

Estimations of Soil Biota and Agricultural Production Interactions

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Preliminary results

Abstract

This paper studies the mutualism relationship linking soil biota and agricultural practices. It presents the point of view of biology and then proposes a point of view of econometric. I then review biological research findings on biodiversity and agroecosystems to show how it is a complex investigation at the scaling but also at the functional levels and how biologists and economists' investigations may not coincide in their expectations. I then propose a two step econometric procedure that allow to estimate the magnitude of the mutualism relationship that links soil natural resources and the agricultural production. This procedure is conducted for different agroecosystems and consists in a first step in estimating the soil resource evolution with dynamic panel data and in a second step in estimating the magnitude of the role of this natural resource and of the chemical input uses in the production. Finally, it is shown that although investigation techniques may not coincide between economists and biologists, the results of this econometric procedure is relevant with biological considerations.

Keywords: agroecosystems, renewable resource, dynamic panel data.

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1 Introduction

The set of species living in a given space, the set of interactions among species and between species and their physical environment, the set of flow of matter and energy that glances through the species and their environment constitute an ecosystem and biodiversity is commonly perceived as a generator of this ecosystem. Nevertheless, the ecosystem is not fixed in the time and its evolution is driven by species' evolution but also, directly or indirectly by the impact of human activities. A particular ecosystem is the agroecosystem, it arises with the influences of agricultural practices on species and is the result of the simplification and the artificialization of the environment. The actual sixth extinction of species and the loss of biodiversity asks the question of the durability and the sustainability of the agricultural systems if artificialization follows its actual trend.

Indeed, the preservation of soil functions in agriculture is the basis of the sustainability of the agricultural systems. These functions are themselves based on the fauna of the soils and its diversity. The soil biota, all plants and animal life of a particular space, regroups the productive biota (crops and livestock), the resource biota (decomposers) and the destructive biota (pests), it is influenced by farmers' agricultural practices that consist mainly in maximizing the productive biota at the expense of the two others. Nevertheless, the resource biota is at the basis of ecosystems resilience since as decomposers they participate in the creation of vegetable mould and as regulators of nutrient cycling enhance the efficiency of nutrient acquisition by plants that may reduce nitrogen run off. The impact of agricultural practices on the resource biota appears through the perturbation of land uses and fields preparation and through the use of xenobiotic compounds such as pesticides and fertilizers. The identification of soil biodiversity, its functions in the ecosystems, and the quantification of the interactions between agricultural production and the soil biota is being referenced by scientists but the differences of scales between economists and biologists investigations -the latter work at the laboratory or micro-plot levels and the former at the farm or regional level- makes difficult to base natural resource conservation policies on only one of these two groups because as mentioned by Swift (2004) there is a possibility that the functions and species change across space.

The objective of this paper is then to estimate the soil biota and agricultural production interactions on some agroecosystems and test whether results are relevant with biological research and findings. I then propose a structural model to estimate soil resource biota and agricultural practices interactions with data on land allocations and crop-wise input use data that can be used to derive tools for natural resource conservation policies. I propose a two steps econometric procedure. The first step consists in estimating the dynamic evolution of the biotic resource as a function of the stock at the preceding period and of the use of xenobiotic compounds. In a second step, the crop specific fertilizers and the predicted resource biota is used as a generated regressor to estimate the magnitude of these two inputs on the production of the agroecosystem. The paper contributes then in

quantifying the magnitude of the mutualism relationship of agriculture and soil biota and proposes an econometric method to estimate this relationship. The method is relatively straightforward in the sense that it does not account for corner solutions and consists in estimating separately the dynamic equation of evolution of the resource in unbalanced dynamic panel data and recovers soil resource biota predictions to use them as a generated regressor in step two.

The paper is organized as follows. In section 2, I present the biological research findings that explain the mutualism existing between soil resources and agriculture and how biological findings can not for the moment allow to calibrate coupled models applied to soil biodiversity. Section 3 presents the structural equation model and then gives the bio-econometric estimations. I firstly describe the data base and then presents the econometric procedure of dynamic panel data. Section 4 presents some conclusions.

2 Biology and Agriculture

In the biodiversity concept at the agroecosystem scale, a distinction has to be established between what results directly of farmer decisions and what results indirectly of these decisions. The former diversity is termed as the "planned diversity" (Swift et al. 2004)- the suite of plants and livestock deliberately retained, imported and managed by the farmer and the later is the "associated biota"-plant, animal and microbial. Nevertheless, the associated biota is strongly influenced by the composition and diversity of the planned biota. While the control of "planned diversity" obeys to economic decisions and biological considerations, the impacts of agricultural practices on the associated biota is the issue in biodiversity conservation.

Swift and Anderson (1993) defined three categories of biota on the basis of their contribution to agricultural ecosystem productivity: productive biota (crops and livestock), resource biota (covercrops, decomposer organisms) and destructive biota (pests, weeds). