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Potential Role of Technology in Increasing Productivity and Income at National Level: A Case of Cell-culture Vaccine against Classical Swine Fever

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Abstract

Classical swine fever (CSF) is one of the important diseases of pigs causing high mortality. The ICAR-Indian Veterinary Research Institute, Izatnagar, has developed a cell culture vaccine for this disease during the period 2002-2008. The vaccine will most probably be marketed by various agencies, in both public and private sectors by 2017-18. The present study attempts to evaluate the potential economic feasibility of CSF control programme using the above vaccine at the national level using economic surplus model. The potential change in total surplus, as a result of CSF control programme is found to be ₹ 53.31 crore per annum. The change in economic surplus and the research & delivery costs was projected to 2030. Using a long-run discount rate of 7.5 per cent, the benefits were compared to research & delivery cost and the NPV, IRR and BCR were calculated. The NPV, IRR and BCR of CSF control programme are found to be ₹ 322.55 crore, 40 per cent and 41:1, respectively. Sensitivity analysis has revealed that the benefits are most sensitive to assumptions regarding lower degree of immunity offered by the vaccine and a higher discount rate. The changes in results of the model, based on baseline assumption, were negligible for changes in assumption in regard to adoption rates, ceiling level of adoption and higher demand elasticity.

Key words: Technology impact, classical swine fever, cell-culture vaccine, ICAR-IVRI

JEL Classification: Q16, O33

Introduction

In India, pig husbandry is considered as an occupation for socially and economically backward classes. The livestock ownership status at the national level suggests that pig production is an economic activity dominated by marginal and smallholders (NSSO, 2003). However, with the changing dietary patterns in favour of animal-based protein sources, pig faming is now being taken up on semi-commercial and commercial lines even by the people of higher castes.

During the period 1970 to 2003, the annual per capita consumption of pig meat in India grew at the rate of 3.93 per cent and of meat consumption grew at the rate of 3.23 per cent (Bardhan, 2007). As per the 19th Livestock Census (2012), the total pig population in the country is 10.294 million in which indigenous animals account for 76.14 per cent. The share of exotic/crossbred pigs in total pig population increased from 21.46 per cent in 2007 to 23.86 per cent in 2012. The main purpose of pig farming is meat production, but it is highly affected by different diseases. The infectious diseases of pigs are important factors which adversely affect the productivity and hence profitability from pig farming.

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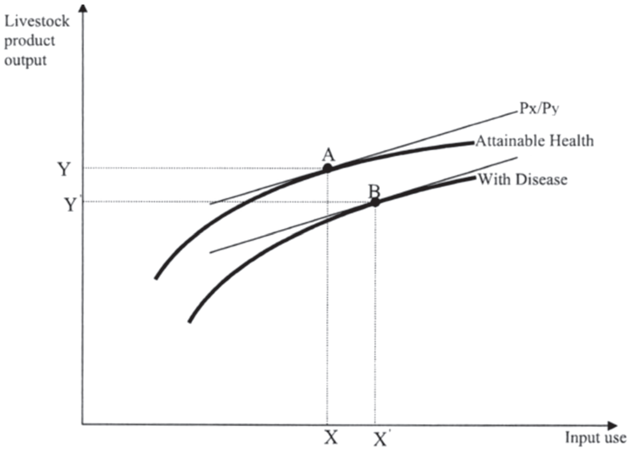

Figure 1. Effect of disease on livestock production
Source: Bennet (2003)

Effect of Disease on Livestock Production

Livestock diseases reduce production efficiency — leading to economic losses at producer and industry levels (McInerney, 1996).

Figure 1 shows the physical effect of a disease on livestock production (inefficiencies in production process) in terms of both output loss and input use. On incidence of a disease, instead of operating at point A on the 'attainable health' production function with output level Y and input-use of X, producers operate at new equilibrium point B, on the disease production function with lower output level Õ2 and/or higher input-use X' , given output and input prices, $\tilde{N}_Y$ and $\tilde{N}_X$, respectively. This suggests that producers readjust to the changed relationship between inputs and outputs achieving a new equilibrium. The effect of animal diseases in a given production system is a reduction of the efficiency with which inputs/resources are converted into outputs/products, decreasing productivity (Otte and Chilonda, 2000; Bennet, 2003).

