Livestock epidemics and catastrophic risk management: State of the art and prospects on economic dynamics

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Abstract
The economic consequences of livestock epidemics have been long studied for purposes of estimating the costs of the veterinary measures. In this paper, we show that this catastrophic risk may have wide market consequences, and that the risk management systems are quite limited to compensate long term impacts in the European context of growing trade. Through a detailed literature review we present the main developments of the economic literature aiming to highlight the economic consequences of animal epidemics such as Foot and Mouth Disease. We acknowledge that a very few studies have focused on the economic dynamics and on the long run effects occurring after an epidemic disease outbreak. We discuss the appropriateness of a dynamic approach to reveal that the de-structuring of the livestock markets affects the production dynamics as well as the whole agricultural sphere, whose financial implications remain poorly studied. In addition, we highlight the importance of taking into account these phenomena for the development of risk management systems, and we emphasize the growing interest of a dynamic Computable General Equilibrium approach.

1. Introduction

European livestock activities are mainly concentrated in a few major production areas. The stability of livestock sectors is therefore of particular importance to regional economic balance. The occurrence of epidemic animal outbreaks – such as Foot and Mouth Disease (FMD) – thus constitutes a risk that is highly detrimental to regional agricultural economy. Epidemic diseases can indeed result in significant market disruption, provoking abrupt changes in the behaviour of economic agents, sometimes lasting in the long run.
The economic risk associated with epidemic disease risk may indeed be considered as systemic and catastrophic. The occurrence of such an event has important economic consequences, going beyond the only loss of production and cost measures of disease control. They may indeed affect all firms in an animal production chain (from the farm supply sector to the retailing sector) and by extension the entire regional economy due to media and market impacts, and regulatory requirements. This context highlights the importance of the implementation of effective mechanisms for risk management when epidemic diseases occur, especially in intensive livestock production areas.
Based on the recent developments of economic literature, this paper aims to identify the economic behaviours and phenomena following an epidemic outbreak, in order to better identify the extent of the economic consequences of epidemic risks, and ultimately enhance the expertise to design management policies.
This text is organized as follows. We first look at the economic consequences of the epidemic diseases and draw up a quick inventory of the current measures of intervention, highlighting the heterogeneity of policies implemented at European level (1.). We then provide a review of economic studies for the evaluation of the economic consequences of epidemic outbreaks, for control strategies and risk management (2.). Thanks to the identification of the main shortcomings of the analysis, we highlight the salient points of management methods of epidemic risk and economic behaviour barely touched upon in the field of animal health, including the importance of taking into account the economic dynamics generated by epidemics and their management (3.). This paper allows us to conclude by outlining new perspectives in the field of economic research and of health risk management.

2. Public and private management of epidemic risk

The high concentration of the European production basins of livestock is an important factor of health risk exposure. The vulnerability to health hazards tends to be reinforced by the increasing openness of agricultural markets and increased flows of goods resulting. It also tends to be enhanced by global warming, that promotes a migration of diseases originally coming from warmer geographic areas, as the recent the case of bluetongue in Europe.

This section focuses on the health risks stemming from the epidemic and on the economic consequences of their occurrence in agricultural markets and more widely. We also address the issue of management modes of this epidemic risk, noting in particular the role of the European public and private stakeholders in the management of such health crises.

2.1. Epidemic diseases: what about markets?

Livestock diseases cause many market distortions. The 2001 health crisis caused by FMD in the United Kingdom highlights the magnitude of the economic effects of animal disease outbreaks. More than 1,800,000 sheep were slaughtered, about 400,000 cattle and 110,000 pigs. Consumption of sheep meat dropped up to 30% in the following months. To avoid any risk of disease, the French health authorities carried out the slaughter of 50,000 animals (mainly sheep) imported or having been in contact with them defensively. For 2001 alone, UK gross domestic product was estimated to fall by more than 3 billion Euros. The media impact of this crisis led to a 9 billion Euros decline of tourism spending that only year and these sectors only regained their previous activity levels until several years later.
In the present section we aim at providing keys for the understanding of the economic determinants of epidemic diseases, and at defining their sources of market risk.

2.1.1. Economic context and risk factors

Farms exposure to health risk is promoted by risk factors such as structural, political or geographical conditions. First, the trade liberalization facilitates the exchange of agricultural products, vectors of pathogens.
In recent decades, the Common Agricultural Policy has been able to protect the European market and to limit its exposure to international competition. Accordingly, livestock farms have had an economic incentive to specialize their production and to increase the size of farms for economies of scale. However now, the phasing out of protection instruments of the CAP and the opening of European markets make livestock sectors more vulnerable to market fluctuations. Specialized livestock farms only derive their viability from their animal product; as a consequence they cannot benefit from an insurance effect related to a diversification of production facilities. Moreover, the growing transit of agricultural products increases exposure to health risk. The concentration of livestock production in small basins also participates to ease the disease transmission from animal to animal, and from farm to farm.

2.1.2. Market risks

The occurrence of animal disease causes health risks of varying magnitude in animal production chains. Endemic diseases are considered as commonly present across geographical areas. Their impact is generally limited to the infected farms and their control is mostly left to the initiative of breeders. At the opposite, epidemic diseases occur in commonly disease-free regions, and as they are highly transmissible their occurrence may be highly detrimental to the livestock sector. This section focuses on epidemic non-zoonotic diseases such as FMD. The occurrence of this kind of disease implies a complex interplay of direct and indirect economic consequences (Junker et al., 2009). The highly contagious nature of certain diseases and/or their zoonotic potential may justify a public intervention. A list of diseases considered as contagious is established by the World Organization for Animal Health.
The **direct effects** of such a disease focus on the supply levels of animals and animal products in the infected country. The supply of animals and animal products is directly impacted, because of the disease consequences on livestock (mortality, morbidity), which affect the technical and economic performance of the farms.
Indirectly, the policies implemented to control the disease have effects on both the supply and the demand for animals and animal products. Indeed, the control strategy has a depressive effect on the supply level, through the decisions of curative and preventive livestock slaughter, through decisions to quarantine or through bans and restrictions on marketing of

animals and animal products. These measures not only include the infected farms, but also those located in a wider area (from a local to the national level).
A disease outbreak and the linked control measures also affect demand, since they can lead to a loss of consumer confidence in some animal products (product perception), even in the absence of known risk to human health. Nevertheless, the disease may have beneficial effects for animal production sectors not affected by the epidemic, since consumers can shift consumption toward animal products whose image is not tarnished by the disease. This makes the market impact of a disease occurrence difficult to grasp.
In an open economy, traditionally exporting countries suffer export restrictions. The amounts originally sold on international markets remain available only on the domestic market and lead to falling prices. While the welfare of consumers increases, on the contrary there is a net loss of surplus to producers. Producers lose their flexibility for marketing opportunities; they become price takers (Schoenbaum and Disney, 2003). However, for importing and disease free countries, the decline in imports creates a situation of excess demand that can help to support prices and/or call a change in the geography of trade.
The economic disruption resulting from an outbreak encourages the private and public stakeholders to develop risk management systems for farms in the relevant markets.

2.2. Defining devices for epidemic risk management

In Europe, the economic policies of epidemic risk management and hedging strategies implemented by different EU countries are not harmonized. Even though some proven systems are set for the management of direct economic losses due to disease, coverage for loss of market suffers from some limitations.

2.2.1. Covering direct losses

The coverage of direct losses includes the compensation for costs of slaughter, the aid for restocking and the compensation for production losses. In Europe, we find a wide range of heterogeneous coverage systems of direct losses, from public to exclusively private systems.
Since 2009 however, Article 70 of the "Health Check" of the Common Agricultural Policy (CAP) provides a common framework for crop insurance animals and plants. It states that "*Member States may grant a financial contribution to premiums for […] animal [...] insurance against economic losses caused by [...] animal or plant diseases*" The considered economic losses concern of bans on marketing and production losses (sick and slaughtered animals...). Article 71 of the "Health Check" of the CAP also provides for the establishment of mutual funds for animal disease outbreaks. It aims at supervising the public support to agricultural mutual funds for the compensation of economic losses related to a disease outbreak. This is to harmonize national measures whose implementation has already been initiated in many countries of the EU and make mandatory membership in mutual funds.

