# **Appendix**

Hessian Matrix = $\left[\begin{matrix}-δ\_{vv}(y+n)&-δ\_{vn}\left(y+n\right)-δ\_{v}&-δ\_{v}y\_{L}\\-δ\_{v}-δ\_{nv}(y+n)&-δ\_{nn}\left(y+n\right)-2δ\_{n}&-δ\_{n}y\_{L}\\-y\_{L}δ\_{v}&-y\_{L}δ\_{n}&y\_{LL}(1-δ)\end{matrix}\right]$

To ensure a maximum, $D\_{1}<0$, $D\_{2}>0$, and $D\_{3}<0$

$D\_{1}=-δ\_{vv}\left(y+n\right)<0$ if $δ\_{vv}>0$, i.e., vaccinations reduce losses at a decreasing rate.

$D\_{2}=δ\_{vv}\left(y+n\right)\left[δ\_{nn}\left(y+n\right)+2δ\_{n}\right]-\left[\left(δ\_{v}+δ\_{nv}\left(y+n\right)\right)\left(δ\_{vn}\left(y+n\right)-δ\_{v}\right)\right]>0$

if $δ\_{vv}\left(y+n\right)\left[δ\_{nn}\left(y+n\right)+2δ\_{n}\right]>$ $\left[\left(δ\_{v}+δ\_{nv}\left(y+n\right)\right)\left(δ\_{vn}\left(y+n\right)-δ\_{v}\right)\right]$

where $δ\_{nn}>0$, i.e., introductions increase losses at increasing rate and $δ\_{vn}=δ\_{nv}>0$, i.e., the marginal value of vaccinations increases with increase in introductions.

$D\_{3}= -δ\_{vv}\left(y+n\right)\left[\left(δ\_{nn}\left(y+n\right)+2δ\_{n}\right)-y\_{L}^{2}δ\_{n}^{2}\right]+\left(δ\_{vn}\left(y+n\right)-δ\_{v}\right)\left[y\_{LL}\left(1-δ\right)\left(δ\_{v}+δ\_{nv}\left(y+n\right)\right)-y\_{L}^{2}δ\_{v}δ\_{n}\right]-δ\_{v}y\_{L}\left[y\_{L}δ\_{n}\left(δ\_{v}+δ\_{nv}\left(y+n\right)\right)-y\_{L}δ\_{v}\left(δ\_{nn}\left(y+n\right)+2δ\_{n}\right)\right]<0$ to ensure a maximum.

Table A1: The Effect of Vaccinations on Livestock Disease Death (when *Vaccinations* is a dichotomous variable) – Marginal Effects from Zero-Inflated Poisson Regression

|  |  |  |  |
| --- | --- | --- | --- |
|  | Cattle Disease Death | Goat Disease Death | Sheep Disease Death |
| *Vaccinations (Yes/No)a* | -0.358(1.60) | -6.59\*\*(3.04) | -6.45\*\*(2.89) |
| *Cattle* | 0.947\*\*\*(0.122) | 0.010(0.091) | 0.472\*\*\*(0.117) |
| *Sheep*  | 0.015(0.094) | 0.230\*\*\*(0.070) | 0.711\*\*\*(0.108) |
| *Goats* | -0.233\*\*(0.098) | 0.867\*\*\*(0.092) | 0.069(0.099) |
| *Transhumance Distance*  | 0.106(0.069) | 0.044(0.056) | -0.159\*\*(0.068) |
| *Grazing Time* | 0.042(0.097) | 0.160\*\*(0.074) | 0.006(0.096) |
| *Watering Time* | 0.029(0.098) | -0.073(0.073) | -0.296\*\*\*(0.093) |
| *Sub-Village Disease Death* | 0.041(0.035) | 0.087\*\*\*(0.032) | 0.108\*\*\*(0.035) |
| Vuong Test (P-Value) | 4.96(0.000) | 5.23(0.000) | 5.30(0.000) |
| aPredicted values from a first-stage logit regression of *Vaccinations (Yes/No)*. \*\*\*, \*\*, \* indicate significance at 1, 5 and 10% levels, respectively.Standard errors for marginal effects are estimated via delta method.  |

Table A2: Relationship between Vaccinations and Livestock Disease Death – Marginal Effects from Zero-Inflated Poisson Regression without Using IV for Vaccinations

