Assessing the economic costs of an outbreak of Foot and Mouth Disease on Brittany: A dynamic computable general equilibrium approach

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Abstract

Epizootic outbreaks such as Foot and Mouth Disease are of great concern for agriculture. In this paper, we quantify the potential dynamic impacts of such a disease on Brittany, a French region with a strong livestock sector. We develop a dynamic computable general equilibrium model with rational expectations that allows us to measure the impacts of culling infected animals and restraining movements of live animals on the livestock sectors and downstream food industries. Our results show that economic losses are spread over many periods even with a one-time shock. The impacts on the primary sectors and downstream food sectors do not move in parallel. The food industries suffer most in the first period while the negative impacts on agriculture are mostly observed thereafter. Credit and wage constraints result in an estimated aggregated loss multiplied by more than 700 per cent. These results challenge the concept of a simple management policy for this disease.

Keywords dynamics, CGE, animal disease, catastrophic event.
JEL code Q11, Q18

1. INTRODUCTION

Epidemic outbreaks are uncertain events of great concern for agriculture and related sectors. Animal diseases, such as foot and mouth disease (FMD), can lead to severe reductions in animal productivity and may even cause animal death. Moreover, FMD is a highly contagious disease and thus can quickly cause large production and economic damages in livestock-intensive regions. Because infected animals are usually killed and movements of non-infected animals in infected areas are prohibited during an FMD outbreak, upstream and downstream industries are also negatively impacted by a reduction in their activity. Livestock farms and industries located outside the infected area may not necessarily benefit from a FMD outbreak. It depends on the price evolution of livestock products which may ultimately decrease if import bans by foreign countries and/or a reduction in domestic consumption are larger than the supply reduction in the infected area. Thus a FMD outbreak can have large economic costs for infected farmers and the whole food chain as well. These costs also extend to the whole economy if other sectors are also directly affected by the outbreak. For example, some studies show that the 2001 FMD outbreak in the United Kingdom (UK) imposed important economic losses on the whole British economy due to the impact on tourism (Blake et al., 2002; O'Toole et al., 2002).

The computation of the expected economic costs of risky events is traditional with classical idiosyncratic risks. This allows for the pricing of private risk instruments, such as insurance, and hence the optimal sharing of these expected costs among economic agents. A FMD outbreak is not presently an insurable risk because expected economic costs are difficult to compute for at least the three following reasons. First, a FMD outbreak is today characterized by an uncertain, presumably low, probability of occurrence with potential considerable and systematic economic losses. From an economic point of view, this first characteristic already makes FMD potentially a catastrophic and non-insurable risk. Second, the economic costs of a FMD outbreak depend on the public measures taken to manage and/or eradicate the disease. Public authorities may implement preventive actions to limit the occurrence and extent of FMD effects, through regular veterinary monitoring. In addition, during the crisis period they can choose among alternative strategies, including the culling of infected herds, the preventive stamping out of animals located around the infected zone, and the vaccination of animals located within a ring vaccination zone. These discretionary public decisions in control strategy have different consequences with respect to the length of measures, the number of killed animals and, hence, the length and magnitude of economic costs. Third, the dynamic dimensions linked to animal production economics add another challenge to the computation of expected economic costs. Effects of a FMD outbreak do not stop with the eradication of the disease since time is obviously needed to rebuild the livestock herd after preventive and curative culling.

With FMD, we are thus presently in a second best world characterised by incomplete contingent markets in the Arrow Debreu sense and potential optimal public intervention. In the European Union (EU), public measures funded by a veterinary fund include, in particular, co-financing of emergency measures for the slaughter of infected animals and the support of a vaccination bank. Exceptional market support measures can also provide support to farmers and breeders affected by restrictions imposed by the veterinary authorities. However, this EU public policy is currently under debate due to the heterogeneous national complementary measures leading to potential distortions on the EU market and to a lack of clear and transparent rules for exceptional market measures.

In this context, the purpose of this article is to provide an assessment of the market and welfare impacts of a potential FMD outbreak in a European livestock-intensive region. Our ultimate goal is to compute the aggregate and dynamic economic costs of such a disease and their distribution both among economic stakeholders and through time. Such an assessment is the necessary first step in designing the optimal articulation of private/public permanent/crisis measures to cope with such stochastic event.

From a methodological perspective, the cost-benefit analyses of FMD have long used static economic models focusing on the direct costs incurred by infected farms. These first analyses have been improved by introducing the indirect effects on other economic agents. This has been done using static input output models (without price effects) or using Partial Equilibrium (PE) and Computable General Equilibrium (CGE) models (with price and income effects). The dynamic dimension has also been introduced into these static cost-benefit analyses. In particular, epidemiological models have been coupled to economic ones focusing on production in order to analyze the costs of the disease over time in relation to the evolution of the animal health context. Recent works have started to include dynamic economic elements in PE models. In particular, Zhao et al. (2006) build a PE model where farmers take optimal decisions based on intertemporal profit maximization behaviours. These authors show that the impacts of FMD change from year to year before returning to a new steady state, which is typical when studying animal supply responses. In the same vein, Rich and Winter-Nelson (2007) and Paarlberg et al. (2008) use PE models to show the short term and long term effects of an FMD outbreak, which are highly dependent on the length of livestock production cycles.

While these dynamic PE analyses provide valuable insights, they measure neither the economic impacts on the full food chain nor the macro-economic impacts of such a disease. Yet determining these effects can be useful in order to define appropriate risk management schemes. This can be done using a dynamic CGE model as pioneered by Philippidis and Hubbard (2005). They use the dynamic version of the Global Trade Analysis Project GTAP model to show the lasting effects of such a disease. However, their analysis uses the GTAP data where the different livestock animals are not distinguished. Hence, the dynamic biological constraints are imperfectly captured in their analysis. Moreover, these authors assume that all primary factor markets are perfect. This implies that labour and land are fully mobile between sectors and that the capital market is efficient: investment by sector is never constrained nor faces sunk transaction costs. Accordingly these authors implicitly assume that the costs of FMD incurred by the livestock and related sectors are shared with all other economic sectors (through the impacts on labour and land) and are efficiently spread over time (through the impacts on sector investment). In other words, these assumptions of perfect factor markets minimize the aggregate economic costs of a FMD outbreak (as already mentioned in another risky context by Leathers and Chavas, 1986). Yet factor markets in the EU are characterized by different distortions/imperfections, such as minimum wages that imply involuntary unemployment, or credit rationing implying constrained sector investment (see, for instance, Blancard et al., 2006).

Our methodological contribution is to build a new dynamic CGE model in the vein of Philippidis and Hubbard (2005) with two additional improvements. The first consists of the explicit specification of all livestock sectors and their herds, so that the dynamic biological constraints are perfectly captured in our analysis. The second is the specification of rigidity/imperfections in labour and capital markets. This allows us to measure the sensitivity of economic costs of a FMD outbreak to these real characteristics of factor markets. Our dynamic CGE model is applied to Brittany which is the most livestock-intensive French region. Brittany ranks first in terms of French milk, veal, pig and poultry production, and second in terms of cattle production. Farm and food processing industries represent 12 per cent of Brittany’s total employment compared to 6 per cent at the national level.

2. MODELLING FRAMEWORK

In this section we present the main specifications of our dynamic CGE model. First we provide a general description of the standard version of our model, highlighting the dynamic behaviours of the producers and the macro-economic closure of the model. Then we describe the livestock sectors with the dynamics implemented to reflect the cattle cycles. Finally we detail the modelling of imperfections/distortions on factor markets.

Our model obviously goes into great detail on the livestock sectors and downstream-related sectors. To do this, we built a Social Accounting Matrix (SAM) for the Brittany region calibrated for the year 2003 owing to data constraints. In particular, the data set on agricultural production costs could be completed thanks to the database of the Common Agricultural Policy Regional Impact (CAPRI) model. This SAM gives information on 50 sectors in total, including 23 agricultural activities and 52 products. Of these products, 24 are agricultural ones. It should be underlined that we allow for multi-product activities, such as the dairy cow activity producing milk, bovine for slaughter, new born calves and organic manure.

2.1. Main features of the model

The basic structure of our dynamic CGE model is standard for a single country model in an open economy (see, for instance, Devarajan and Go, 1998; Vellinga, 2007). On the "static" components of the model, all economic agents are assumed to be price takers. Perfect competition is assumed on all markets and prices ensure market equilibrium. Trade between Brittany and other regions (rest of France, rest of the EU and Rest of the World) is specified in the Armington tradition, with Brittany potentially a large player on foreign regions. Preferences and technologies are represented by globally regular, nested Constant Elasticity of Substitution CES functional forms.

On the "dynamic" components of the model, producers are assumed to maximize their intertemporal profit, subject to capital constraints and investment costs. We assume in the standard case that the financial capital market is efficient: all producers have access to the financial capital market at an exogenous interest rate, so that the financial structure of each firm (ratio of debts to equities) does not matter. One financial structure must still be determined and we assume without prejudice that producers finance all investment outlays by retaining profits and maintaining the number of equities. This assumption fits best with the structure of farm capital mostly owned by farmers. On the demand side, we assume the existence of one representative consumer maximizing an intertemporal utility function subject to intertemporal budget constraints. This representative consumer also participates in the financial capital market by saving at the same exogenous interest rate.

One unavoidable critical issue with dynamic models is the determination of the nature of expectations by economic agents. In this article, we assume that all economic agents have rational expectations. We believe that this assumption fits best with a scenario of an FMD outbreak, which is an uncertain, but presumably low, event. Indeed, rational expectation schemes are consistent with that kind of potential market shock since economic agents – both livestock producers and related industries – do not make their production decisions taking into account a hypothetical epidemic outbreak. Above all, this assumption allows us to abstract from informational welfare issues on the true structure of the economy. This assumption is indeed mainly justified as such by other authors as well (Lence, 2009, for instance). It means that our welfare results constitute the upper bound of the effects of a FMD outbreak.

Since our methodological contributions mostly concern the production side of the model, we describe below the modelling of producers in the standard version of our model. The optimization program of producer *j* is given by:

$$\max \pi_j = \sum_{t=0}^{\infty}\left(\frac{1}{1+r}\right)^t \left(\sum_i \left(P_{i,t}.Y_{i,j,t} - PC_{i,t}.IC_{i,j,t}\right) - PI_{j,t}\left(1+\aleph_{j,t}\right)I_{j,t} - WL_{j,t}.L_{j,t} - WT_{j,t}T_{j,t}\right)$$
$$s.t. \quad F_{j,t}\left(Y_{i,j,t}, IC_{i,j,t}L_{j,t}, K_{j,t}, T_{j,t}\right) = 0 \qquad (1)$$
$$s.t. \quad K_{j,t+1} = K_{j,t}.\left(1-\delta_{j,t}\right) + I_{j,t} \quad ; \quad K_{j,0} = \overline{K}_{j,0}$$

Where $Y_{i,j,t}$ is the production of good *i* by producer *j* at time t (the corresponding price net of taxes/subsidies is $P_{i,t}$), $IC_{i,j,t}$ is the intermediate consumption (the corresponding net price is $PC_{i,t}$), $I_{j,t}$ is the investment level (the corresponding net price is $PI_{j,t}$), $L_{j,t}, T_{j,t}$ the levels of labour and land use (the corresponding net prices are $WL_{j,t}, WT_{j,t}$), $K_{j,t}$ is the stock of physical capital, $\delta_{j,t}$ the depreciation rate of capital. The parameter $\aleph_{j,t}$ represents the unitary transaction cost of capital and, following Uzawa (1969), is specified as follows:

$$\aleph_{j,t} = \frac{\phi_j}{2}\frac{I_{j,t}}{K_{j,t}} \qquad (2)$$

where ϕ_j is the non negative parameter governing the marginal cost of capital installation. $F_{j,t}(.)$ is a constant return to scale production function. The production technology is specified with multi-level nested Constant Elasticity of Substitution functions (with some substitution between capital and labour, as well as between feedstuff ingredients). In the particular case of agriculture, multi-products activities may be encountered as is, for example, the case for the dairy cow sector. The amounts of the various products obtained from those activities are quite interdependent and inflexible, leading us to specify Leontief (fixed proportions) functions. This production function is the first constraint of the producer program. The second constraint concerns capital accumulation: it stipulates that next period capital stock equals the current investment plus the current capital stock and minus the depreciation. It should be noted that, as is usual, investment is assumed to occur at the end of period and is only available for future periods.

