ASSESSING ECONOMIC AND TECHNICAL IMPACTS OF NON EXPECTED WEATHER EVENTS ON FRENCH SUCKLER COW FARMS DYNAMICS: A DYNAMIC RECURSIVE FARM MODEL

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Abstract— **Weather variability can threaten French suckler cow farms which rely on rather extensive forage production. However, flexibility of the production system can help farmer to face crop production shocks. This study aims at assessing how crop yield shocks impact on farms outcomes when adaptive capacity is taken into account. Our objectives are to develop a dynamic model which enables us 1) to predict the optimal mix of production adjustments to face crop yield shocks, 2) to quantify how far the system moves from the equilibrium and how long it takes to return and 3) to measure impact of shocks on economic results when adaptive capacity is taken into account.**

An original dynamic recursive bio-economic farm model integrating detailed technical and biological constraints and coupled with biological sub-models has been built and calibrated to represent an average farm producing charolais finished animals. Crop yield shocks of intensities ranging between -60% and +60% of their average values are simulated in between average years.

A preference for maintaining animal sales and animal live weight at the expense of crop products trade balance is found. Thought, when intensities of shocks get higher, forced sales and important variations of the area of pasture cut are observed. Essential of loss (or gain) of net profit is felt the year of the shock but can be remnant for several years. In addition, gains for good years do not totally compensate loss of symmetric bad ones. Consequently, farms capacity to face risk could be weaken over time. Minimum consumption needs, probability distribution of shocks and successions or combinations of shocks would have thought to be taken into account to assess real capacity of farms to maintain over time.

Keywords: **livestock farm model, dynamic recursive model, crop yield variability**

I. INTRODUCTION

The 113 000 farms producing suckler cows supply around 55% of the beef production in France and represent more than one third of all European suckler cows. Their relative extensive management system helps maintaining large areas under grassland which provide numerous environmental amenities. However, their dependence on pasture crops makes them sensitive to weather variability [1]. Half of the French fund for agricultural calamities is allocated to herbivorous farms. Most of indemnities paid correspond to damages caused by drought on forage crops, mainly in the Massif Central area [2]. Although this public fund is to evolve soon, no insurance alternative is yet available. To some extent, this can be explained by the difficulties to understand and to assess weather events impacts on livestock systems since numerous sources of flexibility can help farmers to cope with these shocks. To face supply shortage, first, animals are able to temporary cope with underfeeding without a tremendous effect on production, under certain conditions, thanks to body reserve [3] or to compensatory growth [4]. Second, decreasing the stocking rate can help lowering herd alimentary needs. Eventually, buying more (or selling less) fodder or concentrate feeds than was planned initially [5] can compensate animal feed shortage. Neglecting those farmers' adaptive capacity can lead to misevaluate shocks impacts [6]. In addition, it is of great interest for farmers to gauge "*how to respond tactically and dynamically to unfolding opportunities or threat to generate additional income or to avoid losses*" [7].

This study aims at predicting how crop yield shocks impact on farm outcomes when adaptive capacity is taken into account.

Modelling offers a comprehensive way to disentangle the complex interactions and mathematical programming (MP) appears relevant to appraise the numerous technical alternative choices and the many constraints existing in farm management. Since suckler cow production cycle lasts several years, decisions may impact not only on the current production and profit, but also on future farm outcomes. Our objectives are then to develop a dynamic model which enables us 1) to predict the optimal mix of production adjustments to face crop yield shocks, 2) to quantify how far the system moves from the equilibrium and how long it takes to return and 3) to measure impact of shocks on economic results when adaptive capacity is taken into account.

The remainder of this article is organized as follows. We expose the modelling approach and model specification in the first two sections. In the following section, we apply this model to a typical suckler cow farm located in the north of the French Massif Central and we simulate several crop yield production shocks with intensity ranging from -60% to +60%. We conclude with a discussion of our method and results.

II. MODELLING APPROACH

Farm models detailing biotechnical specifications can be divided into two broad categories: simulation models and optimisation models. Whole farm model simulation necessitates defining decision rules into a management sub-model [8; 9; 10]. However, these rules are set for a specific context and might turn out to be irrelevant when changes occur. We therefore opt for a bio-economic model (see Janssen et al, [11] for a recent review) which tightens decision variables to a single objective function independent of environment conditions. Static bio-economic livestock models [12; 13; 14; 15] compare farm equilibriums under different conditions. However, contrary to dynamic models which take time explicitly into account, static models do not give the opportunity to study farm responses outside an optimal steady state. Consequently, perturbation caused by a temporary shock or the transition path between two equilibriums when facing permanent shocks cannot be studied. We therefore follow [16; 17; 18; 19; 20; 21; 22; 23] by representing a sequential decision-making process to permit progressive adjustment when new information becomes available. These sequential dynamic models proposed either a fairly small number of variables to be adjusted or limited periods where these adjustments can be made. We want here to take into account the monthly management of a larger number of animal categories existing within the cattle herd, of animal live weight, and of conserved feed and standing grass. Programming methods used in these models, namely Stochastic Dynamic Programming (SDP) or Discrete Stochastic Programming (DSP), are limited respectively by the number of state variables, that is to say the dynamic variables, or by the number of stages where decisions can be readjusted [24]. Model size indeed explodes when variables or stages increase. We therefore adopt a dynamic recursive framework which consists of a sequence of deterministic multi-periodic models.

