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Abstract

The economic consequences of livestock epidemics have been long studied for purposes of estimating the costs of preventive and curative 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 research aiming at highlighting 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 relevance of a dynamic approach to reveal that the de-structuring of livestock markets affects the production dynamics as well as the whole agricultural sector. Financial implications and market constraints remain poorly studied in the livestock epidemics literature. We emphasize the growing interest of a dynamic Computable General Equilibrium approach to reveal the overall effects of epidemic outbreaks on the whole economy. This innovative research raises important challenges for the assessment and implementation of risk management policies.

Keywords: animal epidemic outbreaks, catastrophic risk, risk management

JEL classifications: G32, Q17, Q18

Risque catastrophique et gestion des risques : que savons-nous des maladies épidémiques d'élevage ?

État de l'art et perspectives

Résumé

Les conséquences économiques des épidémies d'élevage ont longtemps été étudiées à des fins d'estimation des coûts vétérinaires de mesures préventives et curatives. Nous montrons, grâce à cette communication, que ce risque catastrophique de maladie peut avoir de vastes conséquences de marché, et que les systèmes de gestion des risques restent, dans le contexte européen actuel d'accroissement des échanges, relativement limités pour en compenser les impacts économiques de long terme. Grâce à un examen détaillé de la littérature, nous présentons les principaux développements de la recherche économique mettant en évidence les conséquences économiques des épidémies animales comme la fièvre aphteuse. Nous reconnaissons que très peu d'études ont porté sur la dynamique économique et sur les effets à long terme survenant après l'apparition d'une maladie épidémique. Nous discutons ensuite de la pertinence d'une approche dynamique permettant de révéler que la déstructuration soudaine des marchés du bétail affecte à plus long terme les dynamiques de production ainsi que l'ensemble du secteur agricole. Les implications financières et les contraintes de marché peuvent révéler leur importance et restent peu étudiées dans les études sur les épidemies d'élevage. Nous insistons sur l'intérêt croissant d'une approche dynamique d'équilibre général calculable pour révéler les effets globaux des épidémies sur l'ensemble de l'économie. Cette recherche novatrice soulève des défis importants pour l'évaluation et la mise en œuvre des politiques de gestion des risques.

Mots-clefs : épidémies animales, risque catastrophique, gestion des risques

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1. Introduction

Western France is a major livestock production area in Europe. Livestock activities (beef, pork and poultry production and to a lesser extent sheep and goat production) take a prominent place and are an essential part of regional economy. 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 the regional agricultural economy. Epidemic diseases can indeed result in significant market disruption, inducing abrupt changes in the behavior 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. In contrast with a hazard that affects a limited number of farms (idiosyncratic risk), this economic risk has a systemic dimension. In a short time, epidemic diseases can reach a large number of livestock farms, the whole market, and even the wide regional economy, both for reasons of pathology (impact on productivity, communicability of the disease) and for reasons of control measures (e.g. marketing restrictions on animals and animal products). Epidemic disease outbreaks are hardly predictable and have a low probability of occurrence. As a consequence, the economic risk can also be described as catastrophic as the occurrence of such an event has important economic consequences, going far beyond the losses of production and the costs of measures of disease control. They may indeed affect all firms engaged in the animal production chain (from the farm supply sector to the retailing sector) and by extension, the entire regional economy due to multiplier effects of those market impacts, and regulatory requirements.

This context highlights the importance of the implementation of effective mechanisms for risk management when epidemic disease outbreaks occur, especially in intensive livestock production areas.

Based on the recent developments of economic literature, this paper aims at identifying the economic behaviors and phenomena following an epidemic outbreak, in order to reveal the extent of the economic consequences of epidemic risks, and ultimately enhance the expertise to design management policies.