Solving this producer program can be decomposed into two steps. The first step determines optimal intra-temporal decisions of production, intermediate consumption, land and labour demands conditional on the production technology, the level of capital stocks and prices. This first step simultaneously determines the periodic capital return (denoted below by $WK_{j,t}$). The second step determines the optimal levels of investment and capital stocks conditional on prices and the initial level of capital stocks ($K_{j,0}$). Indeed, the optimal level of current investment is implicitly determined by the first order condition of the following program:

$$\max \pi_j = \sum_{t=0}^{\infty}\left(\frac{1}{1+r}\right)^t \left(WK_{j,t}.K_{j,t} - PI_{j,t}\left(1+\aleph_{j,t}\right)I_{j,t}\right) \qquad (3)$$
$$s.t. \quad K_{j,t+1} = K_{j,t}.\left(1-\delta_{j,t}\right) + I_{j,t} \quad ; \quad K_{j,0} = \overline{K}_{j,0}$$

The first order condition is then:

$$WK_{j,t+1} + (1-\delta_{j,t})PI_{j,t+1} = (1+r)PI_{j,t} + \phi_j\left((1+r)PI_{j,t}\left(\frac{I_{j,t}}{K_{j,t}}\right) - (1-\delta_{j,t})PI_{j,t+1}\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right) - \frac{PI_{j,t+1}}{2}\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right)^2\right) \quad (4)$$

If we first assume that there are no capital transaction costs ($\phi_j = 0$), this equation simply represents the equality between the marginal cost of current investment at time *t* evaluated at the next period (on the right hand side) and the marginal revenue of that current investment at time *t+1* (on the left hand side). This marginal revenue has two terms, the next period expected capital returns and the next period expected price of the (depreciated) investment good (in case the capital stock is partly sold). The second line of the equation 4 introduces the transaction costs. The first term of the second line is the marginal transaction cost of the current investment (again evaluated at the next period). The second term is the marginal transaction benefit in the case where the capital stock is partly sold in the following period. Finally the last term of this second line captures the lower transaction costs of future investment due to greater capital stock following current investment.

The first order condition just described implicitly determines current investment conditional on existing capital stocks, current and future prices as well as future decisions on investment and capital stocks. Hence a similar first order condition determines the next period investment and so on. The final level of investment for each period will depend on the steady state conditions that we impose on the model. As is usual we impose that, in the steady state, investment by firms equals their capital depreciation.

As explained earlier, in the standard version of the model we assume that the financial capital market is perfect and consequently that all investment decisions are always financed at the exogenous interest rate. This interest rate also influences the decisions of our representative household to consume or save for future consumptions. The amount of domestic savings may not correspond to the level of domestic investment, leading to a modification of the capital account (and of the current account to ensure the balance of payments). In the steady state, we assume that domestic savings equal domestic investment, so that the net debt of our Brittany economy with other regions remains unchanged (see Vellinga, 2007, for a more detailed explanation). With this assumption, we implicitly impose that the exchange rate between Brittany and other regions is fixed. This is justified in our case since Breton products are mostly traded within France.

2.2. The specification of the cattle sectors

In the previous standard programs of producers, we specify only one capital good used in the production process. Dynamics only occur because of the depreciation of this capital good and the associated investment. This does not acknowledge the various steps necessary to produce bovine cattle, nor the fact that the cattle stocks are factors of production and not simply an intermediate consumption. This is, for example, also omitted in the analysis by Philippidis and Hubbard (2005) using the GTAP model. Our methodological contribution is to introduce these cattle stocks as factors of production in the economy. These factors of production depreciate and the resulting cattle stocks also change over time following the decisions of cattle farmers.

More precisely, in order to take into account the dynamic nature of the breeding cycles, our original data set gives details on the distribution of the cattle according to different age classes. We consider six different cattle stocks or herds: dairy cows, suckler cows, male calves and female calves (animals of less than one year old), bulls and heifers (animals of less than two years old). These herds are used by nine different activities due to the distinction between raising and fattening activities (see below). The activities together supply four types of products: bovine for slaughter, milk, organic manure and live animals. The links between herds, activities and products are described in table 1.

Table 1. Disaggregation of the cattle sector

Activities	Herds	Types of Production
Dairy cows	Dairy cows	Milk, bovine for slaughter, dairy cows, male calves, female calves, organic manure
Suckler cows	Suckler cows	Bovine for slaughter, suckler cows, male calves, female calves, organic manure
Raising male calves	Male calves	Bulls, organic manure
Raising female calves	Female calves	Heifers, organic manure
Fattening male calves	Male calves	Bovine for slaughter, organic manure
Fattening female calves	Female calves	Bovine for slaughter, organic manure
Raising heifers	Heifers	Dairy cows, suckler cows, organic manure
Fattening heifers	Heifers	Bovine for slaughter, organic manure
Fattening bulls	Bulls	Bovine for slaughter, organic manure

Source: own elaboration

To illustrate the cattle dynamics, the domestic production of calves comes from the suckler and dairy cow activities. In order to get new productive cows from these domestic calves, two more years are required. In its second year of life, the female calf is raised to become a young heifer, and in its third year it may become a cow and give birth to a new calf, through the dairy or suckler activity, and so on. On the other hand, the male calf can be directly slaughtered for veal production or alternatively raised for the consecutive production of steers or bulls.

To our knowledge, such disaggregation of the cattle sectors in a CGE model has never before been performed. By definition, it allows us to trace the dynamic and lasting impacts of a shock on these sectors and the time needed to return to a new steady state. While an improvement on available models on these grounds, our approach still suffers from at least two limitations. First, cattle scientists may consider it too aggregated since we do not distinguish animal breeds because of data constraints. Indeed, our disaggregation is based on the CAPRI one, where the production costs and revenues of these activities are detailed. Second, we distinguish live animals by their age as if they are all born on the same day (the first day of the period/year). Again, data constraints at present prevent us from going further in the temporal disaggregation of animals and related activities.

Regarding the modelling of our cattle activities, we assume as usual that each farm in each activity maximises its inter-temporal profit. In reality, some farms may pursue different activities (such as dairy farms with milking dairy cows and raising heifers). Our approach of splitting cattle farms by activity is not fundamentally different from splitting mixed farms (for instance, splitting farms producing poultry and crop into two activities). Moreover, some Breton cattle farms are specialised in raising animals, others in fattening animals, others in milking dairy cows. These specialised farms purchase the animals making up their initial herds at each period.

In a similar way to the capital dynamics previously described, we assume that each herd stands for animal capital that depreciates over time and needs investment to maintain its level. This statement induces a new constraint in the program of cattle producers:

$$H_{j,t+1} = H_{j,t}.(1-\delta h_{j,t}) + IH_{j,t} \quad (5)$$

where $H_{j,t}$ is the level of the herd held by activity *j* at the beginning of period *t*, $IH_{j,t}$ is the investment level reflecting the effort level of obtaining new herd. As with physical capital, we assume that the investment is made at the end of the period for the next period production. The parameter δh is the depreciation rate of the considered herd. Annually this parameter δh depreciates totally for young animals ($\delta h = 1$) as these herds represent only temporary states in the life cycle of the animals (e.g. after one year each calf becomes a young heifer or bull). On the other hand, for suckler cows and dairy cows this parameter δh reflects the culling of cows decided by cattle farmers based on the lower productivity of old animals or for sanitary reasons. This parameter is lower than one (all dairy cows are not culled by farms in a steady state solution).