III. MODEL DESCRIPTION

The model is formulated to represent average French suckler cow farms. Such farms consist of beef cattle production based on a suckler cow herd and of grain and forage crop production. This production system must be managed by a farmer over a finite horizon of T years. Each year, indexed by $t =\{1,.. T\}$ is divided into monthly intervals indexed by $month= \{1,\ldots 12\}$. The ‘production year’ starts in April, at the beginning of the grazing season.

A. The production system

The production system is described here distinguishing farmer herd management and farmer crop production management.

Herd dynamics: Twelve annual animal classes characterized by sex (male, female or castrated male), age (from new born to adult) and by production objective (fattening or storage), are introduced to cover the range of animal production in the studied area (table 2). Classes, indexed by *a*, are described by two endogenous dynamics variables: the number of animals and their average live weight (24 state variables in total).

Herd management consists in controlling those dynamics thanks to the 1) monthly control of animal sales, 2) monthly choice of animal diet composition and diet energy content, 3) part of cows for reproduction each year, and 4) annual fattening objectives.

Table1: animal classes introduced in the model

Sub class		stored animals						Fattened animals			
Class name		calves	yearlings	2 y.o. heifer	2 y.o. steer	Primiparous cow	Multiparous cow	2 y.o bull	3 y.o steer	3 y.o heifer	Fat. Cow
age in months	min	0	2	14	14	26	>38	14	26	26	>38
	max	2	14	26	26	38	>38	20	32	32	>38
Live weight in kg	Min	45	93	354	445	499	618	445	662	499	618
	Max	79	466	542	716	629	683	711	801	689	757

The number of animals in each class is initialised for the first period of the planning horizon. Then intra year dynamics are defined by the motion function *f*. This function draws the balance between past number of animals *(NB)*, sales decisions *(AS)*, and mortality *(mort)* (1).

$$NB_{a,t,month} \left| \begin{array}{l} = f_{a,t,month-1}(.) \\ = NB_{a,t,month-1} \times (1 - mort_{a,month-1}) - AS_{a,t,month-1} \end{array} \right. \quad (1)$$

At the beginning of each year (in April), animals change from a class to another because of: 1/ natural ageing process (the number of 1 year old heifers at the end of a year becomes the initial number of 2 year old heifers the following year or calves number depends of the cows number) modelled by a transition matrix *(trans)*, *2/* fattening (*SFAT)* since the model can choose for instance to convert part of the number of two year old heifers into fat heifers (2) and the remaining part into primiparous cows (3) and 3/ reproduction objectives *(Rrate)* since limitation of the percentage of reproductive females for mating can reduce the number of calvings in February (4).

$$NB_{a\_st,t,'april'} = \sum_{a} \left[trans_{a,a\_st} \times f_{a,t-1,month-1}(.) \times \left(1 - SFAT_{a,t}\right)\right] \quad (2)$$

$$NB_{a\_fat,t,'april'} = \sum_{a} \left[trans_{a,a\_fat} \times f_{a,t-1,'march'}(.) \times SFAT_{a,t} \right] \quad (3)$$

$$NB_{a\_calf,t,'febr'} = \sum_{a} \left[trans_{a,a\_calf} \times NB_{a,t-1,'march'} \times Rrate_{t} \right] \quad (4)$$

Where a_st, a_fat and calf are animal sub classes corresponding respectively to stored animals, fattened ones and calves.

Some additional constraints are added to make the model more realistic. Multiparous cows do not undergo an ageing process in our model; consequently, a minimum cull rate is introduced. Moreover, the number of mature cows must be high enough to suckle young animals until weaning in October and no sale of calves is allowed before their fifth month which corresponds to early weaning. As few market opportunities exist for 2 year old stored steers, we assume they cannot be sold.

Animal live weight dynamics (*LW)* are expressed in the same way: initialisation of the live weight for the first period, intra-annual dynamics described by a motion function which depends on the average daily weight gain *(ADG)* realised during each day *(day)* of the month considered (5), and inter year dynamics defined by a transition matrix.

$$LW_{a,t,month} = LW_{a,t,month-1} + day_{month-1} \times ADG_{a,t,month-1} \quad (5)$$

This dynamic variable is bounded between +/-5% of the theoretical live weight (estimated in a sub model described below) which gives the model some flexibility without, according to expert knowledge, threatening reproduction performance and animal health. At the same time the ADG can vary from +/-10% of the theoretical gain in order to allow some compensatory growth. For mature cow, we set gain interval at [-0.5; +0.4] kg per day. The ADG value is a function of the daily net energy balance (NEB). NEB is the difference between on the one hand net energy intake which depends on quantity of feed ingested by each animal and on their energy content, and, on the other hand, net energy requirement that comprises net energy for production (lactation and pregnancy) and net energy to maintain (NEM) live weight constant. A correction term is applied to take into account the differential between theoretical live weights and simulated ones (an animal that weighs more will have higher maintenance needs). Diets are not only characterized by their energy content but also by their fill value (measured by the maximum quantity of this feed a reference animal can ingest) which cannot exceed the intake capacity of the animal. When animals are fed indoors, we consider that fill value of diets proposed by the model have to be close to the intake capacity of animals in order to satiate them (a small percentage can be covered by straw intake).

