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Optimal Livestock Disease Control Models and Their Possible Application to Thailand

by

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Optimal Livestock Disease Control Models and Their Possible Application to Thailand[1]

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Thomas D Murphy[2]

August, 1996

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'The overall goal of this project is to develop and evaluate the .necessary tools to provide decision-makers with reliable animal health information which is placed in context and analysed appropriately in both Thailand and Australia. This goal will be achieved by improving laboratory diagnostic procedures; undertaking research to obtain cost-effective population referenced data; integrating data sets using modern information management technology, namely a Geographical Information System (GIS); and providing a framework for the economic evaluation of the impact of animal diseases and their control.

A number of important diseases will be targeted in the project to test the systems being developed. In Thailand, the focus will be on smallholder livestock systems. In Australia, research will be directed at the northern beef industry as animal health information for this sector of livestock production is presently scarce.'

For more information on *Research Papers and Reports Animal Health Economics* write to Professor Clem Tisdell (c.tisdell@economics.uq.edu.au) or Dr Steve Harrison,(s.harrison@uq.edu.au) Department of Economics, University of Queensland, Brisbane, Australia, 4072.

OPTIMAL LIVESTOCK DISEASE CONTROL MODELS AND THEIR POSSIBLE APPLICATION TO THAILAND

ABSTRACT

There is an increasing focus on disease control programs in developing countries such as Thailand and a growing use of techniques of economic analysis to assist in optimal policy on disease- control. In Thailand, while national vaccination programs have been applied, maintenance of disease free zones in the south and central regions is becoming an increasingly important objective given recent changes in international trade protocol. While several economic assessment techniques can be applied to evaluate disease control programs (Murphy 1996b), this paper will provides a simple bio-economic model that integrates deterministic epidemiological modelling with economic optimising techniques. The model attempts to highlight important economic considerations in the optimal control of FMD within a zoning framework. However as outlined in Murphy (1996b), while this approach provides a useful conceptual framework for determining optimal economic conditions, it is limited in its direct application particularly to national control programs. It is in this framework that cost-benefit approaches, despite their inability to provide essentially optimal solutions, are better able to attribute values to such factors as shadow prices and incorporate the distributional welfare issues associated with national control programs.

Keywords: Foot and Mouth disease, Thailand, livestock disease,

JEL Classifications: Q160, I15

OPTIMAL LIVESTOCK DISEASE CONTROL MODELS AND THEIR POSSIBLE APPLICATION TO THAILAND

1. Introduction

There is an increasing focus on disease control programs in developing countries such as Thailand and a growing use of economic analysis techniques to assist in optimal policy on disease control. The prevalence of Foot and Mouth disease in Thailand has caused significant focus on strategies for its control given its serious impact on livestock such as cattle, buffalo and pigs. FMD is endemic in Thailand where the application of mass vaccination programs has encountered significant difficulties in achieving eradication of the disease. Both legal and illegal movement of livestock between regions and domestically in Thailand has been a major cause of these difficulties. This has hampered an ability to control the contact of susceptible stock with infected herds from other regions. Maintenance of disease-free zones in the south and central regions is becoming an increasingly important objective given recent changes in international trade protocol and the potential to secure higher priced disease-free export markets.

In terms of the disease dynamics represented in Murphy (1996b), the policy of disease-free zoning attempts to eliminate contact between *infectives* and *susceptibles* by establishing zoning procedures that essentially remove susceptibles from exposure to disease. The isolation is a control strategy that enables export of disease-free meat once official recognition is given by trading partners.

Application of a deterministic bio-economic model will be applied here in the context of establishing FMD free zones in Thailand. Even within its simplified framework, it can help identify important economic considerations in optimal control through isolation. First, however, in order to understand disease control, and to represent it mathematically within an economic framework, key factors in the epidemiology of FMD in Thailand will be outlined.

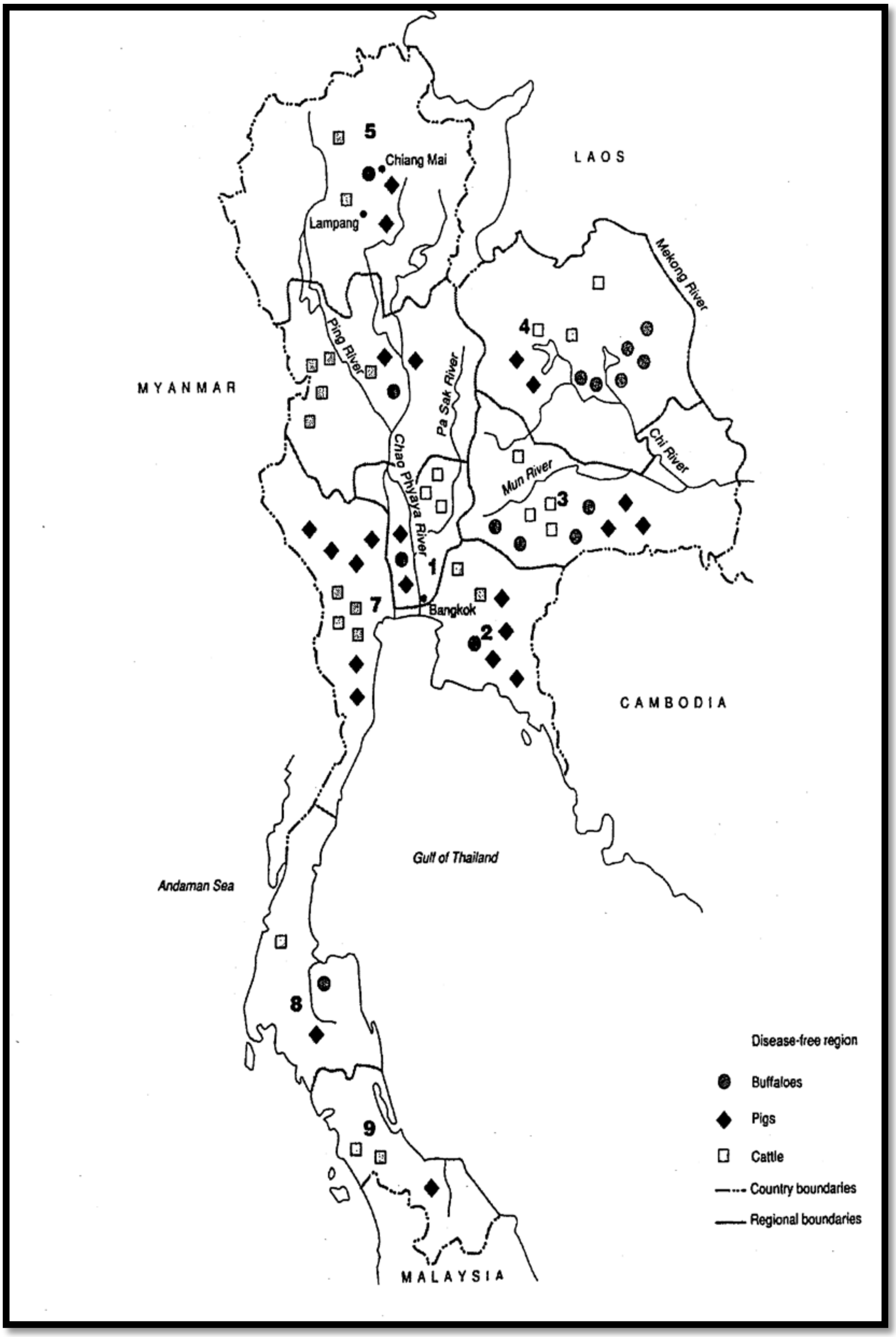
2. Epidemiological characteristics of Foot and Mouth disease in Thailand

Hanyanum (1993) outlines the key features of Foot and Mouth disease in Thailand in terms of susceptibility, infection, herd density and stock movements

1. *Susceptible animal*: The immune status of the animal is the most important host related factor in FMD epidemiology. Sufficient herd immunity acquired by exposure to the virus or by• vaccination, results in decreased virus circulation. Insufficient FMD vaccine, improper vaccination handling or poor vaccination program can result in insufficient immunity which facilitates spread of the disease (Hanyanum 1993 p. 191).

2. *Infectives*: FMD virus is disseminated from infected animals in lesions, exudated secretions, excretions and in droplets of the exhaled air. The virus remains infectious for extended periods in most livestock products: Transmission occurs by direct or indirect contact with infected animals or their excretion secretions or tissues. Aerosol transmission can also result in rapid spread of infection (Hanyanum 1993 p. 191).

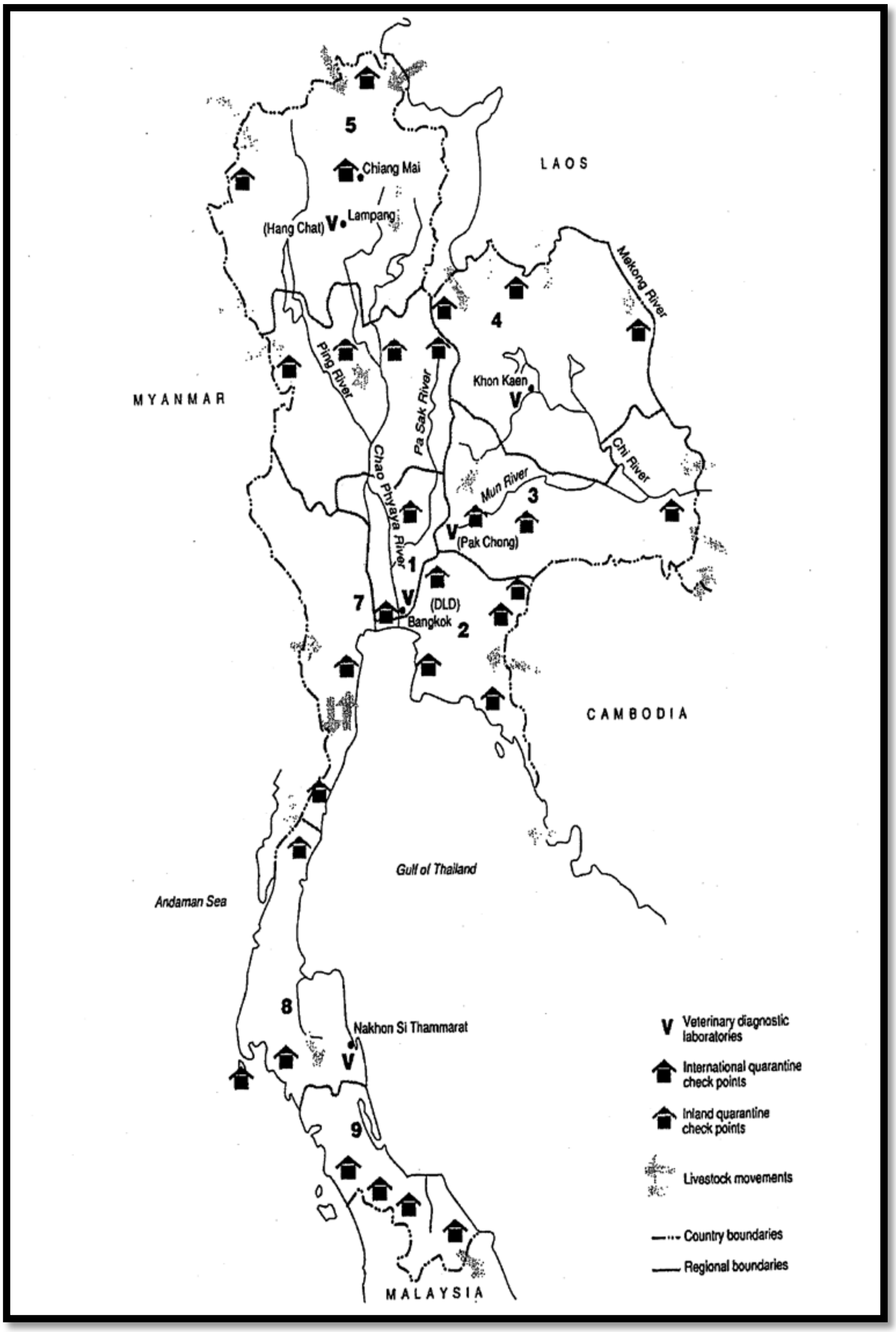
3. *Herd density* is also a significant factor in the spread of the disease due to close contact between animals. Higher density induces stress and affects the nutritional status of the animals resulting in increased susceptibility to the disease. When the density of animals is higher there is larger risk of disease spread. Due to the high density of cattle and buffalo in region 3 and 4 and cattle in region 5 and 6 (see Figure 1), most of the FMD outbreak were reported in these regions. As people in the southern regions prefer growing rubber or mining which offer higher incomes and are less time consuming than raising livestock, the population of livestock animals is much lower in this part of the country and as a result regions 8 and 9 have been announced free of the disease since 1956 and region 2 since 1989 (See Figure 1) (Hanyanum, 1993 p 191).



Source: Hanyanum et al. (1994)

Figure 1: Main livestock areas and FMD disease-free regions in Thailand

4. *Stock movements*: While most of Thailand's borders are natural boundaries such as mountain ranges, rivers and coast lines there are some passes which offer relatively free movement of livestock. Hanyanum (1993) suggests that FMD in cattle is prevalent in provinces along the border such as Chiang Rai which is probably due to smuggling of animals across the border. The higher price differential in the south also provides incentive for stock movement thus movement is often from North and North East to South (See Figure 2) (Hanyanum, 1993, p.191).



Source: Hanyanum et al. (1994)

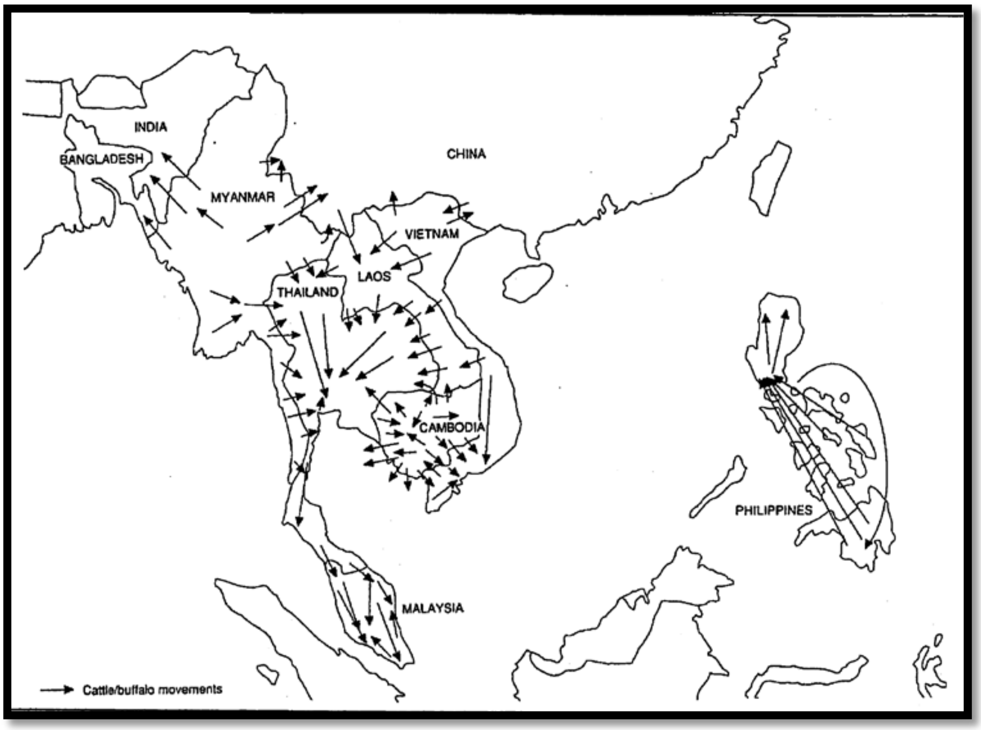
Figure 2: FMD outbreaks, facilities and livestock movement patterns in Thailand

These factors indicate the fundamental difficulties in trying to control disease in Thailand. FMD is a highly infectious disease that spreads easily by contact, air and residue. Eradication can only be achieved if a considerable proportion of the susceptible livestock population is involved in the program. With reference to Murphy (1996b) this problem can be simply represented by ensuring $S_0 < S_c$ through immunisation, isolation or a combination of regimes outlined previously in Murphy (1996a). The inherent difficulties in achieving eradication relate to the high contact rate between those susceptibles and infectives from other regions given the high level of livestock movement. Control programs in Thailand have attempted to eradicate disease through a combination of control regimes.