About the Disease

The classical swine fever (CSF) is one of the important diseases of pigs causing mortality up to 100 per cent. The disease exists in all parts of the country, with high frequency in the North Eastern states. The disease causes huge losses to the pig industry. The economic losses due to CSF result directly due to mortality, retardation of growth, reproductive problems of affected pigs and indirectly by bringing restrictions on exports of pork and pork products (Sarma *et al*., 2008). The infectious agent responsible is a virus CSFV of the genus Pestivirus in the family Flaviviridae. The effect of different CSFV strains varies widely, leading to a wide range of clinical signs. Highly virulent strains correlate with acute, obvious disease and high mortality, including neurological signs and hemorrhages within the skin. The less-virulent strains can give rise to subacute or chronic infections that may escape detection, while still causing abortions and stillbirths.

Incidence of CSF

The two major diseases, viz. Foot and Mouth Disease (FMD) and CSF, which have been reported continuously in pigs by the Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Government of India during the past fifteen years period (1998-2012). The other reported diseases in pigs were Fasciolosis, Coccidiosis, Salmonellosis, enterotoxaemia, Hemorrhagic Septicemia, mange, porcie-Brucellosis and Schistosomiasis. The number of disease incidence and deaths in pigs in different years (1998-2012) are presented in Table 1. During his period, CSF accounted for the highest incidence (61.59%) and deaths (92.07%) in the total incidence and deaths in pigs and the case fatality rate was 23.96 per cent. Verma *et al*. (2004) have reported 24.95 per cent and 11.55 per cent case fatality rate of CSF and FMD, respectively in Haryana. Thakur *et al*. (1998) and Bhattacharya (2001) have reported 46.15 per cent and 43.69 per cent mortality, respectively, in outbreaks of CSF. Deka *et al*. (2012) have reported monthly incidence of 5.4 per cent of CSF in pigs in three North-Eastern states, viz. Assam, Mizoram and Nagaland. The average annual morbidity and mortality rates due to CSF in India have been 0.048 per cent and 0.012 per cent, respectively.

The periodic performance of these diseases over the consecutive five-year periods is presented in Table 2. The average incidence of CSF was highest (6937) during 1998-2002, followed by 6385 during 2008-2012 and was 2801 during 2003-2007. Hence, no distinct pattern in incidence of CSF was observed over the years. However, mortality due to CSF registered an increasing trend over the consecutive five-year periods (808 during 1998-2002, 1291during 2003-2007 and 1764 during 2008-2012). On the other hand, the

Table 1. Number of incidences and deaths due to different diseases in pigs: 1998-2012

Year	Number of incidences				Number of deaths			
	FMD	CSF	Others	Total	FMD	CSF	Others	Total
1998	0	1810	13815	15625	0	595	885	1480
1999	346	8800	0	9146	50	1424	0	1474
2000	16	1305	68	1389	2	75	1	78
2001	163	13224	6824	20211	29	1195	54	1278
2002	21	9546	11	9578	1	753	0	754
2003	83	1156	10	1249	11	520	1	532
2004	182	635	35	852	22	117	0	139
2005	368	4697	178	5243	66	2539	0	2605
2006	15	4519	4838	9372	1	2327	0	2328
2007	7	2996	3370	6373	1	950	0	951
2008	4	2027	5109	7140	0	894	39	933
2009	401	5267	6725	12393	46	1646	264	1956
2010	38	17002	6853	23893	0	2932	178	3110
2011	45	4018	399	4462	0	1371	1	1372
2012	287	3612	71	3970	12	1977	0	1989
Average	131.73	5374.27	3220.40	8726.40	16.07	1287.67	94.87	1398.60
Average case fatality rate (%)					12.20	23.96	2.95	16.03

Table 2. Period-wise average incidences and deaths in pigs: 1998-2012

Particulars	Disease	Sub-periods		
		1998-2002	2003-2007	2008-2012
Average No. of incidence	FMD	109.2	131	155
	CSF	6937.0	2800.6	6385.2
	Others	4143.6	1686.2	3831.4
Average No. of deaths	FMD	16.4	20.2	11.6
	CSF	808.4	1290.6	1764.0
	Others	188	0.2	1872.0
Average case fatality (%)	FMD	15.01	15.42	7.48
	CSF	11.65	46.08	27.63
	Others	4.53	0.01	48.86
	Year	2003	2007	2012
	Population	13519000	11134000	9400000

population of pigs has declined over time, suggesting that the mortality rate due to CSF has also increased during the period.

Disease Management

The recommended measures to control CSF include use of sanitary prophylaxis (disease reporting, strict import policy, quarantine, routine serological surveillance) and medical prophylaxis (use of a modified live-virus vaccine). India requires a total of about 11 million doses of CSF vaccine per year. The vaccine type prevalent in India is Lapinized vaccine, which is developed by the serial passage of CSF virus in rabbits, and the vaccine is processed from the spleen and other lymphoid tissues of the infected rabbits. As the existing lapinized vaccine is produced in rabbits, the large doses are not produced and hence, a major portion of the pig population remain unvaccinated which poses the potential threats for disease outbreaks.

Technology (Cell Culture Classical Swine Fever Vaccine) Development

An effective cell culture based live attenuated freeze-dried vaccine for Classical Swine Fever has been developed at the ICAR-Indian Institute of Veterinary Research (IVRI), Izatnagar. The vaccine has been found to be safe and potent. The field trials have been carried out on a large number of pigs (2300 pigs) at different locations. It provides immunity for a year and has no side effects, even in the pregnant animals.

Competitive Advantage

Presently, lapinized swine fever vaccine is used which is produced by sacrificing a large number of rabbits. The use of a new cell culture vaccine will do away with the killing of rabbits. A large number of doses can be produced by replacing lapinized vaccine by cell culture vaccine. The cost of the cell culture vaccine will be economical than of the existing lapinized vaccine.

The Market

There is huge demand for the cell culture vaccine technology for CSF control. At present, 4 Sate Biological Units (West Bengal, Kerela, Punjab and Assam) are producing the lapinized vaccine. Many private companies and State Biological Units (Institute of Animal Health and Veterinary Biologicals, Kolkata) are interested in taking up this technology. The CSF Cell Culture Vaccine of IVRI has been transferred to Indian Immunologicals, Hyderabad.

The importance of pig meat as a source of animal protein is increasing as revealed by the higher growth rate of per-capita consumption of pig meat as compared to meat consumption as a whole. With increasing pig production to match the rising demand, the demand for vaccine against CSF will be significant. The production of lapinized vaccines in rabbits will not be able to produce the vaccine at a scale which can cover the pig population in the country, especially when CSF has been brought under the national disease control policy of the Department of Animal Husbandry Dairying and Fisheries, Ministry of Agriculture (GoI). The present study attempts to quantify the potential impact of the vaccine in India using an economic surplus model.

Methodology

An economic surplus model (Alston *et al*., 1995) was used to measure the potential benefits of CSF control by cell-culture vaccine as well as the potential benefits of and returns to research aimed at alleviating the disease. A static model of closed economy was used in the analysis. Assuming a closed economy implies that adoption of a cost-reducing or yield-enhancing technology increases the supply of a commodity such as meat. The export of pig meat from India constitutes only about 0.01 per cent of total meat exports in value terms (BAHS, 2015). The increase in supply of pig meat as a result of control programme in the domestic market will reduce the cost of commodity to consumers and the price to producers. The simple case of linear supply and demand curves with parallel shifts was chosen.

In Figure 2, the gross annual research benefits are presented by the area between the two supply curves and beneath the demand curve. This area represents the total increase in economic welfare (change in total surplus) and comprises the changes in producer and consumer surplus resulting from the shift in supply. The consumers are benefitted because they can consume more at a lower price. Although, producers are receiving a lower price for their meat, they are able to sell more, so their benefits also increase. The algebraic derivations of these surpluses are shown in Table 3. It is assumed that the vaccine will be easily accessible at a relatively low cost to the producer and