The animal sub model calculates theoretical live weight and animal requirement of the animal at each period according to INRA (2007) and Garcia and Agabriel (2008) equations. This sub model simulates animal growth assuming a calving occurs on 1st February thanks to Gompertz functions. The theoretical putting on weight of females (cows and three year old heifers) at fattening is calculated as the difference between cumulated gain since beginning of fattening and maximum live weight. Reproduction and maintenance requirements as well as intake capacity are set monthly according to theoretical live weight. Maintenance needs at pasture are increased by 20 % at pasture to account for higher activity.

Crop production management: We consider the five most widespread products in the farming systems studied: grazed grass, hay, maize silage, grain and straw which can be made from four crop productions: permanent and temporary pastures, two cereal crops (to enable sowing cereal crops two years in a row) and maize crop (table 3). These products are described by parameters of qualities (fill value and energy content) and by dynamic variables related to the quantity stored by the farmer.

Crop management consists in controlling those dynamics thanks to the 1) monthly sales and purchases of crop products, 2) monthly choice of haymaking, and 3) annual allocation of area to the different crops

Two different kinds of dynamics are defined for crop products stock. First, stocks of conserved (STv_ng,.,.) produce are classically defined as the balance between inputs (production VH and purchase VB) and withdrawals (herd consumption VC and sale VB) plus the remaining stock of the previous period (6). It is assumed that maize silage can not be traded and that stock quantity can not exceed farm storage capacity for each product. Second, quantity of standing grass available in one period (STv_g,.,.) corresponds to the remaining (after abscission abs) balance between previous biomass stock, grass produced GP, quantity of grass cut for haymaking CUT and herd consumption (7). The coefficient of abscission takes into account losses due to average ageing process and to environmental conditions when grass use is delayed to the following month.

$$ST_{v\_ng,t,month} = \left| \begin{array}{l} +ST_{v\_ng,t,month-1} + VH_{v\_ng,t,month-1} + VB_{v\_ng,t,month-1} \\ -VC_{v\_ng,t,month-1} - VS_{v\_ng,t,month-1} \end{array} \right. \tag{6}$$

$$ST_{v\_g,t,month} = \left\| \begin{bmatrix} ST_{v\_g,t,month-1} + GP_{t,month} \\ -CUT_{t,month-1} - VC_{v\_g,t,month-1} \end{bmatrix} \right\| \times abs_{month-1} \tag{7}$$

Crop product quantities harvested depend on crop acreage decisions *(X)* and on crop yields. Harvested hay quantity corresponds to the quantity of grass cut penalised by a coefficient of loss (20%) because of transport, haymaking etc. The model is then free to decide the quantity cut per month within the limit of the grass availability. A transition matrix (rot) defines the possible successions between crops (8), hence reflecting agronomic constraints (for instance, maize can not be sown two years in a row). In addition, permanent pasture acreage is assumed to remain fixed whereas temporary pasture is implanted for at least five years. Only one fifth of the temporary pasture area can then enter the crop rotation each year. Eventually, the quantity of feed product consumed by the herd is proportional to monthly animal intakes and to animal number. Straw which is considered as litter is proportional to the herd size.

$$X_{t,c} \leq \sum_{C2} rot_{c,c2} \times X_{t-1,c2} \quad (8)$$

The quantity and quality of standing biomass produced each month per hectare is calculated thanks to a sub model of herbage growth [27]. One cut per month at 3 cm above ground level (the length of standing grass beef cattle can graze) is simulated to approach monthly production quantity and quality. The abscission parameter is estimated by dividing for each month the amount of biomass harvested for the current month when there was no cut the month before, by the sum of biomass harvested if there were a cut in the previous and current months. To simplify our model, grass quality of the sward is averaged according to the proportion of the different structural compartments 3 cm above ground level, and hay quality is supposed fixed.

B. Structural constraints

Decisions are restricted by structural constraints regarding land, labour and building. Total acreage allocated to the different crops must be equal to farm usable agricultural area and the acreage of permanent pasture must remain stable. We follow Veysset et al [12] to represent labour and building constraints. First, we limit the number of livestock units and crop growing activities "based on the principle that one livestock unit is equivalent to two hectares of cereal crops in labour terms". Second, we consider that the main building constraint is linked to the number of calves since they are born indoor.

C. Profit and costs

We assess farm earnings by computing their net profit. It is calculated as the difference between yearly products (sales '*SALE*' and Common Agricultural Policy payments '*TOTPREM*') and total costs (variable and fixed costs). Receipts from animal sales take into account the number of animals sold, their live weight at this period and their price *(priA)*. These prices are defined per year and per month, which enables us to introduce price modulation according to theoretical live weight (price per kg usually decreases with live weight for stored animals and increases for finished ones) and to temporary or permanent shocks on prices. Farmer revenue from crop product sales is the combination of quantities of crop products *(VS)* and their price *(priV)* (9).

$$SALE_t = \left| \begin{array}{l} \sum_{a,p} \left(AS_{a,t,month} \times LW_{a,t,month} \times priA_{a,t,month} \right) \\ + \sum_{v,p} \left(VS_{v,t,month} \times priV_{v,t,month} \right) \end{array} \right. \qquad (9)$$

It is important to introduce CAP payments since they strongly influence production decisions in suckler cow farms [12]. The CAP premium specification is flexible enough to take into account the different kinds of direct payments belonging to the first pillar (production support) which were effective between 1998 and 2008 (10). These payments encompass Arable Area Payments *(AAP)*, Product Specific Payments *(PSP)* and Single Farm Payment *(SFP)*. Firstly, under the AAP scheme; different premiums are given according to the area allocated to each crop activity (except fodder crops). PSP comprise special premiums for suckler cows, male premium, slaughtered animals and extensification payment. Under the SFP scheme, farms are allotted payment entitlements considered as constant. Direct payments are reduced in proportion to the modulation rate *(mod)*. However, 5 000€ per farm remain free of modulation.

$$\mathrm{PREMTOT}_t = \left| \begin{array}{l} 5000 + \\ \left[AAP_t + PSP_t + sfp \; - 5000 \right] \times \left(1 - \mathrm{mod} \right) \end{array} \right. \qquad (10)$$

Variable costs can be divided into crop production and animal production costs. Crop production costs include costs assignable to the area of each crop activity, haymaking costs corresponding to the quantity of grass cut, insurance and fuel costs proportional to the total area of land farmed. Animal production costs comprise value of purchased feeds and diverse costs such as veterinary or feed complementation (vitamins, minerals etc.) proportional to the number of livestock units.

D. The decisions problem of the farmer

The objective function: In accordance with classical economic theories, our multi-periodic optimisation model assumes that farmers take their decisions to maximise their expected utility of profit U over a 5 five years planning horizon T (11). Farmers have then to formulate preferences on profit *(Π)* distribution over years. Inter temporal choices involve tradeoffs among benefits occurring at different points in time. They typically include a discount factor on future utility, called Rate of Time Preference (RTP), to take into account farmer's time value of money or 'impatience', and an elasticity of inter-temporal substitution (EIS) which quantifies a 'decision maker desire to smooth out the stream of utility over time so one unit of discounted utility in each period is better than two units of discounted utility in a single period' [28] In the present case, we suppose then that the wealthier the farmer is, the less averse to inter temporal variations he will be and we specify a power functional form for the utility function that corresponds to a Constant Relative Risk Aversion utility function [29].

$$U=\sum_{t=ti}^{T}\left(\left(\frac{1}{1+r}\right)^{t-1}\times\frac{\Pi_t^{\,1-\alpha}}{1-\alpha}\right)+\left(\frac{1}{1+r}\right)^{T}\times\frac{VS^{\,1-\alpha}}{1-\alpha} \qquad (11)$$

Where r is the discount rate factor, 1/α=EIS, and VS residual value of stocks at the end of the planning horizon

Sequential decisions: Farmers are supposed to make their decisions according to the current state of their production system and to their current expectation of future outcomes over the planning horizon T. When new information becomes known, farmers adjust their expectations and then their decisions. We follow [30] and [19] in modelling this double ability of farmers to forecast and to adjust their plan by the mean of a recursive sequence of dynamic optimisations. Let's be *n {1,...N}* a year of the period of simulation and *t {ti...T}* a year of the planning horizon the farmer is supposed to anticipate and *S* a set of state variables characterizing farm at each time. Results corresponding to the optimisation *n* are then {*Sn+ti.,* *.., Sn+t,.. Sn+T*}. *Sn+(ti+1)* becomes then the initial resources of the optimisation *n+1*. Updated forage production information is introduced at this stage. The process is repeated *N* times. Hence what we would observe from the farmers' strategies along the period simulated is *{S1+ti, .., Sn+ti, .. ,SN+ti}.*

IV. CASE STUDY

We apply the model to typical farms located in the northern area of the Massif Central, a well known area for its suckler cow charolais breed production.

A sample of 25 farms that produce mainly charolais young bulls has been extracted from the 'charolais farms' database [31] over the period 2000-2006. Calibration of this model consists in setting parameters to simulate a farming system with structural, economic and biological characteristics close to those of observed farms. Model outputs are then evaluated against technical and economic variables of this dataset.

A. Parameterization and calibration

Animal production: Parameters used in the animal sub model refer to the charolais breed ones [25; 26]. Cull rate (0.24), number of calves born per reproductive female (0.96), sex ratio (0.5) and annual mortality rates (9% for calves, 1% for the others) correspond to average annual records of the 'charolais' database.

Crop production: Herbage growth sub model parameters are calibrated to fit regional average annual production data (R^2=0.13) and weather data are collected from Nevers meteorological station (Meteo France 58160001) (appendix1). Cereal crop yields are set upon 'charolais' database records (appendix2). Fill value and energy content of maize, grain and hay are set according to INRA (2007) (CC0010, FV1770, FF0500).

Cost and profit: Input costs, and output prices are assessed on the basis of the panel dataset over the period 2000-2006. We assume that a crop product price is 20 % higher if the farm buys it (compare to sell it). Animal prices have been regressed on observed live weight per year and per animal (appendix3). Available data regarding harvest cost is expressed per ha whereas haymaking cost is formulated in € per ton in our model. As a consequence, cost per ton is estimated as the ratio between haymaking cost per ha and average abundance of grass per period.

Objective function: We set RTP value at 96% per year and EIS at 7.14 according to estimation based on aggregate annual farm data using consumption and asset return of U.S farms [32].

Structural characteristics: Farm characteristics are averaged upon the 25 studied farms oriented toward the production of young bulls (table 2). However, storage capacity is not filled in the database; values are set therefore in order to be not too restrictive.

B. Evaluation of model outputs against a panel dataset

The main features of the simulated system meet our requirement since the average level of outputs (table 3) lie within an interval which corresponds to the observed mean plus or minus one standard deviation (except for the percentage of pasture area cut which is underestimated). Coefficients of determination and of correlation between simulated and observed variables for the period 2000-2006 show that simulated net profit, beef receipts, CAP payments and concentrate feed per livestock unit can explain the observed variations and direction of changes. Coefficients for the other variables are more or less accurate.

Table 3 : Evaluation of model outputs over the period 2000-2006 against a panel dataset

		Average simulation	Average range observed*	R^2**
Crop production area	% pasture	72	[71 ; 93]	/
	% of cereals	20	[6 ; 24]	/
	% of maize	8	[0 ; 8]	/
% of pasture cut		31	[35 ; 54]	3%
Stocking rate		1.33	[1.10 ; 1.49]	32%
kg of animal sold		409	[276 ; 442]	33%
% of young animals fattened		66	[45 ; 93]	60%
Live weight at sales	3 y.o. heifer	689	[657; 768]	/
	Young bull	711	[600; 776]	/
	Fat cow	757	[727; 813]	/
Concentrate feed consumed in kg /LU		476	[430; 1043]	67%
Economic results in €/ha	GM	768	[555 ; 801]	72%
	animal product	720	[498 ; 773]	80%
	variable costs- cereal product	324	[172 ; 367]	30%
	CAP	319	[243 ; 382]	91%

*Average observation plus or minus one average between farms standard deviation

**evolutions of simulated variables over the period 2000-2006 are regressed on average observed ones

Although our model outputs look globally consistent and accurate, some discrepancies must be recognised:

Table 2:

Total area	Area of perm. pasture	Labour	Housing	Fixed cost in 1000€	Storage capacity (in tons of dry matter) Maize silage	grain	hay	straw
150 ha	81 ha	230 units *	95 calving	78	160	225	810	180

**1 unit per Livestock unit and 2 per ha of cereals*

-1/ the simulated animal live weights at sale remain at the maximum level allowed over time whereas observed ones vary between years and gradually increase. Precise adjustments of animal diets can be costly for farmers in terms of time or feed analysis. These can partly explain why observed live weights are more variable and quantities of grain observed in animal diets are globally high in commercial farms [33]. In addition, availability of feed resources on the market is unlimited in our model whereas in reality it could be problematic some years to buy feed and above all hay. Regarding the observed rising trend, it can be due to genetic improvement that is not taken into account in our model and considered beyond the scope of this study.

-2/ the crop production model reveals some weaknesses. The area of pasture cut is indeed underestimated and its evolution differs greatly from observations (table 1). The pasture growth sub model was validated [10] on pasture at higher altitude. A proper evaluation of this model for the studied area would be necessary to determine if some bias comes from the sub model calibration or from weather data. In addition, pasture management in our model is probably better than what can be achieved in reality since pasture production is known for the whole month and can be allocated to the different end-use (grazing, stock, or haymaking) without wastage. Moreover, risk is not anticipated and consequently no security stock to buffer crop production variations is simulated. Relations between pasture production and feed availability are therefore more closely associated than in reality.

-3/ Abrupt change in production activities is simulated (cease of finished heifers with CAP 2006) but not observed. This problem is due to the optimisation method that chooses most profitable activities. In reality, if two kinds of production have close gross margins, and if the relative advantage of one of them varies over time, farmers would not profoundly reorganise their production and their commercialisation systems on a short term basis because change can be costly in terms of time, skills or risks.

V. MODEL APPLICATION : SIMULATION OF CROP YIELD SHOCKS

A. Method:

In order to assess beef price or crop yield shocks and shock/farm response relationships, shocks of intensities ranging from -60% to +60% of their average values are introduced into the simulated time span, i.e. the year referred to as *"n3"* between average years. We consider that the different animal types or crop production yields are affected in the same proportion. Potential interactions of these shocks with other parameters are not taken into account.

