Modelling complex livestock-agricultural systems at a regional scale: a case study in La Réunion

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Abstract
Réunion Island, situated in the Indian Ocean, presents a unique case study to model regional bio-economic parameters of the dairy industry. It is a good example of a closed system for movement of animals, available labour, consumption of products, and available land. The present study models the dairy sector at a regional (island) level, in close collaboration with key stakeholders, to study the impact of new agricultural policies in terms of changes to subsidy norms, price fluctuations and environment, with reference to nitrogen excess. The model can be used to generate a number of scenarios, to explore the effects of various industry controls, such as fixing the stocking rate according to EU norms, increasing or reducing the milk subsidy, intensification (such as an increase in milk production to 40 million litres per year) and labour and price constraints (such as an increase or reduction in the milk price or a reduction in labour hours). The model is being consulted by the local dairy cooperative as a discussion support tool at a regional scale to look at implications of expanding the sector and its economic, environmental and social impact.

Key words
Regional Dairy, MGLP, livestock-agricultural systems

Introduction
Dairy farming, along with other agricultural activities, is facing important changes from public policy change and/or agro-climate variations. In contrast to farming systems based only on annual crops or short cycle animal systems, the functioning of dairy farming depends on complex interactions between past (e.g., improvement of fodder systems, restocking decisions) and present decisions, the effects of which are extended into the future. Anticipating these changes and evaluating them is critical. A balance between top-down and bottom-up approaches is needed to improve the decision-making processes both at the farm and sector level and to consider the consequences of environmental and policy measures. The classical one-dimensional approaches such as economic cost-benefit or econometric analysis are limited in their effectiveness, due to the multiplicity and to the non-monetarisation of many parameters that affect decisions in dairy farming systems (Louhichi et al., 2004). The work reported in this paper is part of a Marie Curie Project to develop a regional dairy sector Model for the island of La Réunion, France. The 'Ksheera Mod' project, as this model is called, was developed as a progression from the farm-scale modelling work developed during 2000-2004 (Alary, 2004). The objective was to scale-up the modelling of the dairy sector from the farm to a regional level as a discussion support tool for regional decision makers. The issues of economic, environmental and social sustainability of the dairy sector are intended to be evaluated with the aid of the model.

Method
The regional dairy model has been developed with the General Algebraic Modelling System (GAMS) using an Interactive Multiple Goal Linear Programme (IMGLP) approach. The basic structure of the LP model has the form of a standard linear programming model (as given by Berentsen and Giesen (1995) and discussed by Van Calker et al. (2004):
Maximise $(Z = cx)$ (equation 1), subject to $Ax \leq b$ and $x \geq 0$ (equation 2)
where x is a vector of activities; c is the vector of gross margins per unit activity; A is the matrix of technical coefficients; and b is the vector of right-hand side values. The constraints, as given by the second equation,

consist of resource allocation rows, policy constraints and accounting rows. The objective function (Z) maximises returns on inputs (capital, labour etc). The model contains a set of activities for the dairy farming in Réunion (fodder production, milk production, animal feed). Technical constraints in terms of land area, animal units (UGB)/ha, feeding requirements, fodder harvest yields, and labour hours are used as links between activities. Environmental policy is included in terms of N management and the indicator chosen is N contributed from the dairy farms per ha.

The model (Figure 1) centres on the nutrition balance for dairy cows. It takes into account the genetic milk potential of the local cows (4000-8000 litres per cow per year, e.g. the term VL40 refers to cows yielding 4000 litres per year and so on). The young non-milking cows are categorised on their age group from Gen1 (young cows < 6 months) to Gen5 (6-12 months, and so on). These different sets of cows have different nutritional requirements derived from a weekly 'monitoring' of daily intake conduced in 1998-2000 (Hassoun et al, 2000). These nutrients (in the form of UFL unit forage for milk; PDIN digestible protein from nitrogen; PDIE digestible protein from energy; CA calcium; Pho phosphorus; CB crude cellulose) are derived from both fodder and concentrates ration. The nutritive value of the different fodder types and concentrates currently available for the dairy sector result from monthly feed analysis (Grimaud et al., 2002). Fodder types (both occurrence and yields) are associated with sub-regions and a yield co-efficient matrix is applied to the fodder yields and fertiliser application. The fertilisation and mechanisation requirements and costs for each fodder type are considered according to a household survey conducted in 2000 and data collected by the Pastoral Cooperative (UAFP) in the study area. The labour requirements (in hours) for fodder and dairy cow management are considered both from the labour utilisation and cost components points of view. Costs for fertiliser, concentrate supplements, mechanisation inputs, pastures sowing and maintenance, labour, loan repayment, insurance and others inputs are taken into account. The revenue (income) component of the model comprises receipts from sale of milk plus subsidies for milk production, farm performance, sowing new pastures, meadow maintenance and UGB/ha.