This article 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 the European level. We then provide a review of economic studies for the evaluation of the economic consequences of epidemic outbreaks, for control strategies and risk management. Thanks to the identification of the main shortcomings of the analysis, we highlight the salient points of management methods of epidemic risk, and economic behavior 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. 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

At the European and global scale, livestock production is concentrated in a limited number of production areas. Animal densities are high and productions are particularly oriented towards export markets. Within these areas, the control of animal diseases raises a major issue because of the economic weight of livestock farming and the concentration of upstream and downstream industries, since an epidemic disease outbreak could have disastrous consequences on agriculture and local economic dynamism. Currently, this vulnerability to health hazards tends to be reinforced by the increasing openness of agricultural markets and increased flows of living animal and fresh meat resulting. It also tends to be enhanced by global warming, that promotes a shift towards the north of diseases originally coming from warmer geographic areas, as it was recently the case with bluetongue in Europe.

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

2.1. Epidemic diseases: what about markets?

Livestock diseases cause many market distortions. A recent health crisis in the United Kingdom highlights the magnitude of the economic effects of animal disease outbreaks, and illustrates the potential implications of a health crisis. In the UK, the 2001 FMD outbreak led to the slaughter of 2,382,000 animals, including more than 1,800,000 sheeps, about 400,000 bovines and 110,000 pigs. The consumption of sheep meat dropped by 25% to 30% in the following months. To avoid the introduction of the disease, the French health authorities carried out the slaughter of 50,000 animals (mainly sheeps), 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 (Thompson et al., 2002). The media impact of this crisis led to a decline of 9 billion Euros of tourism spending in that year, and these sectors only regained their previous levels of activity until several years later. This specific example is not isolated and many similar cases can also be described.

In the present section, we aim at providing keys for the understanding of the economic determinants of epidemic diseases, and at defining the sources of market risk associated.

2.1.1. Economic context and risk factors

Farms exposure to animal health risk is promoted by risk factors such as structural, political or geographical conditions. First, the trade liberalization facilitates the exchange of vectors of pathogens through the trade of living agricultural products. In recent decades, the Common Agricultural Policy (CAP) has been able to protect the European market and to limit the exposure of sectors to international competition, thanks to subsidies for exports and the establishment of tariff barriers to imports. In other words, this economic environment could help market prices not to suffer from significant changes. Accordingly, livestock farms have had an economic incentive to specialize their production and to increase the size of farms operations in order to realize scale economies.

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 increased exposure to animal health risks. The concentration of livestock production in limited geographical areas also contributes 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 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 (individual or collective) initiative of farmers. 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 in the French *Code Rural* (Article n°D223-21), as for 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, quarantine or bans and restrictions on marketing of animals and animal products. These measures include not only the infected farms, but also those located in a wider area (from a local to the national level).

A disease outbreak and the associated control measures also affect the demand side, since they can lead to a loss of consumer confidence in some animal products, and lead to fears linked to the disease, even in the absence of proven risk for human health. Nevertheless, the disease may have beneficial effects for the animal production sectors not directly concerned by the epidemic, since consumers can shift consumption toward animal products whose image is not tarnished by the disease. As an illustration, we can mention the case of the 1996 health crisis in Germany due to bovine spongiform encephalopathy, after which the beef consumption declined in favor of the pig sector. The economic impact of disease occurrence in the markets is difficult to grasp, because it largely depends on the extent of the impact on levels of supply and demand.

In an open economy and in the absence of a health event, the supply of livestock products can exceed the level of demand in the case of an exporting country. As a consequence, the coexistence of both domestic and international demands may lead to higher prices on the domestic market because of this high level of demand. In this situation, the exporting position of producers dictates the domestic market equilibrium; producers benefit from a market power. When an epidemic disease occurs and causes export restrictions, the amounts originally sold on the international markets remain available only on the domestic market. Consequently, the situation of oversupply in the domestic market leads 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 (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 both private and public stakeholders to develop risk management systems for farms in the relevant markets.

2.2. Defining devices for epidemic risk management

In the European Union (EU), the economic policies of epidemic risk management and hedging strategies implemented by different EU countries are not harmonized. Even though some experienced 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 is meant to include the compensation for the costs of slaughter, the aid for restocking and the compensation for production losses (milk, breeding of livestock ...).

In France, the coverage of those losses is almost exclusively in the public domain. When an outbreak occurs or when an exotic disease emerges, the government has historically played the role of insurer for compensation for economic losses. However, with the emergence or resurgence of certain animal diseases in the recent period, professional associations of health protection successively established a "FMD credit" in 1992 and an "animal health solidarity fund" in 2007 after the 2006 bluetongue outbreak. Nevertheless, most of the efforts of support remains in the public domain as membership in these funds is only voluntary.

With the exception of Denmark, which has a public device similar to that of France, EU compensation schemes involving farmers through levies exist in Germany, Belgium, Greece, Ireland and the Netherlands. The German system of state compensation is based on the tax levies to farmers and compensation amounts are limited; farmers also resort to private systems of insurance for uncovered losses. The Spanish system is based on voluntary private insurance, whose premiums are partially supported by the state.

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.*" (OJEU, 2009)

The considered economic losses concern bans on marketing and production losses of 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 at supporting the market as it is destabilized and causes large drops in prices and thus reduces the farm income.

- Public intervention

French public authorities have no clear procedure to insure indirect losses due to epidemics. We generally observe specific releases of funds to support the productive sectors when market conditions weaken the agricultural sector at a systemic scale.

At the European level, Articles 44 to 46 from the recent Disposition No. 1234/2007 establishing a Common Market Organization (CMO) provide exceptional measures to support the market in the sectors of animal production. 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.*” (OJEU, 2007)

These supports are activated at the initiative of Member States, they only add to national support, and they cannot be implemented unless they are associated with sanitary measures to fight against the disease. Under the same conditions, the Commission may grant financial support to sustain the market during “*disturbances directly attributed to a loss in consumer confidence due to public health, or animal health risks.*” European support to national measures allow the application of principles of solidarity on a larger scale, which is necessary in cases of systemic risks.

• The difficulties of private action

In order to securitize insurance companies facing catastrophic and systemic risks, 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.

To conclude this section, 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 epidemic diseases. This work has emerged from veterinary scientists in the 1960's, which progressively assessed the economic cost and benefits associated with these diseases and their control. The methodologies implemented were inspired from accounting methods and have gradually integrated more complex reasoning, taking into account elements of welfare and exceeding the farm level. In this section, we focus on the close relationship between health risk and economic risk, detailing the behavior of the economic agents involved and their implications at the market level.

3.1. Brief overview of the analytical tools mobilized

The occurrence of epidemic diseases involves various economic costs and changes, which justify the diversity of approaches used in assessing the economic impact of epidemic diseases and their control. The economic literature provides a variety of tools to address issues of various spatial and temporal scales (Rich, et al., 2005). Thus, economic evaluation can be conducted at the farm level (loss of productivity, control measures put in place), but it can also take into account the impact on trade and prices, the impact in terms of employment or the overall economic welfare. Depending on the perspective chosen, the number and diversity of agents involved vary: from local (farms involved) to international level, via levels of analysis sized to multi-sector, regional or national scales.

Early works were placed on the scale of farms and agricultural complex. Mainly inspired from accounting methodologies, they aimed at estimating the losses caused by diseases around the farm, with some weighing the possible mitigation of these losses against the control strategy implemented. In essence multidisciplinary, this work (like Cost-Benefit Analysis (CBA) or linear programming) intended to participate in developing strategies for the management of veterinary health risks.

They generally omitted the indirect effects induced by the disease, such as the effects on markets (trading volume and price) and the welfare effects, although it seems necessary to understand all the economic consequences attributable to disease epidemics. Understanding these phenomena requires the analysis of economic equilibriums, through partial equilibrium models, input-output matrices, multi-market models, and computable general equilibrium models. The market reactions resulting from the occurrence of an epidemic can have a strong impact on farm structures and on various sectors of the economy. Therefore, it seems necessary that their understanding be fully integrated into management systems of the health risks linked to livestock activities.

