities are calculated as:

$$(12.1) \qquad MP_{ij} = \left(\frac{\partial P_i(j)}{\partial x_{ij}}\right) = P(j)\left[\beta_j - \sum_{j=1}^{J-1} P_j\beta_j\right]; \quad \text{and}$$

$$(12.2) \qquad MP_{iJ} = \left(\frac{\partial P_i(J)}{\partial x_{iJ}}\right) = -P_i(J)\left[\sum_{j=1}^{J-1} P_j\beta_j\right].$$

The calculated *MP*s are evaluated at the group means of the variables and reported in the lower part of table 4. Both extension service and use of personal computers increase the probability of immediate adoption, Users, while reduce the probability of being a Nonuser. Use of personal computers in ranching operations increases the probability of adoption by reducing the probability of being a Nonuser, Do-not-know, and Have-not-Heard. Impact of other ranchers on the probabilities shows that it affects immediate adoption and encourages waiting and nonuse. Having a hired consultant reduces the probability of being a Waiter, and marginally improves the probability of immediate adopter, namely, User. The probabilities of being Nonuser and Do-not-know increase with having a paid consultant. Extension contacts, use of PC in ranching operations, and the "ranch club effect" reduce the probability of Have-not-Heard.

Table 5 reports the sensitivity of probabilities of being in each adoption category for different levels of explanatory variables. Probability values reported in table 5 are evaluated at the mean value of the continuous variables. One variable is changed at a time. Increase in herd size improves probability of both potential adoption groups, User and Waiter, up to a certain point and then declines. A herd size increase from 100 to 2,000 increases the probability of being an immediate User, but a herd size over 2,000 reduces the probability. Similarly, the probability of being a Waiter decreases as the herd size increases beyond 1,000. Increase in experience from 15 to 50 years increases the probability of Waiter by 8% and reduces the probability of User by 1%. An increase in land size, say from 1,000 to 100,000 acres, has positive marginal effect on the change in probability of being an adopter; for the User it is about 1% and for the Waiter it is 2%. Increase in education from high school level to college does not significantly alter the probability of being an adopter. However, it reduces the probability of Have-not-heard. As expected, an increase in the number of veterinary checkups has significant impact on the increase in the probability of being an adopter. A rise in the number of veterinary checkups from 0 to 3 increases the probability of immediate adoption by 18% and that of Waiter by 13%.

Next, the difference in the probability of being in each adoption category with respect to the discrete variables is examined. A rancher with a PC, given other variables at their mean levels, has 23% higher probability of being an immediate adopter. The probability of being a cautious adopter, Waiter, decreases by 4% with computer use. Similarly, when extension is the source of information regarding the availability of the *T. foetus* vaccine, the probability of immediate adoption increases by 23%, and that of Waiter adopter increases by 7%. The impact of other ranchers, "ranch club effect," reduces the probability of immediate adoption, but increases the probability of being a Waiter adopter by almost fourfold. Service of paid consultant marginally improves the probability of immediate adoption, but reduces the probability of Waiter significantly. Table 5, therefore, reveals that expansion of cooperative extension programs, further computer orientation,

Table 5. Sensitivity of the Probability of Being in Each Adoption Category

Variable	User	Waiter	Nonuser	Do-Not-Know	Have-Not-Heard
Herd size (*A*)					
100	0.3573	0.1590	0.1051	0.1590	0.2810
500	0.4192	0.2433	0.0325	0.2433	0.2563
1,000	0.4756	0.2393	0.0634	0.2393	0.2100
2,000	0.5214	0.1834	0.1808	0.1834	0.1144
3,000	0.4719	0.1099	0.3713	0.1099	0.0468
Experience (*G*)					
15	0.4734	0.2074	0.0382	0.0121	0.2690
30	0.4657	0.2412	0.0520	0.0120	0.2290
50	0.4646	0.2892	0.0762	0.0119	0.1779
Education (*E*)					
10	0.4691	0.2376	0.0356	0.0117	0.2461
15	0.4601	0.2484	0.0662	0.0124	0.2129
Vet. checkup (*D*)					
0	0.3628	0.1767	0.0856	0.0124	0.3625
1	0.4474	0.2348	0.0557	0.0122	0.2499
3	0.5459	0.3071	0.0398	0.0071	0.1000
Land size (*L*)					
1,000	0.4490	0.2253	0.0774	0.0116	0.2367
5,000	0.4497	0.2262	0.0762	0.0116	0.2363
10,000	0.4507	0.2273	0.0747	0.0117	0.2356
100,000	0.4657	0.2473	0.0519	0.0121	0.2231
Computer use (*H*)					
No	0.3914	0.2534	0.0766	0.0243	0.2543
Yes	0.6296	0.2179	0.1201	0.0000	0.1403
Extension (*B*)					
No	0.3993	0.2245	0.0662	0.0119	0.2980
Yes	0.6266	0.2925	0.0293	0.0121	0.0395
Ranch club (*R*)					
No	0.5388	0.1572	0.0514	0.0002	0.2524
Yes	0.2293	0.5896	0.0703	0.0358	0.0749
Consultant (*M*)					
No	0.4554	0.2714	0.0501	0.0001	0.2230
Yes	0.4696	0.0577	0.1008	0.1562	0.2157

inducement for more veterinary checkups, and finding an optimum herd size could be important policy instruments for a quick adoption of the *T. foetus* vaccine.

