An economic approach to collective management of endemic animal diseases

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Abstract:

The control of animal diseases is an issue of particular interest in animal production chains. Because of their direct impact on production, animal diseases generate income shortfalls for farmers. In some cases, diseases may also have lead to human health problems and undermine market access conditions. Because of these potential negative impacts, some diseases are regulated. But for many communicable diseases, much latitude is given to individual control of the disease by farmers. In the case of a communicable disease, individual management therefore generates an externality, as individual decisions have an impact on the level of risk exposure of other farms to the disease. Thus, the collective result of individual management may differ from the collective expectations. This gap can be reduced by collective actions. The aim of this paper is to provide a conceptual framework for the study of collective management of animal diseases, which will provide management tools to collective managers of animal health. The development of this conceptual framework rests on three steps. We first discuss the means to model the individual decisions of farmer in regard to animal diseases. Then it should take into account the interaction between the epidemiology of the disease and the individual decisions of farmers, by the coupling of epidemiologic and economic models. Finally, collective management tools are introduced in these models in order to test incentives schemes for horizontal coordination. Finally, collective actions are introduced in these models, in order to test devices for horizontal coordination (management of prevalence between farms).

Keywords: Animal health economics - Micro modelling – Bio-economic modelling - endemic animal diseases

Introduction

The control of livestock diseases is a major concern for intensive animal production areas like Western France. Animal diseases are an important source of vulnerability due to the diversity of their impacts. They can create substantial shortfalls for farms, by degrading their technical and economic performance (production losses) and may lead, for some of them, to the loss of commercial opportunities. The control of animal diseases also implies the allocation of resources, both *ex ante* in terms of surveillance and prevention and *ex post* in order to mitigate the sanitary and economic consequences if the disease occurs (curative expenditure, for example). These shortfalls and cost induced by animal diseases weigh heavily on the economy of farms and have wider effect on the competitiveness of animal production chains. Beyond the direct impact of diseases on the livestock sector, animal diseases can have a broader impact on regional and national agricultural economies (animal feed, for example), as well as on firms engaged in the food processing of animal products.

The management of animal health is nevertheless complicated by the varying biological characteristics of the diseases and difficulties arising in their control. The most problematic element probably refers to the transmissible nature of many diseases; contagious pathogens may easily spread from one farm to another. Different transmission modes exist: direct contact between animals from different herds (contact over fences at pasture, for example), animal purchases, environmental contamination, exchanges of contaminated materials between farms… Some diseases are transmitted by animal vectors (insects, small mammals, wildlife). The communicability of pathogens gives rise to externalities, which imply that decisions taken at the farm level may have sanitary – and therefore – economic consequences for other farms with witch the farm is related.

A farmer who decides to protect his herd against a particular disease by vaccinating or adopting strict biosecurity measures (hygiene, quarantine, for example) would create a positive externality, in that its action would benefit to other farmers by lowering the infection pressure (risk of occurrence of the disease). Conversely, a farmer could be encouraged to behave as a free rider seeking to benefits from the efforts of its neighbours, without bearing the costs. This behaviour would generate a negative externality since this behaviour would help to maintain the disease within the geographic area considered. This results in strong interrelationships of individual decisions to control animal disease at the area level. Note also (by analogy with the atomicity assumption of perfect competition) that the epidemiological situation observed across a geographical area may only vary if a sufficient number of farmers in the area implement a given control measure. For communicable diseases, the effectiveness of control measures will often depends on the ability to act in a coordinated manner across a group of operations (horizontal coordination).

This paper focuses on collective actions to control animal diseases, for witch management decisions do not take place on a collective level, but is left to individual initiative (decentralized decision-making). This paper puts specific emphasis on endemic diseases that may not be regulated and their control involves horizontal coordination requirements. The aim of this work is to outline a conceptual framework for understanding the collective management of animal diseases and to present the main implications in terms of research needs.

