Modelling the initial spread of foot-and-mouth disease through animal movements.

ELECTRONIC APPENDIX

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Further figures related to main text.

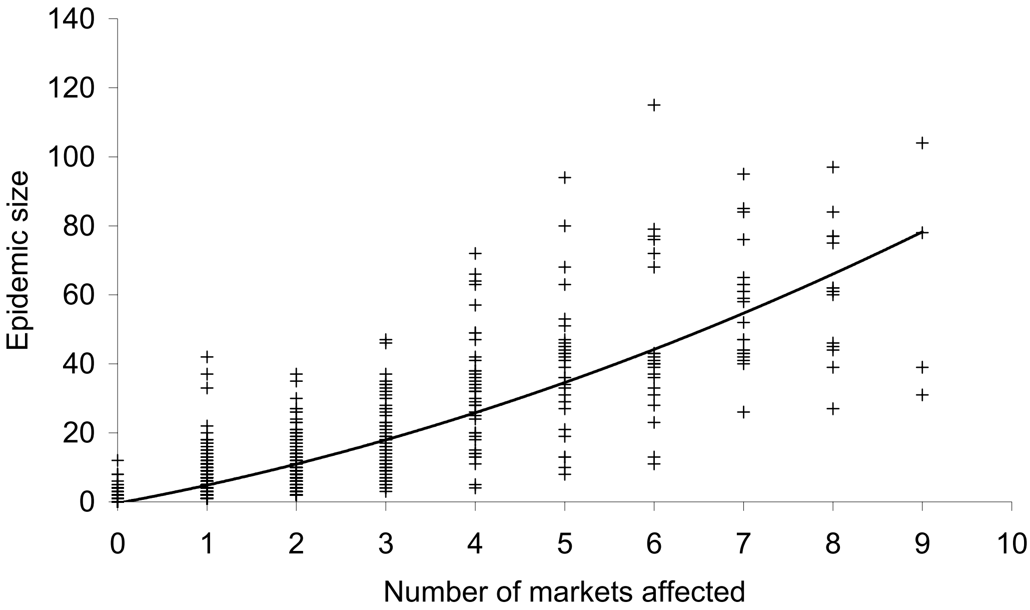


Figure A1. Total epidemic size *versus* number of markets affected for 1600 individual epidemic simulations with single index cases. A quadratic line of best fit is shown. Simulations are for spread through sheep movements only at the 2004 peak in sheep trading.

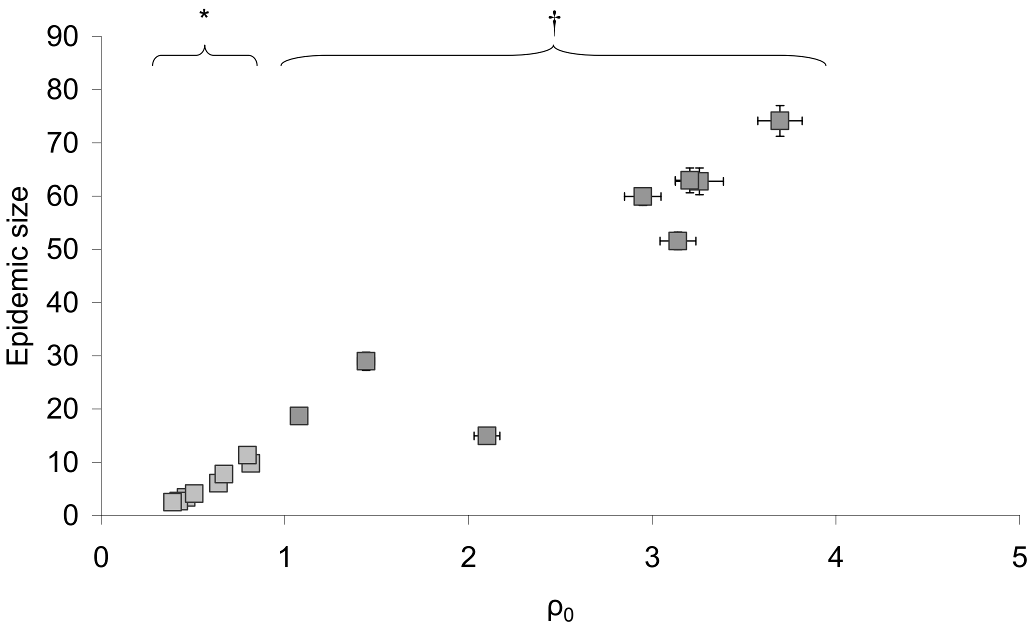


Figure A2. Total epidemic size (y-axis) *versus* ρ_0 measured across the seeds at the at the 2004 peak in sheep trading. Combined results from Figs 5a and b. * sheep movements. † full model.