2.2.2. Covering indirect losses

Indirect losses due to epidemic diseases involve all stakeholders in the sector concerned by the epidemic. The coverage aims to support the market as it is destabilized and causes large drops in prices and thus reduces the farm income.

- Public intervention

Until nowadays, we have generally observed specific releases of funds to support the productive sectors when market conditions weaken the agricultural sector at a systemic scale.
Articles 44 to 46 from the recent Disposition No. 1234/2007 establishing a European single common market organization provide exceptional measures to support the animal markets. Article 44 states that "*The Commission may adopt exceptional support measures for the affected market in order to take account of restrictions on intra-Community and third-country trade which may result from the application of measures for combating the spread of diseases in animals*". These supports cannot be implemented unless they are accompanied by sanitary

measures to fight the disease. The Commission may also grant financial support to the market during "*disturbances directly attributed to a loss in consumer confidence due to public health, or animal health risks*". European support allows the application of solidarity principles on a large scale, which is necessary in cases of systemic risks.

• The difficulties of private action

In order to securitize insurance companies face to catastrophic and systemic risk, private reinsurance may be useful. These private-sector firms would play the role of "insurer of insurers"; they are built on the same principle as conventional insurance companies, by pooling uncorrelated risks. However, as the scale of systemic risk increases, as in the case of epidemic diseases, private funds reinsurance cannot always carry out the reinsurance of conventional insurance systems (Meuwissen et al., 2006). In practice, the private reinsurance is little involved in insurance systems linked to health risks, and that is a reason why the EU has recently proposed the previously mentioned public measures of the single CMO.

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To conclude, the economic consequences of epidemic risks are potentially high as they affect agriculture and other sectors of the economy. Therefore they are subject to public and private actions, which are sometimes limited. The study of these phenomena is discussed in the literature and actually does highlight the economic impact of animal diseases and their control. Their analysis is detailed in the next section.

3. The economic evaluation of the consequences of epidemic disease: literature review

The purpose of this section is to present the main developments in the economic literature relating to epidemics. This field has emerged from veterinary scientists in the 1960's, in order to offer an assessment of the economic cost of the diseases. The methodologies implemented were inspired from accounting methods and they have gradually integrated more complex reasoning, taking into account elements of welfare and exceeding the scale of the single farm. In this section we will focus on the close relationship between health risk and economic risk, detailing the behaviour of the economic agents involved and their implications for markets.

3.1. Direct effects of epidemic diseases: estimating costs and mitigation strategies

The studies on direct effects of disease are mostly focused on agricultural activity and they are relatively numerous in the field of animal health. They were frequently used to estimate the cost of the epidemic, mostly across the farm, but their level of aggregation may also be higher. They are sometimes combined with epidemiological models to simulate and prioritize different control strategies by determining for each the costs and benefits.

3.1.1. Cost-benefit analysis and linear programming

Cost-benefit analyses (CBA) are widely used because they are a quick way to assess the isolated consequences of disease and of control strategies. In this sense, the CBAs are an effective aid to decision for both producers and public authorities and veterinary services. For larger scale studies, farm-scale analyses can be extrapolated to a wider scale by combining CBA with a diffusion model of the disease (Disney et al. 2001). To capture time effects, Perry et al. (1999) conduct a multi-period CBA to assess the costs of management strategies in the case of FMD. However, this type of study remains only suitable in the short term and it quickly reveals its conceptual limits for analysis of long-term. Indeed, the producer behaviour is not explicitly modelled, as well as market interactions between animals and animal products and other agricultural or non-agricultural markets. Using the CBA tools does not permit to observe the economic behaviour implemented as a result of animal diseases.

Linear programming techniques offer more flexibility and allow for changes in producer behaviour over time (e.g. related to the evolution of the epidemic). Based on optimization calculations, this technique permits to define endogenously economic behaviour of farmers over time under different constraints, related to the both contexts of production of health. As

an example, this method allows Meuwissen et al. (1999) to estimate the financial consequences of classical swine fever along the production and processing chain. In this sense, linear programming may help to determine the levels of effort needed to face the emergence of epidemics.
CBA and linear programming give precise estimations of the direct costs of the disease. They are a definite support to the decision for the choice of optimal strategy of struggle. However, these tools face methodological challenges for modelling market behaviour. They remain relevant only if the price effects and economic spillovers are negligible (Rich, et al., 2005).

3.1.2. Lessons from studies of economic equilibrium

Partial and general equilibrium modelling of behaviour of economic agents is likely to provide a more systemic outlook of the economic impacts of animal epidemics. It contributes to the identification of optimal strategies for disease management, taking particular account of potential interconnections between sectors.
Recent studies show that the evolution of the epidemic over time has an economic impact not only on the agricultural sector concerned, but also on other animal and vegetable markets (Paarlberg, et al., 2008, Rich and Winter -Nelson, 2007). Indeed, the invasiveness and spread of the epidemic cause economic consequences of large scale covering losses incurred by the upstream and downstream sectors of the livestock sector. The high stocking rates also increase the risk of severe economic losses from an epidemic disease (Pendell, et al., 2007). The estimated magnitude of these consequences highlights the importance of preventive public policies and of effective mitigation strategies. More generally, the occurrence of an epidemic disease has a direct impact on the economic welfare of a region (Schoenbaum and Disney, 2003). Indeed, the direct impacts of the disease include among other costs of government control and eradication, production losses, loss of business due to declining supply, and the difficulty of re -access to markets.
A systemic view of the consequences of epidemic then allows the definition of more appropriate policies of risk management. Elbakidze and McCarl (2006) deal with the economic trade-off between prevention and control measures for FMD. The authors show that the cost control efforts are heavily dependent on prevention strategies in place, highlighting the catastrophic nature of economic risk. They conclude in favour of an effective prevention strategy to reduce the economic consequences of an epidemic.
As a conclusion, this section of the literature clearly shows the extent of the direct consequences of epidemic disease on the agricultural sphere, and therefore stresses the importance of implementing appropriate management systems. Nevertheless, as pointed Zhao et al (2006), the occurrence of an epidemic outbreak affects market conditions and induces behavioural changes for consumers and producers, as well as trade restrictions. As a result, they impact both on domestic markets (through supply and demand, multiplier effects ...) and on international trade (through volumes and prices of imports and exports). The study of these impacts is the subject of the next section.

3.2. Systemic consequences of epidemic outbreaks

The application of international measures to limit the spread of the epidemic may impact on world agricultural markets. Moreover, the negative media coverage of these diseases can lead to changes in demand behaviour, not only on the consumption of agricultural goods, but also on the attractiveness in areas affected by the epidemic. In this section we detail the induced effects of animal disease outbreaks analyzed in the economic literature, particularly through partial and general equilibrium modelling tools.

3.2.1. Sector effects and international effects

Quantifying the impacts of livestock epidemics on upstream and downstream sectors remains poorly addressed. However, their inclusion stresses the importance of the possible effects of