Formally, the program of each cattle activity is given by:

$$
\begin{aligned}
&\max \pi_j = \sum_{t=0}^{\infty}\left(\frac{1}{1+r}\right)^t \left(\begin{array}{l}\sum_i \left(P_{i,t}.Y_{i,j,t} - PC_{i,t}.IC_{i,j,t}\right) - PI_{j,t}\left(1+\aleph_{j,t}\right).I_{j,t} - WL_{j,t}.L_{j,t} - WT_{j,t}.T_{j,t} \\ - PH_{j,t}.IH_{j,t}\end{array}\right) \\
&s.t. \quad F_{j,t}\left(Y_{i,j,t}, IC_{i,j,t} L_{j,t}, K_{j,t}, T_{j,t}, H_{j,t}\right) = 0 \\
&s.t. \quad K_{j,t+1} = K_{j,t}.\left(1-\delta_{j,t}\right) + I_{j,t} \quad ; \quad K_{j,0} = \overline{K}_{j,0} \\
&s.t. \quad H_{j,t+1} = H_{j,t}.\left(1-\delta h_{j,t}\right) + IH_{j,t} \quad ; \quad H_{j,0} = \overline{H}_{j,0}
\end{aligned}
\qquad (6)
$$

In the objective function, we obviously introduce the expenditures made by each activity to purchase new animals at prices $PH_{j,t}$. We assume that there are no transaction costs when investing in new animals. The production function now includes the level of the herd at the beginning of the period. We assume that there is no substitution between this factor of production and other inputs/factors.

Again, this program can be solved in two steps: first, the intra-period decisions, and second the inter-period investment decisions. From the first step, we obtain the capital return and the herd return (denoted below by $WH_{j,t}$). In the second step, the first order condition implicitly determines the optimal investment in the herd by cattle farms:

$$
WH_{j,t+1} + \left(1-\delta h_{j,t}\right)PH_{j,t+1} = \left(1+r\right)PH_{j,t} \qquad (7)
$$

Similarly, the right hand side corresponds to the marginal cost of investment in the herd in period *t* evaluated in period *t+1*. The left hand side is the marginal revenue of this investment in the herd: it equals the next period expected return for the herd and the next period expected purchase price of the (depreciated) herd. In the case of activities with young animals, this last term obviously equals zero – because one young animal grows and cannot stay within an annual category.

The above programs determine *inter alia* the domestic demand and domestic supply of live animals. Trade in these live animals with France is also permitted in our model. We depart here from the Armington specification and assume that live animals are homogenous products. However, we assume that Brittany is potentially an influential region affecting these prices in other regions. As for any other products, prices ensure that these markets are in equilibrium.

2.3. Specification of imperfections in factor markets

i/ On the labour market

In the standard version of our model, labour is assumed to be fully mobile between activities and no public intervention prevents a real wage decrease following a negative economic shock such as a FMD event. Yet involuntary unemployment amounts to around 8 per cent of the active population in Brittany in recent years. There are certainly many different reasons for this situation, one being the minimum wages imposed by public regulation. In the second version of our CGE model, we acknowledge this feature of the labour market in order to assess its impact on the welfare effects of a FMD outbreak.

Formally, we consider that unemployment is due to the existence of minimum wages, below which the demand for labour cannot be satisfied. In order to introduce this regulation into our model, we constrain real wages not to fall below their base value and assume that there is some unused labour endowment. This mechanically induces rigidities in the labour market because changes in labour demand will result in changes in labour supply, given the assumption that the labour supply is perfectly elastic. This quite simplistic representation of the labour market cannot best reflect the French employment structure, nevertheless this specification has long been used in the literature, as mentioned by Gohin and Moschini (2006).

ii/ On the financial capital market

In the standard version of our model, the financial capital market is assumed to be perfect. Producers face no constraints when investing, except the terminal steady state condition where investment equals depreciation. For example, they can invest more than the current profit if they expect an increase of future capital returns (see program 3 and the first order condition 4). Yet sectors facing economic crisis (a severe drop of capital returns) are often credit constrained leading, for example, the French public authorities to intervene *inter alia* in credit markets (such as taking interest charges and postponing debt repayments). Moreover, a large economic literature has developed which identifies the extent to which farmers are credit constrained (such as Phimister, 1995). In the case of French agriculture, Blancard et al. (2006) show that almost all farms suffer from credit constraints when financing their investments.

Accordingly, we develop a new version of our CGE model where we try to take into account this well established fact. This is, however, not immediate as our CGE model focuses on the real side of the Breton economy and moreover assumes rational behaviour (hence excluding informational issues leading to credit constraints). We thus specify a reduced form constraint on investment. We assume that current investment by firms is constrained if current capital return decreases below a threshold level. Formally, we introduce the following constraint for all sectors:

$$I_{j,t} \leq I_{j,0} \cdot \left(\alpha . \frac{WK_{j,t}}{WK_{j,0}} + \beta \right) \tag{8}$$

where 0 is the calibrated year without the FMD outbreak, α, β are reduced form parameters governing the severity of the investment constraint. For example, if we impose $\alpha = 0, \beta = \infty$, then the constraint is never binding. On the other hand, if we impose $\alpha = 1, \beta = 0$, then the current investment level must be lower than the pre-FMD level if the current capital return is lower than the pre-FMD capital return. This reduced form constraint thus allows us to impose investment restrictions on sectors facing a drop of their capital return. For example, if a FMD outbreak leads firms to temporarily decrease their activity, their current profit decreases. They may face difficulties in financing their current investment despite potential future positive prospects following the resolution of the FMD outbreak.