A1. Spatial statistics.

The spatial distribution and clustering of risk through ρ_0 can be determined from its experimental semivariogram (Bailey & Gatrell, 1995). For each possible pair of holdings *i* and *j* with known coordinates s_i and s_j, the distance between them $h_{ij} = \|s_i - s_j\|$ and the difference in their values for ρ_0, $\delta\rho_{0ij} = \rho_{0i} - \rho_{0j}$, were calculated. Holdings with $\rho_0 = 0$ were omitted. The experimental semivariogram of $\delta\rho_0$ was then calculated using bin sizes of 1 km for *h*:

$$\gamma^*(h) = \frac{1}{2n}\sum \delta\rho_0^{\;2}$$

Should there be spatial clustering of ρ_0, then γ^* would increase with distance *h* and reach an asymptote *C* or 'sill'. Figure A3 shows the experimental semivariogram for ρ_0 for all movements data at the autumn peak in sheep trading. Even at the lowest distances, no sill can be seen; ρ_0 is essentially homogeneous, with no local clustering. At distances above 400 km, the semivariogram model becomes inappropriate due to geographical limitations. The range of influence *a* at which the sill is reached can be obtained by fitting a spherical model:

$$\begin{aligned} \gamma^*(h) &= C\left(\tfrac{3h}{2a} - \tfrac{h^3}{2a^3}\right) & h \le a \\ &= C & h \ge a \end{aligned}.$$

Fitting the spherical model by least-squares to the experimental semivariogram found a range of influence of less than 2 km, suggesting that ρ_0 has no local structure. The large variation in ρ_0 within communities is shown in Fig. A4.

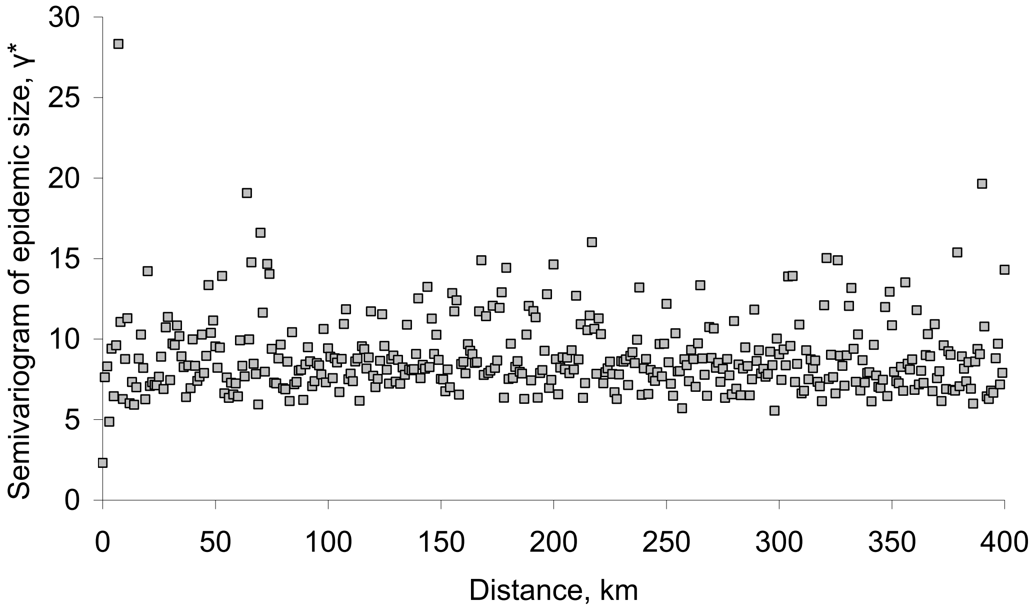


Figure A3. The empirical semivariogram γ^* of ρ_0 versus distance between holdings (km) at the autumn 2004 peak in sheep trading, using all movements data.