3. Control of Disease in Thailand

Control measures for FMD in Thailand have been implemented since 1956 based on the Animal Epidemic Act. The major activities of an FMD control strategy stated in Hanyanum (1993) are national vaccination programs undertaken in order to try and eradicate disease through immunisation, control of animal movement (disease-free zoning in the south), and stamping out.

Mass vaccination for national eradication involves many problems including the substantial costs that would be required to vaccinate all cattle in Thailand. It has been estimated (Chaisrisongkram 1994) that vaccination of all susceptible animals would require as much as 42 million doses of vaccine per year. This level is beyond the resources currently available to animal health organisations in Thailand (Chaisrisongkram 1994). The nature of Thailand's control programs therefore constitute a mixture of livestock movement controls that both vaccinate in high infection areas and control livestock movement particularly into such regions as the non-vaccinated FMD free-zones in the central and southern part. While significant movement control procedures are undertaken in Thailand there are still problems with the illegal movement of cattle between regions and between the countries of South East Asia (see Figure 3).



Source: Ozawa (1993)

Figure 3: Movement patterns of cattle and buffalos in South-East Asia

The national policy objectives are moving toward regional eradication that establish zones that are FMD-free and gradually extending these zones outwards until the general areas can be classified as disease free. As Ellis (1993) noted these programs must evolve systematically over a number of years as control measures are extended and intensified.

While a form of disease-free zoning exists in Thailand, in order for the country to establish a system that meets the requirements of the Office of International des Epizooties (OIE) (similar to those in Zimbabwe and Botswana) substantially more funding is required. Governments are understandably reluctant to outlay necessary funding commitments unless they can be assured that the viability of such programs warrant government support and intervention. Governments need to be confident that the total subsidies involved can be sustained over the years and that expenditure on particular control programs is an optimal and efficient allocation of resources.

The following model provides an assessment of the viability of establishing and maintaining zoning within a simple bio-economic framework and provides support (subject to certain assumptions) for the viable application of government subsidies.

4. Bio-economic Model of Disease

Approaching disease free zoning from an ex-ante position and adopting the simple representation of disease dynamics outlined in Murphy (1996b) we represent the zoning procedure as essentially an isolation of susceptibles into FMD free zones and in the process removing them from exposure to disease outbreaks. This control strategy ensures a source of healthy stock for export given comprehensive isolation of susceptibles and adequate border controls.

In analysing this scenario within a simple bio-economic approach we will assume a representative Thai firm is exporting livestock (cattle, buffalo, pigs). It is assumed the stock is sourced from a non-vaccinated region of healthy though susceptible animals and due to trading regulations can only export removed (isolated) stock for trade (given strict border controls).

Therefore, the objective functional of a representative exporting firm is assumed to be

$$Max\ (u,v) \int_0^T (p_1 R(t) + p_2 S(t) - cu^2 - dv^2)\, e^{(-it)} dt \qquad (1)$$

This objective functional states that: *a representative exporting firm will try to maximise profits- profit being the net value (P_1 and P_2) received from each healthy animal in the disease free zone(R) and the resource stock of susceptibles (S)* respectively. *R* denotes a state variable representing the status of livestock in relation to disease, in this case *removed individuals* given their isolation *(u)* into the disease free zone.

The costs of the controlling the disease are represented by two terms *c* and *d*. The first cost term represents the per unit set up costs of isolating susceptible livestock into a disease free zone. The second cost *d* term represents the per unit maintenance costs associated with maintaining total border controls around this zone. Logically maximising the profit associated with these zones is constrained by the costs associated with control of disease. Disease dynamics constrain the maximisation of profit given the costs of control associated with isolation of susceptible animals.

The objective therefore, is essentially to apply a control in the form of isolation of susceptibles (u) and border control (v) that maximise export profits subject to the dynamics of the disease controls of S,I,R[1].

$$\frac{dSt}{dt} = -uS(t) - S(t)\beta I \quad (2)$$

$$\frac{dI}{dt} = \beta S(t)I + (1-v)\zeta R(t)I(t) \quad (3)$$

$$\frac{dRt}{dt} = uS(t) - (1-v)\,\zeta R(t)I(t) \quad (4)$$

Where u ∈ (0,1) $\beta\zeta$ = const., where ζ is contact rate between *R* (Removes) and *I* (Infectives), v ∈ (0,1) where 1 is total border control. Therefore stating a Hamiltonian function the objective is to see what relationship is derived from applying a control that maximises the profit from the disease control strategy.

$H = (p_1R(t) + p_2S(t) - cu^2 - dv^2)e^{-lt} + \lambda(-uS(t) - I\beta S(t)) + \mu(I\beta S(t) + I(i - v)\zeta R(t)I(t)) + \gamma(uS(t) - I(1 - v)\zeta R(t)I(t))$

Differentiating with respect to control u and control v produces, after some rearranging

$$u = -\frac{1}{2}\frac{S(t)(\lambda - \gamma)}{ce^{(-it)}}.$$

$$v = -\frac{1}{2}\frac{\zeta R(t)I(t)(\mu - \gamma)}{de^{(-it)}}$$

The first solution provides the optimal level of isolation of susceptibles in order to maximise export profits. Conversely the second solution provides the optimal level of zonal quarantine or border controls necessary to maximise profits of a representative exporting firm. Optimality exists where $\gamma > \lambda$. and $\gamma > \mu$.

5. Results and Policy Implications

These solutions provide interesting outcomes in that they highlight important policy implications based on economic marginal relationships. In the first control, the optimal level u (isolation of susceptibles) that maximises the profit of an exporting firm is determined by the net marginal value of isolation of susceptibles to removes (↑ - \) multiplied by the number of susceptibles as a proportion of discounted per unit costs of isolation ($de^{(-it)}$). This is then multiplied by a set proportion (½), a standard characteristic of most quadratic objective functionals.

5.1 *Optimal isolation control*

The interpretation of such as result provides some interesting economic. and policy implications for establishing a zoning system. The model outcome suggests that if the net marginal value of isolation is positive ($\gamma > \lambda$) then a positive optimal control (u) will exist. Essentially this is saying that assuming a higher marginal value associated with isolating susceptibles into an FMD free zone exists (given price premiums associated with trade), then specific optimal control will always maximise profits.

Consider the case however where $\gamma < \lambda$, that is the marginal value of isolation of susceptibles is less than the marginal value of susceptibles alone. Logically a negative optimal condition exists if marginal value (\) of the exportable stock does not exceed the marginal value of susceptibles or resource stock (↑). In this scenario, it does not "pay" in economic terms for investment in isolation to proceed. This is unless of course the per unit set up costs of isolation of susceptibles (c) are represented as a negative value in the model - for then a positive optimal control is logically obtained.

This scenario suggests therefore that only through *subsidisation* of set up costs could the representative exporting firm profitably undertake zoning. Extending the policy implications of this outcome suggests that governing bodies (i.e. regional or national governments) may need to subsidise the per unit isolation of susceptibles (e.g. subsidised transport costs) in order for the zoning to be profitable. Given the significant national benefits associated with the establishment of trade in livestock commodities and the substantial "flow-on" effects to other downstream industries such as the feed industry, (in Thailand this represents up to 70% of livestock marketing costs) this subsidisation could be argued as beneficial.

However as the world moves toward more liberalised trade and the increased scrutiny applied under recent GATT regulations concerning the subsidisation of agricultural industries, there may need to be significant justification of such a policy. However an interpretation of the second control solution (v) provides further justification for a support policy for zoning.

5.2 *Optimal border control (v)*

In respect to the second control, the optimal level of quarantine (border control v) that will maximise the returns to a representative firm exporting R, is determined by the contact rate (≈) between infectives and removes within the FMD-free zone (≈ RI), multiplied by the difference in marginal value of disease infected stock to the exportable herd (μ-\). This is as a proportion of discounted per unit costs of border control (maintenance costs). The logical assumption that the marginal value of healthy protected stock exceeds those of diseased stock suggests that maintenance of the zoning system through border controls should always generate a positive optimal policy.