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

The studies on direct effects of disease are mostly centered 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 of them the costs and benefits.

3.2.1. Cost-benefit analysis and linear programming

Basic CBAs are built on accounting methods to calculate the direct expenditures incurred by the diseases. They are widely used because they are a quick way to assess the specific consequences of disease and of control strategies. In this sense, 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 higher level by combinating CBA with a diffusion model of the disease (Disney et al. 2001). To capture time effects, Perry et al. (1999) conducted 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-run and it quickly reveals its conceptual inappropriateness for long-run analysis. Indeed, the producer behavior is not explicitly modeled, as well as market interactions between animals and animal products and other agricultural or non-agricultural markets. Using the CBA tools does not allow us to observe the economic behavior implemented in reaction to animal diseases.

Linear programming techniques offer more flexibility and allow for changes in producer behavior over time (e.g. related to the evolution of an epidemic). Based on optimization calculations, this technique allows to define endogenously economic behavior of farmers over time under different constraints, related to the both contexts of production and health. As an example, this method was used by 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 constitute useful tools to support decision in terms of choice of an optimal control strategy. However, these tools face some methodological challenges for modeling market behavior. Indeed, they remain relevant only if the price effects and spillovers to other industries are negligible (Rich, et al., 2005).

3.2.2. Lessons from studies of economic equilibrium

Partial and general equilibrium modeling of behavior of economic agents is likely to provide a more systemic view of the economic impacts of animal epidemics. This kind of modeling contributes to identify optimal strategies for disease management, taking particular account of the 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 crop markets (Paarlberg, et al., 2008, Rich and Winter -Nelson, 2007). Indeed, the invasiveness and spread of an epidemic cause economic large scale consequences including the losses incurred by the upstream and downstream sectors of the livestock sector. The high livestock densities also increase the risk of severe economic losses resulting 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 ex-ante expenditures in preventive strategies may have both economic and veterinary advantages compared to ex-post control costs. They conclude in favor of an effective prevention strategy to reduce the economic consequences of an epidemic.

To conclude, the literature clearly shows the extent of the direct consequences of epidemic disease on the whole agricultural sector, and therefore, stresses the importance of implementing appropriate management systems. Nevertheless, as pointed by Zhao et al (2006), the occurrence of an epidemic outbreak affects market conditions and induces behavioral 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 considered in the next subsection.

3.3. 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 behavior, not only on the consumption of agricultural goods, but also on the global attractiveness of the areas concerned by the epidemic. These indirect effects are diffuse but remain fully involved in the destabilization of the markets following an epidemic outbreak. In this subsection we detail the induced effects of animal disease outbreaks analyzed in the economic literature.

3.3.1. Sector effects and international effects

Quantifying the impacts of livestock epidemics on the upstream and downstream sectors remains poorly addressed. However, their inclusion stresses the importance of the possible effects of animal health crises on this level, especially for manufacturing industries, and especially for markets mainly turned towards the domestic market as that of beef (Rich and Perry, 2010). The trade implications of an outbreak of FMD 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, the occurrence of an epidemic disease is sometimes accompanied by a decrease of demand for the concerned products. A main reason for this drop comes from health embargoes putted in place to prevent disease spread outside the borders of affected countries. This has been observed during various recent health events. Thus, during the epidemic of classical swine fever epidemic 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 restrictions on trade with direct impact on the levels of prices paid to producers (Panagiotou and Azzam, 2010). These two cases of BSE have modified trade patterns in animals and animal products in these traditionally exporting markets. After reopening the Canadian border to beef imports from the United States, the US price level has not returned gradually to its former 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 outbreak. In the longer term, it was found that the BSE crisis had finally little effect on the 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 households in the U.S. (Marsh et al., 2008).