health crises on this scale, especially for manufacturing industries and for markets mainly turned towards the domestic market as that of beef (Rich and Perry, 2010). The trade implications of an FMD outbreak affects many other areas related to agricultural livestock, foremost among which there are the animal feeding markets (Paarlberg et al, 2008).
At the international level, we generally observe a decrease of demand for the animal products when an epidemic disease occurs. A major reason for this drop comes from health embargoes put in place to prevent disease spread outside the borders of infected countries. This has been observed at various recent health events. Thus, during the epidemic of classical swine fever in the Netherlands in 1997-1998, the surplus of pig raising activity dropped because of export restrictions (Mangen and Burrell, 2003). The 2003 bovine spongiform encephalopathy (BSE) outbreaks in Canada and the United States have also led to trade bans with direct impact on the levels of prices paid to producers (Panagiotou and Azzam, 2010). These cases have changed the pattern of trade in animals and animal products in these traditionally exporting markets. After reopening the Canadian border to beef imports from the U.S., the price level has not regained its previous level, but stabilized at a level of 35% lower than pre-crisis. However, the reopening of trade with Japan has led to greater export than before the onset of the disease. In the longer term, it was found that the BSE crisis has finally been little effect on domestic prices of livestock. In contrast, the reaction of other governments (Japan, Korea) had a greater impact and trade restrictions have been considered an important factor in lower prices, rather than the reaction of the U.S. households (Marsh et al., 2008).
Morgan and Prakash (2006) explain the strong international impact of episodes of localized epidemics by the growing internationalization of animal markets, by the soaring global demand in livestock products and by the high concentration of livestock in the main exporting basins. Indeed, in case of an epidemic, these factors are conducive to high price disturbances in international markets. Nevertheless, the volumes available on the international markets are poorly affected thanks to a quick increase of supply from free countries.
These examples of impacts on agricultural markets support the idea that the epidemic risk management must integrate these disturbances. Post-epidemic market shocks have an economic impact that affects the entire livestock market, and they may induce spillovers in the linked industries. Moreover, demand levels for livestock products may be more generally affected by changes in consumer behaviour.

3.2.2. Effects on the demand behaviours

Consumption patterns are influenced by the occurrence of epidemic diseases. They may change in a more or less sharp and permanent way as a result of concerns expressed by consumers. Levels of demand for livestock products may shift due to deviations of preferences of domestic demand (Junker et al., 2009). For example, consumption levels fell up to 20% during the recent France FMD crisis. Economic modelling can account for the effects of changing demand on prices and demand levels in agricultural goods.
Demand behaviours remain closely linked to risk perception by consumers (Mazzocchi et al., 2007), not necessarily when the risks for human health are found. The media coverage of a health event is likely to alter the consumer perception of the products concerned. In light of recent health scares, it appears that when the consumers perceive a health risk, they can divert their consumption of animal product over variable time (Tonsor, et al., 2009). Nevertheless, this diversion of consumption generally benefits to other animal production sectors. Therefore, the occurrence of epidemic diseases has potentially significant impacts on demand levels, which can variously affect the animal production sectors. Böcker and Hanf (2000) explain changes in consumer confidence in the health quality of food in two stages. In the early moments after the media coverage of the health crisis, food fears relate to a wide range of products, which they turn away, possibly in favour of substitutes. Thereafter, usually a few months later, a partial return of confidence in demand is observed for these products. One can indeed observe sustainable diversion of part of the demand for meat products after a health

crisis. Nevertheless, as pointed Park et al. (2008), in most cases, the occurrence of epidemics in the beef industry actually induced falls in consumption and a return to its original level by about a year and a half. The recent example of avian influenza in France showed a shorter loss of confidence, lasting about a quarter (Magdelaine et al., 2008).
Moreover, an economic evaluation of the 2001 FMD outbreak in the United Kingdom showed that the losses associated with the disease greatly exceeded the agricultural framework. Sectors directly related to tourism spending have indeed suffered a financial loss level equivalent to that of the agricultural sector and a decline in gross domestic product (GDP) of 0.2% was observed (Thompson et al., 2002). It seems that the economic activities related to tourism have indeed been significantly affected by negative media coverage related to health crises in the livestock sector. This result was corroborated by studies involving the use of general equilibrium (CGE) (Blake et al., 2002, O'Toole et al., 2002). The estimated market consequences of this crisis has highlighted that the most affected sectors were those related to tourism and food distribution. Concerning agriculture, the conclusions remain more mixed: the economic losses associated with the disease and control measures were in large part offset by higher prices for beef, following the tightening of supplies.
Understanding of economic phenomena arising from health crises in the livestock sector is authorized by the modelling of economic equilibrium; it highlights the fact that health crises quickly become crises image. Their economic impact can affect whole economies and disrupt the agricultural markets and activities. They underpin the need for establishing strong support to the territories and to the farming profession.