In general therefore the model supports the qualitative assessments in other studies (Murphy 1996b) that development of disease free zoning is potentially beneficial and results in positive returns given valid assumptions on the value of the shadow price (*that is* $\backslash > \uparrow > \mu$). If however the per unit isolation costs of setting up these zones needs subsidisation, then ready justification can be sought from the positive optimal value associated with establishing border control. In other words it should always pay in economic terms to establish zoning given the assured long term profitability of maintaining border controls. A simple graphical simulation of this control scenario is provided in Figures 1-4 in Appendix 3 with given values for u and v to help illustrate the control process.

Given that (within the assumptions of this model) the "resource pool" of susceptibles is effectively a non-renewable one (that is they become either infectives or removes with no regeneration) then effectively removes and infectives will reach their own limit bounded by the total amount of stock N (given constant population assumption (that is $R + I = N$ *given* S *eventually* $= 0$). Figures 1-2 (see Appendix 3), assumes there is no leakage between zones (v=1), therefore it is obvious that as total profit is a function of the number of removes (*Price * Quantity*), it will be determined by the marginal difference in the removal rate of susceptibles relative to the infection rate of this stock. The *stability* of this system is therefore reflected in this relationship, whereby assuming v = l (total border control) isolated and infectious cattle will increase at this relative rate until susceptibles numbers are exhausted-providing the limit to total profit.

In Appendix 3, Figure 3 and 4 represent the scenario whereby infectives are able to enter the disease-free zone at a rate $(1 - v)$*I. As can be noted, due to the high susceptibility of the stock within the zone once border controls are broken (removes are now *technically* susceptibles given their unvaccinated status) and the limited direct removal of the infection, the infection spreads rapidly. Given no immediate treatment of infectives this will increase until no healthy stock remains. While this relies on numerous simplified assumptions it illustrates the high risks associated with maintaining non-vaccinated disease free zones whereby little to no immunity exists given the provisions of disease free trade that stock cannot come from vaccinated regions. It further highlights the importance in the expenditure associated with border controls and livestock movement whereby the system only operates if $1 - v$ is less than p (the critical value associated with relative removal rates of secondary infection)[2].

5.3 Limitations of Approach

While this approach provides a useful conceptual framework for determining optimal economic conditions for disease controls it often experiences difficulty in obtaining a closed form solution. The maximum principle asserts that optimal control u (*t*) must maximise the rate of increase of total assets, however in the case of this model, in order for the optimal choice of u (*t*) to be made, the actual value of the ↑ (*t*) needs to be known. As Clark (1990) noted the maximum principle in optimal control theory often reduces to a problem of determining λ (*t*), which by analytical methods has found to be difficult and in many cases impossible even within simplified frameworks as outlined here (Clark 1990, p.106)

This was evident in the application of optimal control theory to *exposte* analysis (once zones have already been established) of disease free zones. The complexity of the models specification is immediately evident given the need to represent the disease dynamics individually within each zone and therefore necessitating the determination of numerous adjoint variables (i.e. $\lambda_1\lambda_2\gamma_1\gamma_2$).

The variety of zonal specifications in regard to disease control (ie specified levels of vaccination) as can be seen in Table 1 in Zimbabwe and Botswana, is complex and impacts on the ability of the specified control to “reach” all parts of the system, even within a simplified two zone framework (Vaccinated and Non vaccinated). Siljak (1978) outlined this problem in control theory as one of "reachability". As mentioned in Siljak (1978) the behaviour of the physical system (eg. biological population) can be altered efficiently by feedback control (eg. u, v). The principle of the feedback is to choose inputs to the system as functions of its output so that the closed loop system accomplishes a desired controlled behaviour. Essentially the inputs therefore have to “reach” each part of the state or system and that all part of the system are *represented* by the outputs. The structuring of separate zones within the specification of *exposte* analysis meant a difficulty in the control (immunisation) applied in the outer (vaccinated) zone being sufficiently represented in the relevant outputs of the non-vaccinated zone. Trying to improve this reachability by means of interacting contact rates proved unsatisfactory.

6. Modelling Control Policies for FMD

This paper outlined the relevance of export orientated control strategies such as zoning given recent changes in global trading conditions. Application of a simple bio-economic model in this paper, applied to livestock disease control, validated the potential economic worth of establishing and maintaining FMD- free zones within disease endemic countries. Given the potential trading benefits for Thailand in livestock export and the importance of export in general economic development, the commitment of governing bodies to regional or national eradication is justified given the long term benefits associated with eradication.

6.1 Overview of modelling approaches to disease control strategies

Bennet (1992, p.64) noted that for livestock health and disease control decisions, information is needed on:

1. The disease and production system
2. The physical effects of the disease and the subsequent effects on the production system
3. The incidence and prevalence of the new disease
4. Technologies and options available to control disease and improve health and productivity
5. The impact of disease and control options on other systems (eg human health)
6. Evaluations of the effects of disease and of strategies for control

Economic and epidemiological modelling techniques have a role to play on providing information on several of these aspects. As noted in Murphy (1996b) there have been a variety of epidemiological and economic models applied to assist policy makers in Thailand in the best ways to control and evaluate FMD.

The simple bio-economic model applied in the previous section provided a simple integration of deterministic epidemiological modelling with economic optimising techniques in order to highlight important economic considerations in the optimal control of FMD (within a zoning framework). The model provides an optimal solution (based on marginal relationships) for a control that maximise the objective functional of a representative firm. The specification of this model suggests that the optimal policy concerning regional freedom of disease is essentially determined by the level of susceptibles (*S*) multiplied by the difference in marginal value (net value) of susceptibles to the isolated stock (↑ - \) relative the discounted per unit costs of isolation. It essentially states that control of disease via isolation of susceptibles will maximise net export profits given the marginal value of isolation (marginal value of your exportable herd) exceeds the value of un-isolated stock. If there is no net value associated with zoning then a positive optimal control can only exist if the per unit costs of isolation are subsidised for the representative exporting firm. This is a logical, interpretable solution albeit a conceptual framework.

The solution of optimality for the second control - the quarantine level or border control (*v*) provides a similar interpretation but with important differences. It is assumed that in reality the marginal value of the isolated stock should always exceed the marginal value of the infectives. Given this assumption, regardless of the optimal conditions in setting up the system (isolating the susceptibles) *maintenance* of the zoning system (border controls) should always warrant positive economic return. This has important policy implications suggesting that even if initial subsidisation is necessary (and possible given international trade agreements) it should be warranted given long term benefits associated with trade and disease eradication. Though this is a basic modelling approach it provides some useful general comments of the economic considerations that are necessary it analysing specific programs as mentioned above.

Figure 4 illustrates how the bio-economic nature of the optimal control solution complements the criteria for optimal control programs illustrated in McInerney (1988). Optimal control theory applied to biological populations in this manner complements the proposition put forward by McInerney (1988) and Howe (1988) that economic assessment of disease control programs should determine intrinsically the optimal level of disease control and therefore the optimal use of resources. Traditional approaches such as cost-benefit analysis do not in themselves provide optimality conditions in assessing disease control programs, more so a comparison of acceptable uses that can be prioritised according to B/C (benefit-cost) ratios. It is the determination optimal conditions based on marginal analysis according to McInerney that lies at the heart of economic analysis. In this manner economics becomes a part of disease control analysis and not just an adjunct to it - a constant criticism put forward in numerous studies on the role of economics and epidemiology in decisions on animal health management (McInerney,1988, 1991; Howe,l988).