The challenges of this research are at two levels. At the societal level, this research aims to make available to collective animal health managers more effective decision tools. These managers are involved in the definition of sanitary policies across an area (eradication, control of the spread of a disease). Management decisions are currently taken on the basis of epidemiological approaches which implicitly assume that the measures advocated by the collective manager will be systematically implemented by the farmers. These approaches generally omit the fact that decisions to implement the measures are decided on a voluntary basis by each farmer on the basis of their own economic interests, regardless the collective goal promoted by the collective manager. This reasoning can lead the managers to make wrong decisions (waste of resources, choice of wrong types of intervention …). The effectiveness of collective actions should be improved by introducing incentives to remove the potential obstacles to measures adoption par the farmers. From an academic point of view, the work outlined a challenge for economic analysis. Different tools exist in many sub-disciplinary fields (agricultural economics, but also human health economics, environmental economics, economics of risk and uncertainty, theory of agency, etc.) that could be judiciously combined to develop a relevant analytical framework. It is also beyond and enrich standard economic approaches by integrating the contributions of epidemiological modelling. The main idea developed in this paper is the coupling of economic and epidemiologic models. The difficulty lies in the fact that individual decisions are part of an epidemiological context and given in return, the epidemiological context is influenced by individual decisions (aggregated). The purpose of the work to be done is the construction of a tool for decision support, by revisiting the terms of collective action in animal health management and taking explicitly into account the decentralized nature of decision-making process.

The implementation of this approach involves three steps that will be successively discussed in the paper, namely: 1) the modelling of the farmer's individual decisions in regard to animal health management, 2) the coupling of epidemiologic and economic models to assess the outcomes at a collective level, and 3) the design of incentive mechanisms.

1.- Modelling individual behaviours

The first step attempts to model the farmer's decision process in regard to animal disease management. The key assumption is that farmers behave rationally. The decision to implement – or not – a control measure is individually taken by farmers on the basis of their own economic calculation. Control decisions are usually taken in a broader context of resource allocation, which implies a tradeoff between disease management and other uses of scarce resources (money, labour). The economic behaviour of the farmer is influenced by several factors, including the economical context, the institutional setting, the farm and farmer's characteristics and biophysical factors, among which animal diseases (Chilonda et Van Huylenbroeck, 2001) (figure 1.).

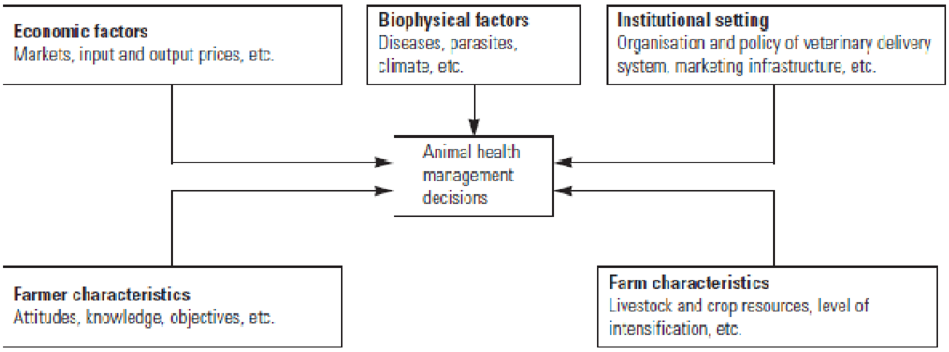

Figure 1.- **Conceptual model of factors influencing decisions made by small-scale farmers in animal health management** (Chilonda et Van Huylenbroeck, 2001).

The challenge in modelling farmers' individual behaviours in relation to animal health is to take into account the fact that individual control decisions are taken in regard to a particular disease at two levels: (1) at the farm level the sanitary status of the herd (within-herd prevalence, expression of the disease) will have an impact on production; (2) but also, in the case of a communicable disease, for a group of farms in contact, the expression of the disease (between-herd prevalence) will impact on the probability for a farm operating in an area to be infected due to animal purchases, neighbourhood contacts, airborne transmission, etc. To model these individual behaviours, it becomes necessary to model the impact of the disease on the production on the one hand, to establish a relationship between the output and the control inputs on the other hand. Finally, in the case of communicable diseases, the model should take into account the uncertain nature of the herd's infection.