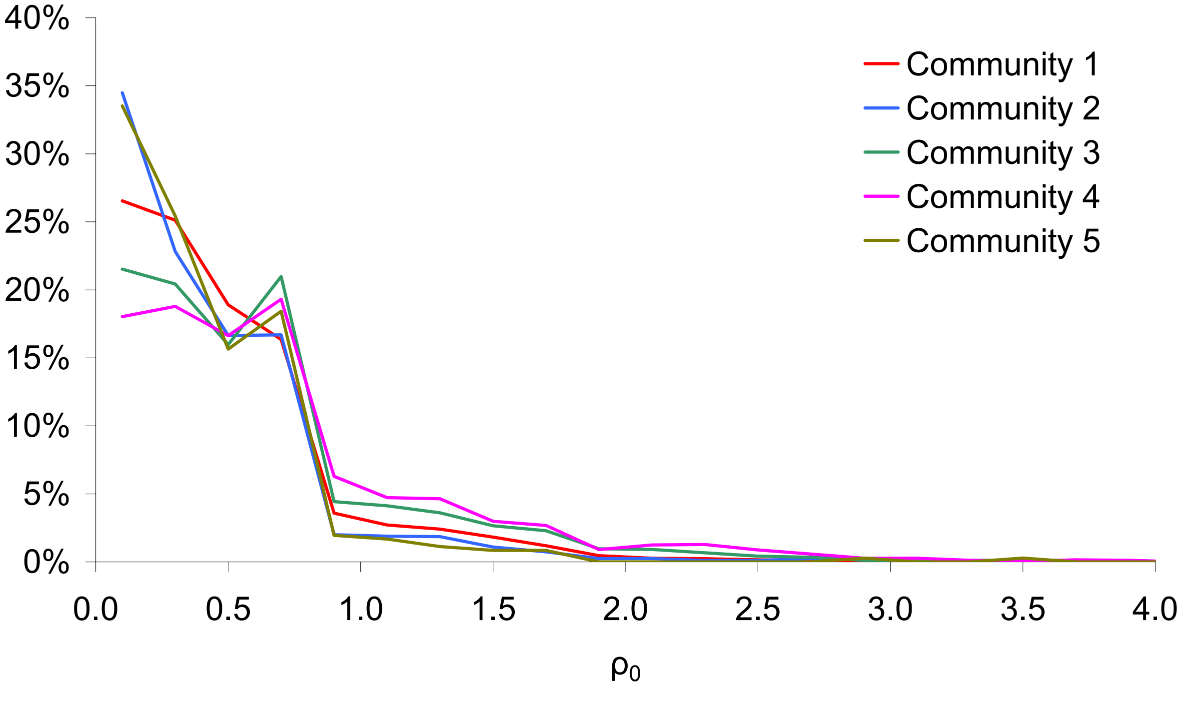


Figure A4. Histograms of ρ_0 values as in Fig. A3, according to community. Zero values have been omitted.

A2. Parameter sensitivity.

The key model parameters in these simulations that must be inferred from data are the three transmission probabilities μ_{m_sheep}, μ_{m_other} and μ_{sheep}, and the rate β, the effects of varying which are explored in Fig. A5. Epidemic size tends towards an asymptote for large μ, as for large batches, a relatively small value for μ is sufficient for most batches to become infectious ($m \rightarrow 1$) (The distributions of batch sizes are shown in Fig. A6). However, close to the default values described in § 2.3, epidemic size is proportional to the values of μ used, even for quite large departures from the default values. Epidemic size is less sensitive to the value of β used, with a low slope of epidemic size *versus* β. As was seen earlier, local spread has little effect on the geographic spread of disease (Table 1; Figure 5).

Setting the three parameters μ to one gives a 'worst-case' scenario, where all movements are potentially infectious and disease spreads through the whole network. In this case, epidemic size for sheep movements only was 590, and for the full model, 2100.

The temporal and geographical (or rather, community) patterns of epidemic sizes are robust when the parameters μ are varied around their default values, as shown for seasonal epidemics in Figure A7, and for epidemics seeded in different communities in Figure A8. Figure A9 suggests that when adjusting the two parameters μ_{m_sheep} and μ_{sheep} simultaneously, the effects are multiplicative (as seen by the additive effects on the log-scale plot). Similarly, no interaction between μ_{sheep} and μ_{m_other} was seen (Figure A10).

All simulations discussed above used a fixed epidemic period of 28 days. Considering other lengths, epidemic size shows exponential growth, as shown in Fig A11. Fitting an exponential curve to these data fitted well and gave a doubling time for epidemic size of 6·4 days. Thus, early detection of the epidemic has the greatest effect in reducing its size.

References

Bailey, T.C. & Gatrell, A.C. 1995. *Interactive Spatial Data Analysis*. Longman, Harlow, UK.

