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SUMMARY

Modelling interactions between farming and fishing activities : the case of the Saloum Delta, Senegal

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Abstract

This paper studies the relations between farming and fishing in the Senegalese region of Saloum river delta, an area which is highly dependent on primary activities, and where a farming crisis due to the combination of decrease in export prices, deteriorating climate conditions and increasing demographic pressure has led to a growing diversification towards fishing. The case is first surveyed in empirical terms, then a qualitative bioeconomic two-sector model is presented. In a third time, the model is used to represent the dynamics of the system, characterised by a succession of four different stages, as extra labour supply pours into the fishing sector. In a fourth time, a econometrical validation of the model is proposed. A conclusion of the analysis is that there is little hope of restoring the fisheries of the area, if new opportunities of income are not made available to the local population.

Keywords

Fisheries management, economic development, economic diversification, Saloum delta biosphere reserve.

1. Introduction

The relation between population growth, ecosystem and economic activity has been investigated long ago (Malthus, 1798 ; Boserup, 1970). This relation is not simple, due to the influence of several factors (Quesnel, 1994), such as the dependency of the economic system on local natural resources, the access of population to these resources, and its possibilities of economic diversification. When the economy is highly dependent on agricultural exports, world-market and climate may also play a major role. Such conditions are met in the Saloum river delta zone (Senegal), where peanut-growing and fishing are the main sources of monetary income for local households. The socio-economic evolution of this area is strongly influenced by three major trends : a fast population growth, a downward trend of peanut price on the world market, and an episode of unusual drought since the 70' (Chauveau, 1984 ; Charles-Dominique, 1994 ; Cormier-Salem, 1994 ; Cormier-Salem ; 2000 ; Dahou and Weigel, 2003).

This paper proposes a model simulating the consequences of these trends on the dynamics of local farming and fishing, with special attention to the interactions between these two activities. After an empirical view of the subject, the model is described, and scenarios of evolution are presented. Finally, a econometrical validation of the model is carried out.

2. Description of major trends influencing the Saloum Delta economic system

The Saloum river delta, which was declared a man-and-biosphere reserve (*Réserve de Biosphère du Delta du Saloum*, or RBDS) in 1981, is a part of the region of Sine-Saloum. It covers 500,000 ha (Dia, 2003), representing 21% of the Sine-Saloum region, and 2,5% of the whole territory of Senegal. Its resident population was 610,500 persons in 1997, amounting to 38% of the total population of Sine-Saloum and 7% of whole population of the country. During the same year, a number of 1320,700 persons were estimated to live on the Saloum delta natural resources (DPN, s.d. ; DPS, 2001).

Population growth is fast in Sine-Saloum. The population of this region was multiplied by 11.5 between 1904 and 2001 (source DPS), which corresponds to an average growth rate of 2.5% a year over the XXth century, higher than the corresponding rate at the national scale (2.2%). In 1997, the population growth rate was 2.8% in the Delta, 2.3% in the Sine Saloum region, and 2.7% at the national scale. Part of this growth is due to a positive migratory flow related to the rapid development of peanut-growing up to the beginning of the 60' (Lacombe, 1974 ; Lericollais et al., 1987 ; Milleville and Serpantié, 1994). Since that time, emigration has developped as a consequence of increasing land shortage, a tendency that was strengthened by worsening climatic and economic conditions in the 70' (see below). Nonetheless, population density remained high in the region, specially in the Saloum delta area : while the population density was 44 inhabitants per km^2 on the average at the national scale in 1997, it was 68 inhabitants per km^2 in the Sine-Saloum region, and reached 122 inhabitants per km^2 in the delta zone.

As other Sahelian regions, Sine-Saloum has endured a period of unusual drought since the beginning of the 70'. The yearly quantity of rainfall, which was over 1000 mm in the 50', dropped to an average of 528 mm during the years 1972-2002 (fig. 1). This phenomenon had negative consequences on the quality of soil (Milleville and Serpantié, 1994 ; Perez and Séne, 1995 ; Dia, 2003), and on agricultural productivity.

Another problem was caused by the decreasing price of peanut on the world market. According to FAO data, the average export price of Senegalese shelled peanuts, expressed in constant CFA francs, decreased by 55% between 1972-1981 and 1986-1993. The increase which followed the devaluation of the CFA franc in 1994 was far from completely reversing this trend : during the years 1995-2001, the average price of senegalese shelled peanuts was still 39% lower than the 1972-1981 level (CFA francs, 2001 general price level). The negative trend of export price reverberated on the price paid to local producers, which has been directly linked to the world price since 1968 (fig. 2).

The economic system of the Saloum delta is highly dependent on farming and fishing.
Farming, which is mainly non-irrigated, relies on two major types of production : peanut for export, and millet for local consumption (Lacombe, Lamy and Vaugelade, 1973 ; Lericollais et al., 1987 ; Guigou, Lericollais and Pontié, 1995). As regards peanut, during the last 40 years, the Sine-Saloum has provided 46% of the total production of Senegal on the average. However, in this area the average value of peanut production (in constant CFA francs) has been cut approximately by 40% between the early 70' and the 90'. Taking demography into account makes this decrease even more severe : the per capita value of peanut production in the Sine-Saloum region has been cut by approximately two-thirds since the early 70' (fig. 3). The negative effect of the decreasing export price was supplemented by a downward movement of crops : the yearly output of the region, which varied between 400,000 and 500,000 tons during the 60', has dropped to an average of 350,000 tons during the last two decades. Besides the likely influence of price on producers behaviour, two factors account for this decrease in crops : climate change and population growth. The first factor resulted in lower returns on cultivated land and decrease in total surface devoted to peanut-growing, as some previously cultivated areas became unsuitable for cultivation. The second factor also resulted in dimishing areas devoted to peanut-growing, due to increasing demands for alternative uses of land, such as millet-growing for feeding the local population.

Population growth, long-lasting rain shortage and decreasing price of peanut on the world market seem to be the three main factors accounting for the agricultural crisis in Sine-Saloum (fig.4). Problems related to population growth appeared first. As soon as 1934-38, they resulted in moving households from overpopulated villages to so-called « new lands », which were formerly uninhabited. Similar measures were taken between 1972 and 1979, and concerned 7,760 people (Lericollais et al., 1987). However, the long-lasting drought, by causing irreversibility damage to the quality of soil (desertification) might be the main factor of the crisis.

The farming crisis favoured the development of fishing activities in the delta area (Guigou, Lericollais and Pontié, 1995 ; Cormier-Salem, 2000 ; Dahou and Weigel, 2003): the number of canoes, which was around 1200 in 1974, jumped to more than 1800 in 1979. Traditionnally in Senegal, fishing was a specialty of particular ethnic groups, even though these ethnic groups were initially composed of farmers (Cormier-Salem, 1989). Nowadays, the population of Sine-Saloum may be split into four main categories : exclusive farmers, exclusive fishers, farmers-fishers (i.e. farmers with a secondary fishing activity), and fishers-farmers (i.e. fishers with a secondary farming activity). According to a field-survey we have realised in the delta in 2003, the group of people living mainly on fishing was composed of 69% of exclusive fishers, and 31% of fishers-farmers. A similar typology may be realised concerning the villages of the region (Bousso, 1996). Induced by demographic, climatic and economic factors, diversification towards fishing was facilitated by an institutional factor, which is the situation of free and open access prevailing in the fishing industry. It was also stimulated by some investments such as a fish processing plant in 1975 , which represented the main commercial outlet for fishers of the delta area (this plant was closed in the 90' due to coastal erosion).
As a result of this diversification, landings first rapidly increased, jumping from 3,000 tons in 1954 up to 49,000 tons in 1978. However, they fell drastically after that year and, since 1982, the average yearly landing quantity has been around 10,000 tons (fig.5), a situation which is to be related to evidences of overfishing (Diouf, Barry and Coly, 1998).