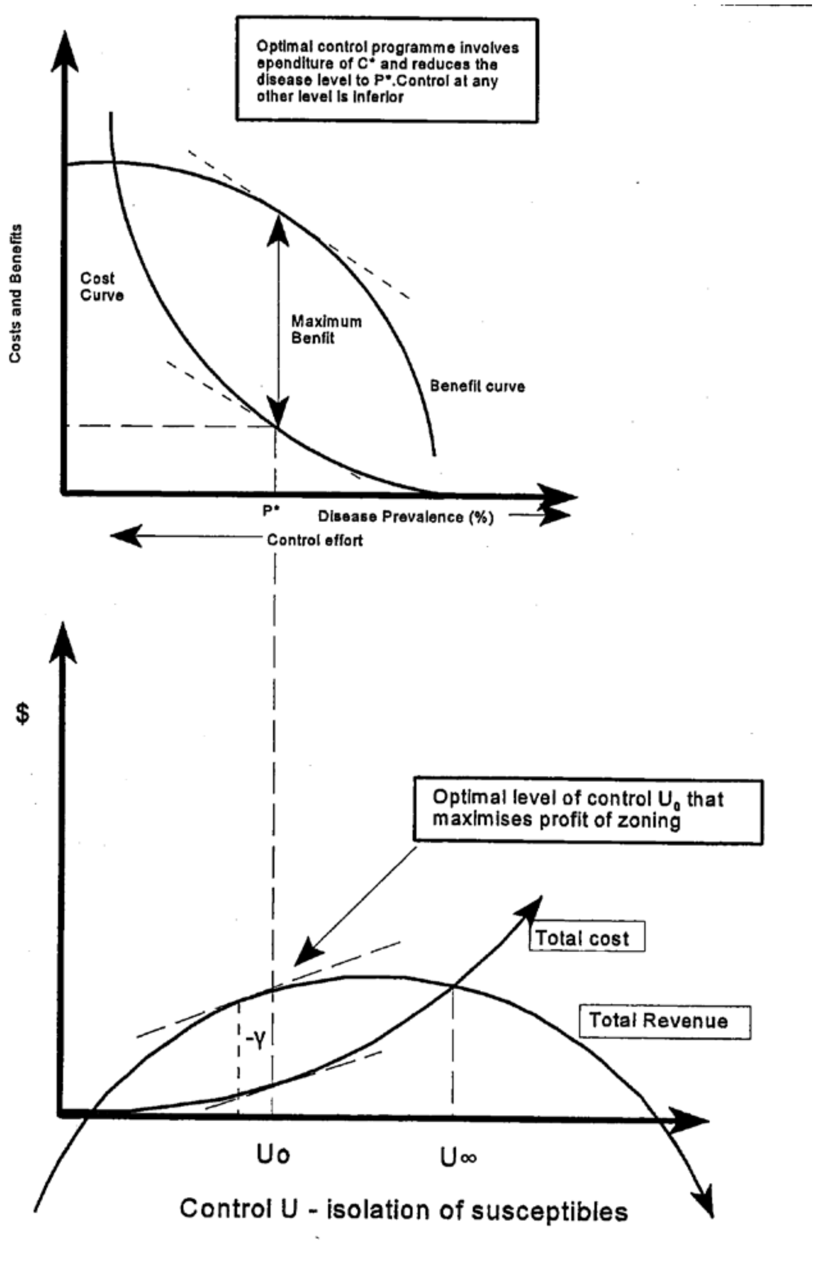


Figure 4: Optimal level of control using Bio-economic approach

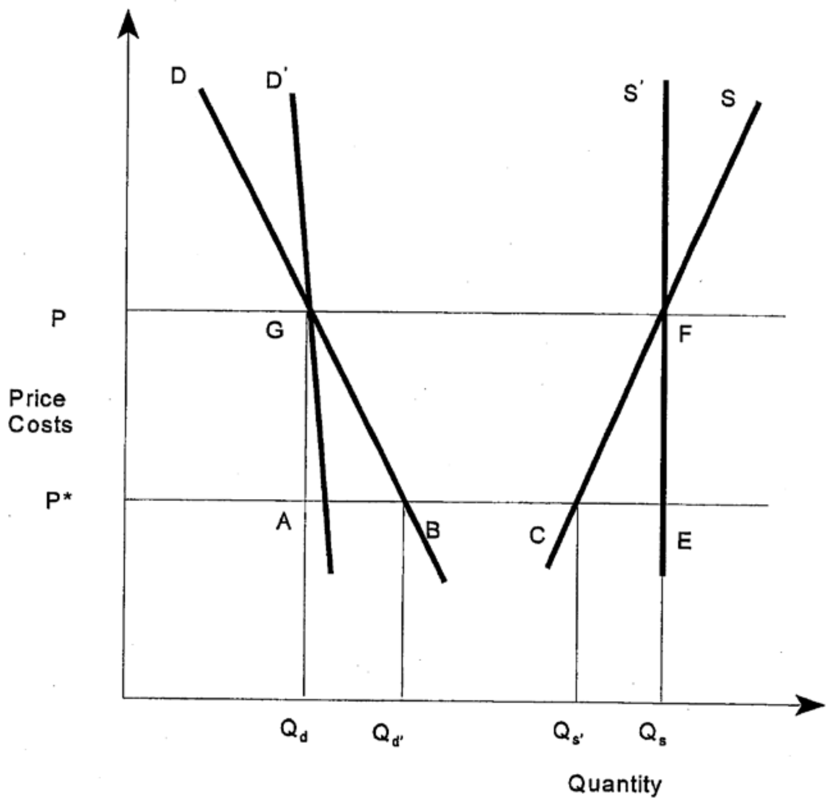
6.2 Extending Benefit-Cost Approaches to Zoning

The optimal control approach provides optimality conditions that complement ideal economic principles. However its difficulty is in attaining closed form solutions, particularly in determining a direct value for shadow prices (i.e. λ and γ). For the optimal control level to be specified it is these essential economic variables that need to be determined. Due to problems in attaining closed form solutions (a precise value for the optimal control) and aspects of reachability, the optimal control approach even within a simplified framework is limited in its direct application particularly to national control programs. It is in this framework where cost-benefit approaches, despite their inability to provide essentially optimal solutions, are able to better attribute values to such factors as shadow prices and can incorporate the distributional welfare issues associated with national control programs.

In terms of a national disease control program like zoning, an approach is necessary that represents the complex dynamics of the disease and yet also incorporates the economic impact on trade. While cost-benefit models are often applied to a variety of national programs concerning disease control they have been criticised for an inability to measure the indirect effects of trading bans. For export-orientated strategies such as zoning an extension of recent studies by Dijkhuizen (1992) would be beneficial for future analysis. As Dijkhuizen (l992) states economic decisions on national programs require an integrated approach that includes the effects of different conditions and scenarios considering

1. The spread of disease
2. Direct costs of prevention and eradication
3. Indirect costs of prevention and eradication

Dijkhuizen (1992) and Dijkhuizen and Berentsen (1992) outline a dynamic modelling approach that attempts to quantify and include the indirect effects of FMD due to export bans. The principles of this are illustrated in Figure 5. The figure indicates the supply and demand for a country exporting a certain product. At level *p* producers supply amount q while consumers demand amount *qd* with the difference *Qs-Qd* being exported. With an outbreak of disease a new equilibrium will occur at a lower price level effecting the welfare of both consumers and producers (Dijkhuizen, 1992). With a drop in price producer surplus is reduced to area *PFCP* and consumer surplus is increased to area *PGBP*.



Source: Dijkhuizen (1993, p.5)

Figure 5: The market situation for a country exporting a product

Dijkhuizen (1992) applies a dynamic modelling approach in which he claims to integrate the epidemiological and economic aspects of disease control, incorporating the modelling of export bans as an extra component. A simulation based on Markov chains approach was undertaken to compare the spread of the disease for different control strategies in a population with and without preventative vaccination. In the export model, specifications are stated on the products affected by the trade embargoes, the market to which these products are delivered and the actual reaction on these markets. The advantage of this approach is that it incorporates consumer welfare issues and therefore is a far more encompassing approach than many studies that just consider producer welfare issues.

An extension of this analysis to include zoning as a further control alternative would be interesting given it is a trade-orientated control strategy and is a combination of vaccination and non-vaccination programs across regions. Assuming ex-post analysis, an outbreak in the non-vaccinated zone would incur significant costs and would require significantly higher removal and possibly stamping out given the need for this zone to secure zonal freedom and the direct premiums that such a zone incorporates. Simulation of the disease spread would need to include parameters that represented varying quarantine levels and the probability of leakage between zones based on these levels as they determine the extent and nature of outbreaks in the non-vaccinated zone.