Morgan and Prakash (2006) explained the strong international impact of episodes of localized epidemics by the fact that the livestock industries and animal markets are becoming more internationalized, because of the surge in global demand of livestock products and the high concentration of livestock sector in the main exporting geographical areas. Indeed, in case of an epidemic, these factors are responsible for 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. Some countries can indeed benefit from sanitary embargoes; they also have export capacity and are not directly affected by the disease.

These examples of impacts on agricultural markets support the idea that the epidemic risk management should integrate these disturbances. Post-epidemic market shocks have an economic impact that affects the whole livestock market, and they may induce spillovers in the linked industries. Moreover, demand levels for livestock products may be more generally affected by modifications in consumers' behavior.

3.3.2. Effects on the demand behaviors

Consumption patterns are influenced by the occurrence of epidemic diseases. They may evolve 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). Indeed, animal health crises have an incidence on consumption levels, which fell up to 20% during the recent France FMD crisis

(Lesdos-Cauhapé et al., 2007). Economic modeling can take into account the effects of changing demand on prices and demand levels in agricultural goods.

Demand behaviors remain closely linked to risk perception by consumers (Mazzocchi et al., 2007), not necessarily when the risks for human health are proved. The media coverage of an animal health event is likely to alter the perception that consumers have towards the products concerned. In regard to recent animal health scares, it appears that if the consumer perceives a risk for his health, he can divert his consumption of animal product for a longer or shorter time (Tonsor, et al., 2009), even if the risk to human health is not proven. 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 animal production sectors. Böcker and Hanf (2000) explain changes in consumer confidence in the health quality of food in two stages. First, during the first moments after the media coverage of the health crisis, fears of food consumers relate to a wide range of products, which they turn away, possibly in favor of substitutes. In a second time, usually a few months later, there is a partial return of confidence in demand for these products. One can indeed observe sustainable diversion of part of the demand for meat products after a health crisis. Nevertheless, as pointed by 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 after the illness. The recent example of the avian influenza crisis in France (2005-2006) exhibits a loss of confidence for a three month period (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 sector. Sectors directly related to tourism spending have indeed suffered a financial loss levels 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 Computable 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 controversial: the economic losses associated with the disease and control measures were in large part compensated by higher prices for beef, because of the tightening of supplies.

However, these studies have not taken into account the effects of embargoes, particularly in terms of impact on the markets and farm incomes.

Understanding of economic phenomena arising from animal health crises in the livestock sector, which is allowed by the modeling of economic equilibrium, highlights the fact that health crises can modify the whole economy of the affected region. They disrupt the agricultural markets and activities and they may quickly become confidence crises on the quality of the product. They underpin the need for establishing strong support to the territories and the farming profession.

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 multi-sector, regionalized and dynamic approaches will help to give new insights on economic consequences 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 on epidemic diseases (market impact and management) highlight the extent of the effects of health crises. Nevertheless, as revealed by the review of the economic literature, 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 at suggesting some innovative ways of research to provide a more complete consideration of market behavior 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 published in the literature related to the assessment of the economic consequences of epidemic outbreaks are based on a static framework as emphasized previously. Nevertheless, some recent studies have begun to think about economic dynamics resulting from such animal health crises. Zhao et al (2006) have combined epidemiological and economic models to analyze the possible effects of an FMD outbreak on breeding decisions. In the same vein, the study of Paarlberg et al (2008) showed the effects of short term to long term to an FMD outbreak, which were highly dependent on the length of livestock production cycles. The analysis proposed by Rich and Winter-Nelson (2007) also shows the existence of dynamic effects of an FMD outbreak through a multi-market model.

These few studies show that the shock induced by an outbreak can cause changes in the livestock breeding decisions, which result in productive and long-term economic consequences. This market disruption is an integral part of the indirect consequences of this catastrophic risk.

