A Cost-Effectiveness Study of Animal disease Eradication Strategies: Foot-and-Mouth Disease in Ireland

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The primary focus of this paper is to evaluate the cost-effectiveness of alternative control strategies for a number of simulated outbreaks of Foot-and-Mouth disease (FMD) in Ireland, examining for the first time, the potential role of emergency vaccination in the country. This analysis is ex ante – looking forward rather than back at past performance, and considering costs and benefits under possible scenarios for FMD control policy and trade opportunities.

FMD is one of the list A diseases (most infectious and economically damaging) of the OIE (Office international des épizooties - World Organisation for Animal Health). Following the 2001 Irish outbreak, after a lapse of sixty years, the vulnerability of our farm and non-farm economy to the threat of exotic livestock diseases was exposed. There has been much study of the economic consequences of the outbreak;[1] however little emphasis has been placed on an evaluation of control and eradication strategies.

There were a number of motivating factors in undertaking such a study, not least the importance of agricultural trade to Ireland,[2] and the increasing threat of transboundary animal diseases due to globalisation, wider market integration and increased animal movement. In the current climate of moving towards greater agricultural trade liberalisation, given the huge movement of animals, future outbreaks are not just likely but

[1] O'Toole, Matthews & Mulvey (2001), OIE/FAO (2001), EU (2002), INDECON (2002)
[2] Irish Exports of Agricultural and Agri-food produce amounted to €6,736m in 2002 (Irish Central Statistics Office)

inevitable; therefore it is vital that the hazards and control of another epidemic be confronted and an evaluation of alternative control strategies be undertaken. Ireland has lost its isolated position on the world scale and can no longer automatically claim its island status and freedom from disease. The question of balancing the risk of epidemic and the benefit of animal movement arises.

"The FMD crisis of 2001 was a most significant event, from a variety of perspectives. The threat posed by the disease held open the prospect of real and substantial economic damage, not alone in agriculture but across a number of sectors, with attendant social consequences throughout the country".

(Joe Walsh TD, Minister for Agriculture and Food)

The speed at which FMD of the Pan-Asia O type spread within the EU in 2001, was unprecedented in the history of FMD, as was the scale of the outbreaks. 6.5m animals were slaughtered in the UK, 285,000 in the Netherlands, 63,000 in France and 53,000 in Ireland. The outbreak had serious repercussions for Irish farming and food industries, the haulage sector and other suppliers of services to farming, and tourism sectors. Economic damage was however, minimised due to the speed and effectiveness of the control strategy put in place. The INDECON report on the single Irish outbreak found that it cost the Exchequer €107m and that had the efforts to prevent further spread not been successful, the adverse impact on Ireland's GDP could have reached €5.6 billion (a decrease of 6%), with job losses of up to 12,000 and the potential devastation to 20 million susceptible livestock (INDECON, 2002). Tourism was the main loser; losses were estimated at €210m in first six months of year. The agri-food sector actually benefited from the outbreak by around €107m due to the impact of the UK outbreak, which resulted in higher than expected export prices for livestock exports, particularly sheep meat.

Many lessons have been learned since 2001. EU Member States are now required to have improved contingency plans in place, for use in the event of another FMD outbreak. The economic costs of a potential future outbreak could well prove much higher and it is therefore important that an animal health strategy be put in place that minimises the likelihood and extent of future outbreaks. The new EU Directive (2003/85/EC) on FMD control permits the use of emergency vaccination as part of an FMD control strategy. The slaughter of infected animals and "dangerous contacts" (susceptible animals on epidemiologically linked holdings) remains the principal tool for tackling an outbreak, but the potential use of vaccination as an adjunct to the basic culling policy is now being considered. As such, each Member State is obliged to prepare a cost-benefit analysis of alternative control strategies. Using an integrated approach, combining an epidemiological model and an economic model, alternative control strategies will be compared here during hypothetical outbreaks using a computer-simulation model, and their cost-effectiveness assessed. The study will provide outputs in terms of a range of epidemiological, economic and resource requirement measures under a wide range of different scenarios for each of the alternative control strategies.