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The economic literature on the economic consequences of health crises in livestock shows their systemic nature, the extent of their market impact and the importance of their understanding for the establishment of management systems. The exploration of multisector, regionalized and dynamic approaches can help give new insights on economic fluctuations from health risks. These prospects are the subject of the next section.

4. On the utility of a dynamic approach to public management of epidemic risk

Economic studies relating to epidemic diseases highlight the extent of the effects of health crises. Nevertheless, as revealed by the literature review, few studies are still exploring the long-term economic effects of catastrophic risks and the consequences potentially undermining the structures of farming. This section aims to suggest innovative ways of research to provide a more complete consideration of market behaviour towards risk, in order to identify the place and timing of public action for their management.

4.1. Catastrophic risk and market dynamics

The main studies relating to the consequences of the epidemic on the agricultural structure provide a framework for static analysis, as emphasized in the literature review. Nevertheless, some recent studies have begun thinking about economic dynamics resulting from these crises. Zhao et al (2006) analyze the effects of on the dynamics of breeding decisions after an FMD outbreak. On the same model, the study of Paarlberg et al (2008) shows the effects of short term to long term to an FMD outbreak, which are highly dependent on the length of livestock production cycles. Rich and Winter-Nelson (2007) also show the existence of dynamic effects of an FMD outbreak through a multi-market model.
These few studies show that the market shock induced by an outbreak can cause changes in the livestock breeding decisions, which result in long-term productive and economic consequences. This market disruption is an integral part of the indirect consequences of the catastrophic risk.
Moreover, the demand behaviour and decisions on rules of trade are also changing consecutively to the occurrence of a health crisis. Modelling these various phenomena in dynamic CGE is able to propose a joint study of inter-temporal disturbances related to supply,

to demand, to international markets, and their feedback effects. Similarly, this type of study provides a regionalized framework as to measure the systemic effects of a health crisis on the entire economy of an area of study.

4.1.1. Understanding the production dynamics

Market risks affect the behaviour of farmers. The prospect and the observation of falling prices may encourage them to change their production decisions, which in turn will affect the amounts offered and consequently the prices.

In general, the occurrence of demand shocks and changes in the cost of production factors give rise to cycles of production (Rosen et al., 1994). The herd structure is thus a function of external economic factors. According to the animal production considered, the production cycles have varying duration. The responsiveness to changing market conditions is not easy for all types of livestock farms. The adjustment speed of supply for livestock is indeed variable among animal species and production systems. In the case of cattle farms, the inelasticity is due to the relatively low fertility rate of cows and the time needed for breeding or fattening cattle. These several-years periods explain that production decisions are prior to business decisions; they condition the volumes available on the markets. Production choices are based on expectations about future market conditions. Cyclical fluctuations of economic courts, due to significant delays in biological processes in beef production (Chavas, 2000) and swine production (Chavas, 1999), may be compatible with effective management of an animal population with rational expectations.

The price changes induced by market reactions to a health risk are a signal to producers, who react through various production decisions. Depending on the nature of the expectations of producers, they may result in a persistent supply shock over time. The destabilization of markets following a health event can therefore have lasting consequences on the markets, because of the disruption of production structures.

4.1.2. Financial consequences for the livestock sector

The destabilization of farming systems as a result of these market shocks has implications on the farm. The market turbulence induced by the disease can cause significant fluctuations in income levels for farmers. When they cannot be maintained by measures of price support, farmers may be forced to resort to borrowing to maintain income and investment levels. Nevertheless, this debt induces additional expenditures related to interest on loans, which may threaten the solvency of the financially most vulnerable farms. A bankruptcy risk can then arise from this economic risk (Gohin, et al., 2010). Quantifying that risk as part of a dynamic CGE modelling can provide more comprehension of the long-term effects of epidemics.