Moreover, the demand behavior and decisions on rules of trade are also changing consecutively to the occurrence of an animal health crisis. As pioneered by Philippidis and Hubbard (2005), modeling these various phenomena in dynamic CGE will allow the proposal of a joint study of intertemporal disturbances related to supply, demand, international markets, and their feedback effects. Similarly, this type of study provides a regionalized framework as to measure the systemic effects of an animal health crisis on the whole economy of a considered geographical area, as Western France. As far as we know, previous studies did not include livestock dynamics and market constraints.

An innovative dynamic CGE approach of the consequences of catastrophic risk including those elements may provide the opportunity to enrich the knowledge about the market consequences of an epidemic to support the implementation of management policies. To this end, this modeling approach may consider expectation schemes and market constraints (e.g. financial constraints) as well as livestock cycles and dynamics to measure the implications of such crisis on income and regional welfare.

4.1.1. Understanding the production dynamics

The occurrence of an epidemic disease modifies the behaviors of economic agents. These are related to the available information about the risk and its perception. These behavioral changes have economic implications, which must be included in the indirect economic effects induced by epidemic diseases. The prospect of falling prices, investment constraints as well as many other decision parameters may interfere with the productive strategy. This will in turn affects the amounts offered and consequently the prices.

In general, the occurrence of demand shocks and changes in the cost of inputs 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 different lengths. For example, poultry production is characterized by short production cycles.

Poultry producers are able to counter the possible reduction of demand by reducing production capacities. Thus, during the 2005-2006 episode of avian influenza, the fall in demand, mainly due to the loss of export outlets, has led the industry to put less chicks up. With the recovery in demand following the lifting of the sanitary embargo, the industry has been able to adapt quickly to new circumstances, by setting up more chicks.

This responsiveness to changing market conditions is not as easy for all types of farms. The adjustment speed of supply for livestock is indeed variable among animal species (and production systems). In the case of cattle farms, this inelasticity is due to the relatively low fertility rate of cows and the time needed for breeding or fattening cattle. These long breeding periods (several years in the case of cattle) explain that production decisions are prior to business decisions; they set up the volumes available on markets. Production choices are based on expectations about future market conditions. Cyclical fluctuations of prices, due to significant delays in biological processes beef production (Chavas, 2000) and swine (Chavas, 1999), may be compatible with effective management of an animal population assuming rational expectations.

The price changes induced by market reactions to the health risk are a signal for 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 an animal 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 an epidemic disease can cause significant income fluctuations for farmers. When the income cannot be maintained by price support measures, farmers may be likely to borrow to maintain consumption. This debt nevertheless induces additional expenses (related to loan interests), which may threaten the solvency of the most financially vulnerable farms. The economic risk can then become a risk of bankruptcy (Gohin, et al., 2011). Quantifying that risk as part of a dynamic CGE modeling will provide more comprehension of the long-term effects of shocks due to an epidemic.

Long-run effects of catastrophic risk on the farm may be identified by a dynamic CGE modeling taking into account changes in demand and supply in such a particular epidemiological context. This innovative research will help study the role and development opportunities of management tools of the economic consequences of epidemic risk in the agricultural sector.

4.2. Prospects for the management of epidemic risk

The review of the economic literature on catastrophic animal health risks has led us to identify some key elements of its management and has given rise to some interesting research perspectives - the dynamic modeling of market behavior - to capture long term effects of a disease outbreak. 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 that may suffer the farms, which complicates the development of farm income insurance mechanisms because it undermines the strategies of risk diversification for insurance companies (Skees and Barnett, 1999). In the context of climate risk on major crops, Miranda and Glauber (1997) showed 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 costs that the private insurance companies should bear could sharply raise insurance premiums.

The financial system has tools to fulfill 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 that face a strong systemic component in their portfolio of risks in case of an outbreak. Conversely, these bonds also attract financial markets, which are interested in investing in agricultural markets as it may be a source of diversification of their own risk.