Two epidemiological models are used, both using different methodology, and their results compared. The EMPRES Information System (EMPRES-*i*) Transboundary Animal Disease (TAD) Simulator (Durand and Gerbier: 2001, FAO) uses Markov Chain methodology and the Spreadmodel (Schoenbaum: 2000, USDA) is based on the Reed-Frost equation. Both are state-transition models with two components; states and transition probabilities. They are based on a probabilistic or stochastic process; a model of sequences of events where the probability of an event occurring depends upon the fact that a preceding event occurred.[3] The population is considered in terms of possible 'states' that herds could be in.[4] Transition probabilities represent the probability that the herd will move to state *j* in the next period when presently in state *i*. The key aspect of the analysis is the set of probabilities of herds moving from one state to another, summarised in the form of a transition probability matrix. During any time period, depending on various factors, a herd has a probability of remaining in that state or moving to another (a transition). Probabilities depend on production and environmental conditions and control strategies adopted.

Probability of transition from susceptible to infectious (p_i) in a particular week (j) is a function of fraction of infectious farms in previous week ($fi_{(j-1)}$) and the dissemination rate (dr):[5]

$$\mathbf{P}i_j = 1 - \exp^{[-dr\,(j-1)\,\times\, fi\,(j-1)]}$$

The Epidemiological models trace the path of disease spread and the economic model (a Computable General Equilibrium (CGE) model) GTAP (Global Trade Analysis Project)) will outline the direct and indirect costs associated and evaluate the supply and demand effects (knock-on effects) for the economy. The objective is to calculate the economically optimal control strategy for each scenario with the results being used to decide on control measures during possible FMD epidemics in the future.

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[3] Miller 1979

[4] Susceptible to disease, latent (infected but not infectious to other herds), infected and capable of spreading disease, immune after recovery or vaccination or dead or destocked as a result of disease.

[5] Dissemination rate depends on factors such as herd density and movement (gradually decreases with movement controls etc.) and the fraction susceptible, immune or removed depends on control strategy in question.

Markov Chain and Reed-Frost models are both chain binomial models. In these models, new cases of disease occur in a series of stages (Hurd and Kaneene, 1993). The number of cases at any stage will have a binomial distribution depending on the numbers of infectious and susceptible individuals at the previous stage. These models are fully stochastic, discrete-time and continuous-entity. They assume that the period of infectiousness is relatively short and of constant duration and that there is a constant probability of infection in each serial interval. Markov models or chains are mathematically equivalent to chain binomial models with a finite state and discrete-time parameter (Ekboir, 1999). Reed-Frost models are a special case of the chain binomial where the expected number of cases for the epidemic can be derived deterministically from the recursive formula: $C_{t+1} = S\,(1\text{-}q^{Ct})$ where C is the number of cases at time t, S is the number of susceptible individuals, $q = 1 - p$, and p is the probability of effective contact (Fine, 1977).

The economic impact of an outbreak is outlined using CGE analysis. This is an analytical approach looking at the economy as a complete system of interdependent components (industries, households, investors, government, importers, and exporters). The GTAP model is a multi-regional, static, applied general equilibrium model based in neo-classical microeconomic theory with international trade described by an Armington (1969) specification (products differentiated by country of origin). Perfect competition is assumed in all sectors and all regions produce a full complement of commodities. Importantly, economic shocks on one component create ripple effects throughout the system (Anderson & Nielsen, 2000:8).

If an FMD control programme were initiated potential costs would have four components:

Direct costs of control strategies are relatively easily identified and can be quantified as they can be equated with certain resource expenditures incurred by producers of livestock and by relevant government authorities.

(i) *Eradication costs* include cost of slaughter, compensation for destroyed animals and materials, cleaning and disinfection of infected premises, and quarantine enforcement.

(ii) *Production losses* arise from lost production in depopulated premises and industries linked to the livestock sector. Although FMD has a very high mortality rate among young animals, it usually only reduces milk and beef production in older animals. Stamping out and depopulation.

Indirect or consequential costs are more difficult to identify and measure since they theoretically extend to all sectors of the economy:

(iii) *Trade restrictions:* Revenue forgone as a result of denied access to markets. Access to markets (if any) restricted to lower price markets (the international beef market is segmented into FMD-free and FMD endemic markets with the price difference between the two segments for meat of similar quality being as high as 50%).