Thanks to a dynamic CGE modelling taking into account the changes in demand and supply, these long-term effects of catastrophic risk may be useful to study the role and the development opportunities of management tools for the economic consequences of epidemic risk in the agricultural sector.

4.2. Prospects for the management of epidemic risk

The analysis of the economic literature on catastrophic health risks has identified some key elements of its management and raised research perspectives - the dynamic modelling of market behaviour - to capture long term effects. The following section contains forward-looking elements for long term management of catastrophic risk.

4.2.1. Issues about private action

Systemic effects of catastrophic risks induce a high degree of spatial correlation of market losses for the agricultural sector. It hardens the development of insurance mechanisms of income support because it undermines the strategies of risk diversification for the insurance companies (Skees and Barnett, 1999). In the context of climate risk on major crops, Miranda

and Glauber (1997) estimated that in the presence of systemic risk, insurance systems themselves are twenty to fifty times more exposed to risk than in more conventional and stochastically independent risks. In these circumstances and without adequate security assurances through reinsurance or public aid, the potentially exorbitant cost borne by the private insurance companies could sharply raise insurance premiums.

Tools exist in the financial system to fulfil an insuring role when risks are highly correlated (Mahul 2001). "Catastrophe Bonds" (Cat Bonds) are based on a risk transfer of agricultural production from insurance companies to investors in capital markets. Cat bonds operate the same way as conventional bonds; they are loans to corporate issuers by investors who, in turn, earn interest and repayments at the end of each agreement period. In return, investors agree to waive their interest and repayment of capital under certain conditions such as catastrophic events (as is the case of epidemic) (Vedenov, et al., 2006). These contracts transfer risk to capital markets. They are therefore attractive to insurance companies facing a strong systemic component in their portfolio of risks in case of an outbreak. Conversely, these bonds also attract financial markets, interested in investing in agricultural markets as it may be a source of diversification of their own risk.

Bypassing the public sector on matters of reinsurance may be possible by designing innovative general pattern of agricultural insurance including both classic and catastrophic risks (Phélippé-Guinvarc'h and Cordier, 2006). The authors show that the insurance industry can adopt strategies for full risk management, by sharing their expertise and transferring the highest risks to the financial sectors through futures contracts on prices or on crop yields.

More structurally, the integration of the agricultural sector in production, processing and retailing chains including may contribute to the sharing of production risk over a wider range of players. The introduction of futures contracts between growers and processors of animal products could also help share the risk, thanks to price settings before the marketing. Thus, the producer may receive an income guarantee that may prevent him to undergo strong fluctuations of prices induced by epizootics (Meuwissen et al., 2001). In fact, the adoption of these strategies was little progress, partly because of increased exposure to risk for the slaughtering sector. Actually, meat processors do not have any economic interest to support agricultural market risks, as the entire livestock marketing chain could suffer the consequences of any failures by slaughtering firms.

The ability to secure insurance markets for the loss of market of these systems is not questioned, but however private solutions remain unable to manage many economic risks. Health policies reflect their role in collective control of animal health and management of epidemics, as we shall explain in the next section.

4.2.2. Issues and development of public action

Animal health is a great public concern. It responds to a societal demand, and its maintenance needs expenditures that private actors are not always able to bear alone (Sumner, et al., 2006). Epidemic diseases are furthermore subject to significant uncertainties: moral hazard and negative externalities associated with past outbreaks, emergence of new diseases, systemic economic consequences, etc. These circumstances justify public intervention, and urge it to adopt measures to manage animal health, especially in areas where livestock takes an important economic role. Modelling the systems of public intervention in dynamic CGE may give guidance to the public authorities for the establishment of management systems. The issues relating to public intervention are the subject of this section.