The crisis affecting the two major economic activities of the Sine-Saloum region has led an increasing number of people to emigrate in search of alternative sources of income. According to a survey realised in some villages of the area, the migratory balance in these villages was –0.9% between 1983 and 1985, to be compared with –0.3% between 1969 and 1971 (Lericollais et al., 1987)[1].

To sum up, the diversification of the local economy towards fishing may be regarded as a response to the farming crisis induced by a combination of demographic, climate and market changes. It resulted in overfishing, and the following step was emigration. The model which is presented in the next section of this paper intends to describe formally this process.

3. Presentation of the model

The model describes a two-sector economic system, where sector 1 is farming, and sector 2 is fishing. Local manpower is supposed to be qualitatively homogenous, and may be employed in either of these two sectors. In each sector, the level of employment represents the production effort applied to the relevant natural resource, ie. land in one case, and fish biomass in the other. Effort exerted in each sector is the result of constrained profit maximisation decisions at the individual level[2]. However, a major difference between sector 1 and sector 2 is due to the fact that, while land is privately owned, fish stocks are a common-pool resource. The access to this resource is open and free, which results in rent dissipation. The following presentation of the model is split into to parts : technology, and producers behaviour.

3.1. Technology

In sector 1 (farming), the output Y_1 is an increasing function of the cultivation effort E_1 exerted on land, which is a fixed factor. As a result, the marginal product of effort ($dY_1 \ / \ dE_1$) is a decreasing function of E_1. Another factor influencing the level of crops is climate : we assume that Y_1 depends on the yearly abundance of rainfall, which is represented by an indicator β (fig. 6). The production function relying on these assumptions is the following :

(1) $$Y_1 = \beta . E_1^{\alpha} \qquad \beta > 0 \quad , \quad 0 < \alpha < 1$$

In sector 2 (fishing), the output Y_2 is an increasing function of the fishing effort $E_{2,}$ as well as of fish biomass X. According to the standard Schaeffer hypothesis (Schaefer, 1957), we assume that fishing mortality is proportional to fishing effort or, to put it in another way, that catches per unit of effort (CPUEs) are proportional to resource abundance :

(2) $$Y_2 \ / \ X = q.E_2 \qquad \Leftrightarrow \qquad Y_2 \ / \ E_2 = q.X \qquad q > 0$$

where q is a technical parameter (« catchability coefficient ») representing the efficiency of fishing. Contrasting with sector 1, the natural resource in sector 2 is variable, and depends (inter alia) on fishing effort. Following here again the basic Schaeffer model, we assume that the equilibrium fish biomass is a linearly decreasing function of fishing effort :

(3) $$X = K.(1 - q.E_2 \ /r) \qquad K > 0 \quad , \quad r > 0$$

where K is the equilibrium biomass of unexploited stock (« carrying capacity » of the ecosystem), and r is the intrinsic growth rate of X, i.e. the natural growth rate that would be observed if environmental conditions were not limitating. By combining the two above relations we get the equilibrium production function of the fishery :

[1] However, the interpretation of these figures is not straightforward, because they include migratory flows inside the Sine-Saloum region.
[2] We assume that outputs of both sectors are fully marketed. As regards farming activities in the Sine-Saloum area, this assumption fits well with peanut-growing, but not so with millet-growing and other agricultural activities mainly oriented towards self-subsistence.

(4) $\quad Y_2 = K.q.E_2.(1 - q.E_2 / r)$

Contrasting with sector 1, the production function in sector 2 is not monotonous (fig. 7): when effort E_2 increases beyond a certain level ($E_{2MSY} = r / 2.q$), output Y_2 starts decreasing (the level of output $Y_2 = r.K / 4$ corresponding to E_{2MSY} is the *maximum sustainable yield* of the fishery, or MSY). This is a consequence of the negative impact of fishing effort on the equilibrium level of fish biomass, which in turn impacts negatively the catches : once fishing effort has gone beyond the critical point E_{2MSY} , the negative effect of decreasing fish biomass on catches overruns the positive direct effect of increasing effort. This peculiarity of the production function of the fishery would be of little importance if fish stocks were managed in the same way as land : no rational producer would venture on the decreasing slope of the production curve, which clearly corresponds to inefficient production schemes. However, in the case of the fishing industry, the common-pool character of the resource creates an opportunity for such situations (see below), the likeliness of which is a direct function of anthropic pressure and technical fishing efficiency.

3.2. Producers behaviour

In each sector, individual producers[3] are supposed to be profit maximisers. However, this assumption has different implications in the case of farming, which makes use of a privately owned resource, and in the case of fishing, which is based on the use of a common-pool resource.

In both cases, profit is defined as the difference between the value of output and the cost of production effort :

(5) $\quad \pi_i = P_i.Y_i - C_i.E_i \qquad (i = 1 , 2)$

where P_i is the unit price of the output of sector i, and C_i is the unit cost of effort in the same sector (these unit prices and costs are supposed to be independent of the level of local activity). If C_i includes, as it should, all the elements constituting the opportunity and use costs of the anthropic factors lying under the synthetic notion of « effort », then so-called « profit » is in fact the resource rent.

In the case of farming, producers will adopt the level of effort maximising π_1 under the technical constraint of the production function (1), plus a possible constraint concerning available manpower (see below). As a consequence, in any circumstance, effort in sector 1 will not go beyond the level :

(6) $$E_1^* = \left(\alpha.\beta.\frac{P_1}{C_1}\right)^{\frac{1}{1-\alpha}}$$

maximising (5) (with $i = 1$) under (1) (fig.8).
The situation is different with fishing. In sector 2, the level of effort :

(7) $$E_2^* = \frac{r}{2.q}.\left(1 - \frac{1}{K.q}.\frac{C_2}{P_2}\right)$$

maximising π_2 under the constraint of the production function (4) is not an upper limit to fishing effort. The common-pool character of the resource results in negative crossed externalities between fishers (each fisher's catches being negatively influenced by other fishers effort), which in turn induce each producer to develop his own fishing effort beyond the point that would correspond to overall profit maximisation (the private marginal product of effort being higher than its social marginal

[3] In the case under review, the producing unit is usually a household.

product). Supposing the access to the fishery is free and open, the upper limit to fishing effort corresponds to the situation where ($\pi_2 = 0$), i.e. where resource rent is totally dissipated (fig. 9). In fact, if there is no external constraint on fishing effort (or catches), this situation will correspond to the bioeconomic equilibrium of the fishery. The corresponding level of effort is obtained by making π_2 equal to zero in relation (5) (with $i = 2$), and by combining the result with relation (4). By doing so we get :

$$(8) \qquad E_2^{**} = \frac{r}{q}.\left(1 - \frac{1}{K.q}.\frac{C_2}{P_2}\right)$$

It should be noted that E_2** is always higher than E_2* (in the simple Schaeffer model used here, $E_2^{**} = 2.E_2^*$), a result which is the consequence of the negative externalities between producers fishing the same stock(s). In the same time, while E_2* is always lower than the level of effort E_{2MSY} (an efficient level of effort has to be on the increasing side of the production curve), E_2** may be higher or lower than E_{2MSY} , according to circumstances. The condition for E_2** being higher than E_{2MSY} is the following :

$$(9) \qquad E_2^{**} > E_{2MSY} \Leftrightarrow \frac{C_2}{P_2} < \frac{K.q}{2}$$

By improving the technical efficiency of fishing (q) and lowering the real unit-cost of fishing effort (C_2 / P_2), technical progress increases the probability of fulfilling condition (9), which means that free and open access equilibrium of the fishery is on the decreasing side of the production curve. In the following developments, we will assume this condition holds, a realistic assumption in the case under survey.