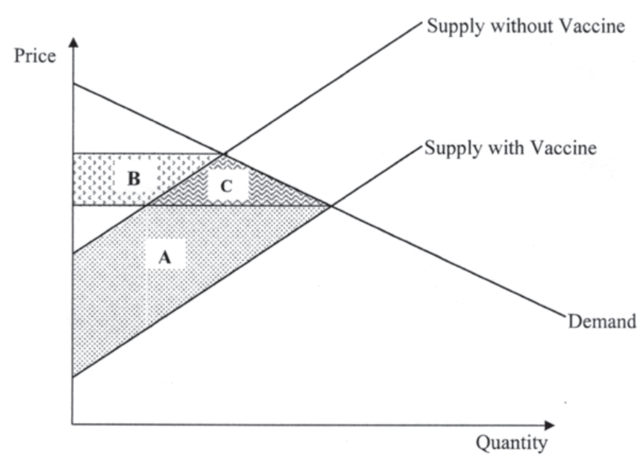

Figure 2. Measuring change in total surplus

Table 3. Calculations of change in total surplus due to CSF vaccine

Parameter	Formula
Elasticity of supply	$\varepsilon = [(\delta Q_s/Q_s) / (\delta P_s/P_s)]$
Elasticity of demand	$\eta = [(\delta Q_d/Q_d) / (\delta P_d/P_d)]$
Gross proportionate productivity gain per head (per cent)	$E(Y) = (Q_1 - Q_0)/Q_0$
Gross cost change per tonne (per cent)	$C = E(Y)/\varepsilon$
Input cost change per head (per cent)	$E(c)$
Input cost change per tonne (per cent)	$i = E(c)/(1+E(Y))$
Net proportionate reduction in cost per tonne output (per cent)	$k = C - i$
Price (₹/tonne)	P
Quantity (tonnes)	Q_0
Relative reduction in price	$Z = K_t \times \varepsilon/([+ s)$
Change in total surplus (₹)	$K \times P \times Q_0 [1+(0.5 \times Z \times s)]$
Change in consumer surplus (₹)	$Z \times P \times Q_0 [1+(0.5 \times Z \times s)]$
Change in producer surplus (₹)	$(k-Z) \times P \times Q_0 [1+(0.5 \times Z \times s)]$

Table 4. Sources and vales of economic surplus input data

Parameter	Value	Source of information
Elasticity of supply (ε)	1	Assumed (Montes *et al*., 2008)
Elasticity of demand (η)	1	Assumed (Montes *et al*., 2008)
Gross proportionate productivity gain per head (per cent) (E(Y))	19.36	Computed
Gross cost change per kg (C)	19.36	Formula
Input cost change per head [E(c)]	2.50	Expert Opinion
Input cost change per kg (i)	2.09	Formula
Net proportionate reduction in cost per tonne output (per cent) (k)	17.27	Formula
Price (₹/kg) (P)	120	Probable Value
Quantity ('000 tonnes) (Q_0)	468.58	BAHS (2015)

the treatment required in the case of incidence of CSF will be reduced. Table 4 presents the sources and values of parameters to be used in the economic surplus model.

The gross annual research benefits, measured by the change in total surplus, represent the maximum potential benefits to society from a new technology. To estimate the likely net benefits accruing to present research, some uncertainties will be considered like the uncertainty surrounding if and when the research may be successful, the uncertainty in the proportion of farmers who will adopt the vaccine and the rate at which they will adopt. The economic surplus model accounts for such uncertainties by the use of probabilities. It will thus be necessary to estimate the most probable research and adoption lags, the probability of research success, and the probable ceiling level of adoption. The parameters regarding probability of success are shown in Table 5 and Table 6 which summarize the assumptions for baseline analysis of potential returns to CSF vaccine research.

Using the change in total economic surpluses as benefits and the research and delivery cost as costs of the control programme, the following economic criteria were calculated to ascertain the economic feasibility of the vaccination process.

Table 5. Expert opinion regarding probability of developing a vaccine to control the productivity losses due to CSF within next 10 years

Probability of success (%)		
Low estimate	Most likely estimate	High estimate
80	90	100

Net Present Value (NPV)

$$NPW = \sum_{t=1}^{n} B_n/(1+i)^n - \sum_{t=1}^{n} C_n/(1+i)^n$$

Benefit Cost Ratio (BCR)

$$BCR = \frac{\sum_{t=1}^{n} B_n/(1+n)^n}{\sum_{t=1}^{n} C_n/(1+i)^n}$$

where,
B_n = Year-wise benefits
C_n = Year-wise costs
n = Number of years (1 to n), and
i = Discount rate.

Results and Discussion

To measure the gross proportionate productivity gain per head [E(Y)], it was assumed that cent per cent vaccination of pig population will remove the incidence of disease. If disease-induced productivity loss is mitigated, then the avoided loss can be imputed as gain in productivity due to the technology (vaccine). To have an estimate of this avoided productivity loss, it is first required to have an estimate of incidence rate of CSF.