Given the national policy significance of such a program, this modelling approach would also need to determine the national impact of regional export bans. How spatially integrated the livestock markets are between these zones determines how an export ban and reduced price associated with it will affect the welfare of producers and consumers outside of these zones. The nature of establishing such zones over large areas generates national price gradients across zones with higher prices naturally established for exportable stock in these zones. This creates a policy issue in itself in determining the location of zones. Griffith (1992) noted this was the experience in Botswana and Zimbabwe where considerable debate surrounded the eventual location of FMD free zones. As the movement of both legal, and more importantly illegal stock tend to follow these price gradients, the existence of higher priced regions in itself increases the incentive for illegal trade of livestock across zones.

7. Importance of livestock export for economic development

One of the fundamental reasons behind the growing use of rigorous economic analysis in decisions on optimal disease control, is the significant cost of the disease in trade loss. Thailand has been significantly constrained in terms of commercial production and export in its cattle and pig industries. Given the growing commercialisation of the swine and cattle industries in Thailand and the general policy objectives of developing international trade in livestock commodities an effective zoning system in the South that met OIE requirements could generate significant foreign exchange earnings.

While the cattle industry in Thailand is growing, it is significantly constrained 'in production expansion due to the limited available pasturelands. However the swine industry in Thailand has the potential to develop into a significant exporting industry. As noted in the past this potential has been constrained by constant disease outbreaks and significant government regulations. Murphy and Tisdell (1995) noted the potential of immediate pig exports to Taiwan where it could compete competitively given appropriate disease control programs and low feed costs. While the industry is vulnerable to a reduced supply of domestic feed and the rising level of labour costs that have recently slowed the growth of the Thai poultry sector, intensive larger scaled pig industries could potentially follow in the footsteps of poultry as one of Thailand's leading international competitive industries.

One of the fundamental reasons behind the significant investment suggested by International health agencies such as the OIE for regional eradication and FMD-free zoning is the importance placed on export of livestock for the overall economic growth in the economy. Export orientated disease control strategies such as FMD-free zoning, especially given the recent changes in international regulations, is an essential approach that must be considered by all countries that aspire to trade in livestock.

Disease control is an essential link in the relationship between agricultural development and overall economic development given the importance placed on efficient livestock production systems (James and Ellis, 1979). The nature of this relationship and the inherent role of agricultural in economic development is an essential consideration in how disease control strategies fall within the context of overall economic objectives- especially export orientated policies such as Thailand.

The precise role of trade in agricultural products in the economic growth and development of developing countries is not entirely clear or without contention. Tisdell and Harrison (1994) cited Hubbard (1986) in his analysis of theories concerning export lead growth. In Hubbard's study of Botswana livestock exports, he identified two strands of theory concerning exports and economic growth. The neoclassical hypothesis portrayed the relationship between exports and economic growth as a “cumulative and harmonious process” while neo-marxist theories portrayed a negative relationship between trade and economic growth of “colonised or dominated territories as a feature of global capital accumulation” (Harrison and Tisdell, 1995).

Prebisch (1959 in Ghatak 1985) was one of the first economists to focus attention on the dependence of less developed countries (LDC’s) on agricultural products in their trade stating that it resulted in a secular downward trend in the terms of trade of the less developed countries (LDC) relative to Developed countries (DC’s). Prebisch states that LDC’s are losing out in their trade with DC’s and the way to develop their economies is through industrialisation protection and import substitution and therefore focus more on developing manufacturing then progressing agricultural trade. This argument has come under criticism at different times for it uses an analysis of declining terms of trade, an analysis whose outcome depends totally on what base period was taken in its estimation (Ghatak, 1985).

While Prebisch's theory holds some validity, the increased trade in agricultural goods such as livestock resulting from regional eradication from disease-free zones can play a significant role in promoting the economic development of developing countries such as Thailand. Studies by Kerr (1988), Jawara (1988), Cunningham (1988 cited in Harrison and Tisdell 1995) and Ghatack et al. (1984.) have all indicated the significant role of livestock and agricultural exports in the economic growth and development of developing and developed countries alike. Ghatak et al. (1984) suggested,

- Exports of agricultural goods such as livestock can help fund the imports of capital goods, technology, manufactured products and other commodities essential for sustained economic growth of developing countries. The rapid economic growth and industrialisation of Thailand was spearheaded by the export of agricultural goods such as rice and poultry which earned valuable foreign exchange.

- Many developing countries have a comparative advantage in the production of agricultural goods. Export led growth models of trade indicate that it would be at an advantage for this country to specialise in production and export surplus production. This would be exploiting trade as an "engine of growth" and ensuring rational allocation of resources.

- As in the case of Thailand, even when a country raises its standard of living, trade in agricultural industries such as livestock still remain an important policy for stimulating economic growth for a number of key industries. This has been the experience of Canada in recent years.

- Trade by developing countries in agricultural products can lead to increased incomes within the LDCs and increased demand for industrial goods and other kinds of services in these countries. Therefore the growth in trade and the associated economic growth of the country is a benefit to the LDC. Thailand's significant economic growth was spearheaded by the expansion of the agricultural industry in the 1960s with the export of rice and poultry generating significant foreign exchange earnings.

8. Implications for future control programs

Such broad social and private benefits illustrate why export orientated strategies such as disease-free zoning have become an important part in the international and national control programs applied to FMD control in Thailand and other developing countries throughout the world. The significant costs of such programs however ensure that the role of economic analysis will remain essential to national government policy concerned with disease control.

As studies by Howe (1988), McInerney (1988) and Hugh Jones (1985) have suggested, the challenge for animal health economics is to integrate appropriately the fields of economics and epidemiology to a point where disease control is analysed as an economic phenomenon. The modelling approach applied has attempted to provide simplified representation of this process. The optimal control approach in this paper, apart from indicating the viability of establishing and maintaining zoning systems, also attempted to highlight how a biological process and the economic principles of optimality can be soundly integrated into a "bio-economic framework". While this approach has limitations, further research into the applications of control theoretic modelling to direct policy applications is warranted. As Bailey (1975) suggested, the extent to how more sophisticated application of control theoretic approaches can be assimilated into actual decision making process is a matter which is of considerable practical importance and which needs a good deal further application (Bailey, 1975).

With political hostilities presently subsiding in Indo-China, the commercial value of livestock increasing over the last two decades, and recent changes in world trade regulations, there is incredible scope for the development of efficient and viable control programs for FMD countries such as Thailand to derive substantial economic benefit. How well these optimal disease control programs are evaluated and monitored within rigorous economic analysis will help determine the efficiency of these programs and the validity of their application. As the negative externalities of economic growth in the South East Asian region are increased, trade in legal and illegal movement of livestock and more intensive livestock production (therefore, higher susceptibility to a rapid spread of FMD), the costs and value of control programs will continue to increase. As this process continues, so too will the role of the economist become a natural part of the decision process in determination of optimal control policies for FMD in South East Asia.

9. Notes

1. The model in simulation utilises a discrete time analogue.

2. $P = \gamma/\beta$ in Kennack and McKendrick's model.

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APPENDIX I

TABLE 1. FMD CONTROL ZONES IN ZIMBABWE

- **A Wildlife zone** : This zone contain no cattle and any cattle that were present in the zone have now been slaughtered. In some areas this zone is adjacent to a buffer zone rather then a vaccination zone. Where this zone is not adjacent to a vaccination zone there is a double fence which has a space of 71\2 m between the two rows of fencing. The wildlife zones are on the periphery of Zimbabwe .Moving towards the centre of the country the next zone encountered is a vaccination zone.

- **Vaccination zone :** In a vaccination zone all cattle are vaccinated every 6 months against foot and mouth disease. This zone abuts a buffer zone.

- **Buffer Zone :** Cattle in this area have not been vaccinated and their movement into the centre of this country is strictly controlled. The boundary between the vaccination zone and the buffer zone is delineated by a roadway and farm fences on each side of the roadway .No other boundary fences are exist between these two zones. All fences are checked regularly by ministry of lands and agriculture personnel, and a total of 800 fence workers are employed by the ministry to ensure the integrity of the fences. Inside the buffer zone is a clear zone in which animals can move from one province to another.