In this alternative version with investment constraints, the program of producers (the second step) becomes:

$$\begin{aligned} &\max \pi_j = \sum_{t=0}^{\infty} \left(\frac{1}{1+r} \right)^t \left(WK_{j,t} . K_{j,t} - PI_{j,t} \left(1 + \aleph_{j,t} \right) I_{j,t} \right) \\ &s.t. \quad K_{j,t+1} = K_{j,t} . \left(1 - \delta_{j,t} \right) + I_{j,t} \quad ; \quad K_{j,0} = \overline{K}_{j,0} \\ &s.t. \quad I_{j,t} \leq I_{j,0} \cdot \left(\alpha . \frac{WK_{j,t}}{WK_{j,0}} + \beta \right) \end{aligned} \tag{9}$$

The first order condition is modified so that:

$$WK_{j,t+1} + (1-\delta_{j,t})(PI_{j,t+1} + \mu_{j,t+1}) = (1+r)(PI_{j,t} + \mu_{j,t})$$
$$\phi_j \left((1+r)PI_{j,t}\left(\frac{I_{j,t}}{K_{j,t}}\right) - (1-\delta_{j,t})PI_{j,t+1}\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right) - \frac{PI_{j,t+1}}{2}\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right)^2 \right) \quad (10)$$

$\mu_{j,t}$ is the Lagrangian multiplier associated with the investment constraint and hence measures the price of this constraint. This equation is indeed very similar to the former first order condition. When the current constraint is binding (the current multiplier is positive but the next period one is not), the investment level is determined by the constraint and this first order condition determines the price of the capital good which is necessary to obtain that level of current investment. However, if the current multiplier is zero and the one in the next period is positive (hence, next period investment is a constraint), then this equation shows that there is an incentive to invest more in the current period.

By calibrating the parameters α and β, we can make investment more or less constrained. We explore this in the simulations, to which we now turn.

3. SIMULATIONS

An unexpected FMD outbreak alters the economy by different mechanisms acting on supply, demand and trade. On the supply side, the major impact of a FMD outbreak is that it may induce massive mandatory culling not only of infected animals but also of animals located in the infectious zone as designated by the public authorities. On the demand side, the major impact is the immediate (usually negative) reaction of domestic consumers and then a gradual partial/complete recovery to pre-FMD consumption levels. On trade, major impacts are due to restrictions on the movements of live animals (no imports/exports) and import bans on livestock products from foreign countries. In our simulation of a hypothetical FMD outbreak, we focus on the supply shock and trade shock on live animals. We exclude the domestic demand shock and the trade shock on livestock products because we lack precise information on trade between Brittany and other regions (according to available statistics, most trade is realised with other French regions but part of this is certainly then exported to the rest of the EU and the Rest of the World).

More precisely, we simulate the economic consequences of a public decision to cull 10 per cent of the total cattle herd as a response to a FMD outbreak (a one-time period supply shock). This represents about 200,000 cattle and is comparable to the 2001 UK case, where more than 4 million of the total 55 million animals were culled. In addition, at the initial year of this simulation we consider that such culling is accompanied by a preventive sanitary ban on the movement of live animals. From the second year of simulation this sanitary ban is lifted.

We first assess the consequences of this FMD scenario with the standard version of our CGE model and then use the alternative versions with imperfections on factor markets. When using these different dynamic versions, we need to determine the horizon needed to reach a new steady state. Results below are computed assuming that 15 years are needed to reach a new equilibrium. We performed the same simulation with horizons of 10 years versus 20 years and our results appear robust. Before interpreting the results, we recall that our dynamic CGE model is calibrated on a SAM that is an annual database, as commonly observed in CGE studies; the results below refer to annual time step estimations. As a result, the specifications of our data and model lead us to consider the FMD outbreak as an event lasting a year, which is obviously longer than most real cases (which last from three to six months).

3.1. Impacts of a FMD scenario with perfect factor markets

i/ Market impacts

Production impacts on selected agricultural commodities from the standard version of the model are provided in table 2. By definition, we find that in the FMD year, domestic production of milk (and dairy products) and cattle (and beef) decreases by 10 per cent. We observe that other farm sectors/productions are affected as well. In particular, domestic pig production increases slightly, by 0.87 per cent, owing to a price effect on the domestic demand side. Indeed the decrease in cattle production induces a price increase of 1.86 per cent in beef (see table 2), hence penalising beef domestic consumption to the benefit of pig domestic consumption. The domestic prices of dairy products and milk also increase in the first year owing to the reduced domestic supply (by, respectively, 2.51 per cent and 4.47 per cent). We also find that domestic wheat production increases (by 2.94 per cent). The interpretation of this is as follows. The decrease in the cattle herd is supposed to occur at the beginning of the period. Farmers have fewer animals to feed and accordingly they reduce their fodder acreage in favour of cereal or oilseed production. This extra production of wheat is mostly exported and is accompanied by a small price decrease (0.41 per cent). This induces lower feed costs for the livestock sectors and hence the small decrease in domestic pig prices (0.2 per cent). The nature of all these market results is quite standard in a static CGE framework.

Much more interesting and original are the results for the period just after the FMD outbreak. We find that one year after the outbreak, domestic milk (dairy product) production is greater than the pre-FMD level (by 5.67 per cent) while the domestic cattle (and beef) production is lower (by 14.34 per cent). In order to understand these results, it is useful to report the evolution of cattle herds, production, trade and price of live animals (see tables 3 and 4).

From these tables, we observe that before the FMD outbreak Brittany imports calves and heifers and exports young cows. During the outbreak period, these trade flows are not permitted. This implies in particular that the herds of cows are increasing at the beginning of the second period: the herd of dairy cows increases by 5.67 per cent (similarly to the domestic production of milk) and the herd of suckler cows by 58.91 per cent. Consequently, the domestic production of calves increases in the second period (by around 15.2 per cent). Despite these increases, the domestic production of beef decreases because other herds at the beginning of the second period (calves, heifers and bulls) are decreasing compared to the pre FMD level, by as much as 48 per cent for the herd of female calves. There are two explanations for this decline. The first is the reduced domestic production from the FMD period due to the killing of cows. The second is the impossibility of importing calves during the FMD period. Hence the herd of female calves at the beginning of the second period is lower. The arguments are similar for other herds. With these lower herd levels at the beginning of the second period, the domestic production of the corresponding activities necessarily decreases. We should note here that a third mechanism applies which partially compensates for these negative effects on the domestic production of beef: the competition between the fattening and raising activities of calves and heifers. Beef prices are high in the first periods of the simulation and fattening activities decrease less than raising activities due to these favourable prices. For example, the activity of fattening female calves decreases by 38.28 per cent compared to a decrease by 51.73 for the activity of raising female calves.