In the economic literature, little attention has been paid to the formalization of farmer's behaviour in regard to animal disease control in a neoclassical way. This issue emerged in the late 1980s in the United Kingdom (McInerney, 1996). Based on the production function concept, basic microeconomic approaches were implemented 1) to show how the disease could alter the shape of the production function (McInerney, 1988), 2) to define the loss-expenditure frontier concept, which highlighted the tradeoffs made by the farmer between the production losses caused by the disease on the one hand, and control expenses on the other hand (McInerney, Howe and Schepers, 1992). The adopted approach is the minimization of the economic cost of the disease (understood as the sum of the losses induced by the disease and the control expenditures). In the 1990s, the question of the profile of the loss-expenditure frontier was discussed by Tisdell (1995), who also adapted McInerney's framework to the multiple diseases management. Finally, inspired by developments in the economic literature on pesticide use (damage abatement function), Chi et al. (2002) have finally taken in consideration the problem of modelling the farmer's behaviour in regard to animal diseases, with a particular focus on the tradeoff between preventive and curative expenditures. In this latter work, the farmer's decisions are based on the level of the disease, which simultaneously covers the prevalence and severity.

The main limitation of these first attempts to formalize the farmer's animal health decisions is that they consider a farm in isolation and do not take into account the fact that the farm faces a risk of infection. Decisions are taken in regard to the epidemiological situation of the herd, and the epidemiological situation within the herd is only influenced by the farmer's decisions. This assumption may only hold in the case of non-communicable diseases. For communicable diseases, it is reasonable to assume that the farmers takes primarily into account the herd's sanitary conditions (prevalence and severity of the disease) when taking his decisions in regard to disease control, but the risk of infection (or re-infection) of the herd remains influenced by the inter-herd prevalence in the geographical area considered.

The modelling of farmers' individual behaviors in regard to animal disease management will have to take into account: (1) the epidemiological situation of the herd, which could lead to a first integration of epidemiological elements (within-herd model) because the possible evolutions of the herd's epidemiological situation will affect the actions implemented by the farmer, and ; (2) the between-herd epidemiological situation, which constitute an external risk for the herd. The model should then take explicitly into account the risk and uncertainty which vitiates the decision-making process.

A crucial element for our concerns is the inclusion of time in our model The choice of a type of model (static vs. dynamic) is intimately linked to the livestock system considered which involves different length of longer or shorter rearing cycles of the respective disease and control measures available (single decision on the planning horizon vs. repeated decisions). For repeated decisions with fully reversible choice, a static model can be used. Rat-Aspert and Fourichon (2010) used a decision tree at each time step to formalize the decision of farmers. But when the decision is not fully reversible, and when evolution of the epidemiological state of the farm account for the decision, using dynamic programming seems necessary. This issue also raises the question of the planning horizon of the farmer (reasoning taking into account the dynamic reasoning versus steady state). The nature of the choice of farmers that is modellised (discrete choices such as vaccination or standard consumption model with continuous variable) leads to different tools. For a discrete choice, a decision tree can be used, while for a continuum of choice, farmers' choice must be modellised by the profit optimization of a production function. The latter case allows studying the tradeoff in resource allocation between control expenditures and other farm inputs.

Depending on the characteristics of the disease considered, it is also conceivable to improve the realism of the model from different aspects. The model could, for example, explicitly address problems of information (imperfect information on the local epidemiological context, for example). It could also take into account risk aversion of the farmer, for example.

2. Coupling of epidemiologic and economic models

The first step that modelled individual behaviours does not account for an important issue in animal diseases: for transmissible diseases, the sanitary situation of a farm (within-herd prevalence) has an impact on the sanitary situation in an area (between-herd prevalence), and vice versa. So, when a farmer protects his own herd, he also protects the other herds, by reducing the probability for other herds to be infected. Individual management of transmissible disease therefore creates a positive externality. This second step aims to evaluate the impact at a collective scale of decision taken at an individual scale by a large population of farmers. To that purpose, models designed to represent individual behaviours must be coupled with an epidemiologic model at a between-herd level, taking into account the spread of the disease when means of control are - or not - implemented at the scale of farms. The coupling of economic and epidemiologic models is an idea that emerged nearly 20 years ago, leading in health economics to the sub-disciplinary field of economic epidemiology (Brito et al. 1991; Philipson, 1999 ; Gersovitz and Hammer, 2001 and 2003). It is only very recently that early works sought to transpose this approach to the issue of collective control of endemic animal diseases (Gramig, 2008; Rat-Aspert and Fourichon, 2010).