4. Modelling the dynamics of the economic system

In this section, we analyses the dynamics of the two-sector economic system depicted by the model. The external determinants of this dynamics are : i) population growth ; ii) climate change (diminishing rainfall) ; iii) change in market conditions (decreasing export-price of agricultural good). In a first step, we assume given climate and market conditions, and we analyse the impact of population growth on farming and fishing. In a second step, we introduce changing climate and market conditions, and we investigate the resulting perturbations on the dynamics of the system.

4.1. Dynamics under given market and climate conditions

For a given set of prices and unit costs and under given climate conditions, the quantity of effort that will be devoted to each sector depends on the demographic conditions prevailing in the area under survey. For the sake of simplicity, let us assume here that no migratory flow exists between this area and the rest of the world, and that local labour supply increases at constant rate a over time :

$$(9) \qquad dE / dt = a.E \qquad\qquad a > 0$$

At each moment, the total effort devoted to farming and fishing is constrained by :

$$(10) \qquad E_1 + E_2 \leq E$$

Combining relations (9)(10) with relations describing the operation of sectors 1 and 2 leads to a representation of the dynamics of the economic system in four stages (these stages are presented graphically on figures 10 to 12, devoted respectively to employment, profit, and fish biomass).

Stage 1 : Scarce labour ($E < E_1^* + E_2^*$)

The first stage corresponds to the situation where E is lower than the sum ($E_1* + E_2*$) of farming and fishing effort corresponding to separate maximisation of profit in each sector. Then constraint (9) is binding (which means labour is locally scarce), and producers will allocate their effort in such a way that overall profit ($\pi_1 + \pi_2$) is maximised, under constraints (1), (4) and (9). In other words, E_1 and E_2 will be the solutions of the following maximisation problem :

Find : $(E_1, E_2) \geq 0$
such that : $(\pi_1 + \pi_2) \to \max.$
subject to :

$$Y_1 = \beta.E_1^{\alpha}$$
$$Y_2 = K.q.E_2.(1 - q.E_2 / r)$$
$$E_1 + E_2 = E$$

This problem may be solved by using the method of Lagrange's multipliers. The solutions are:

$$(11) \qquad E_1 = \left(\alpha.\beta.\frac{P_1}{C_1 + \lambda}\right)^{\frac{1}{1-\alpha}}$$

and :

$$(12) \qquad E_2 = \frac{r}{2.q}.\left(1 - \frac{1}{K.q}.\frac{C_2 + \lambda}{P_2}\right)$$

where λ is the multiplier associated to the labour constraint, and may be considered as the *opportunity cost* of labour employed in each sector[4]. In this stage of evolution of the local economic system, global value of output and global profit are an increasing function of available labour force (E).

Stage 2. Fishery as an outlet to extra-labour supply, output still growing ($E_1* + E_2* < E < E_1* + E_{2MSY}$)

A second stage is reached when the global labour supply E goes beyond ($E_1* + E_2*$). At the precise moment where ($E = E_1* + E_2*$), λ becomes zero as the labour constraint ceases to be binding, and the total effort is distributed between farming and fishing according to E_1* and E_2* respectively (which are the values obtained by making λ equal to zero in (11) and (12)). When ($E > E_1* + E_2*$), employment stops increasing in sector 2, as farmers have no incentive to increase effort beyond E_1* on the land they cultivate. But it is not so with fishing, where the resource is common, and access to this resource is free and open. Therefore, in this stage of evolution, the situation is frozen in the farming sector (assuming stable market and climate conditions), and additional labour will pour into the fishing industry, where rent will start to decrease. However, landings continue to increase, due to the fact that the level of fishing effort E_2* marking the frontier between the two first stages is located on the increasing side of the production function (4). As a consequence, in the second stage of evolution of the system, global employment and global output still increase, while global profit is on a declining trend.

Stage 3. More effort, less landings ($E_1* + E_{2MSY} < E < E_1* + E_2**$)

The third stage is reached when fishing effort goes beyond the level corresponding to MSY, i.e. when ($E_2 > E_{2MSY} \Leftrightarrow E > E_1* + E_{2MSY}$). At this moment landings start decreasing. Due to the institutional characteristics of the access to fish resource, this trend does not prevent additional labour force to pour into the fishing sector, as long as profit is maintained above zero in this sector. The third stage of evolution of the two-sector economy is therefore characterised by increasing employment, but decreasing profit and production.

[4] In the system considered here, C_i is only the use cost of effort spent in sector i. If constraint (9) on available effort is not binding, then opportunity cost of effort (multiplier λ) is zero, and the cost of effort is limited to its use cost.

Stage 4. System locking, emigration as an outlet ($E > E_1* + E_2**$)

The economic system reaches a fourth stage of evolution when labour supply goes beyond ($E_1* + E_2**$). At the moment fishing effort reaches level E_2** (free and open access equilibrium), profit becomes zero in the fishing sector, and effort stops increasing. In the fourth stage of evolution, employment and output are stabilised, profit in the fishing sector has completely disappeared, and unemployment grows as population continues to increase. This is the time for emigration.

4.2. Impact of changing market and climate conditions

In the above description, price and climate parameters have been held constant. However, it has been noted in the first part of the paper that decreasing export price of peanut and decreasing rainfall have plaid a significant role in the dynamics of the Sine-Saloum economic system. Let us now introduce these changes in the model.
Decreasing trend in rainfall is modelled as a diminishing value of parameter β in relation (1) describing the production function in the farming sector. The consequence is a decrease in the level of effort E_1* corresponding to maximum employment of labour force in farming (fig.13). As a result, stage 1 of the dynamics of the system is shortened, and extra-labour force starts to pour earlier into the fishing sector. This perturbation passes on the following stages of the process (fig. 15 and 16).

A similar consequence is obtained in case of a decreasing price of agricultural output. In this case, the real unit-cost of effort in sector 1 (C_1 / P_1) is increased, which means graphically that the straight line representing the real cost of effort in fig. 8 rotates counter-clockwise around the origin. Here again, the consequence is a decrease in E_1* (fig.14), with a shortening in stage 1.

In both cases, taking into account climate and market changes that have been observed in the study-case results in accelerating the process previously described.

5. Econometrical validation of the model

The statistical data[5] concerning the millet and peanut growing as well as those concerning fishing of Sine Saloum come from the Management of Fishing, of the Management of the Agriculture and the Management of the Forecast and the Statistics of Senegal.

5.1 The production function of peanut

The theoretical model presented in this article supposes that the function of production of peanut for the year t has the following form:

$$Y_{1,t} = \beta_t \times E_{1,t}^{\alpha}$$

where: :

- $Y_{1,t}$ is the production of peanut for the year t,
- β_t is the indicator of rainfall for the year t:
- $E_{1,t}$ is the effort of production of peanut for the year t:
- α is supposed to be constant on the whole of the period considered and $0 < \alpha < 1$ (diseconomies of scale assumption)

[5] Certain analyses have been carried out over the period 1960-2000 whereas others have been carried out over one shorter period (such as from the years 1970) because of the non-availability of certain data (number of motorized canoes, peanut price paid to the producer).