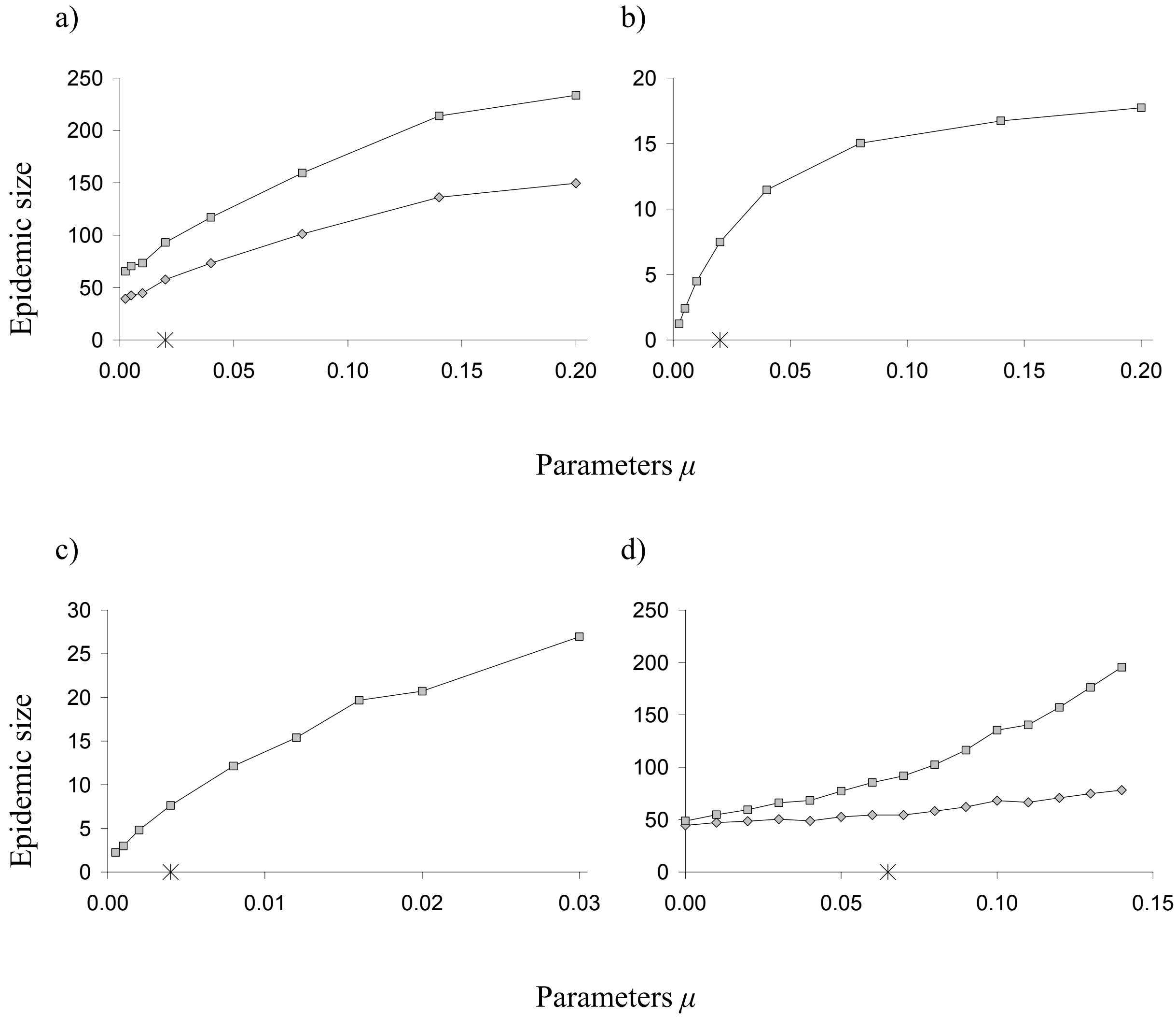
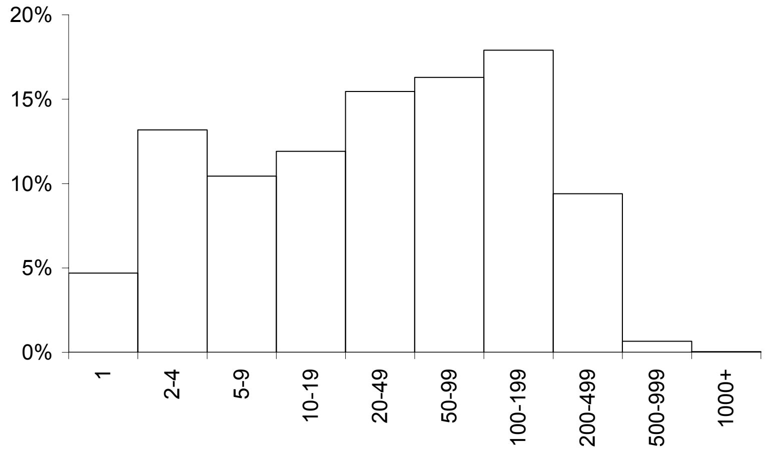