The main idea is that, in the case of a non regulated endemic disease, the individual decision of farmers to manage a disease at the herd level is made based on the health status of livestock and the local epidemiological context. The prevalence of the disease in the area, as well as the health status of the herd, are key elements in decision-making. The decision affects the local epidemiological context. The dynamic coupling of an epidemiologic model (which describes the evolution of the local epidemiological context based on the decisions taken by the farmers) and an economic model (which describes the decision making of farmers according to the local epidemiological context) allows combining, in a unified framework the contributions of economic and epidemiological approaches. This reasoning can be illustrated on the basis of Rat-Aspert and Fourichon. (2010) (figure 2.)

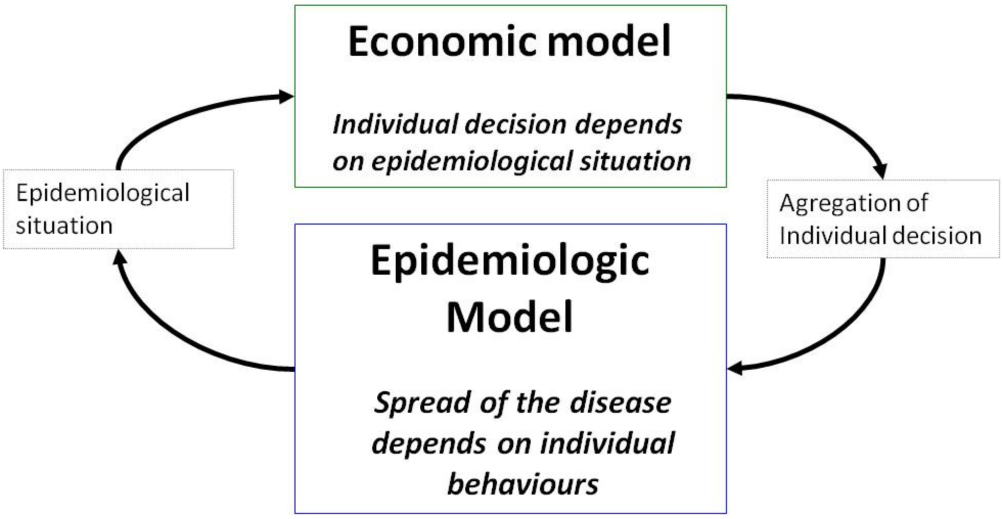

Figure 2.- Coupling economics and epidemiology

In the case of a management decision repeated over time (i.e. the farmer decides each time period to act or not against the disease), such an approach allows to follow the evolution of the prevalence and level of effort by farmers over time. Feedbacks between individual decisions and prevalence lead to fluctuations related to the fact that control efforts made by the farmer depend on the external risk. This high degree of effort has an impact on the prevalence of the disease in the area, which in turn may cause farmers to change their levels of effort. It follows that these changes in prevalence may - or may not - result in an equilibrium. Figure 3 gives an example of these situations for an endemic disease controlled by voluntary vaccination