- Supporting the producers and the supply levels

After a market shock related to a health event, maintaining the income levels and supporting structures of animal production can be achieved by setting up systems of income insurance, as Gohin et al (2010) stress it. These mechanisms may amount to loans at reduced rates to counter the risks of indebtedness or to measures in order to encourage the formation of a readily releasable savings, so as to enable farmers sustain themselves by their own activity.

The establishment of franchises or compulsory contributions may help reduce bias due to the asymmetry of information and limit the moral hazard of non-participants to bio-security measures (Gramig et al., 2009). Dynamic modelling of public support and of financial incentives can reveal changes in farmer behaviour that they induce.

Solutions to postpone the marketing are also possible to counter falling prices. The storage of carcasses can indeed help limit the influx of animal products on the market and thereby support prices. Those stocks may be marketed thereafter when market conditions are more profitable. Moreover, support measures for processing are also an important modelling issue of management measures to limit the market impacts. Indeed, under public leadership, industrial sectors may act as a buffer during periods of falling prices. The processing of fresh and perishable animal products into more shelf-stable products may lead all or part of the surplus of animal products to new markets that are less tense than for fresh products. Modelling such measures of process management may show their ability to limit fluctuations in prices received by producers.

- Preventive actions, control strategies and zoning

The public management of epidemics first needs the establishment of preventive measures to minimize their spread and thus their effects. Governments play a critical role in providing incentives to private actors in the management of animal diseases (Gramig, et al., 2006). An essential point is the encouragement to report disease outbreaks in the early times. Responsiveness is a key to a successful strategy, as the economic effects are even stronger than the disease spread widely (Devadoss et al., 2006). In addition, bans or restrictions on exports can be extremely costly to the livestock sector, hence the importance of early detection of disease to reduce these periods (Mahul and Durand, 2000).

The choice of an optimal strategy may still require a period of implementation, corresponding to the minimum time to acquire sufficient information about the disease, to calibrate the veterinary control measures and therefore cost management (Mahul and Gohin, 1999). Moreover, regardless of health management, public authorities send signals to markets, especially the demand sectors by influencing their own risk perception.

Management and mitigation of economic impacts of animal diseases also call for solving the problem with identifying infected areas and with land management. It was notably raised by Mahul and Durand (2000), which assessed the consequences of an FMD outbreak in France through the simulation of trade restrictions at various geographical scales. Trade restrictions to a level smaller than the country is likely to help restrain the market risk and thus minimize its impact. The zoning issue is particularly important for the French Western regions. Although the spread probability of an epidemic outbreak occurring in a remote region can be low, a decision to restrict trade for the whole national territory may have a heavy economic impact. The statement of an area as free or infected is thus crucial in terms of impacts on agricultural markets. Modelling the market effects and the welfare effects linked to the extent of the trade restrictions areas may highlight spatial issues of the risk management.

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To conclude, the behaviour of market participants cause economic dynamics that are a source of market instability. They are an integral part of economic factors to be considered for an optimal management of epidemic risk. The study of these economic disturbances emphasizes the importance of an appropriate government intervention in crisis management, including measures of income support and measures to limit the productive effects relating to the uncertainties over the duration of the health risk and of the trade restrictions. A dynamic CGE modelling of production and market behaviours can provide new insights to achieve this goal.

5. Conclusion

In this paper we investigate an almost neglected field of study that is the long-run effect of catastrophic shocks on agricultural markets. Indeed, although direct losses and short-term effects are already well understood, the long run market effects of epidemic outbreaks do not

benefit from an expanded literature. Their comprehension raises the issue of how to cope with risk and uncertainty on agricultural markets due to catastrophic risks. We argue that a dynamic CGE model focused on the livestock sector may provide a general framework for the simulation of private and public management measures and for the measure of the wide effects of catastrophic risks in a local economy. One crucial issue is the effectiveness of physical markets regulation versus a financial intervention in order to improve the resilience of the economy to this catastrophic risk.

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