Based on the discussion in the earlier paragraphs the objectives of the models are to maximise revenue (profit), maximise labour efficiency and minimise N excess.

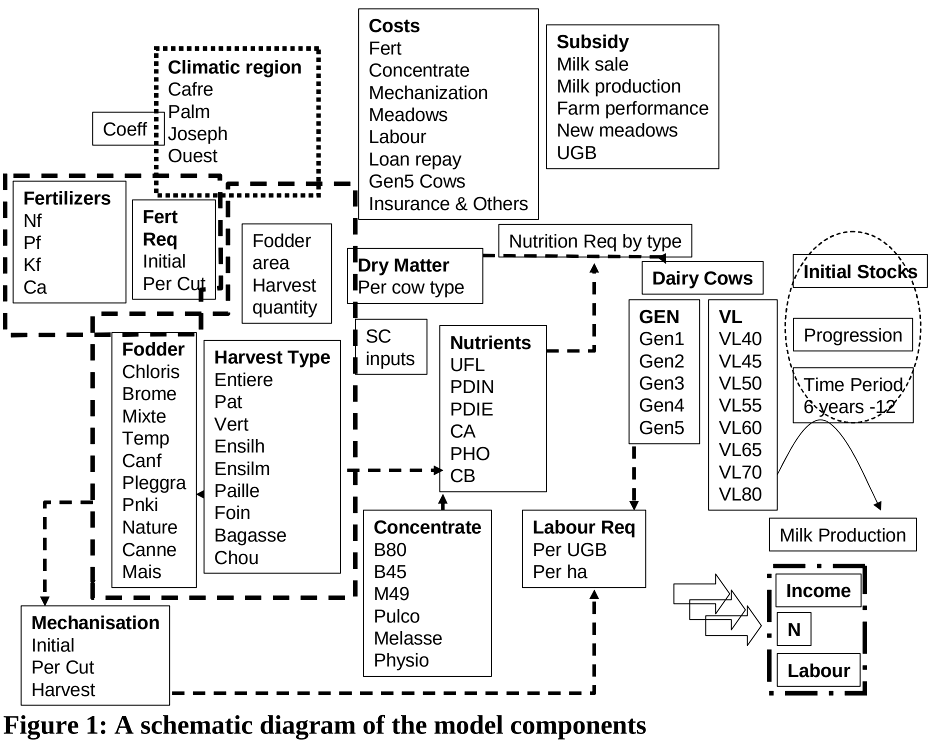

Figure 1: A schematic diagram of the model components

Scenarios

Scenarios refer to the outcomes of the optimising an objective function such as income and evaluating the conditions. It is possible to establish an interactive procedure with the help of the modelling system, which allows the users to formulate their own scenarios, characterised by different indicator values and reformulating their scenarios by `playing' with the model (Romero and Rehman, 1989; Pitel, 1990). This exercise will give the user a better under-standing of the behaviour of the real system and, consequently, some understanding for the positions of other interest groups in the bargaining process (Zander and Kächele, 1999). The scenario analysis consists of detecting the reaction of endogenous variables of the model to the various changes in exogenous parameters, such as prices, policy instruments and technologies. The aim of this analysis was to study the impact of different assumptions, relating to these parameters, on the model outcome and behaviour. The results of each scenario analysis will be compared to those of the reference scenario, in order to isolate the economic effects of the exogenous change introduced in the scenario (Louchichi et al., 2004). A sample set of scenarios are given in the Table 1 for the following scenarios:

S1: Land area 1854 ha; Milk price 0.40€/L; Subsidy 0.083€/L; Conc price 0.26€/kg; Interest rate 0.05%; Genetic progression normally distributed; Rate of Fertility 0.83
S2: Land area 1854 ha; Milk price 0.38€/L; Subsidy 0.083€/L; Conc price 0.26€/kg; Interest rate 0.05%
S3: Land area 2317 ha; Milk price 0.40€/L; Subsidy 0.083€/L; Conc price 0.26€/kg; Interest rate 0.05%
S4: Land area 1854 ha; Milk price 0.40€/L; Subsidy 0.083€/L; Conc price 0.26€/kg; Interest rate 0.05%; Skewed towards higher genetic potential

VL40	VL45	VL50	VL55	VL60	VL65	VL70	VL80
5.00	8.00	10.00	10.00	15.00	25.00	20.00	7.00

S5: Land area 1854 ha; Milk price 0.40€/L; Subsidy 0.083€/L; Conc price 0.26€/kg; Interest rate 0.05%; Rate of fertility 0.50 (new born are lower. However, more Gen5 cows, which become productive earlier, are bought to maximize profit and still maintain the 6 UGB/ha upper bound as the objective is to maximize profit)

Table 1: The modelled consequences of a range of scenarios

			Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
S1								
Base	Milk Production	'000 lts	27237	34333	36248	38814	38464	41397
	Milking Cows		5616	5955	6525	6203	6800	7297
	Land Area (ha)		1299	1474	1677	1665	1790	1854
	Profit		2908066	5508900	5548651	6165699	6086683	6889400
S2								
	Milk Production	'000 lts	27240	34336	36249	38812	38456	41388
	Milking Cows		5617	5956	6526	6204	6801	7298
	Land Area		1299	1474	1677	1665	1790	1854
	Profit		2363619	4823216	4824212	5388859	5315464	6062282
S3								
	Milk Production	'000 lts	28118	36924	39994	43095	42597	46279
	Milking Cows		5920	6452	7235	6859	7547	8157
	Land Area		1367	1646	1852	1842	1990	2074
	Profit		3041176	6001917	6430951	7134845	6970494	8036187
S4								
	Milk Production	'000 lts	28745	36231	38254	40968	40610	43707
	Milking Cows		5616	5955	6525	6204	6804	7300
	Land Area		1299	1474	1677	1665	1790	1854
	Profit		3667604	6468736	6561391	7252175	7165268	8045819
S5								
	Milk Production	'000 lts	26216	35120	41138	49409	49409	49409
	Milking Cows		4785	5962	7139	8107	8107	8107
	Land Area		1160	1376	1642	1851	1854	1854
	Profit		3133585	6479878	8143024	10605059	10463679	10497026

Scenario 1 (S1) is the base scenario. In this scenario the land area is current at 1854 ha. The price of litre of milk is 40 euro cents and the subsidy is 8.3 euro cents per litre. The interests of the stakeholders, in this case the local dairy cooperative, are focused on milk production. In Scenario 2 (S2), the price of milk has been reduced by 2 euro cents (from 40 euro cents to 38 euro cents). There is an 18% decrease in profit compared to S1 in year 1 while there is no significant change in other variables. In scenario 3 (S3) maximum land area that can be utilized for the dairy sector has been increased by 25% compared to S1. The milk production increased by about 10%, the milking cows also by about 10% and the profit by 14% when compared with S1. Scenario 4 (S4) focuses on the genetic progression of the milking cows (with reference to Milk yields per cow per year) over the years. In Scenario 1 (S1) the genetic progression has been assumed to be normally distributed with mean around 5500 litres per year. In S4, the genetic progression is skewed towards higher genetic potential assuming that newer breeding techniques, introduction of higher yielding breeds may be possible in the following years. As can be expected, there is an increase of 5% in milk production and about 14% in profits. There is no change in the number of milking cows or land area compared to base scenario S1.

In scenario 5 (S5), the focus is on the fertility rate of the milking cows in the island. The fertility rate is reduced to 50% (from existing 83% and as in S1). There is a decrease in land area used, milking cows and milk production and only a marginal increase in profits compared to S1 in year 1. However, from year 3 onwards there is a significant increase in these variables. This is because the model chooses to augment its animal resources by purchasing more Gen5 cows in case of changes in fertility rates or other factors that might effect the animal progression (with reference to optimizing on the number of milking cows). Gen5 cows are productive in a short time span than the new-born cows and are cost effective in terms of feed costs. Therefore, as per the model it is profitable when the new born cows are low and facility to import Gen5 cows is available.