B. Results:

Production adjustments: Five aggregated indicators of production management are calculated to appraise adjustments of production management in year *n3* when beef price *(a)* or crop yield *(b)* shocks occurred (figure 2). They correspond to the rate of variation (differential between production decision values in year *n2* and in year *n3* divided by their values in year *n*2) of the following aggregated variables:

- 'animals sold' which takes into account the number of animals sold and their live weight at sale (and indirectly their age)
- 'grain in animal diet' which gives insight into diet composition,
- 'weight gain' which is the animal live weight gain accumulated over the year by the different animal classes (class size is not included),
- 'pasture cut' which is equal to the number of hectares cut multiplied by number of cuts,
- 'crop trade balance' which corresponds to the quantity of crop produce sold minus the quantity bought, and provides information about adjustment of feed supply,

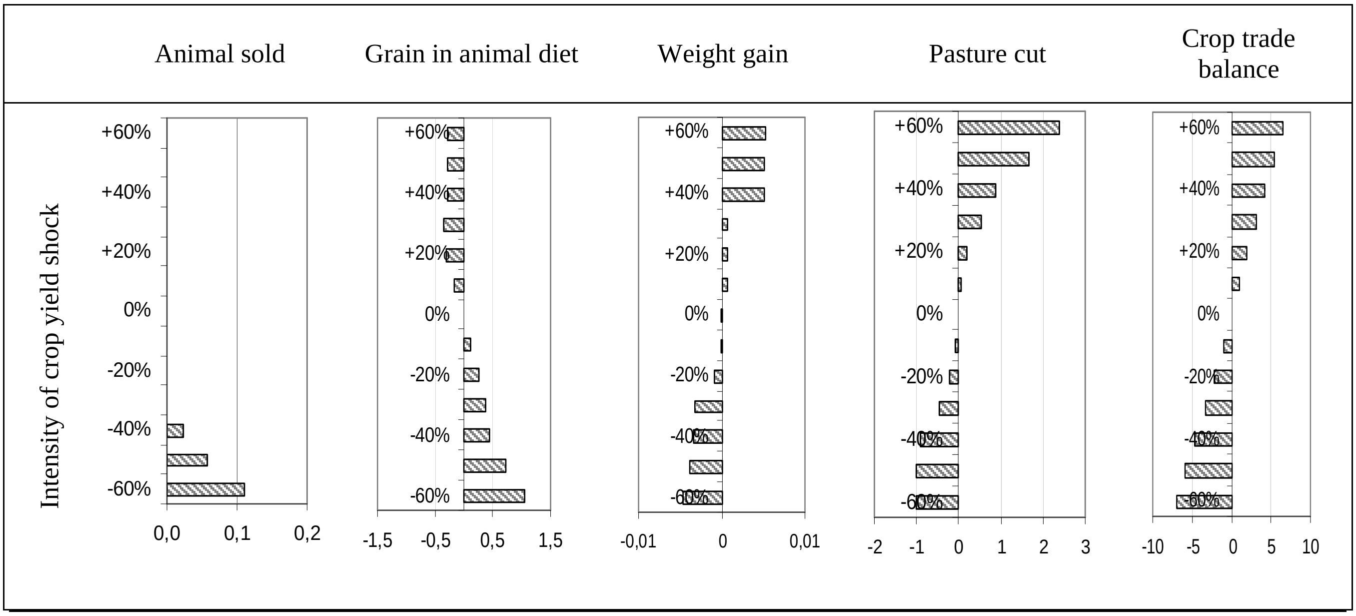

Figure 2: Rate of variation of production management indicators between year of shock occurrence (n3) and equilibrium level according to shock intensity (a: beef price shock, b: crop yield shock,)

A preference for maintaining animal sales is found for shocks of intensities ranging between -30% and +30%. Grains partly compensate the variation in forage products in animal diet. Consequently, the trade in crop products is modified. As expected, sales are greater in good years whereas purchases increase in bad years. The areas of pasture cuts are positively correlated with crop yield shocks. When the intensity of shocks increases, the variation in animals sold increases too in order to decrease variable costs. Animal weight gains tend to increase for favourable shocks and decrease for adverse years. However these variations are not very significant.

Evolution of productions: Consequences of these adjustments on animal production are actually very slight for shocks of moderate intensities (figure 2) since adjustments of sales and weight gains are minor. Important negative shocks have more profound impacts and several years are necessary to rebuild the herd. In all cases, these adjustments generate a negative or nil cumulated differential of animal production over the time span simulated. However, our model cannot increase animal sales more than its equilibrium level because of structural and biological boundaries.

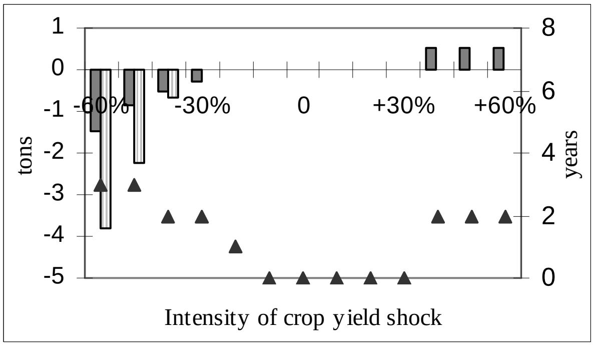

Figure 2: Impacts of crop yield shocks on beef production dynamics. Grey bars are differential of beef production for year n3, striped bars correspond to cumulated differential of beef production and triangles represent the number of years necessary to come back to equilibrium.