Not having the data relating to the population working in the peanut growing, we suppose that they can be calculated for the year t from the total cultivated peanut surface $S_{A,t}$ of this same year and from the average cultivated peanut surface per capita[6] ω presumed constant on the whole of the studied period:

$$E_{1,t} = \frac{SA_t}{\omega}$$

Consequently, the peanut production function can be written in the following way:

$$Y_{1,t} = \beta_t \times \left(\frac{SA_t}{\omega}\right)^{\alpha}$$

However, this relation between total cultivated peanut surface for the year t and the peanut production for this same year is validated empirically by the following linear regression[7]:

$$\ln Y_{1,t} = -0,578 + 0,435 \times \ln R_t + 0,617 \times \ln SA_t + u_t \qquad t = 1960,....,2000$$
$$(-0,475) \quad (4,172) \qquad (3,759)$$

(.) : student t
$R^2 = 0,44$
R ² adjusted = 0,41

where :

R_t corresponds to the rainfall of the year t
u_t is the term of error

So:

$$Y_{1,t} = 0,561 \times R_t^{0,435} \times SA_t^{0,617} + \varepsilon_t$$

This equation thus makes it possible to estimate the confidence intervals of the parameters α and β. In simulations carried out, we use the average value of each parameter and not the interval.
Thus, α = 0,617 and $\beta = \omega^{0,617} \times 0,561 \times R_t^{0,435} = 0,5 \times R_t^{0,435}$

Then we obtain the following equation:

$$Y_{1,t} = 0,5 \times R_t^{0,435} \times E_{1,t}^{0,62}$$

[6] This average surface is supposed be equal to 0,84. Indeed, a study carried out by Roch (1972) concerning the village of Darou Rahman II also located in the peanut basin of Senegal estimates at 1,42 ha the average surface cultivated by a man and at 0,26 ha those cultivated by a woman. If the assumption is made that there are as many women as men cultivating peanut, this cultivated average surface is thus equal to 0,84 ha.
[7] The assumptions of normality, of non-multicolinearity between the explanatory variables, of absence of autocorrelation of the residues as well as the assumption of stability of the regression in time were validated. There is not thus significant correlation between the rainfall of the year t and the total cultivated peanut surface of the same year. The explanatory variables are significant with a threshold of 5%.

5.2. Long-term effect of the rainfall drop on the total cultivated peanut surface

The analysis of the (bilateral) correlation indicates a positive, significant correlation to the threshold of 1 %, between the total cultivated peanut surface of the year t and the average rainfall over the 10 last years

Correlations

		SA	PLUV10
SA	Correlation of Pearson	1,000	,436**
	Sig. (bilateral)	,	,004
	N	41	41
PLUV10	Correlation of Pearson	,436**	1,000
	Sig. (bilateral)	,004	,
	N	41	41

**. The correlation is significant on level 0.01 (bilateral).

SA: the total cultivated peanut surface for the year t
PLUV10: the average of rainfall over the ten last years

This positive correlation is explained on the one hand by the process of salinization[8] due to a rainfall deficit following a persistent dryness. This phenomenon makes uncultivated in an irreversible way the grounds causing a reduction of allocated surfaces allocated to this cultivation. Moreover, a durable fall of rainfall causes a progressive disinterest of the producers because of a fall of the peanut growing return.

5.3 Impact of the demographic growth on agriculture

The analysis of the (bilateral) correlations indicates a positive, significant correlation with a threshold of 1%, between the population of Sine Saloum of the year t and the total cultivated millet surface of the same year as well as a negative correlation between the total cultivated peanut surface to the year t and the total cultivated millet surface to the year t .

Correlations

		POP	SM	SA
POP	Correlation of Pearson	1,000	,728**	-,599**
	Sig. (bilateral)	,	,000	,000
	N	41	41	41
SM	Correlation of Pearson	,728**	1,000	-,485**
	Sig. (bilateral)	,000	,	,001
	N	41	41	41
SA	Correlation of Pearson	-,599**	-,485**	1,000
	Sig. (bilateral)	,000	,001	,
	N	41	41	41

**. The correlation is significant on level 0.01 (bilateral).

Pop: the total population of Sine Saloum for the year t
SM: the cultivated millet surface for the year t
SA: the cultivated peanut surface for the year t

[8] The surface of the salted grounds was estimated, in 1991, to 10% of the total surface of Sine Saloum (CSE).

Indeed, the demographic growth of Sine Saloum being accompanied by an increase in the requirements in food for the population and in particular for the requirements in millet, which is the principal food crop in Sine Saloum, surfaces necessary to the production of millet thus increase, causing a reduction in the peanut production because of the levelling off of surfaces suitable for cultivation since years 1960 (Lericollais et al.. 1987).

5.4 Impact of the fall in the peanut price paid to the producer on the peanut cultivated surfaces

The analysis of the (bilateral) correlation indicates a positive, significant correlation with a threshold of 1%, between the total cultivated peanut surface at the year t and the average[9] of the peanut price paid to the producer over the 5 last years.

Correlations

		SA	PRPRO5
SA	Correlation of Pearson	1,000	,483**
	Sig. (bilateral)	,	,009
	N	28	28
PRPRO5	Correlation of Pearson	,483**	1,000
	Sig. (bilateral)	,009	,
	N	28	28

**. The correlation is significant on level 0.01 (bilateral).

SA: the total cultivated peanut surface of the year t
PRPRO5: the average of peanut prices paid to the producer over the 5 last years

Jointly to the drop of rainfall, the downward trend of the peanut prices led to a demotivation of certain producers compared to the peanut growing then resulting in a reduction in cultivated peanut surfaces.

5.5 Interactions between agriculture and fishing

The farmers distribute their production effort between the peanut growing and fishing. The production effort allocated to peanut is measured by the total cultivated peanut surface. The production effort allocated to fishing is measured by the number of motorized canoes[10].

The relation existing between the total cultivated peanut surface for the year t and the number of motorized canoes for this same year was shown empirically by an econometric analysis, based on the following linear regression[11]:

$$\ln \mathrm{PirM}_t = \underset{(3,072)}{9,785} + \underset{(1,893)}{0,289} \times \ln \mathrm{PirM}_{t-1} - \underset{(-1,821)}{0,8} \times \ln \mathrm{SA}_t + u_t \qquad t = 1974,....,2000$$

[9] A correlation realized between the total cultivated peanut surface of the year t and the price of this good in the same year is not significant, which means that the peanut producers react not according to the current price but according to the tendency of the prices

[10] Indeed, these last require to operate a significant number of individuals. They thus constitute the exclusive outlet of the surplus agricultural labour. Conversely, the non-motorized canoes require little labour and employ consequently only the family circle members of the boat owner.

[11] The assumptions of normality, of non-multicolinearity between the explanatory variables, absence of autocorrelation of the residues as well as the assumption of stability of the regression in time were checked. The explanatory variables are significant with a threshold of 10 %.