Table 2. Production and price impacts (in % with respect to the initial steady state production)

Period	1	2	3	4	5	15
Production						

Milk/Dairy prod.	-10,00	5,67	-0,34	-0,27	-0,05	-0,00
Cattle/Beef	-10,00	-14,34	-3,38	-0,91	-0,72	-0,36
Pig	0,87	0,23	0,14	0,07	0,05	0,03
Wheat	2,94	-0,89	0,72	0,05	0,00	-0,01
Price						
Milk	4,47	-2,12	0,16	0,12	0,03	0,00
Cattle	4,15	5,73	1,18	0,20	0,13	0,07
Pig	-0,20	0,00	-0,04	-0,02	-0,01	0,00
Wheat	-0,41	0,19	-0,09	0,00	0,01	0,00
Beef	1,86	2,76	0,60	0,16	0,13	0,06
Dairy products	2,51	-1,26	0,08	0,06	0,01	0,00

Source: own elaboration

At this stage, one may wonder why it is not possible to quickly rebuild the pre-FMD herd levels by either importing more or exporting less just after the FMD period. From table 3, it appears that Brittany effectively imports many more heifers and, to lesser extent, exports fewer cows in the second period. But this is not sufficient to retrieve pre-FMD levels, simply because availability of these live animals in other regions is not unlimited. For instance, we find more imports of heifers at an increased price (by 7.31 per cent, see table 4). These second price effects on live animals are much more muted compared to those observed during the outbreak period where trade was not permitted (with an increase of 148.03 per cent for female calves due to reduced supply and import bans).

Returning to the impacts on markets (table 2), the increased production of milk is consistently accompanied by a price decrease (by 2.12 per cent) while the reduced production of beef induces an increase in price (by 2.76 per cent for beef, 5.73 per cent for cattle for slaughter). On other markets, results become more marginal. However, we underline that domestic wheat production decreases by 0.89 per cent in the second period. Again, this is explained by competition on the land market with an increase in areas of fodder to feed the increased herds of cows.

Moving to the second period after the outbreak, we find quite limited price/quantity effects on most markets, with the exception of beef. The domestic production of beef is still 3.38 per cent lower than the pre-FMD level (period 3 in table 2) because the herd structure has still not recovered its initial steady state. In particular, adult animals (heifers and bulls) are still less numerous at the beginning of the second year as it takes time to grow these animals (table 3). In the steady state solution, the market impacts are very modest. We observe just a slight decrease of beef production, of cattle imports and a slight expansion of the suckler herd.

Table 3. Impacts on the cattle (number of animals and in % with respect to the initial steady state level)

Period	Pre-FMD	1	2	3	4	5	15

Cattle herd structure							
Dairy cows	766.500	-10,00	5,67	-0,34	-0,27	-0,05	0,00
Suckler cows	135.100	-10,00	58,91	8,86	-2,76	1,89	2,07
Male calves	502.944	-10,00	-30,74	0,41	-0,95	-0,98	-0,43
Female calves	637.472	-10,00	-48,00	-0,91	-1,35	-1,28	-0,64
Heifers	527.200	-10,00	-21,35	-6,01	-0,46	-0,67	-0,29
Bulls	119.500	-10,00	-10,00	-20,46	-1,16	-1,56	-1,06
Domestic production of live animals							
Male calves	386.000	-10,00	15,25	1,32	-0,72	0,30	0,37
Female calves	367.772	-10,00	15,13	1,30	-0,71	0,29	0,37
Heifers	460.586	-10,00	-51,73	-1,26	-1,43	-1,33	-0,61
Bulls	119.500	-10,00	-20,46	-1,16	-1,56	-1,54	-1,06
Cows	482.000	-10,00	-21,66	-5,81	-0,33	-0,55	-0,14
Trade of live animals							
Male calves	-116.064	-100	-49,03	-8,51	-1,83	-4,70	-3,07
Female calves	-269.700	-100	-22,80	-4,96	-2,06	-3,13	-2,00
Heifers	-66.614	-100	310,26	5,14	4,62	4,10	2,05
Bulls	0	0	0	0	0	0	0
Cows	223.640	-100	-12,60	-7,04	-3,31	-2,08	-1,59

Source: own elaboration

Table 4. Impacts on the price of live animals (in euros per animal and in % with respect to the initial steady state level)

Period	Pre-FMD	1	2	3	4	5	15
Male calves	129	123,02	-3,31	-0,44	-0,09	-0,24	-0,16
Female calves	122	148,03	-1,29	-0,25	-0,10	-0,16	-0,10
Heifers	525	23,62	7,31	0,25	0,23	0,20	0,10
Bulls	577	18,74	16,40	-0,69	-0,24	-0,14	0,00
Cows	1,021	-8,26	2,73	1,47	0,68	0,42	0,13

Source: own elaboration

ii/ Welfare impacts

We now examine the welfare impacts of our scenario, looking first at the value added (net of taxes/subsidies) from the different activities (table 5). We find that the dairy cow activity finally gains during the FMD outbreak period by as much as 62.8 million euros (5.57 per cent) mainly because of the milk price increase and the lower production costs (including feed). The nature of this result is not original per se (see, for example, Mangen and Burrell, 2003). More surprising is the lower net value added generated by other cattle activities. This decreases by 54.4 million euros (4.26 per cent). This result is surprising because these activities also gain from the cattle price increase and the lower feed costs. However, they suffer from being unable to import calves for fattening or raising purposes (the domestic price of calves increases strongly in the FMD outbreak period, see table 4) as well as being unable to export young cows (the domestic price of young cows decreases in the FMD outbreak period). Indeed it appears that the heifer raising activity is the most heavily penalised (by 86.4 million euros or 17.84%).

These effects on the cattle sectors are obviously major among agricultural activities. Globally we find that the value added generated by agriculture slightly increases (by 1 million euros or 0.03 per cent). In fact, other agricultural sectors lose slightly in the first period; for instance, wheat activity loses owing to the lower price of wheat (see above).

Not surprisingly, we find that the beef and dairy industries suffer from the FMD outbreak by respectively 28 (16.98 per cent) and 22.2 (11.40 per cent) million euros. The loss is thus greater for the beef industry and much greater than the decrease in production volume (10 per cent). The economic logic for this is as follows. In both industries, raw agricultural products represent a large share of production costs. The value added generated is rather small and, in the case of the Breton dairy industry, serves mostly to pay wages to workers. However, the small value added generated by the beef industry is used to pay wages to workers and to provide dividends for capital holders. In other words, in the initial situation, the capital invested in the beef industry is relatively more important than the capital invested in the dairy industry. The consequence of this is that the dairy firms are unable to smooth the price effects of the FMD while the beef firms have some latitude to absorb part of the shock (by reducing dividends). This is indeed what explains most of the difference in the evolution of beef/dairy prices with respect to cattle/milk prices. We find that the price of these two agricultural products increases by a rather similar percentage (around 4.2 per cent) and the dairy product price increases more than the beef price (2.51 per cent compared to 1.86 per cent). At this stage, the major question is why the beef firms do not buy cattle at a lower price and/or sell beef at a higher price. On the foreign output markets, the Breton beef firms have a smaller share than the Briton dairy firms; hence the same reduction of volume (in percentage) logically has a lower output price effect. The question then is to determine why the beef firms buy cattle at prices that high. In fact, they have no current interest in this as this reduces their current capital return. But it is in their future interest to ensure the future supply of cattle for slaughtering and hence their future activity and capital returns.