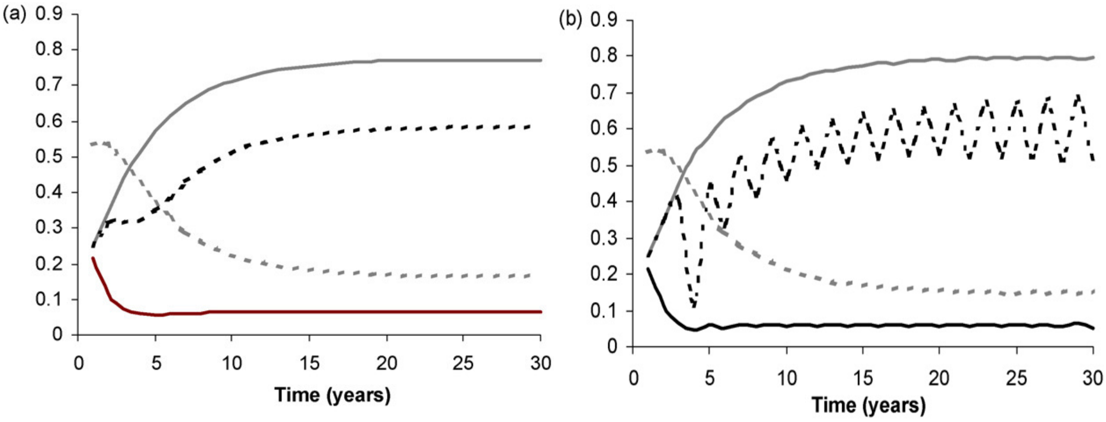

Figure 3. - Evolution over time of the proportions of herds in the state Susceptible S (grey curve), Infectious I (black curve), Recovered R (grey dotted curve) and Vaccinated V (black dotted curve) herds with (a) a strong heterogeneity of losses and with (b) a smaller heterogeneity of the losses

The coupling of economic model to an epidemiologic model also allows the study of epidemiological and economic equilibrium (Figure 4). The economic model determines the effect level of effort by farmers, depending on the prevalence of the disease. The epidemiologic model provides value for its prevalence as a function of the intensity of efforts of farmers.

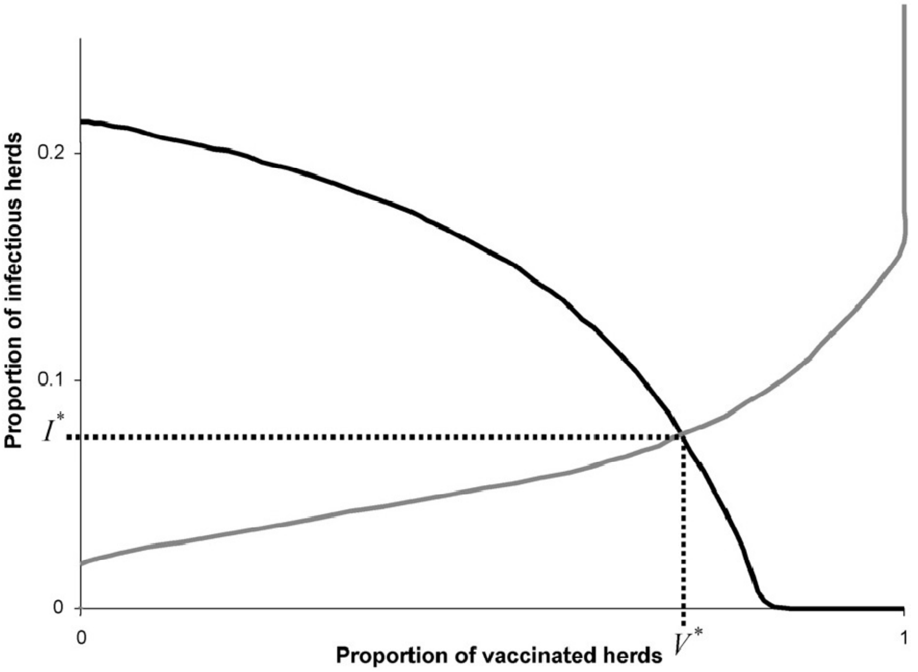

Figure 4. - The relationship between the proportion of infectious herds and the proportion of vaccinated herds. The grey curve shows the proportion of farmers with a susceptible herd who decide to vaccinate their herd as a function of the prevalence, the black curve shows the prevalence of the disease at the equilibrium for a given value of the proportion of vaccinated herds. The crossing of the two curves gives the value of the prevalence I* and of the proportion of vaccinated herds V* at the equilibrium.

Between-herd prevalence is an indicator of the probability for a farm to be infected by the disease, the level of effort made by farmers (from the economic model) is, in our example, an increasing function of the prevalence (shown by the gray curve in Figure 3). This is the case for disease control through vaccination (the higher the prevalence, the higher the risk of infection is, and the higher the willingness of farmers to protect their herds by vaccination). On the other hand, the effort to control leads to a decrease in prevalence (positive externality associated with disease control) (black curve). The comparison of the epidemiologic model and economic model then determines the prevalence and control efforts of farmers to reach the endemic equilibrium. This equilibrium is achieved when the control effort made by farmers for a given level of prevalence corresponds to the effort needed to obtain that prevalence. This simple representation of the confrontation between decision and epidemiology has similarities with the representations of the market and perfect competition. Atomicity of farmers involves they make their decision based on the prevalence but do not have the power to "fix" prevalence. The homogeneity of farmers and of the prevalence ("perfect mobility" of the pathogen) induces a shared risk between all the farmers: each farmer suffers the same prevalence. Perfect information is a key assumption of obtaining the equilibrium: farmers have perfect knowledge of between-herd prevalence, allowing them to adjust the control effort according to the prevalence.