Figure A5. Parameter sensitivity at the at the 2004 peak in sheep trading. Number of cases per seed (□) and those caused by animal movements only (◇) *versus* a) μ_{m_other} (full model), b) μ_{sheep} (sheep movements only), c) μ_{m_sheep} (sheep movements only), and d) β (full model). Default parameter values are marked by *. Means of 2000 seeds in 400 simulations.

a)



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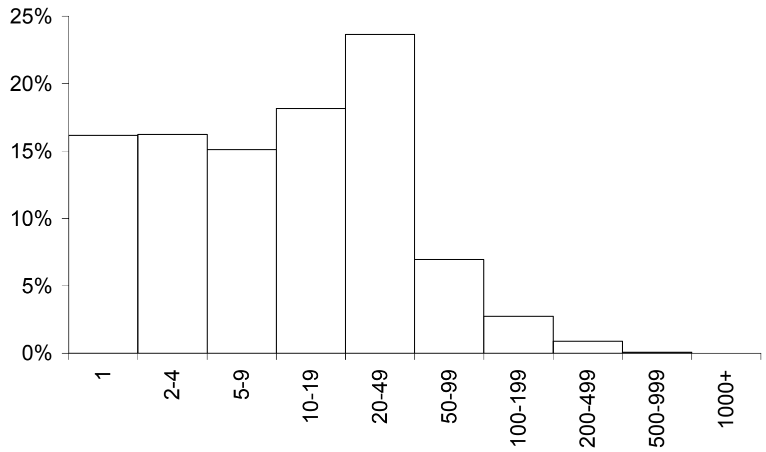

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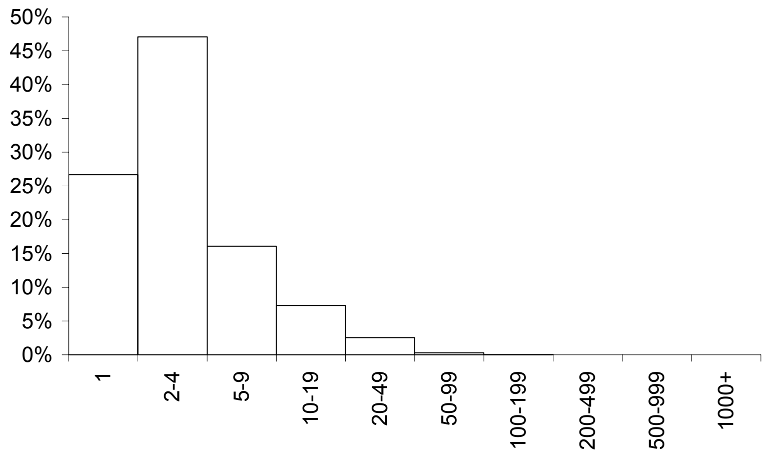
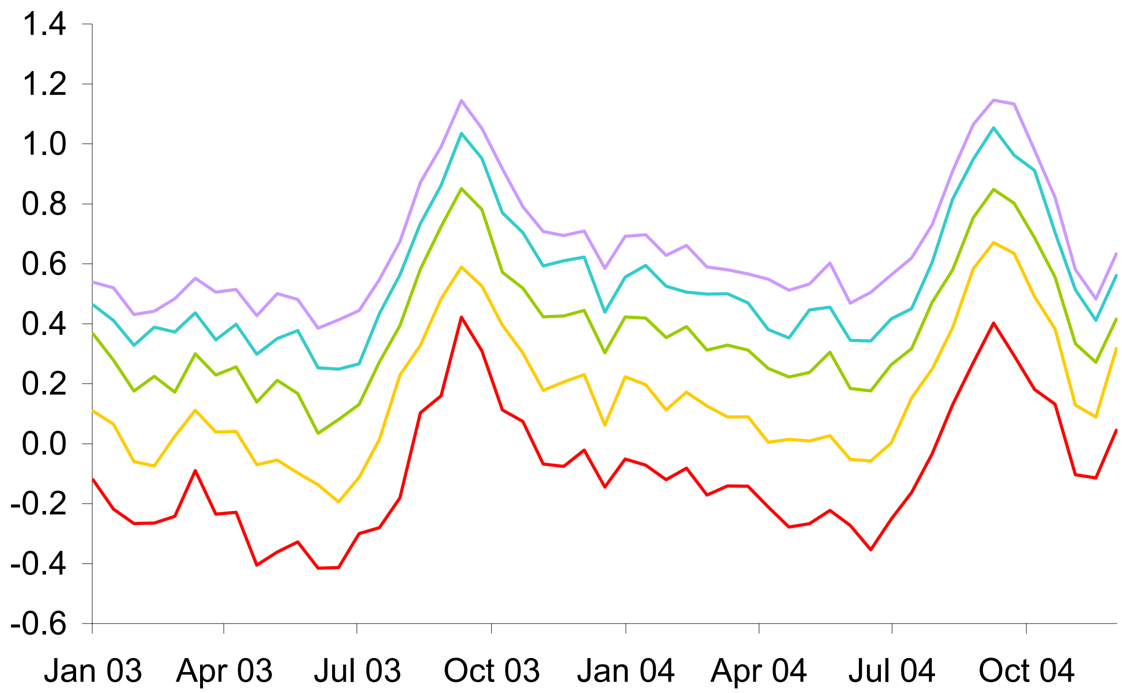