- **Clear Zone :** This clear zone then surrounds the EEC catchment area .Animals that move into the EEC catchment area can do so from the clear zone .All such cattle must be date code branded and can enter the EEC catchment zone once they have been resident in the clear zone for at least 12 months.

- **EEC Catchment Zone:** This zone compromises the greater part of Zimbabwe and lies in the central part of the country. In this area cattle are grown for slaughter at export approved abattoirs for European Union consumption.

Source Griffiths,1993.

APPENDIX 2

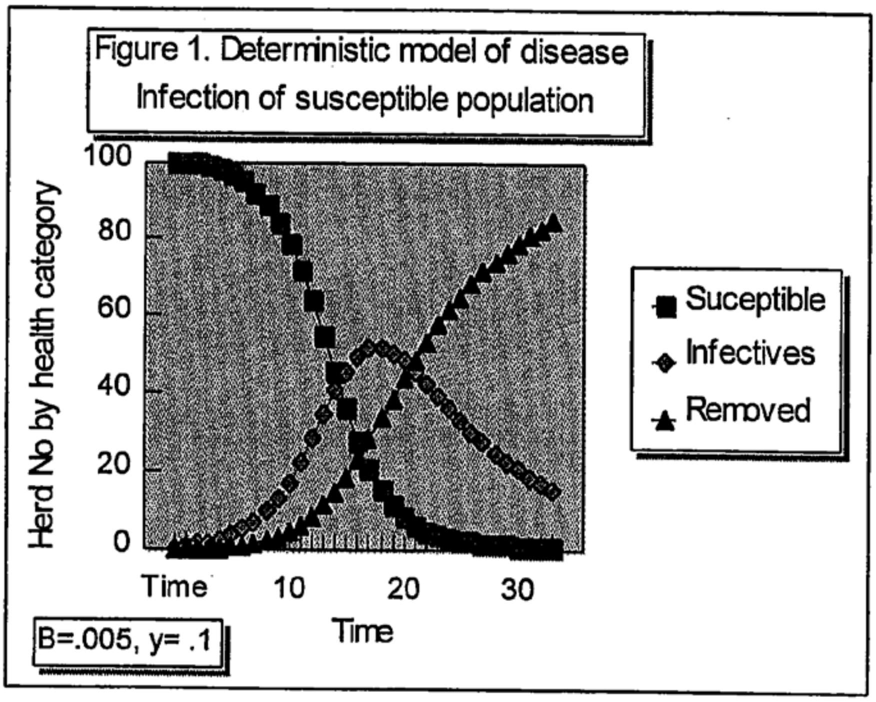
Figure 1. Deterministic model of disease
Infection of susceptible population
Herd No by health category
100
80
60
40
20
0
Time
10
20
30
Time
Suceptible
Infectives
Removed
B=.005, y= .1

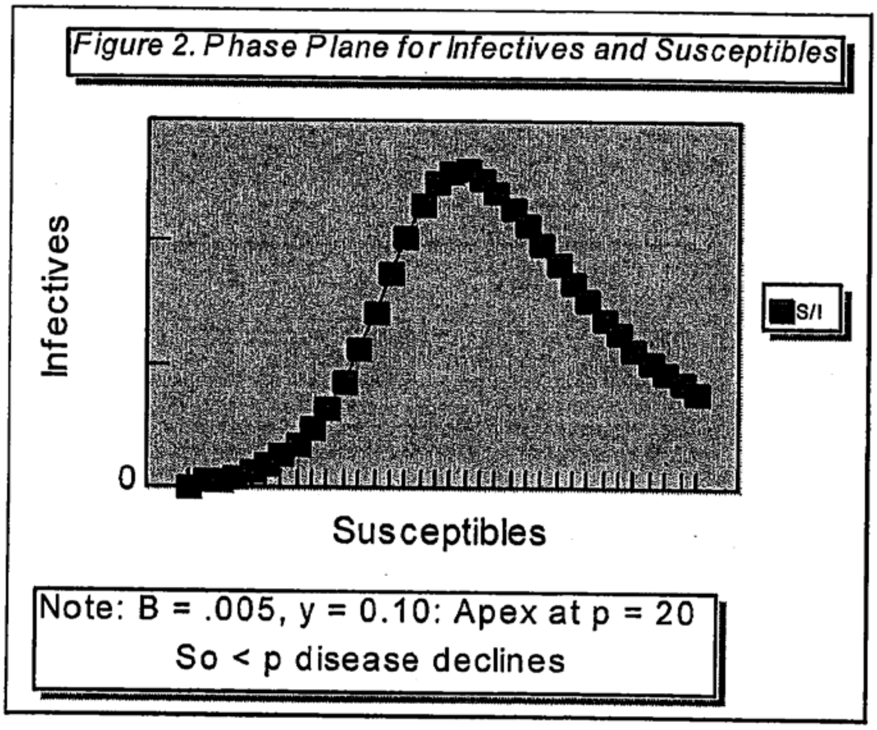
Figure 2. Phase Plane for Infectives and Susceptibles
Infectives
0
Susceptibles
S/I
Note: B = .005, y = 0.10: Apex at p = 20
So < p disease declines

APPENDIX 3

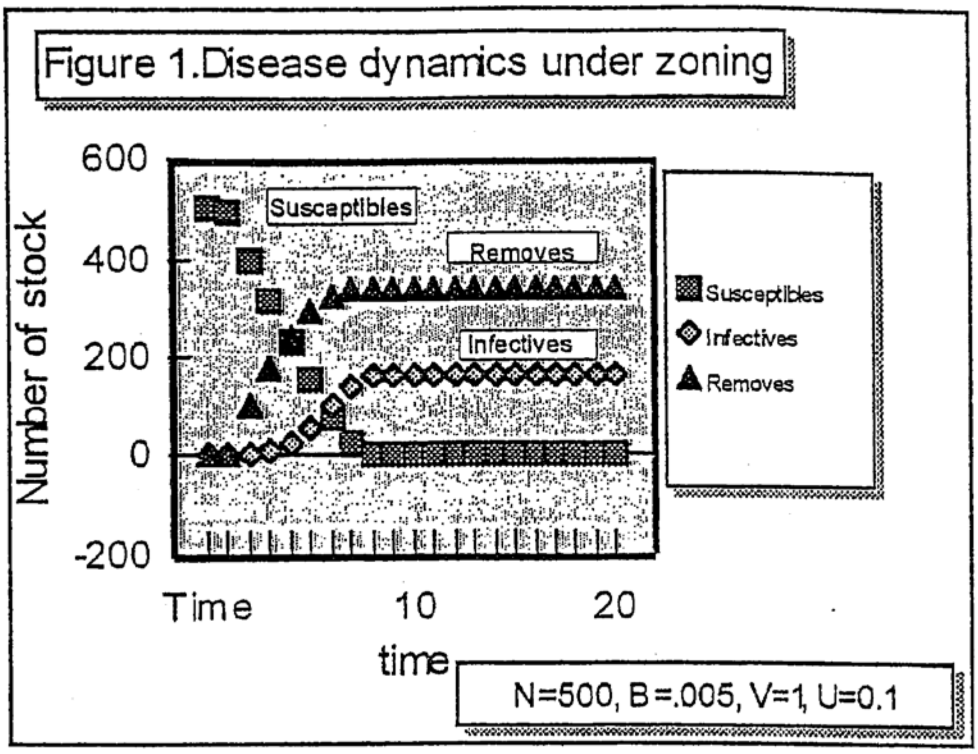
Figure 1.Disease dynamics under zoning
600
400
200
0
-200
Number of stock
Susceptibles
Removes
Infectives
Time
10
20
time
Susceptibles
Infectives
Removes
N=500, B=.005, V=1, U=0.1