Evolution of net profit: Impact of shocks on net profit, when taking tactical decisions into account, increases with shock intensity. The essential of the loss is felt in the year of the shock but the effects can continue to be felt for several years (figures 3).

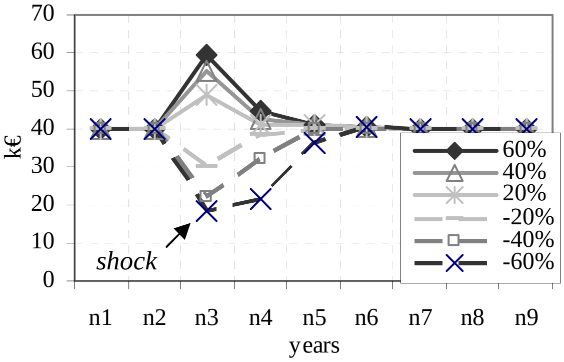

Figure 3: Evolution of net profit per year according to the intensity of crop yield shocks that occurred in year n3 (only half the shocks are represented in order to keep figure readable)

When cumulated over a long period, gains and losses compared to the average situation are not symmetrical: profit surplus for good years cannot entirely compensate for profit losses (figure 4).

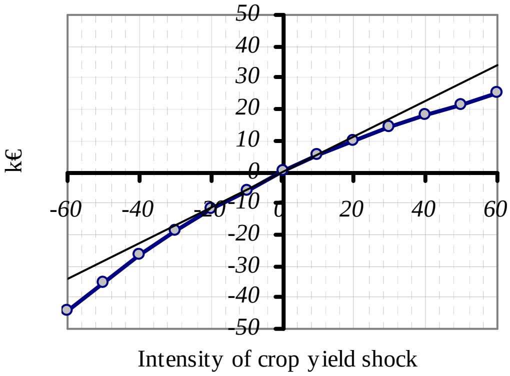

Figure 4: Cumulated differential of net profit following a shock, where interlinked circles are simulated points and dashed lines draw the tangent lines through the origin

VI. DISCUSSION

Objective of the model is to assess relationships between shocks, optimal adjustments and farm outcomes. This section aims at discussing 1/ whether our modelling choices to provide flexibility that reflects the range of possibilities farmers have to adapt to weather conditions, and the relevancy of model results that depends on 2/ their contribution to make clearer relationships between shocks and farm adjustments and 3/ the insights given to uncover farm capacity to cope with shocks

A. Model flexibility

Flexibility is the ability to adapt quickly to different circumstances. It depends then on the range of activities available, on adjustment possibilities and on farm constraints that may limit changes.

Range of production activities proposed: Our model provides a wide range of animal production possibilities. Females can be sold at 49 different periods, males at 24 periods and at each of these period animals can be sold at more or less 5% of their theoretical live weight. A monthly defined price takes into account depreciation or appreciation of animals when getting older and then heavier. This makes it possible to favour some periods of sales without forbidding others. Some weaknesses come from the fact that calving day is fixed and does not give as many possibilities as in the real situation, namely calving from autumn to spring. In addition, it is sometimes advised to limit risk of feed produce shortage to have two calving periods [5]. In our model, modifying the calving day would necessitate adjusting some model parameters. However, it does not seem reasonable to introduce two periods of calving: variables related to animal production would be multiplied by two and given the already high number of activities, model size would considerably increase. Few crop activities are proposed. In addition, marginal or innovative production technologies are not proposed; neither are diversification activities. The purpose of this model is to study main stream suckler cow farms and it cannot be used for a farm specialised in cereal crop production. It focuses instead on detailing intra-year animal, pasture and conserved feed management adjustments to seasonal conditions.

Production adjustments available: Short term adjustments (i.e. monthly decisions) are related to number and live weight of animals sold, animal diet composition and energy content, purchase and sales of crop products, and the quantity of grass harvested. These decisions can be revised each month if more information becomes available. These sources of adjustments provide a wide range of possibilities for the model to dynamically adapt to shocks. However, some can argue that as we do not offer the possibility to buy animals as did for instance [34], the time simulated for recovery after a shock may be overestimated. Our decision is motivated by two aspects. Firstly, our model does not include possibilities such as saving or borrowing to finance investments. Secondly, most farmers prefer to raise animals coming from their own farm to reduce health problems due to foreign animals. Deciding sequentially the end use –grain or forage for instance- of some multi-purpose crop productions such as wheat [17] or maize [8]. Notwithstanding, these practices may be efficient and innovative, but they are not currently widespread within the studied area. In this version of the model, we have concentrated on detailing the sources of adjustments most commonly used in France.

Limitation of adjustments by model constraints: Adjustments are limited by different constraints related to farm structure or animal biology. At equilibrium, some constraints are at the upper bounds. For instance, the simulated farm can hardly adapt to favourable conditions by producing more or heavier animals, or by decreasing pasture production. This limitation could have been partially offset by introducing possibilities for labour hiring and investments. However, those who did, had most of the time to add additional constraints to limit enlargement [35]. We therefore face the same problem. Moreover, dual values of constraints displayed in GAMS outputs gives valuable insights to appreciate the propensity for enlargement according to the different scenarios studied. Our models can though adapt to shocks by producing less or by producing differently, modifying for instance diet or herd composition.

B. Adjustment of farm production management following shocks

To assess which farm decisions might be the most suitable to face price or weather condition shocks, a high number of parameters and a complex system of interactions have to be taken into account. A better understanding of these interactions is at stake. Some farm models have simulated impacts of price and weather condition variations on farm dynamics [36; 37; 38; 39; 40]. When tactical decisions are taken into account, applications focus most of the time on one or two kinds of tactical decisions such as pasture management [9; 10], multi purpose crop production [8; 17], adaptable crop acreage [16], cattle sales [20; 21], animal sales and supplementary feeding [18; 23] or test different kinds of adjustments successively [41; 42]. These applications endeavour chiefly either to assess benefits of a tactical adjustment relative to an inflexible strategy or to understand why farmers do not intensify their production system more. The main interest of our model application is to understand how the optimal mix of adjustments –animal sales, crop product trade, animal feeding, and haymaking- can be combined together to face shocks. The application brings to light the progressive mobilisation of the different kinds of adjustments according to shock intensity with a preference for maintaining animal production at the expense of crop product balance. However, economic and political contexts as well as farm characteristics are likely to modify this optimal mix: an increase in cereal price such as in 2007 would for instance limit adjustment of grain in animal diet, or more decoupled CAP payments would favour adjustments of animal sales. Further investigations would be needed as well to assess how shock frequency and simultaneous shocks can modify optimal mix of production adjustments.

C. Capacity of farms to cope with shocks

It is of interest to assess if farmers would be able to maintain their activity over time in spite of disturbances. One condition is to avoid bankruptcy. By estimating impacts of crop yield and beef price shocks on farmers' earnings, this application can contribute to a vulnerability assessment or at least to a '*minimum potential vulnerability*' one [43], , i.e. an assessment of farm sensitivity to shocks when adaptive capacity is taken into account (vulnerability is a composite of exposure to shocks and ability to manage these shocks). The simulated beef production system is found to be very resilient as it can handle very important price and crop production shocks and bounce back to equilibrium. However, we should take into account the minimum consumption needs of the household, possibilities of loans to smooth out consumption over time, and fixed costs such as interest rates on loans or taxes and cash saving, to have a more realistic view of the capacity of farmers to cope with shocks [44]. This study also underlines that positive shocks do not totally compensate negative ones. This can result in a progressive weakening of the farm's capacity to cope with risks.

VII. CONCLUSION

The model was designed to characterise the evolution of farm outputs when challenged by market and crop production shocks. The application provided here helps to understand how the different sources of adjustments –animal sales, crop product sales and purchases, animal diet, and haymaking- can be combined to face temporary crop yield and beef price shocks, and above all how the optimal mix is modified according to shock intensity. It can contribute as well to assessing the farm's capacity to handle shocks. However, '*ability to manage shocks or hazards is a complex function of existing behaviour that themselves represent long term or structural adaptation to predictable shocks, crisis behaviour and by external responses (policy) to a predicted and actual crisis*' [45]. The next step will be to introduce risk anticipation in the decision sub model in order to study jointly shock anticipation decisions and shock adjustment decisions.

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APPENDICES

Appendix 1: Parameters related to forage production

	April	May	June	July	Aug.	Sept.	Nov.
Cost to harvest hay in €/100kg	15.5	5.6	3.3	4.1	4.8	5.0	/
Abscission ('abs')	0.96	0.79	0.59	0.60	0.72	0.81	0.84

Appendix2: Crop production parameters

	Grain (1st cereal)	straw	maize
Average yield	56	35	90
Average price at sale	11	5	/

Appendix 3: Average animal prices over the period 2000-2006:

	Apr.	may	Jun.	Jul.	Aug.	Sept.	Nov.	Dec.	Jan.	Feb.	Mar.
cow	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59
fcow	1.59	1.59	1.59	1.59	1.59	1.58	1.61	1.63	1.64	1.64	1.64
fheif3	1.52	1.57	1.62	1.65	1.67	1.70					
fmal2	1.76	1.77	1.78	1.79	1.80	1.81					
fsteer2	1.79	1.81	1.82	1.83	1.84	1.85	1.86	1.86	1.86	1.86	1.86
heif1	2.27	2.24	2.21	2.19	2.16	2.13	2.10	2.08	2.06	2.04	2.02
heif2	1.55	1.63	1.70	1.77	1.84	1.92	1.91	1.90	1.89	1.88	1.87
mal1	2.51	2.48	2.44	2.40	2.36	2.32	2.28	2.24	2.21	2.18	2.15
prim	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59

Note : prices take into account theoretical animal live weight at each month

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