Figure A6. Distributions of batch sizes for all movement data for 2003 and 2004. a) pigs; b) sheep; c) cattle.

a)



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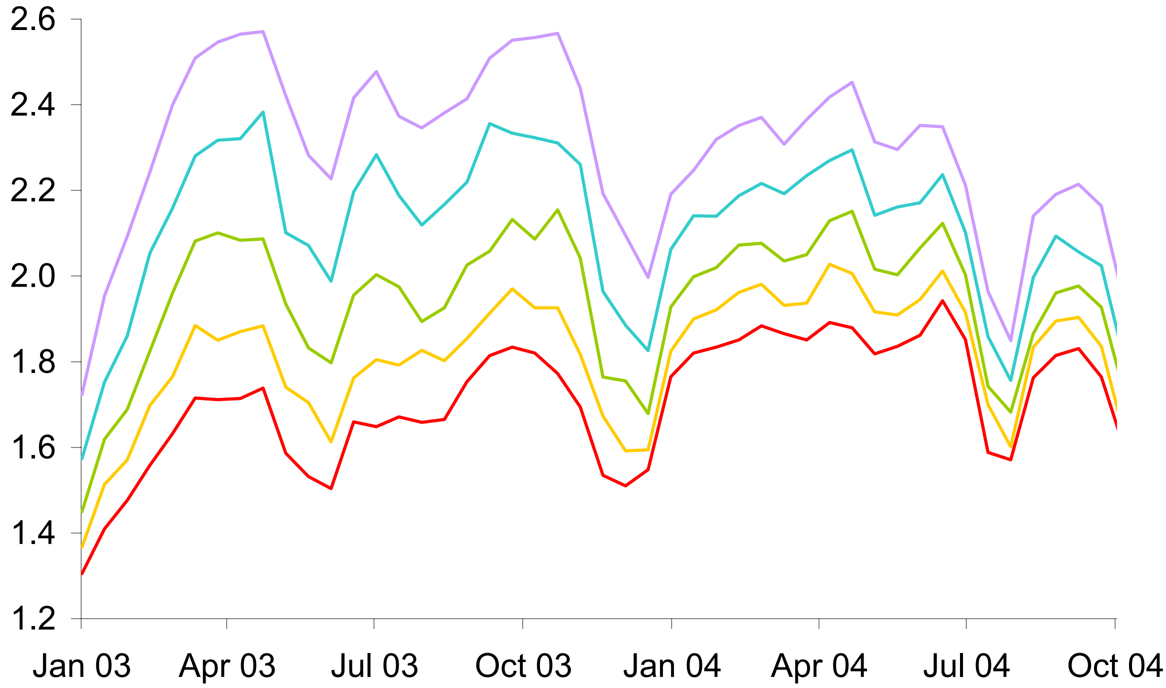

Figure A7. Parameter sensitivity. Log10 of the number of cases per seed (means of 2000 seeds in 400 simulations). a) transmission through sheep movements only, varying μ_{sheep}; b) full model, varying μ_{m_other}. μ_{sheep} and μ_{m_other} = 0·005 (red), 0·01 (orange), 0·02 (green), 0·04 (blue), and 0·08 (violet).