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | *Cattle Disease Death* | *Goat Disease Death* | *Sheep Disease Death* | *Cattle Disease Death* | *Goat Disease Death* | *Sheep Disease Death* |
| *Vaccinations (Count)* | -0.79\*\*\*(0.293) | -4.34\*\*\*(0.595) | 1.01\*(0.59) | - | - | - |
| *Vaccinations (Yes/No)* | - | - | - | -0.813\*\*(0.351) | -5.05\*\*\*(0.711) | 0.93(0.666) |
| *Cattle* | 0.940\*\*\*(0.112) | 0.084(0.315) | 0.345\*\*\*(0.108) | 0.928\*\*\*(0.111) | 0.055(0.314) | 0.372\*\*\*(0.108) |
| *Sheep*  | 0.025(0.087) | 0.209\*\*\*(0.067) | 0.627\*\*\*(0.100) | 0.021(0.089) | 0.208\*\*\*(0.066) | 0.64\*\*\*(0.101) |
| *Goats* | -0.218\*\*(0.096) | 0.830\*\*\*(0.086) | 0.038(0.094) | -0.215\*\*(0.096) | 0.847\*\*\*(0.087) | 0.027(0.096) |
| *Transhumance Distance*  | 0.101(0.068) | 0.010(0.054) | -0.164\*\*(0.067) | 0.110(0.068) | 0.021(0.054) | -0.176\*\*\*(0.067) |
| *Grazing Time* | 0.037(0.089) | 0.192\*\*\*(0.071) | 0.074(0.091) | 0.027(0.093) | 0.185\*\*\*(0.070) | 0.085(0.092) |
| *Watering Time* | 0.010(0.096) | -0.046(0.071) | -0.265\*\*\*(0.091) | 0.025(0.095) | -0.029(0.071) | -0.275\*\*\*(0.091) |
| *Sub-Village Disease Death* | 0.033(0.035) | 0.084\*\*\*(0.031) | 0.125\*\*\*(0.032) | 0.033(0.034) | 0.083\*\*\*(0.031) | 0.123\*\*\*(0.034) |
| Vuong Test (P-Value) | 4.80(0.000) | 4.56(0.000) | 5.24(0.000) | 4.83(0.000) | 4.59(0.000) | 5.14(0.000) |
| \*\*\*, \*\*, \* indicate significance at 1, 5 and 10% levels, respectively.Standard errors for marginal effects are estimated using the delta method. |

Table A3: Relationship between Anthrax and CBPP Vaccine and Livestock Disease Death – Marginal Effects from Zero-Inflated Poisson Regression

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | *Cattle Disease Death* | *Goat Disease Death* | *Sheep Disease Death* | *Cattle Disease Death* | *Goat Disease Death* | *Sheep Disease Death* |
| *Anthrax Vaccine* | 0.911(0.776) | -5.63\*\*\*(1.51) | -4.17\*\*\*(1.53) | - | - | - |
| *CBPP Vaccine* | - | - | - | -1.08\*\*(0.517) | -0.519(0.515) | -0.659(0.898) |
| *Cattle* | 0.913\*\*\*(0.111) | -0.084(0.084) | 0.385\*\*\*(0.108) | 0.923\*\*\*(0.112) | -0.022(0.085) | 0.414\*\*\*(0.109) |
| *Sheep* | 0.006(0.087) | 0.191\*\*\*(0.066) | 0.648\*\*\*(0.100) | 0.043(0.088) | 0.217\*\*\*(0.066) | 0.653\*\*\*(0.101) |
| *Goats* | -0.226\*\*(0.096) | 0.797\*\*\*(0.084) | 0.020(0.096) | -0.237\*\*(0.096) | 0.783\*\*\*(0.084) | 0.015(0.096) |
| *Transhumance Distance* | 0.117\*(0.069) | 0.025(0.054) | -0.186(0.671) | 0.111(0.070) | 0.009(0.054) | -0.196\*\*\*(0.066) |
| *Grazing Time* | 0.034(0.092) | 0.213\*\*\*(0.070) | 0.066(0.091) | 0.038(0.093) | 0.211\*\*\*(0.070) | 0.071(0.091) |
| *Watering Time* | 0.031(0.095) | -0.030(0.071) | -0.265\*\*\*(0.091) | 0.017(0.095) | -0.036(0.070) | -0.267\*\*\*(0.091) |
| *Sub-Village Disease Death* | 0.036(0.033) | 0.088\*\*\*(0.030) | 0.114\*\*\*(0.034) | 0.033(0.037) | 0.081\*\*\*(0.030) | 0.116\*\*\*(0.033) |
| \*\*\*, \*\*, \* indicate significance at 1, 5 and 10% levels, respectively.Standard errors for marginal effects are estimated using the delta method. |

Table A4: The Effect of Vaccinations on Livestock Abortions – Marginal Effects from Zero-Inflated Poisson Regression

|  |  |  |  |
| --- | --- | --- | --- |
|  | Cattle Abortions | Goat Abortions | Sheep Abortions |
| Vaccinationsa | 0.835\*\*(0.41) | 1.65\*\*(0.758) | 0.413(0.808) |
| Cattle | 0.234(0.185) | 0.081(0.123) | 0.089(0.149) |
| Sheep  | -0.091(0.143) | -0.008(0.093) | 0.952\*\*\*(0.142) |
| Goats | 0.425\*\*(0.177) | 0.423\*\*\*(0.118) | -0.249\*(0.129) |
| Transhumance Distance  | 0.204\*(0.113) | -0.002(0.076) | -0.171\*(0.088) |
| Grazing Time | -0.010(0.159) | 0.170\*(0.103) | 0.177(0.126) |
| Watering Time | 0.269\*(0.162) | 0.315\*\*\*(0.106) | 0.240\*(0.122) |
| Sub-Village Abortions | 0.173\*(0.089) | 0.108\*(0.056) | 0.133\*\*\*(0.036) |
| Vuong Test (P-Value) | 2.91(0.001) | 3.95(0.000) | 3.96(0.000) |
| aPredicted values from a first-stage regression of *Vaccinations*. \*\*\*, \*\*, \* indicate significance at 1, 5 and 10% levels, respectively.Standard errors for marginal effects are estimated via delta method. |

Table A5: Relationship between Herd Introductions and Livestock Disease Death – Marginal Effects from Negative Binomial Regression without Using IV for Introductions

|  |  |  |  |
| --- | --- | --- | --- |
|  | *Cattle Disease Death* | *Sheep Disease Death* | *Goat Disease Death* |
| *Cattle Introductions* | -0.002(0.002) | - | - |
| *Sheep Introductions* | - | -0.023(0.019) | - |
| *Goat Introductions* | - | - | -0.167(0.115) |
| *Cattle* | 0.735\*\*\*(0.156) | 0.001(0.001) | 0.008(0.010) |
| *Sheep*  | 0.399\*\*(0.199) | 0.275\*(0.143) | 0.740\*\*\*(0.141) |
| *Goats* | 0.378(0.256) | 0.508\*\*\*(0.153) | 0.038(0.094) |
| *Transhumance Distance*  | 0.007(0.009) | 0.003(0.008) | 0.002(0.007) |
| *Watering Time* | -0.162(0.183) | 0.108(0.140) | 0.067(0.091) |
| *Sub-Village Disease Death* | 0.116(0.651) | -0.338(0.569) | 0.331(0.577) |
| Likelihood Ratio Test Statistic (P-Value) | 40.6(0.000) | 3297.5(0.000) | 823.4(0.000) |
| \*\*\*, \*\*, \* indicate significance at 1, 5 and 10% levels, respectively.Standard errors for marginal effects are estimated using the delta method.  |

Table A6: Relationship between Herd Introductions and Livestock Abortions – Marginal Effects from Negative Binomial Regression without Using IV for Introductions

|  |  |  |  |
| --- | --- | --- | --- |
|  | *Cattle Abortions* | *Sheep Abortions* | *Goat Abortions* |
| *Cattle Introductions* | -0.032\*\*\*(0.006) | - | - |
| *Sheep Introductions* | - | 0.038(0.127) | - |
| *Goat Introductions* | - | - | -0.004(0.115) |
| *Cattle* | 0.671(1.01) | 0.009(0.009) | -0.008(0.010) |
| *Sheep*  | 0.041(0.027) | 0.143(0.160) | 0.008(0.012) |
| *Goats* | 0.015(0.032) | 0.616\*\*\*(0.180) | 0.018(0.094) |
| *Transhumance Distance*  | -0.004\*\*(0.001) | -0.004(0.008) | -0.002\*(0.0007) |
| *Watering Time* | 0.068\*\*(0.028) | 0.179(0.152) | 0.040\*\*\*(0.012) |
| *Sub-Village Abortions* | 0.091\*\*\*(0.016) | 0.192\*\*\*(0.049) | 0.099\*\*\*(0.031) |
| Likelihood Ratio Test Statistic (P-Value) | 561.7(0.000) | 298.5(0.000) | 784.1(0.000) |
| \*\*\*, \*\*, \* indicate significance at 1, 5 and 10% levels, respectively.Standard errors for marginal effects are estimated via delta method.  |