(.) : student t
$R^2 = 0,39$
R^2 ajusted $= 0,31$

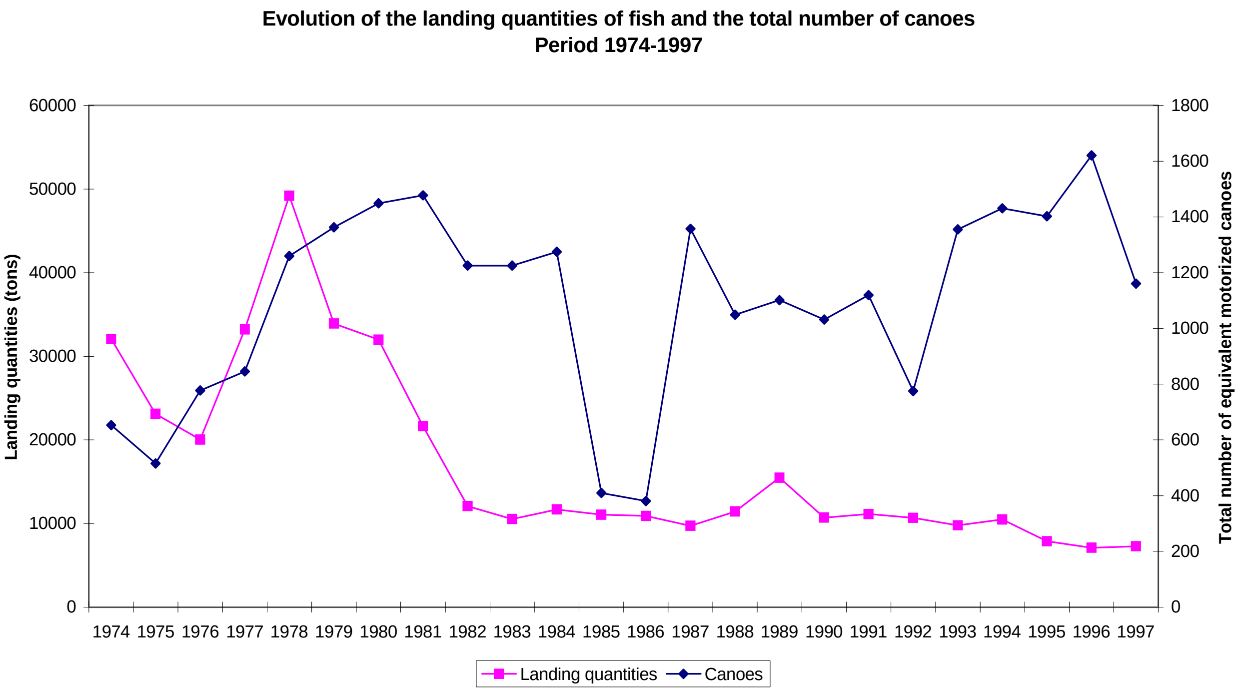
where:

$PirM_t$ is the number of motorized canoes for the year t
$PirM_{t-1}$ is the number of motorized canoes for year t-1,
SA_t is the total cultivated peanut surface for the year t
u_t is the term of error

$$PirM_t = 17765 \times PirM_{t-1}^{0,289} \times SA_t^{-0,8} + \varepsilon_t$$

Indeed, if the price of peanut paid to the producer[12] and/or if the production of peanut[13] drops, the cultivated peanut surface decreases. Consequently, the number of people who can produce peanut falls: this surplus of labour is thus available for the fishery sector; thus the number of active motorized canoes increases. It is interesting to notice that the number of motorized canoes at the year t depends also partly on the number of active motorized canoes of the previous year : this observation could mean that there is a of " ratchet effect". For example, an increase of 1000 ha of the cultivated peanut surface at the year t in accordance with a reduction of 1000 ha of this same surface at year t-1 does not mean that the number of motorized canoes in t will return on its level of t-1 (it will remain on a slightly higher level).

5.6 The production function of the fishery



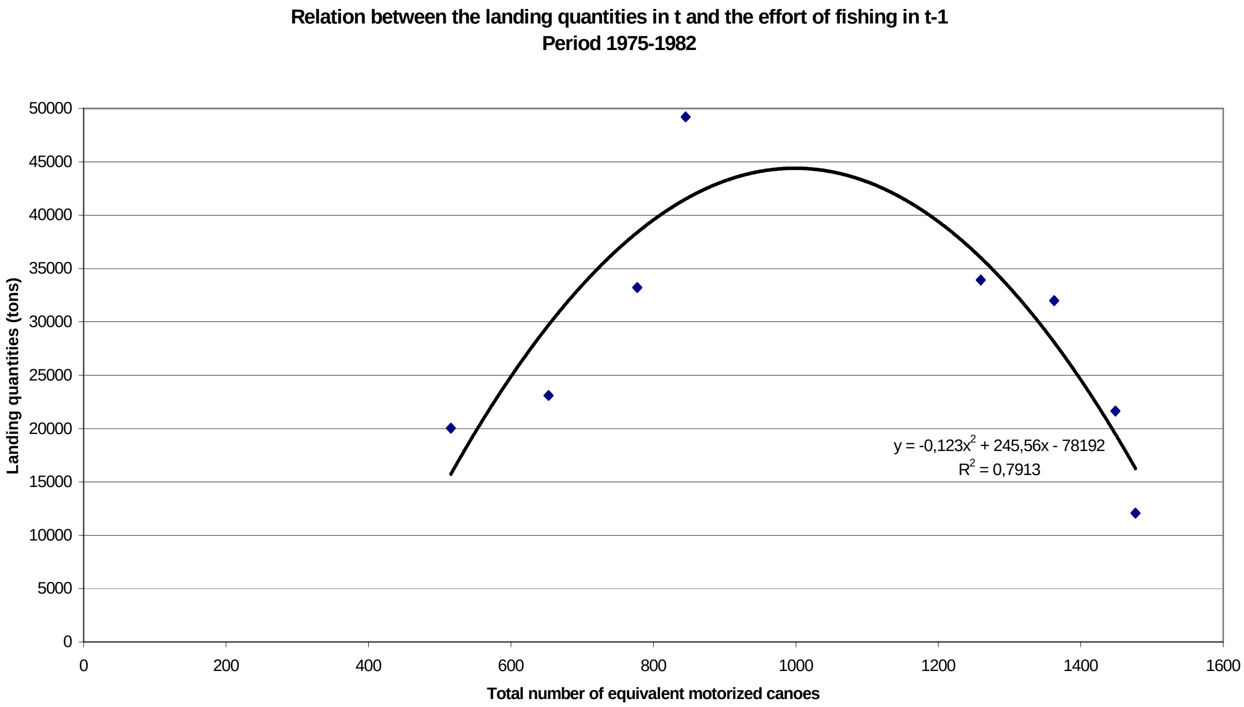
[12] Cf the relation between the peanut price to the producer and the total cultivated peanut surface (5.4)

[13] Cf the relation between the peanut production and the total cultivated peanut surface (5.1)

We observe that the volume of the landings of Sine Saloum has strongly decreased since 1978 after having known a significant increase between 1976 and 1978. From 1982, the volume of the landings has been stabilized on a low level of approximately 10 000 tons per year.

The total number of equivalent motorized canoes[14] had strongly increased over the period 1975-1981 then had decreased[15] over the period 1981-1992 and finally had increased again.

From 1982, it seems not to exist a correlation between the number of canoes and the landing quantities of fish. On the other hand, over the period 1974-1982, there is a relation between the number of canoes of the year t-1 (effort of fishing of the previous year) and the landing quantities of fish of the year t. This relation is materialized by a curve in conformity with that presented in the model of Schaeffer, model on which our analysis of the effort of fishing is based.



[14] We suppose, according to a study carried out by T.Bousso (1996), that the motorized canoes land 4 times more than the non-motorized canoes, which makes it possible to calculate a total number of "equivalent motorized canoes" in the following way: Nb eq. motorized canoes = Nb motorized canoes + 0,25*nb non-motorized canoes

[15] The strong reduction in the number of canoes in 1985 and 1986 is connected with the fact that an industry of manufacture of fish meal based on pelagic species fished with the purse seine was forced to change activity following problems of provisioning. Consequently, the units of fishing with the purse seine did not find any more outlets for their pelagic species and were in their turn forced to reconvert themselves into other techniques of fishing. However, the redeployment requires a certain time because of the importance of the investment.

6. Concluding remarks

This paper has presented, both in empiric and formal terms, the dynamics of relations between farming and fishing in the Sine-Saloum area. The Saloum delta case illustrates the fact that the evolution of a fishery may be highly dependent on factors that are clearly external to the fishing industry, such demographic growth, or consequences of lower export prices and lower rainfall on local farming. A conclusion is that, under such circumstances, fisheries management will most likely fail to reach its targets if it does not properly take into account the more global context of the local socio-economic system. As regards the case under survey, limitation of fishing effort, which seems necessary to restore both fish stocks and profitability of the sector, has little chances of success if alternative sources of income are not made available to the local population. The fact that the Saloum delta has been promoted to the rank of Biosphere reserve might create opportunities in this field, for instance by helping fishers to diversify their activity towards ecotourism.