Table 5. Impacts on net value added for different activities (million euros and in % with respect to the initial steady state level)

Period	Pre-FMD	1	2	3	4	15
Dairy cows	1,127	62,8 5,57%	41,3 3,66%	2,4 0,21%	-0,3 -0,03%	0,1 0,01%
Other cattle	1,275	-54,4 -4,26%	-267,8 -21,00%	-38,4 -3,01%	-6,8 -0,53%	-3,3 -0,26%
Total agriculture	3,973	1,0 0,03%	-225,3 -5,67%	-37,8 -0,95%	-7,4 -0,19%	-3,1 -0,08%
Beef industry	165	-28,0 -16,98%	-37,4 -22,64%	-8,4 -5,10%	-1,4 -0,86%	-0,5 -0,29%
Dairy industry	195	-22,2 -11,40%	11,3 5,79%	-0,9 -0,45%	-0,6 -0,31%	0,0 0,00%
Food industries	2,372	-39,6 -1,67%	-21,8 -0,92%	-7,4 -0,31%	-1,1 -0,05%	-0,3 -0,01%

Source: own elaboration

Breton food industries globally experience a negative evolution of their value added during the FMD outbreak period due the previous effects on the beef and dairy industries. It should be noted that the animal feed industry also suffers from a FMD outbreak (by 1 per cent) while the pig and poultry industries gain (by respectively 0.8 and 0.4 per cent).

Turning to the second period, impacts on the value added are still consequential. The dairy cow activity still gains (by 41.3 million euros or 3.66 per cent). This is now mainly explained by the increased volume of production and the lower costs of young cow while the output price effect is now working on the opposite (negative) side. It appears that other cattle activities lose significantly in this second period (by 267.8 million euros or 21 per cent). The main reason is the much lower level of herds at the beginning of this second period (by as much as 48 per cent for female calves, see table 3). This is the delayed impact of the restriction concerning the movement of animals (including the imports of calves). One additional reason is that the reintroduction of competition from foreign products limits the price increase of domestic live animals. This impact on other cattle sectors largely determines the aggregate negative impact on agriculture (by 225.3 million euros or by 5.67 per cent). Hence we find that the negative impact of a FMD outbreak on agriculture mostly occurs in the immediate next period. By contrast, the aggregate negative impact on the food industries is lower in the second period (by 21.8 million euros or 0.92 per cent). The dairy industry is now benefitting from an activity increase while the beef industry is still suffering from a loss of activity. As for other cattle sectors, the beef industry suffers most in the immediate periods following the FMD outbreak.

From this second period to the steady state solution, we find that impacts on value added quickly converge to their steady state values. In the steady state solution, impacts are marginal; the only significant impacts concern the beef industry and the other cattle sectors. They are both affected by less than 0.3 per cent due to the reduced level of activity by period 15.

The macroeconomic impacts of our scenario are reported in the first column of table 6. Before interpreting these results, we recall that we develop a dynamic CGE model with one representative household. We are thus unable to identify the impacts on each type of household (farm versus non-farm) but only the aggregate impacts. This representative household owns primary production factors (labour, land, physical and cattle capital) and thus receives the corresponding factor returns. With these returns (net of taxes/subsidies) forming the household income, the representative household consumes final goods and saves for future periods. The periodic consumption of final goods provides some satisfaction (utility). The FMD outbreak alters the household income and prices, hence the final consumption. In table 6, we first report the periodic equivalent variation which is the periodic amount of money (euros) that the representative household is ready to pay to accept the scenario (for more details on the way it is computed, see Keen, 1990). We find that this annual equivalent variation is negative and amounts to only 3.8 million euros. This is quite low compared to the value added losses of the agricultural and food sectors (38 million euros in the first period, 246 million euros in the second period, 3.4 million euros in the steady state period). This is first explained by the fact that other sectors in the economy may not suffer. Indeed we find that the total value added generated in the second period decreases by 163 million euros (compared to the 246 million euros for agriculture and food sectors together). This is mostly explained by the fact that the representative household saves less and globally maintains its consumption expenditures following the income drop. This is reflected in the increased global debt at the steady state with respect to foreign economic agents: this debt increases by 273.8 million euros. In other words, Breton investments are financed to a greater extent by foreign agents. In fact, the representative household has no incentive to save more because it always perceives the same exogenous interest rate. We also report the steady state valuation of other assets (land, physical capital and cattle herd). The values of these assets are relatively stable. In the last row of table 6, we aggregate the annual equivalent variations with these "wealth" effects by discounting all values with the exogenous interest rate. The resulting discounted aggregate welfare amounts to a loss of 168.9 million euros. This level is indeed consistent with the size of our shock: we assume that 10 per cent of the initial cattle herd is killed and lost. These lost animals are initially valued at 141 million euros. We also assume that trade in live animals is no longer permitted in the first period. This represents a loss of 151 million euros of net export earnings. This second component of the shock can, however, be partly smoothed by postponing trade until the future periods while the killing of infected animals is a definitive loss. In other words, the aggregate loss is lower than the shocks owing to compensating price effects. We check this result by performing another FMD simulation where trade in live animals is permitted during the outbreak period. Then the aggregate loss amounts to 86.9 million euros for a shock of 141 million euros.

Table 6. Macro economic impacts (in million euros)

Version of the model	Perfect factor markets	Constraint on investment	Constraint on wages	Both constraints
Annual Equivalent variation	-3,8	-0,5	-34,1	-88,3
Value of land	-2,9	-76,0	-3,8	-85,4
Value of physical capital	6,4	-127,7	-43,9	-367,5
Value of cattle herd	1,6	-69,5	1,8	-70,3
Value of foreign debt	273,8	265,8	435,4	226,3
Discounted welfare	-168,9	-264,7	-585,4	-1276,9

Source: own elaboration

3.2. Impacts of a FMD scenario without perfect factor markets

i/ With constraints on investment

The results presented so far are obtained in a context that is very close to a first best world: firms are always able to finance their investment at an exogenous rate to return to pre-FMD steady state levels. We now assess the sensitivity of these results to some real features of factor markets, starting with the possibility that firms are credit constrained. As mentioned in the previous section, we can introduce such a feature into our model by introducing constraints on investment. We now assume that cattle sectors and downstream industries (dairy and beef industries) are potentially constrained in the amount of investment.