Table 6. Summary of assumptions for baseline analysis of potential returns to CSF vaccine research

Research Period (2002-2008): 06 years
Research Costs: Total ₹ 2,21,22,200 deflated at 2016 level
Probability of research success (%): 90.00
Adoption period: 10 years
Ceiling level of adoption: 80 per cent
Long-term discount rate: 7.5 per cent
Cost of vaccination*: ₹ 7/dose
Production cost includes ₹ 2.50 (most probable cost of each dose of vaccine) and ₹ 4.50 (per dose vaccination cost)

A review of literature on sero-prevalence of CSF in pigs as reported by various authors (Kumar *et al*., 2007; Jindal *et al*., 2008; Barman *et al*., 2012; Ratnaprabha *et al*., 2012; Deori *et al*., 2012; Nandi *et al*., 2011; Shivaraj *et al*., 2013 and Choori *et al*., 2015) was carried out to estimate the pooled number of cases of the disease and the Table 7 presents the results of these sero-prevalence studies. In some papers, the sero-prevalence was reported for pigs as such without any reference to the age of the animal. Kumar *et al*. (2007) and Jindal *et al*. (2008) have reported sero-prevalence separately for pigs less than 3 months of age and more than 3 months of age. The age-wise prevalence as reported by Kumar *et al*. (2007) and Jindal *et al*. (2008), was used to apportion the prevalence of CSF in piglets (< 3 months) and adult pigs (> 3 months) to get the pooled age-wise prevalence of CSF.

Table 8 compiles the results, pertaining to serological surveys, obtained in the literature review to give the pooled morbidity and mortality rates. These rates were ultimately used in this study to obtain the estimate of benefits to be gained from use of the cell-cultured vaccine against CSF.

As given in Table 8, based on the literature, morbidity and mortality rates in pigs due to CSF are 52.04 per cent and 42.09 per cent, respectively.

Table 7. Sero-prevalence results as reported in published literature

Authors	Total No. of samples	No. of positive samples	Morbidity rates (per cent)	No. of positive cases resulted in deaths	Mortality rates (per cent)	CFRs (per cent)
Nandi *et al*. (2011)	881	596	67.65	-	-	-
Shivaraj *et al*. (2013)	517	173	33.46	-	-	-
Kumar *et al*. (2007)	175	105	60.00	85	48.57	80.95
Deori *et al*. (2012)	122	52	42.62	-	-	-
Choori *et al*. (2015)	218	89	40.83	-	-	-
Jindal *et al*. (2008)	306	168	54.90	112	36.60	66.67
Barman *et al*. (2012)	58	12	20.69	-	-	-
Ratnaprabha *et al*. (2012)	114	55	48.25	-	-	-

Table 8. Morbidity and mortality rates as obtained from literature review

Age groups	Sample size	Cases	Deaths	Morbidity rate (%)	Mortality rate (%)
< 3 months	1215	1095	960	90.12	79.01
> 3 months	1234	182	72	14.75	5.83
Pooled	2454	1277	1033	52.04	42.09

Imputing these rates on the pig population of country (according to 19th Livestock Census, 2012), the number of cases and deaths were worked out as 53,76,287 and 43,45,990, respectively. Assuming a live body weight loss of 20 per cent for infected pigs and average yield 40.26 kg for each pig (GoI, 2014), the gross productivity gain (in terms of live body weight) was worked out as 19.36 per cent per head.

The potential change in total surplus, as a result of CSF control programme, is estimated to be ₹ 53.31 crore per annum. The yield increase, as a result of vaccination, mainly occurs by avoidance of disease incidence and deaths caused due to it. The increase in yield in turn results in reduction in cost per kg of output. The estimated reduction in cost, as a result of vaccination, would be 17.27 per cent. The higher yield as a result of control programme would increases the supply of pig meat. Both consumers and producers would be benefitted from this change. In this case of CSF control by cell culture vaccination, as unitary elasticities were assumed for both demand and supply, benefits to producers and consumers are same. Kristjanson *et al*. (1999) had, however, reported higher potential benefits to producers than to consumers as result of trypanosomiasis control in African animals in the case of meat production.