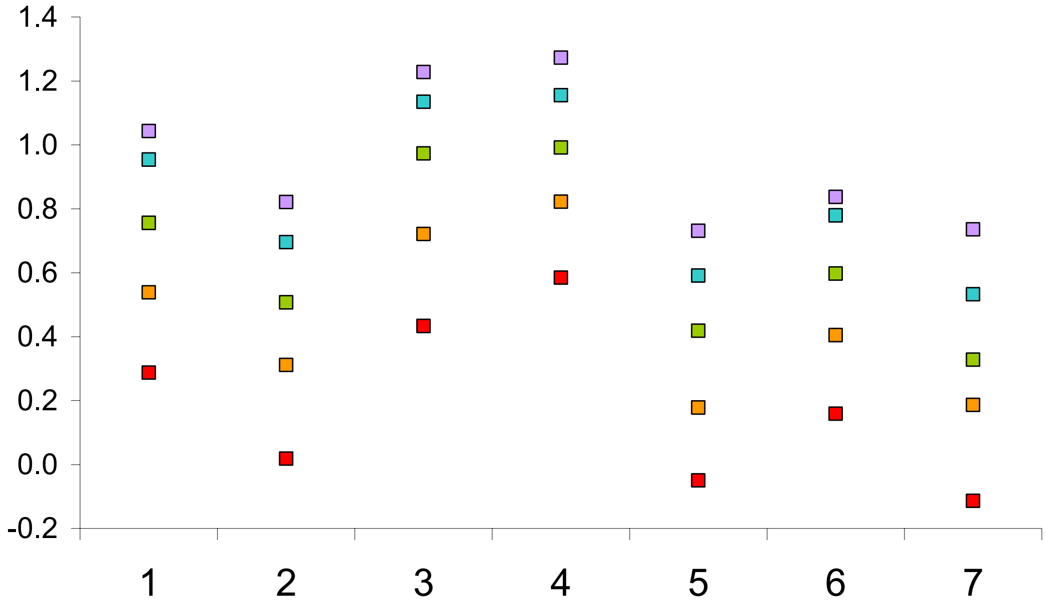

Figure A8. Parameter sensitivity. Log10 of the number of cases per seed for transmission through sheep movements only for different values of μ_{sheep}. μ_{sheep} = 0·005 (red), 0·01 (orange), 0·02 (green), 0·04 (blue), and 0·08 (violet). Epidemics were seeded at the 2004 peak in sheep trading in the numbered community. Means of 2000 seeds in 400 simulations.

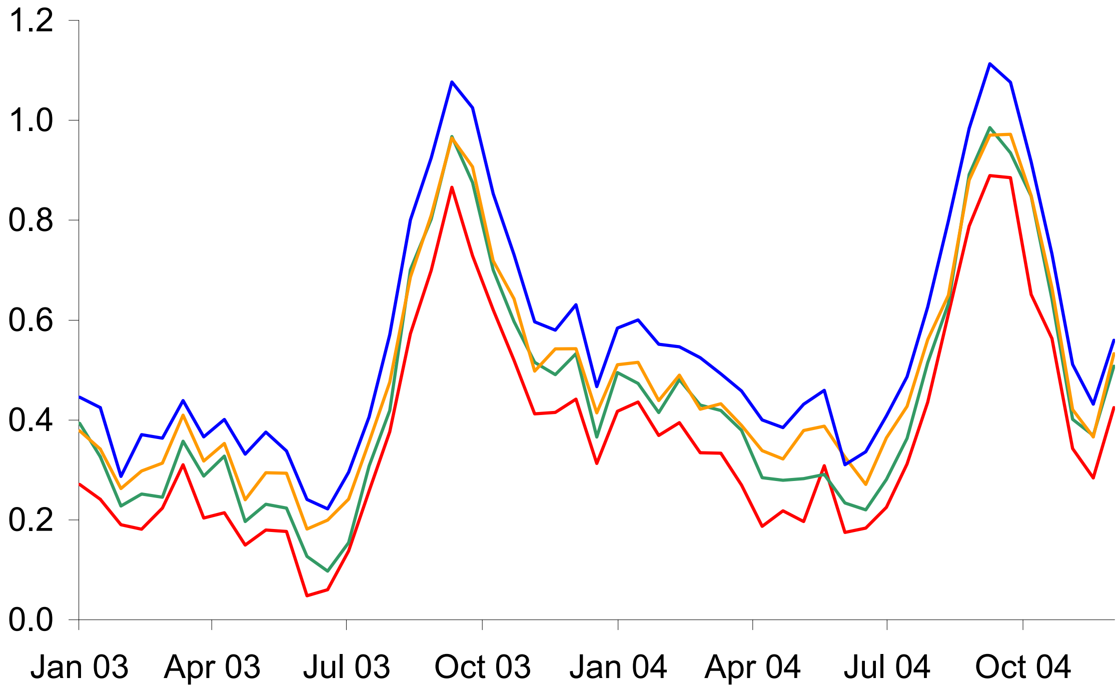

Figure A9. Parameter sensitivity. Log10 of the number of cases per seed for transmission through sheep movements only for different values of μ_{sheep} and μ_{m_sheep}. μ_{sheep} = 0·02 (red, green) and 0·03 (orange, blue); μ_{m_sheep} = 0·004 (red, orange) and 0·006 (green, blue). Means of 2000 seeds in 400 simulations.