To calibrate the two parameters governing the severity of the constraint, α and β, we need two pieces of information. First, we assume that if the current capital return is 5 per cent lower than the pre-FMD steady state capital return, then the constraint becomes binding. Second, we assume that if the current capital return decreases by 25 per cent compared to the pre-FMD level, then firms are constrained to not invest at all: they may even be forced to dis-invest. Formally, we impose that $\alpha = 5, \beta = -15/4$. These parameters imply that, if the current capital return equals the pre-FMD level, then firms are allowed to invest 25 per cent more than before the constraint becomes binding. We admit here that we have little information to justify these parameters. For instance, Blancard et al. (2006) find that 99.7 per cent of French arable crop farms are credit constrained and one unit relaxation of the credit constraint will add 1.35 to farm profit in the long run. They develop a static framework that hinders direct use of this information in our setting. Nevertheless, by assuming that firms are initially not constrained, our calibration can be seen as introducing moderate investment constraints.

Table 7. Production and price impacts with investment constraints (in % with respect to the initial steady state production)

Period	1	2	3	4	5	15
Production						
Milk/Dairy prod.	-10,00	8,35	1,12	0,09	-0,02	0,06
Cattle/Beef	-10,00	-14,57	-11,90	-12,48	-12,50	-7,36
Pig	0,97	0,24	0,34	0,42	0,45	0,41
Wheat	3,05	-1,11	0,53	0,30	0,36	-0,05
Price						
Milk	4,52	-3,14	-0,46	-0,03	0,02	-0,01
Cattle	4,18	5,04	2,97	3,26	3,30	1,55
Pig	-0,20	0,02	-0,08	-0,10	-0,11	-0,10
Wheat	-0,41	0,25	-0,04	-0,01	-0,02	0,05
Beef	1,86	2,81	2,25	2,37	2,37	1,35
Dairy products	2,51	-1,83	-0,26	-0,02	0,01	-0,02

Source: own elaboration

The market impacts of the same FMD scenario with investment constraints are reported in table 7. The impacts obtained in the first period are roughly similar to those obtained with the standard version of the model. However, starting from the third period results on the beef/cattle variables are very different. In particular, we observe that the domestic production of cattle and beef decrease by 11.9 per cent (compared to 3.38 per cent with the standard version). The main reason for this is that cattle sectors and the beef industry are not allowed to invest as much as they want, given their market views in the first and second periods. Accordingly the physical capital stock starts becoming the limiting factor in these sectors, whereas only the size of the cattle herd was limiting in the previous results. In other words, following the FMD outbreak, few enterprises are allowed to pursue their investment levels to maintain their production capacity. This also takes time to be reflected in market equilibrium. In fact, it appears that the economy reaches a completely new steady state equilibrium characterised by much lower beef production (7.36 per cent).

The new market impacts are obviously accompanied by new welfare impacts. In particular, we find that the other cattle sectors lose in the terminal period by 8.10 per cent (compared to 0.26 per cent with the standard version). For the beef industry, the loss in the terminal period now amounts to 6.6 per cent (compared to 0.29 per cent with the standard version). In macro-economic terms, the aggregate cost of the FMD is greater and reaches 264.7 million euros (see table 6). Not surprisingly, we find that the value of physical capital significantly decreases (by 127.7 million euros). Land values also decrease (by 76 million euros) as a result of lower animal production.

ii/ With constraints on wages

Results obtained so far assume that the labour market is perfect with a fixed endowment of the working force in Brittany. Real wages adjust to ensure that the demand by activities equals this fixed supply. With the standard version of our model, it appears that wages slightly decrease in the first few periods (by 0.71 in the first, 0.34 in the second, and 0.06 in the third). This does not recognise the fact that there is involuntary unemployment. We now introduce a constraint on real wages, so that they cannot fall below pre-FMD levels.

The market impacts of our FMD scenario with the wage rigidity are quite close to those obtained with the standard version. This result is again not original (see, for instance, Gohin and Moschini, 2006). Nevertheless, the macro-economic impacts are significantly modified. The annual equivalent variation now decreases by 34.1 million euros and the debts increase by 435.4 million euros (see table 6). Overall, the aggregate discounted cost of the FMD outbreak amounts to 585.4 million euros, which is 2.5 times greater than the estimate obtained with the standard version of the model. The reason is that some workers become unemployed in the first periods of simulations: total employment decreases by 0.6 per cent in the first period and by 0.4 per cent in the second period. In the steady state solution, total employment has decreased by 0.026 per cent. This still represents an increase of 0.3 per cent of total unemployment (the unemployment rate is 8 per cent in the initial situation). So two main effects on the aggregate welfare effects are revealed: one is the income loss that was generated by these newly unemployed workers; the other is the income loss from capital/land returns for other households/workers.

iii/ With both constraints

We perform a final simulation where both constraints on investment and wages are specified. As expected the market impacts are close to those obtained with the constraint on investment only. However, it appears that the macro-economic impacts are large. Both constraints interact to give a discounted welfare loss of as much as 1,276.9 million euros (see table 6). This is 7.5 times higher than our first estimate with perfect factor markets.

4. Conclusions

In this paper we investigate the dynamic effects of an outbreak of FMD which is usually considered to be a catastrophic shock on agricultural and food markets. We build a new dynamic CGE model focused on a French livestock intensive region with a detailed representation of the livestock sectors dynamics. We find diffuse effects of a FMD outbreak that have not previously been identified in the economic literature. In particular, we show the differentiated dynamic impacts on livestock and downstream sectors. On aggregate, the livestock sectors are not immediately penalised by such a disease because of compensating price effects but they suffer most after the outbreak when these price effects dampen. By contrast, downstream sectors suffer most during the outbreak period and then partially recover. Our CGE approach also allows us to focus on the factor markets and their role in smoothing the shock over time and over sectors. When we assume that the factor markets are not perfect because of financial constraints (credit limitations) and institutional constraints (minimum wage), economic equilibrium can only reach a second best position with forced unemployment and foreclosure. The aggregate cost of a potential FMD outbreak appears to be highly dependent on the assumptions made concerning the factor markets.

These results raise the issue of how to cope with uncertainty on agricultural and food markets. They provide new insights into the current attempt to harmonize European risk management policies in animal health and into the quantification of the market effects of catastrophic risk in agriculture. With our dynamic estimates of the sectoral and aggregate costs of a hypothetical FMD outbreak, further work should be devoted to assessing different physical and financial risk management policies.

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