Impact of Vaccination against CSF

The change in economic surplus and the research & delivery cost were projected to 2030. Overall, as opined by experts, the vaccine will be marketed from 2017-18 at all-India level and the ceiling level of 80 per cent vaccination will be reached by 2025. The change in total economic surplus and research & delivery cost were projected from 2002 (starting year of the project) to 2030, after adjusting for the above adoption pattern. Using a long-run discount rate of 7.5 per cent, the benefits were compared with research & delivery cost and the NPV, IRR and BCR were calculated. The NPV, IRR and BCR of CSF control programme have been found to be ₹ 322.55 crore, 40 per cent and 41:1, respectively. Thus, from the point of view of these economic criteria, investment in research on developing a cell culture vaccine against CSF is economically viable.

Sensitivity Analysis

There can be variations in many of the assumptions while calculating the returns to CSF control programme, especially when the benefits and costs are projected in distant future. In this context, sensitivity analysis was carried out to ascertain the effect of changes in some of the baseline assumptions. The results of these analyses are presented in Table 9. Under the first scenario (conservative), it was assumed that the rate at which vaccination increased per annum was lower by 5 per cent as compared to the baseline assumption. It was also assumed that ceiling vaccination level will remain at 60 per cent. Given this scenario, NPV decreased by ₹ 97.92 crore and IRR and BCR decreased to 37 per cent and 37.50:1, respectively.

In an optimistic scenario, it was assumed that the rate of increase in vaccination per annum was 5 per cent more and the ceiling adoption level will reach 100 per cent vaccination target. In this case, the NPV increased by ₹ 71 crore, while IRR and BCR increased to 43 per cent and 42:1, respectively. The discount rate chosen for the analysis was 7.5 per cent. Under a different scenario, a higher discount rate (10%) was adopted to ascertain the effect of higher discount rate on the benefits. It was assumed that high discount rate discourages investments with long-term benefits (Kristjanson *et al*., 1999). At this higher discount rate, NPV declined by ₹ 122 crore and IRR and BCR, declined to 37 per cent and 38:1, respectively.

In the pessimistic scenario, assuming that the vaccine would provide immunity to 70 per cent of animals, the benefits of the PPR control programme

Table 9. Sensitivity of estimated vaccine impact to assumptions

(in crore ₹)

Assumptions	NPV	IRR	BCR
Conservative estimates regarding adoption			
(i) Adoption rate declines by 5 per cent per annum as compared to baseline assumption	224.63	37.00	37.50
(ii) Ceiling adoption level is 60 per cent	(-97.92)		
Optimistic estimates regarding adoption			
(i) Adoption rate increases by 5 per cent per annum as compared to baseline assumption	348.47	43.00	41.88
(iii) Ceiling adoption level of 100 per cent	(+25.92)		
Higher discount rate (10%)	199.97 (-122.58)	37.00	38.22
Vaccine affording 70 per cent immunity	250.32 (-72.23)	38.00	32.13
Conservative estimate regarding success rate (80%)	285.22 (-37.33)	39.00	36.47
Optimistic estimate regarding success rate (100%)	360.03 (+37.75)	41.00	45.77
Higher demand elasticity (η = 2)	328.61 (+6.06)	40.00	41.86

Note: Figures within parentheses indicate changes in NPV from the baseline values

decreased by ₹ 72 crore and the IRR and BCR decreased to 38 per cent and 32:1, respectively. Assuming conservative estimate regarding potential success rate (80%), the NPV declined by ₹ 37 crore and in the optimistic scenario, when a cent per cent success rate was assumed, the NPV increased by about ₹ 38 crore. IRR in the case of conservative success rate assumption, decreased to 39 per cent, while in the case of optimistic success rate assumption, increased to 41 per cent. Under the assumption of higher demand elasticity (η=2), to account for possibility of increased price sensitivity, the NPV decreased by ₹ 10 crore.

Conclusions

The incidence of CSF is considered one of the important health constraints in pig rearing. The study has assessed the potential impact of a cell culture vaccine developed at ICAR-IVRI against CSF by using economic surplus model. The study has revealed significant benefits of CSF control programme using the cell culture vaccine. The sensitivity analysis has revealed that the benefits are most sensitive to assumptions regarding lower degree of immunity offered by the vaccine, higher discount rate and conservative estimate of success rate of the vaccine. The changes in the results of model, based on baseline assumption, were negligible for changes in assumption in regard to adoption rates, ceiling level of adoption and higher demand elasticity. The control of diseases involves optimization of resource allocation decisions at the national level because the inputs it uses are scarce and have alternative uses. In this regard, it is hoped that the study would provide valuable inputs towards formulating various livestock health intervention efforts.

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