(iv) *Knock-on effects for the non-agricultural sector: e.g. d*ownstream effects for tourism and other sectors as a result of movement restrictions etc.

Control and eradication costs would depend primarily on the scale and duration of the outbreak. Expected losses are defined as the probability of an outbreak multiplied by the estimated cost. Estimating the probability of an occurrence is difficult; however the rapid spread of a pandemic strain of FMD in 2001 clearly demonstrates the ability of the virus to infiltrate a wide geographical area. Factors crucial in determining the magnitude of the economic impact include: trading partner reactions, rate of disease spread, containment, eradication and multiplier effects.

Three issues are to be examined here, using GTAP:

(1) *The impact of a reduction in the number of animals*: The impact of the reduction in the number of animals can be thought of as a direct cost associated with a particular control strategy; with production losses in depopulated premises and industries linked to the livestock sector. So for example, GTAP can be used here in a base simulation to estimate what happens with a decrease of a certain level of cattle output i.e. what happens with x% less availability? Cattle losses may be seen as being a small component relative to indirect costs but there are a number of issues that need to be taken into account. Knock-on price effects arising from the slaughter of some animals will also be important (offsetting compensatory effects – price of remaining cattle and substitutes will rise). All of these issues can be examined in a CGE framework.

(2) *The impact of movement/trade restrictions:* Again, there are a number of issues at play here. Revenue forgone as a result of denied access to markets is important. If access is limited to lower price markets, subsequent impacts should also be assessed. Very simply, there are three types of costs for the agricultural sector associated with

being excluded from markets; the extra costs involved in keeping stock on farms, the extra costs associated with the treatment (heat or otherwise) of produce before it can be sold/exported and the losses involved in selling produce in lower-price (e.g. FMD endemic) markets. Is there a gap between the extra costs involved in keeping the animals on farms longer than usual and compensation received? The type of scenario envisaged is also important i.e. is the outbreak Europe-wide, is regionalisation in place, is there large-scale diversion of trade etc?

(3) *Knock-on (indirect) effects* for the economy: Major losses were felt by the tourism sector in the aftermath of the 2001 outbreak. Data is available on visitor numbers during that period and this can be modified for the simulations undertaken here. Downstream effects for other sectors can also be estimated.

The use of a CGE model to estimate the economic costs of a number of simulated outbreaks for the Irish case is an innovative undertaking and should prove useful in the event of future outbreaks. It is envisaged that a number of different scenarios be undertaken and issues such as whether or not the Irish outbreak is part of a wider European phenomenon will be important. CGE analysis is potentially a way of calculating subsequent trade effects and taking account of similar outbreaks in other countries. The impact on production, prices, trade patterns and national economic welfare, when Ireland adopts a particular control strategy can all be evaluated. The data on the economic impact will be collected for a simulation based solely on culling and one where the use of emergency vaccination is allowed in order to provide the basis for a cost-effectiveness comparison. The impact of changes in relative prices as a result of denied access to high price markets will prove interesting for a small, open economy like Ireland, heavily reliant on livestock trade. The economic effects for both the agricultural and other sectors (e.g. tourism) will be investigated for producers, consumers and government and should also prove useful for the policymaker. The question to be answered is whether targeted vaccination can shorten the duration of the epidemic, reduce its total costs and facilitate the return to disease free status as quickly as possible. The paper adds to the growing literature in the area of animal health economics and builds on some recently published papers on the strategic use of emergency vaccination in the event of an outbreak in France, the Netherlands, the UK and US.[6]

The role which emergency vaccination can play in an Irish context, in controlling an outbreak, alone or in conjunction with culling needs to be assessed but this must be done on economic grounds. A change in the OIE trade rules in May 2002, reducing the minimum period before a country can re-apply for full trade status when vaccination has been used, from twelve months to six, has aided the case for the use of emergency vaccination, as has experience gained in 2001 and a number of scientific advances made in relation to vaccination.