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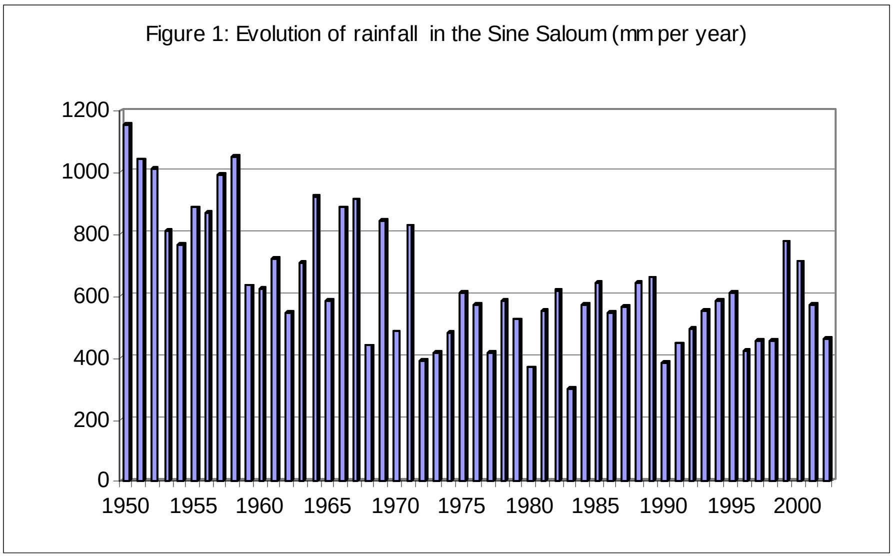


Figure 1: Evolution of rainfall in the Sine Saloum (mm per year)

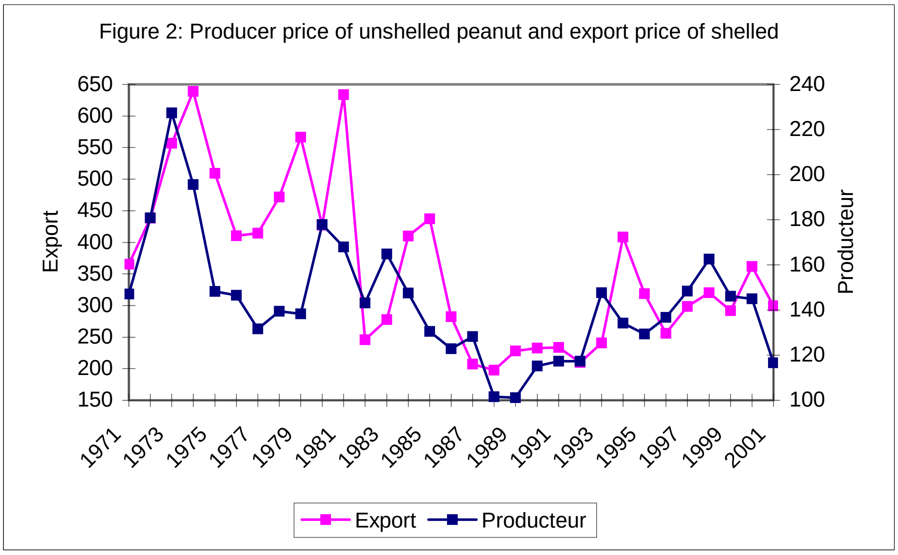


Figure 2: Producer price of unshelled peanut and export price of shelled

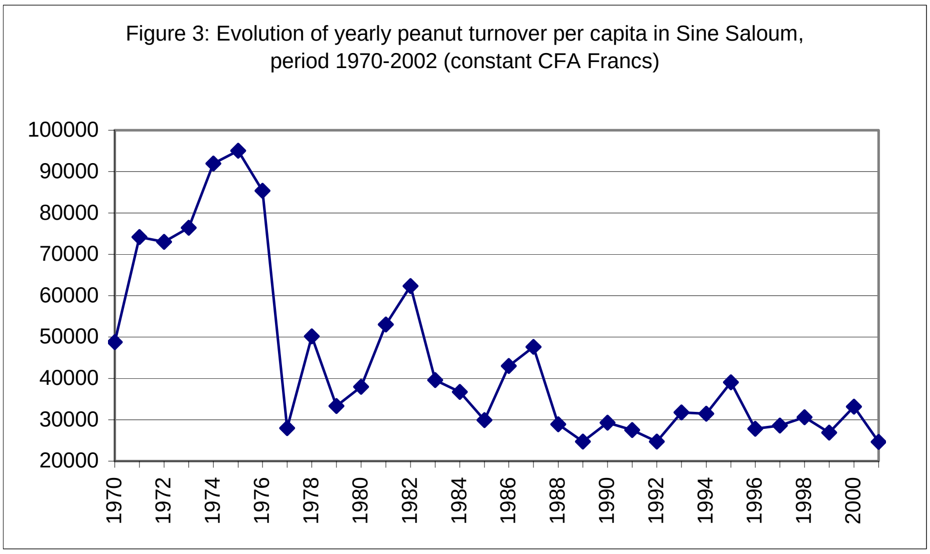


Figure 3: Evolution of yearly peanut turnover per capita in Sine Saloum, period 1970-2002 (constant CFA Francs)

Figure 4 : Impact of population growth, drought and decreasing price on local peanut industry.