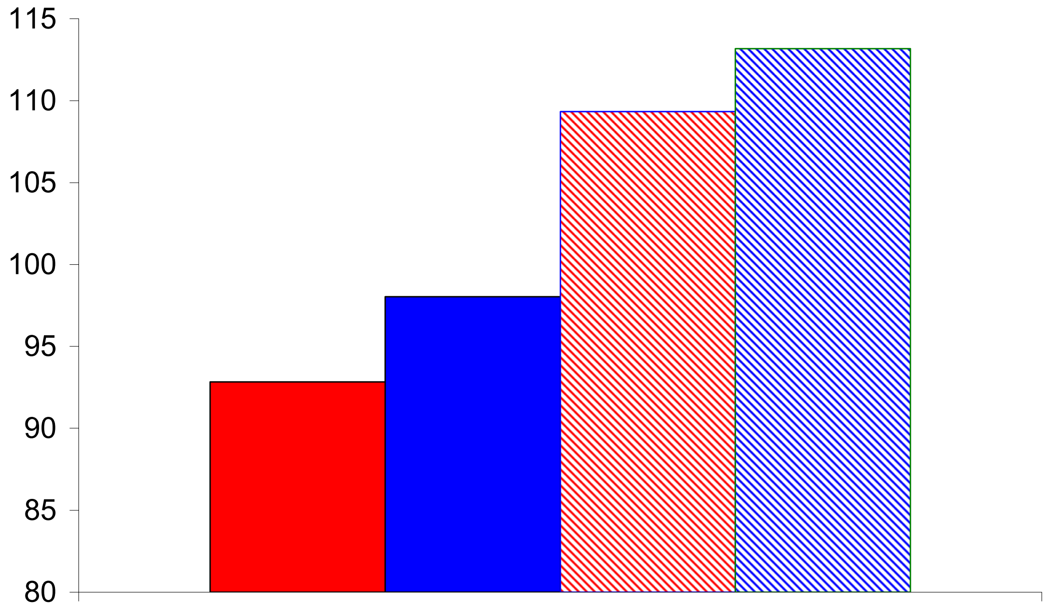

Figure A10. Parameter sensitivity. Number of cases per seed for transmission through sheep movements only for different values of μ_{m_other} and μ_{sheep}. Epidemics were seeded at the 2004 peak in sheep trading in the numbered community. Means of 2000 seeds in 400 simulations. Red: μ_{sheep} = 0·02; blue: μ_{sheep} = 0·03; solid: μ_{m_other} = 0·02; striped: μ_{m_other} = 0·03.

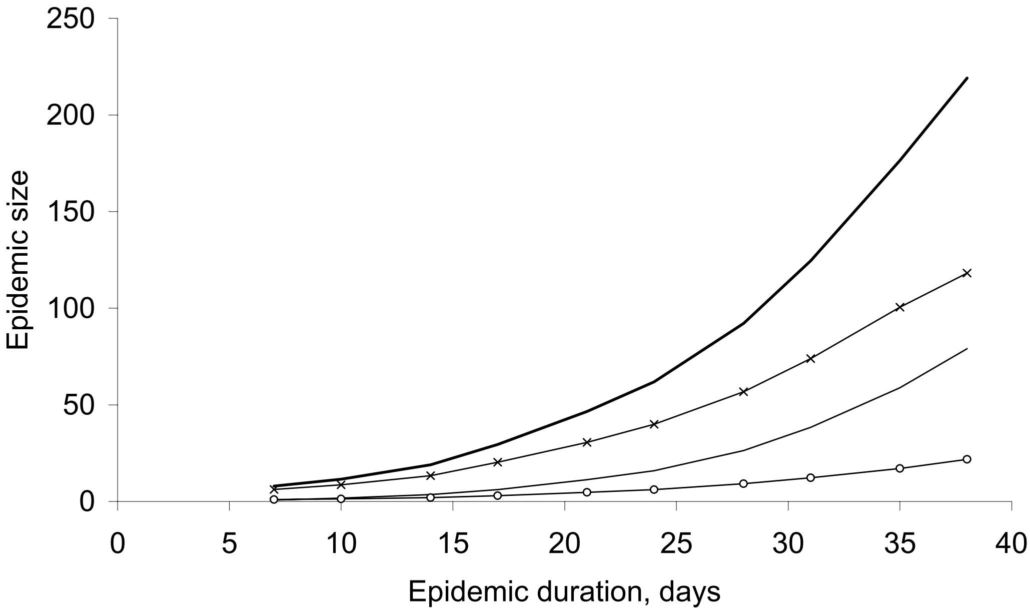

Figure A11. Parameter sensitivity at the at the 2004 peak in sheep trading. Number of cases per seed *versus* epidemic length (days). Full model (total infections, black solid line; composed of infections caused by movement, ×; infections caused by local spread, no symbol; and infections from SOAs, ○). Means of 2000 seeds in 400 simulations.