The implications of employing emergency vaccination in Ireland, a country heavily dependent on exports, should prove especially interesting, as will the assessment of the relaxation of OIE rules in this area and whether or not they are actually adhered to. In the Irish case a vaccination campaign would only be socially optimal if additional export losses associated with the delay of slaughtering the vaccinated animals were offset by the gains of reducing the duration of the epidemic. Any decision to employ emergency vaccination, as

[6] Durand & Mahul, 2000; James & Rushton, 2002; Tomassen et al, 2002; Schoenbaum & Disney, 2003.

part of a future control strategy would have to take account of the impact such a campaign would have on the trading environment.

I am currently carrying out simulations for the Irish case and although I had hoped to include results here this has not been possible due to some delays in getting access to data. The empirical analysis will however be completed very soon, the laborious task of compiling a comprehensive list of Irish specific parameter values for the epidemiological models is complete, work has been done on the economic model and therefore results are imminent.

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As the background paper has already outlined the relevance, motivation and objectives behind the research; below is a general proposal for the layout of the poster presentation.

"Animal diseases that cross borders need an immediate and effective regional or international response" (FAO/OIE) 1. Objectives 2. Materials & Methods 3. Table 	***Epidemiology and economics are separate scientific areas but are very much complementary when the goal is the efficient management of animal health.*** (FAO) **Epidemiological Model** ↓ **Economic Model** ↓ **Cost-Effectiveness Analysis**	 4. Figure 5. Summary of results 6. Conclusion ***In an increasingly inter-connected world, viruses, like people travel more easily.*** (The Economist 22/10/2005)

The above diagram gives an initial idea as to what the poster presentation will comprise. Firstly the objectives of the research and the motivation behind it will be outlined. An explanation of the approach taken will follow with some reference as to why certain regions were chosen and some detail on the regional variation in farm type and herd density. The differing shape of agricultural systems across the country is interesting and something that should be emphasised here. The four regions chosen for study are given in the table below:

Region	**No. of Farms**	**Area (hectares)**
Intensive dairying (South)	56,128	2,994,238
Marginal mixed (West)	35,263	1,537,812
Intensive fattening (Midlands)	19,699	1,159,547
Border and Northern Ireland	54,029	2,575,663

Source: Teagasc, Census of Agriculture (draft)

Cross-border co-operation (between the Republic of Ireland and Northern Ireland) in the event of an outbreak is also important and is something which will also be dealt with here.

The second section will go on to examine methodology, the integration of the epidemiological and economic models and the intuition behind them both. The models will be explained in detail and the Markov Chain, Reed-Frost and CGE methodology described (as briefly discussed in the accompanying background paper).

An introduction to the area of veterinary and animal health economics and an insight into the general nature of the disease will follow. The epidemiology and policy context of FMD control is examined and the relevant legislation will then be outlined with the Animal

Health Code of the OIE and international trading rules summarised. With the increased integration of international markets it is important that policies be co-ordinated against infectious animal diseases like FMD. Economics-based decision criteria are crucial in establishing future guidelines in the area of animal disease risk management and control. Below is a basic categorisation of costs associated with an outbreak:

Costs associated with alternative control strategies

Direct expenditure on disease control

(Resource costs incurred by farmers and relevant public authorities – extra resources used in the control and ultimate eradication of the disease e.g. services, personnel, drugs, equipment)

- Animal deaths/lost production
- Slaughter and disposal
- Drugs/vaccine
- Cleaning and disinfection
- Quarantine restrictions
- Surveillance costs
- Other e.g. transportation
- Compensation costs

Indirect/induced effects

(Disruption to agriculture and other industries due to the chosen elimination strategy on dairy/livestock industries in the infected area etc.)

- Trade restrictions and change in the extent and value of imports by trading partners i.e. revenue forgone as a result of denied access to markets.
- Production losses outside of agriculture as a consequence of its control
- Additional costs to farmers – gap between compensation paid and true value?

Finally, some illustrative outbreak scenarios are simulated; including one where emergency vaccination is adopted as part of the control strategy and one where it is not. The results of the scenarios are then analysed, an overall evaluation of control strategies is given and the results of the empirical analysis clearly outlined.