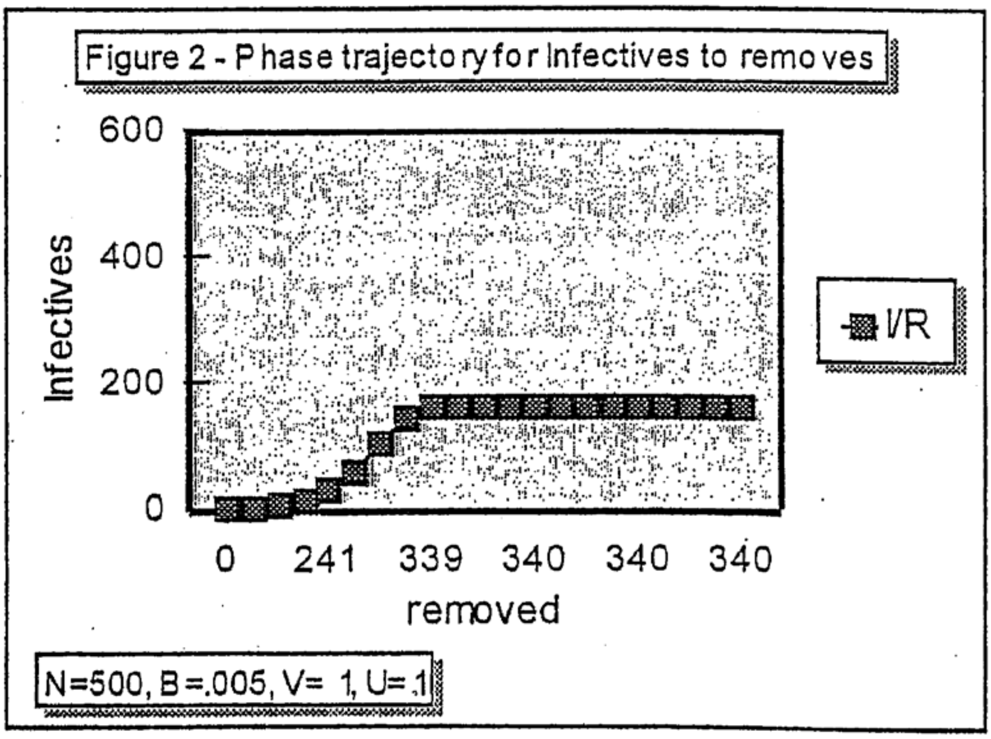
Figure 2 - Phase trajectory for Infectives to removes
600
400
200
0
Infectives
0
241
339
340
340
340
removed
I/R
N=500, B=.005, V= 1, U=.1

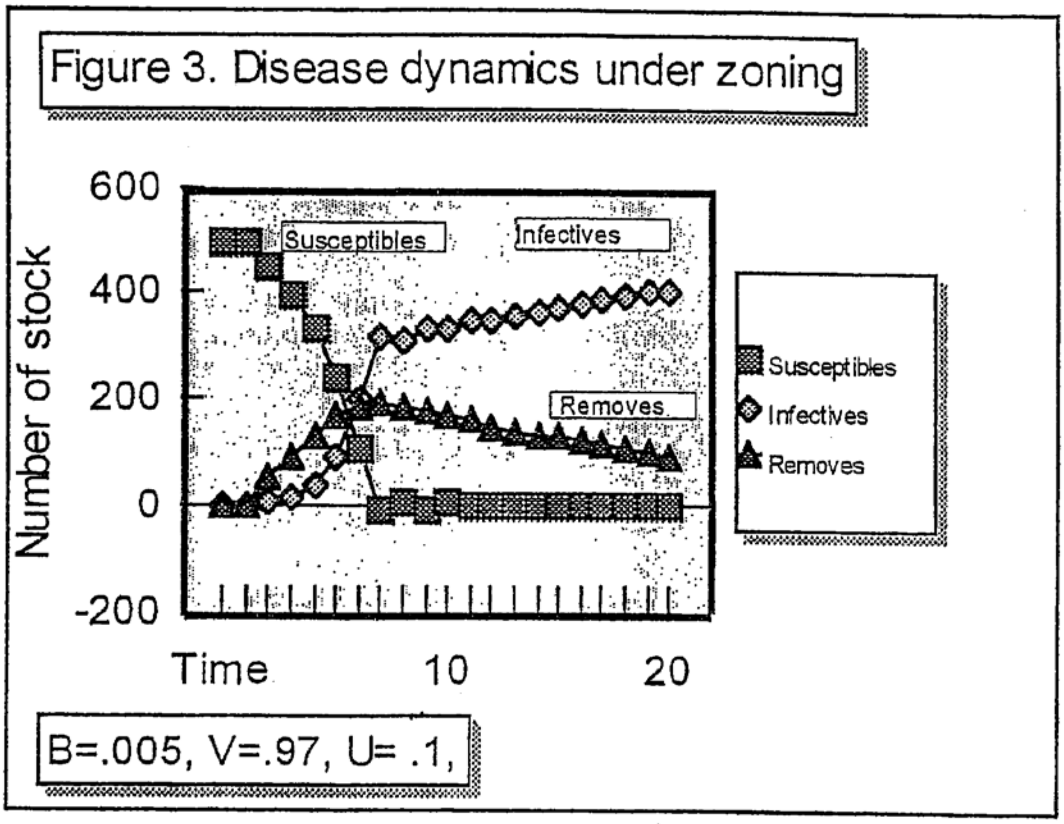
Figure 3. Disease dynamics under zoning
600
400
200
0
-200
Number of stock
Susceptibles
Infectives
Removes
Time
10
20
Susceptibles
Infectives
Removes
B=.005, V=.97, U= .1,

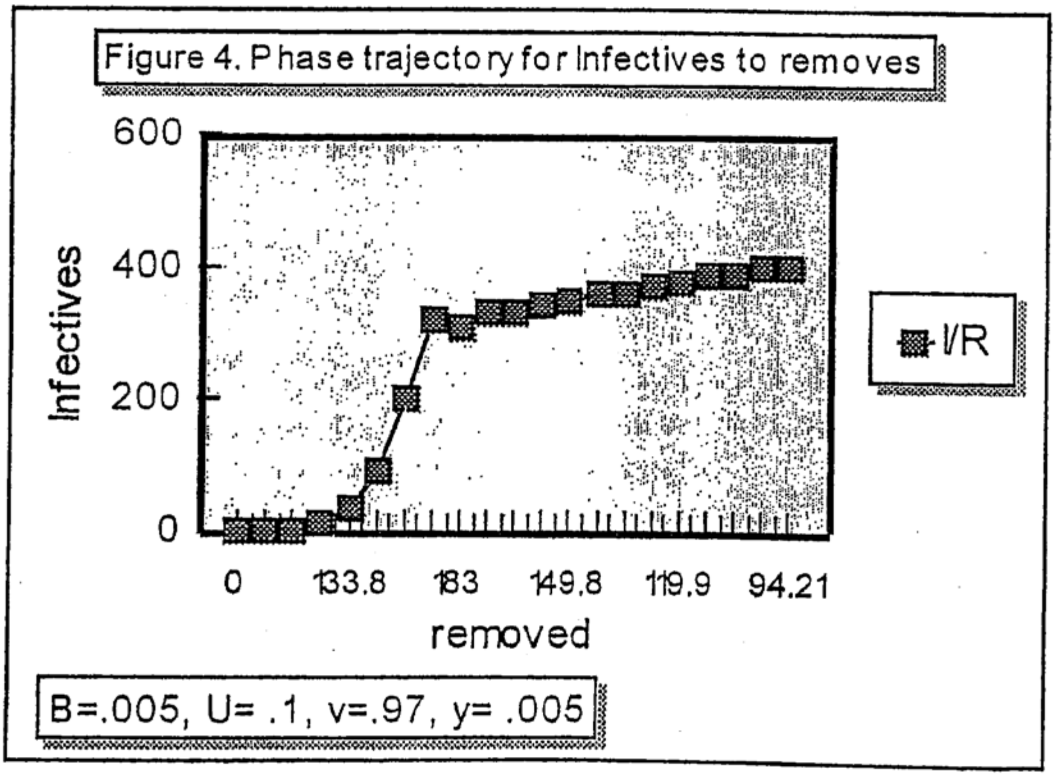
Figure 4. Phase trajectory for Infectives to removes
600
400
200
0
Infectives
0
133.8
183
149.8
119.9
94.21
removed
I/R
B=.005, U= .1, v=.97, y= .005

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