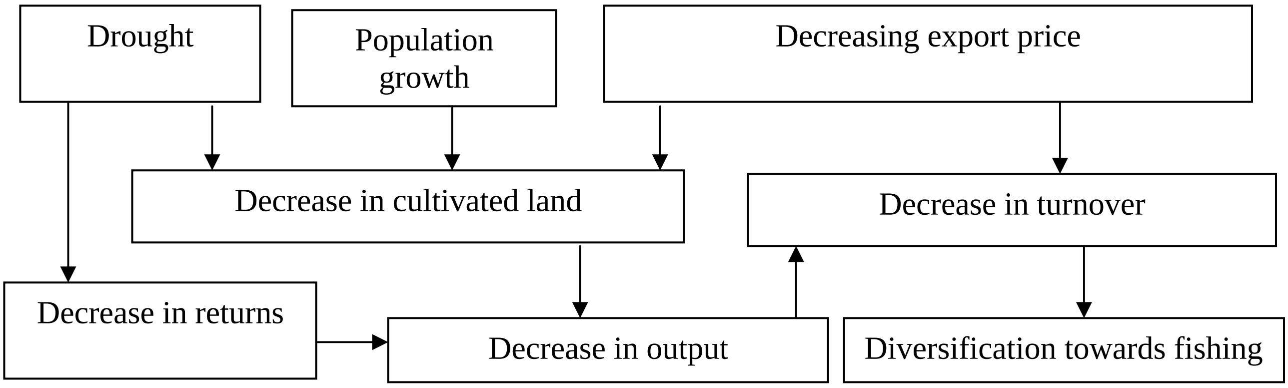


Figure 5 : Evolution of fish landing in Sine Saloum on ton, period 1954-2002

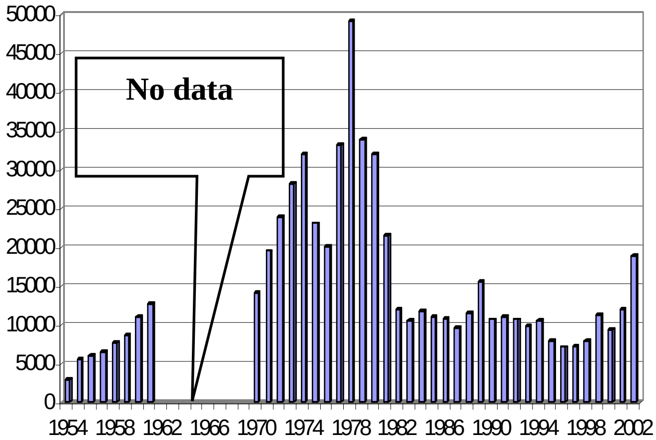


Figure 6: Production fonction of the farming sector

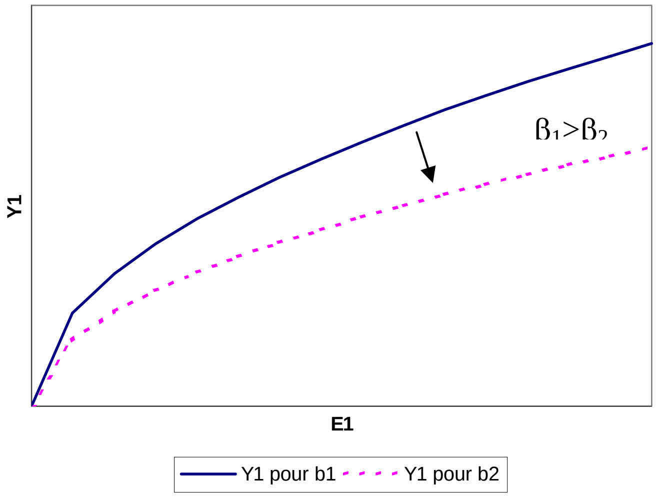


Figure 7: Production fonction of the fishing sector

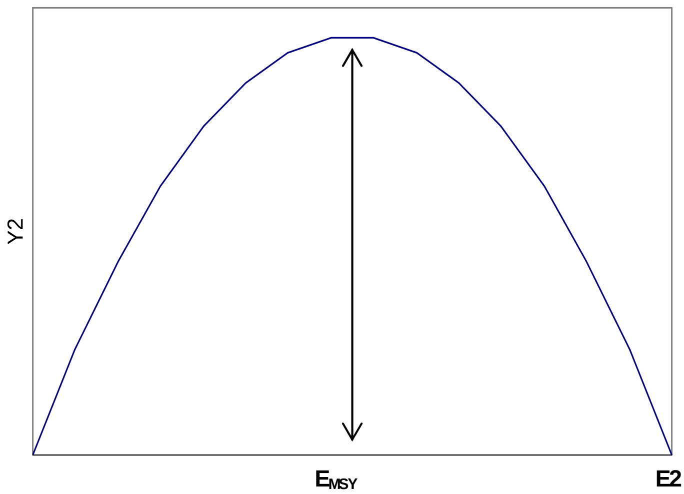


Figure 8: Economic equilibrium of the farming sector

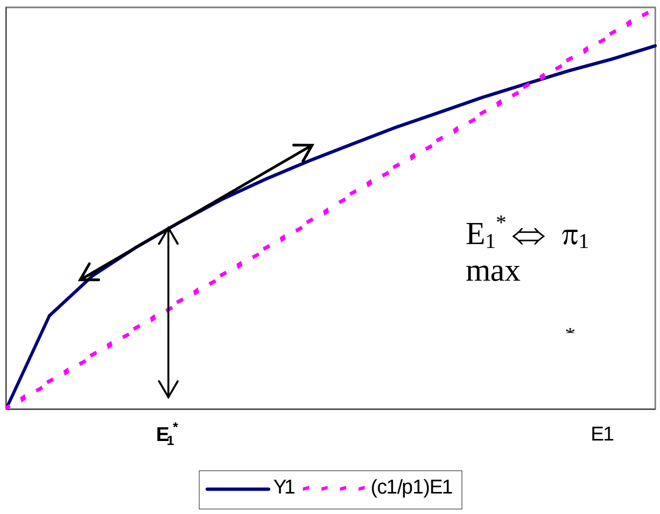
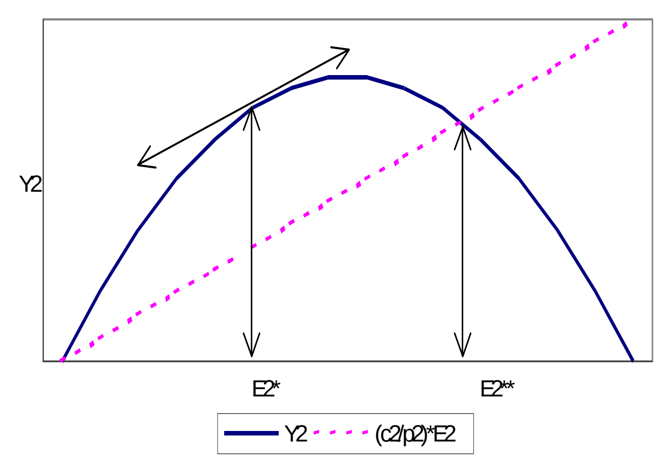


Figure 9: Economic equilibrium of the fishing sector



$E_2^* \Leftrightarrow \pi_2 \max \qquad E_2^{**} \Leftrightarrow \pi_2 = 0 \qquad E_2 \leq E_2^{**}$