This solution is also being considered by Phélippé-Guinvarc'h and Cordier (2006). They studied the possibility of bypassing the public sector on matters of reinsurance. The authors define a general pattern of agricultural insurance, including both classic and catastrophic risks. The authors showed 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, integrating the agricultural sector in production chains (including the processing sector and possibly the retailing one) may contribute to share production risk over a wider range of players. In the case of animal products, the introduction of futures contracts between growers and processors of animal products could also help to share the risk, thanks to price settings before the marketing. Thus, the producer may receive an income guarantee that may prevent him from undergoing strong fluctuations of prices induced by epizootics (Meuwissen et al., 2001). The effects of falling prices may be mitigated if the processor is positioned in different markets, based on the enhancement of various raw materials. In fact, the adoption of these strategies was not widespread, partly because of increased exposure to risk for the slaughtering sector. Actually, meat processors do not have any economic interest to bear 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 market losses of these systems is not questioned, however private solutions remain scarce. Animal 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 requires expenditures that private actors are not always able to bear alone (Sumner, et al., 2006). Epidemic diseases like FMD or BSE and the emergence of new diseases are furthermore subject to significant uncertainties: moral hazard and negative externalities associated with potential past outbreaks, 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. Modeling the systems of public intervention using a dynamic CGE may give guidance to governments for the establishment of management systems. The issues relating to government intervention are the subject of this section.

• Preventive actions, control strategies and zoning

The public management of epidemics first requires the establishment of preventive measures to minimize their spread and thus their economic consequences. 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 incentive to report disease outbreaks in the early times. Responsiveness is a key to a successful strategy, as the economic effects are even stronger when the disease spread widely (Devadoss et al., 2006). In addition, bans or restrictions on exports can be extremely costly for 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). 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 scales (from the region to the country). Trade restrictions to a level smaller than the country is likely to help restrain the market risk and thus minimize its impact at the national level. The zoning issue is particularly important for Western France. 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. Modeling the market effects and the welfare effects linked to the extent of the trade restrictions areas may highlight spatial issues of the risk management.

• Supporting the producers and the supply levels

After a market shock related to an animal health event, maintaining the income levels and supporting animal production structures after a market shock can be achieved by setting up income insurance mechanisms, as Gohin et al (2011) underlie. These mechanisms may consist in subsidized interest rate loans to counter the risks of indebtedness/failure or to measures in order to encourage the constitution 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 to 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 modeling of public support and financial incentives can reveal changes in farmer behavior.

Solutions to postpone the marketing of animal products are also possible to counter falling output 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. Note that in the cattle sector, living animals may also be held longer at the farm, which cannot be done in the case of poultry for example. Modeling this process management may measure the economic consequences of such a policy and its potential public costs of implementation. Moreover, the market impact of support measures for processing is also an important modeling issue of management measures. Indeed, industrial sectors may, under government leadership, 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. The study of such a measure would show its ability to limit fluctuations in prices received by producers.

To conclude, the behavior of market participants cause economic dynamics that constitute 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. The planned developments of the research (CGE modeling of the dynamics of production and market behaviors) 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 –income, welfare– of catastrophic risks in a local economy.

Various crucial issues are raised by this kind of research. First, it may participate to policy research with respect to the necessary redefinition of common and harmonized European risk management measures to face the market consequences of epidemic outbreaks. In order to smooth the market effects of an animal health crisis, stakeholders may have a trade-off between various regulation mechanisms. One interesting question that remains to be explored is the effectiveness of physical markets regulation versus a financial intervention in order to improve the resilience of the economy to this catastrophic risk. More generally, thanks to dynamic CGE study, the economic research on market effects of epidemic disease outbreaks may provide useful guidelines for the potential reorientation of public support to agriculture within the EU and the role of risk management mechanisms in securing farm income.

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