Conclusion

Estimation of a multinomial logit model indicates a wide difference among five categories of respondents in their responses to possible adoption of *T. foetus* vaccine in their ranch operation. These responses have been explained in terms of respondents' human capital and production endowments. Estimates show that potential adoption of the vaccine by cattle ranchers in Nevada is about 62%, based on Users and Waiters categories. The analysis further identifies the factors and/or ranchers' characteristics that may affect the adoption of the vaccine. Cooperative extension programs, use of computers, veterinary checkup of the herd, and herd size were found to be very important factors significantly influencing the probability of early adoption. The difference between high school and college education does not influence the probability of adoption significantly.

The probability of not using the vaccine reduces with a increase in herd size. The impact of a hired consultant and other ranchers are also positive.[14] Cooperative extension programs and veterinary checkups reduce the probability of Nonuse. One important finding is the inverse relationships between the probability of Do-not-know and Have-not-heard with herd size. Further investigation should be directed to check why the smaller (in terms of herd size) cattle ranchers are undecided in their use of the vaccine and/or have no idea of the existence of such a vaccine in spite of the fact that at least one vaccine has been commercially available for the last four years. Veterinary checkups and computer use reduce the probability of being in the Do-not-know and/or Have-not-heard categories. Although the cooperative extension programs have reduced the probability of being in the Have-not-heard category; their impact on comparable probabilities for the Do-not-know category is found to be minimal.

Given the recent federal government initiative of combining research and extension activities under Cooperative State Research, Extension and Education Service (CSREES), findings of this study have implications for targeting resources and activities to achieve coordinated research and extension programs. Some policy conclusions for further adoption of the vaccine highlight the need for (*a*) development of cooperative extension programs targeting the ranchers either reluctant to adopt and/or who are unaware of the vaccine; (*b*) development of computer-network-based cooperative education; (*c*) promoting regular veterinary checkups; (*d*) development of programs to educate ranchers about the long-run impact of the Trichomoniasis disease; and (*e*) encouraging alternative range management practices, such as using virgin bulls, fencing herds, and so forth.

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[14] Quite often the information obtained from other ranchers is actually extension information disseminated through a neighbor rancher. One of the reviewers indicated this point and we are thankful for that.

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Appendix

Table A1. Recovered Coefficients of the Multinomial Logit Model

Parameter	$\ln(P_2/P_1)$	Parameter	$\ln(P_3/P_1)$	Parameter	$\ln(P_4/P_1)$
β_{O21}	−4.0033	β_{O31}	−1.3859	β_{O41}	−12.6825
	(−1.3192)		(−0.9064)		(−1.5489)
β_{G21}	0.0225	β_{G31}	0.0157	β_{G41}	−0.0085
	(0.7423)		(0.7895)		(−0.2350)
β_{A21}	0.0930	β_{A31}	−0.0399	β_{A41}	−1.8740
	(1.3441)		(−0.6658)		(−2.3491)
β_{E21}	1.3143	β_{E31}	0.2040	β_{E41}	8.4563
	(0.6996)		(0.2121)		(1.7200)
β_{B21}	1.3105	β_{B31}	2.2791	β_{B41}	12.4841
	(1.0270)		(2.7969)		(2.6494)
β_{L21}	−1.3362	β_{L31}	−0.1577	β_{L41}	0.3070
	(−1.2040)		(−0.2337)		(0.1874)
β_{D21}	0.9214	β_{D31}	−1.2157	β_{D41}	14.3475
	(0.6349)		(−0.9251)		(2.4931)
β_{H21}	−0.0046	β_{H31}	0.0007	β_{H41}	0.0341
	(−0.9047)		(0.3788)		(2.2948)
β_{M21}	−0.3184	β_{M31}	0.0639	β_{M41}	−3.7007
	(−0.6508)		(0.3059)		(−2.0368)
β_{R21}	−2.5077	β_{R31}	−0.7312	β_{R41}	−19.9086
	(−1.8038)		(−0.8615)		(−2.2539)

Parameter	$\ln(P_3/P_2)$	Parameter	$\ln(P_4/P_2)$	Parameter	$\ln(P_4/P_3)$
β_{O32}	2.6174	β_{O42}	−8.6792	β_{O43}	−11.2967
	(0.8448)		(−0.8475)		(−1.3682)
β_{G32}	−0.0068	β_{G42}	−0.0310	β_{G43}	−0.0242
	(−0.2126)		(−0.6386)		(−0.6616)
β_{A32}	−0.1328	β_{A42}	0.3056	β_{A43}	−1.8341
	(−1.5753)		(0.3522)		(−2.2999)
β_{E32}	−1.1103	β_{E42}	7.1420	β_{E43}	8.2523
	(−0.5807)		(1.1812)		(1.6645)
β_{B32}	0.9686	β_{B42}	11.1735	β_{B43}	10.2049
	(0.7901)		(2.3438)		(2.1985)
β_{L32}	1.1785	β_{L42}	1.6432	β_{L43}	0.4647
	(1.048)		(0.9330)		(0.2785)
β_{D32}	−2.1370	β_{D42}	13.4261	β_{D43}	15.5631
	(−1.4114)		(2.2891)		(2.6666)
β_{H32}	0.0054	β_{H42}	0.0388	β_{H43}	0.0334
	(0.9751)		(2.4400)		(2.2468)
β_{M32}	0.3824	β_{M42}	−3.3823	β_{M43}	−3.7646
	(0.7617)		(−1.8825)		(−2.0621)
β_{R32}	1.7765	β_{R42}	−17.4009	β_{R43}	−19.1774
	(1.1708)		(−1.8902)		(−2.1631)

Note: *t*-Statistics are in parentheses. Glossary: *O* intercept, *G* experience, *A* herd size, *E* education, *B* extension, *L* land size, *D* vet. checkup, *H* computer, *M* consultant, and *R* other rancher.