As a measure of the social dimension of sustainability in the dairy sector, the number of working hours for farm labour is considered. The average hours of work are currently 10-12 hours per day per farmer. One of the objectives of the farmers is to reduce the working hours to develop a healthier work-life balance. In the model, this aspect is explored by considering the hours work needed to tend to the animals and on mechanisation. Two scenarios are explored: Labour Scenario 1 and Labour Scenario 2 (LS1 & LS2) where the parameters are as in Scenario 1 (S1) discussed above but with the labour hours fixed at 10 hours and 8 hours per day respectively.

According to the outcome of the model, both these options are possible. However, there is a change in profit. The profit decreases by about 2 % in the first year to about 16 % by the sixth year if the working hours are reduced from 10 hours to 8 hours per day. These figures could be used to discuss the options that farmers have to reduce their working hours and the impact on their income and to what degree they would be willing to forgo a percentage of their income for the additional free hours.

Validation

According to Hazell and Norton (1986 – quoted by Louchichi et al. 2004), calibration in modelling is based on the determination of real parameter settings specific to each farm type, and validation assumes that the model reflects the base year situation (i.e. to check that the model reproduces the real activities and bio-economic conditions observed). Year 2006 was taken as the base year and since the model time step is six months, validation was also attempted for the first six months of the year, i.e. January-June 2006. Table 2 below illustrates the deviations from reality and observed. The difference in the fodder area is in part an effect of the maximising profit objective, which results in reaching the upper bound of the UGB per ha (6), and in part because of the theoretical nutrient requirements used in the model. On a broader scale, the objective of the model is income maximisation, which may not be the objective of all the farmers. Moreover, the model optimises for all the 12 periods (the life cycle of the model) together in the same run.

Table 2: Deviation between the observed data and the simulation for the base year

Characteristics			Comparison between observed data and simulation % (for base year 2006)		
Fodder Area	Dairy cows	Milk Production	Fodder Area	Dairy cows	Milk Production
1857 ha	4121	11720	8.29	-0.34	1.16

Conclusions

Livestock and fodder in the dairy system of Réunion have a strong and complex inter-relationship which has been integrated in this regional modelling approach. The time-step of the model has been fixed at 6 months, which is suitable for following the progression of dairy animals based on studies of Grimaud et al. 2002; and Hassoun et al. 2000, and for dealing with such livestock situations as in Réunion The component of UGB per ha, is a key component in terms of its use as a key constraint and also in terms of revenue (UGB subsidy). This aspect in the model is non-linear (as both land and UGB are dynamic over the model time-step). An innovative approach has been developed to handle the non-linearity. The non-linearity component has been then integrated into the largely linear model. The economics of the model have been simplified (scaling up from the farm level model of Louchichi et al. 2004) though all the relevant income and expenditure components have been considered (the details of the data could not be given here because of limitation of number of pages).

The model was developed in close collaboration with the Dairy Cooperative and CIRAD field and research staff. The base scenario of the model mimics the current setup very closely and we had extensive discussions on the modelled future scenarios both with the researchers and the Cooperative staff. On the request of the Cooperative, a GUI is being developed to access the model effectively. The model has been able to integrate multiple and diverse data sets from the different sources such the dairy cooperative, the pasture cooperative, the concentrate cooperative, the animal scientists, nutritionists and others. The model developed is intended to be utilised as an exploration tool to generate ‘what if?’ scenarios and to visualise a general ‘pathway’ on the consequences of different sets of actions based on the objectives of the stakeholders. The objectives of the industry are reaching the allotted 'quota' of production within the constraints such as the EU Nitrate directive, for example. This could mean higher income and employment opportunities. At the same time, the external driver is the competition for scarce land between urban development/agriculture and dairy uses. This is a complex situation and the model can be used as a discussion support tool to look at ‘what if?’ scenarios (considering constraints such as land and environmental norms) with objectives such as achieving the milk production targets. Subsidies are important drivers of the dairy industry in the EU context and any changes in the subsidy regime would have significant impact on the industry in its current state. Transformational changes such as producing niche market products have been discussed in the cooperative; they see a potential for these developments but they may take a while to seep into the system. In an Australian context, the modelling work has relevance in an environmental context, calculating the N surplus and modelling the environmental and financial impact of any regulations that might be imposed on N per ha as in the EU.

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