The illustration above is based on strong assumptions it would be interesting to relax (taking account of imperfect information regarding the prevalence of the disease in the area, irreversibility means of control, for example). Note also that elements of game theory could be mobilized to formalize potential strategic behaviour of farmers (free-riding behaviour, for example).

3. Design of incentive mechanisms

When the individual control of disease induces positive externalities, the efforts of farmers may be insufficient to achieve a collective optimum, since individual decisions do not usually take into account their impact on collective risk. In human health, Brito et al. (1991) have shown, for example, that a voluntary vaccination strategy is strictly dominated by a benevolent dictator status, maximizing the collective welfare (defined as the sum of individual utilities). The results of individual management of diseases at farm level may then differ in various respects of collective expectations, leading to a need to manage collectively this risk.

Producers may want to influence collectively the management of a disease and its impact in their area. Their goal may be epidemiological (disease eradication, limiting viral circulation) or economic (maximizing collective welfare). To do so, the collective decision-maker can develop individualized plans to control at the farm level (tests on farm animals, remediation). They can also incite farmers to control the disease (by providing financial incentives to management, through vaccination or through biosecurity measures, the implementation of control plans at the farm level). The establishment of networks of exchange of animals based on their health status is also possible. However, the success of collective action depends on their acceptance by farmers. Collective management of the disease can also include measures of risk sharing. Infection of livestock by the disease poses a risk, a mean for collective management of that risk is to pool it through insurance mechanisms. This pooling of risk may also impact on individual decisions of farmers.

Predicting the outcome of these collective actions of animal health management is complicated because it must take into account individual choices in the implementation of control actions. Thus, integration of collective actions in epidemiologic and economic models is a support tool for decision makers. It is introduced into the decision model an effect related to the means of collective management in place (financial incentives to individual management for example). This type of model allows to test scenarios and also to optimize means of collective control. It is important to distinguish two stages in the implementation of the action of control. As a first step, actions are implemented, they have an impact on the epidemiological situation. In a second step, equilibrium of the epidemiological situation is reached. This equilibrium may be endemic or control action may lead to eradication. Modelling should look at these two stages. The epidemiological desired equilibrium may be a result of the model (equilibrium maximizing the objective function of a manager) or may be exogenous to the model (when the manager's objective is epidemiological: eradication or reduction target in terms of prevalence). The search for the optimum balance does not require a dynamic model since the results at equilibrium can be calculated. However, for more complex models, the equilibrium values are taken from simulations of the evolution of the disease and the decisions of farmers obtained using dynamic models. This dynamic modeling is also necessary to optimize the means of achieving equilibrium in the case of an equilibrium set exogenously, but also to verify that the equilibrium is achievable in the case of an equilibrium optimizing the collective welfare. This objective function must take into account the costs for the manager and profits for farmers. The question of the function to be optimized depends on the purpose and means of the manager. Indeed, to take the example of farmers' health management groups, a large portion of the funds allocated to the control comes from contributions from farmers themselves. Since management is not regulated, looking for optimum balance incentives / penalties as proposed by Brito et al. (1991) does not seem possible (farmers' groups can easily provide incentives to management, but the introduction of penalties seems inconceivable). Collective management is thus a reallocation of resources from farmers.

Conclusion

Because of feedbacks between farmers' individual decisions and disease spread, it is necessary for the study of endemic communicable and non-regulated diseases, to couple an epidemiologic model describing the evolution of the disease in an area and an economic model describing farmers' decisions based on the health status of their livestock and local epidemiological context. This conceptual framework should be the basis for the development of integrated models, for testing and optimizing tools for collective control of animal diseases. The implementation of this framework for diseases of interest is an important research issue in the field of animal health economics. The coupling of economics and epidemiology can found another application for externalities due to asymptomatic carrying of pathogens. In this latter case, the externality affects the transformer who can be interested in the management of the disease.

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