Figure 10: Dynamics of employment

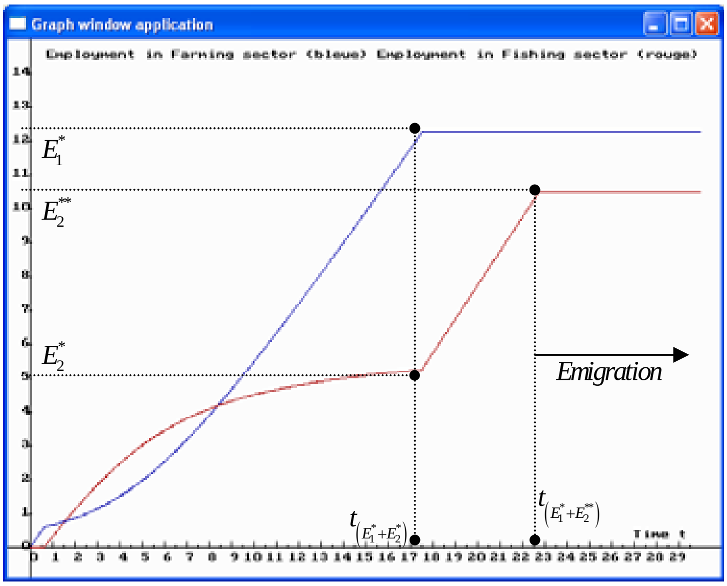


Figure 11: Dynamics of profits

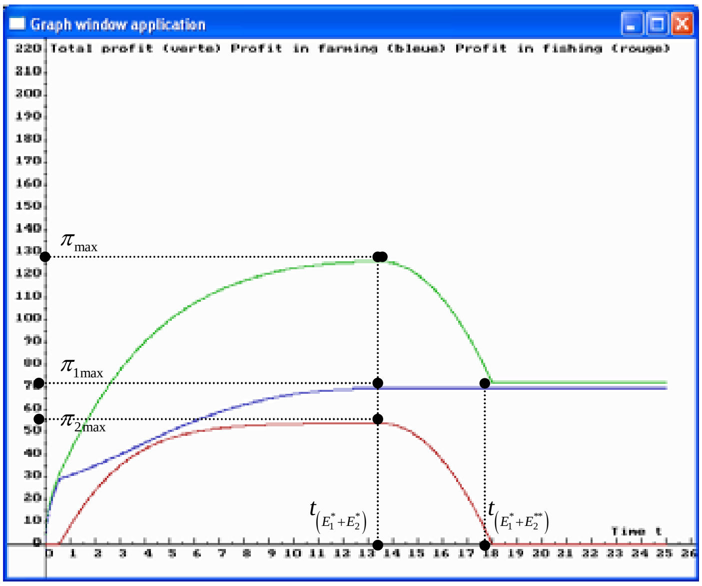
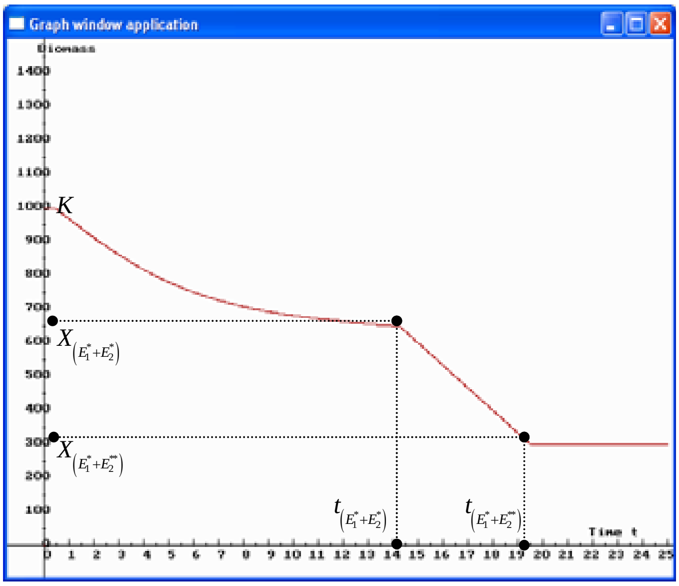


Figure 12 : Dynamics of fish biomass



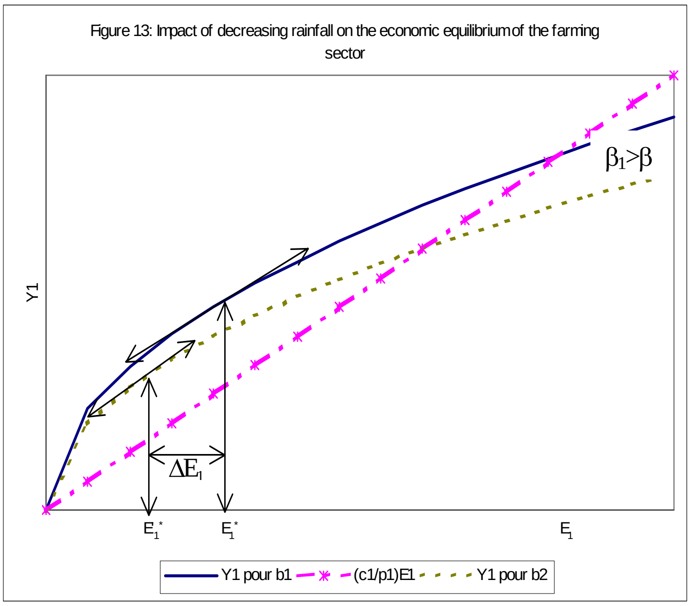


Figure 13: Impact of decreasing rainfall on the economic equilibrium of the farming sector

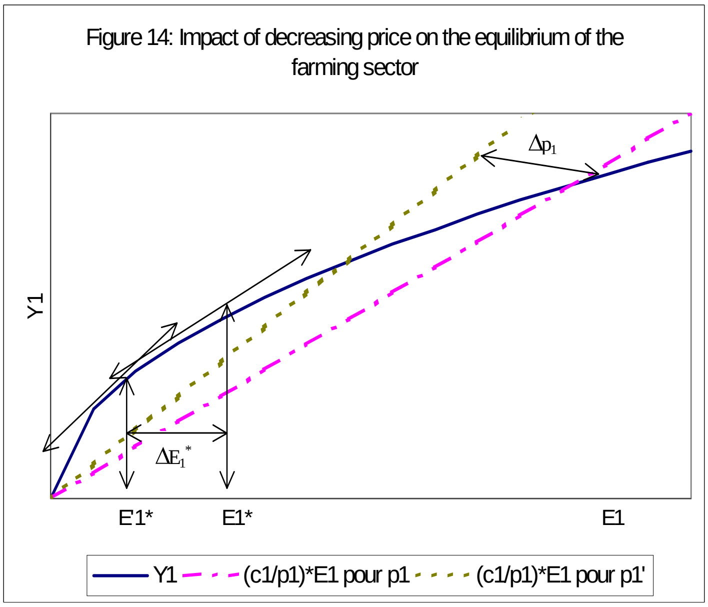


Figure 14: Impact of decreasing price on the equilibrium of the farming sector

Figure 15: Impact of decreasing rainfall on the dynamics of employment in the farming sector

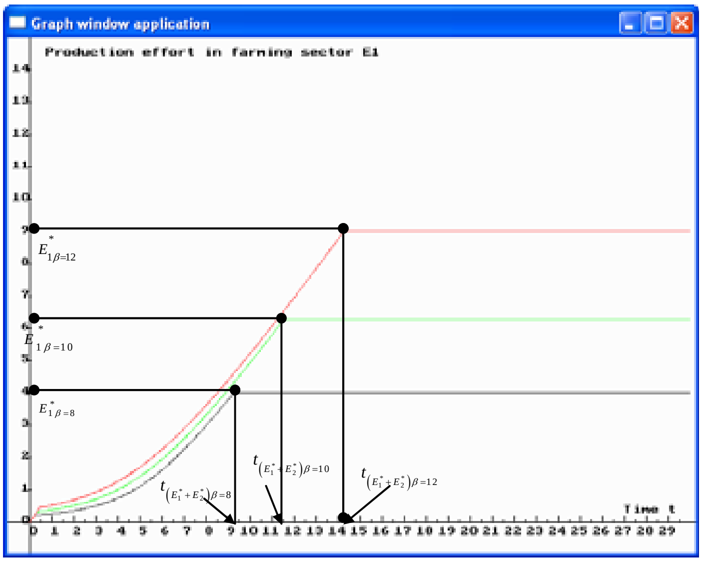
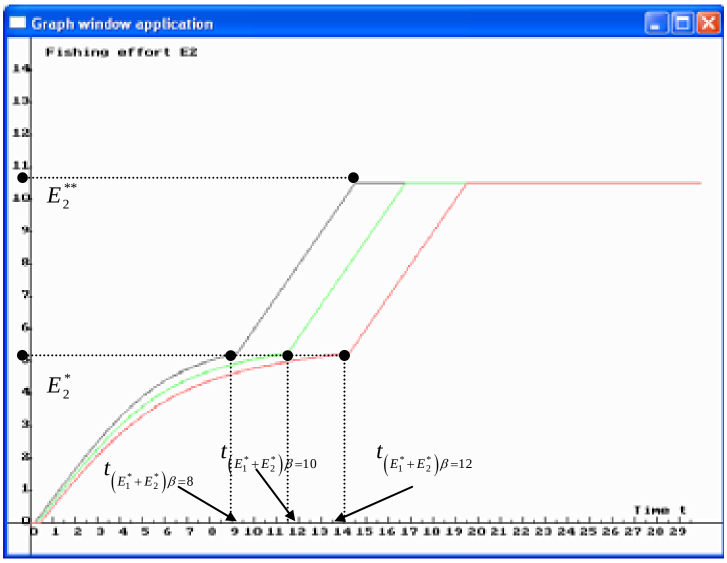


Figure 16: Impact of decreasing rainfall on the dynamics



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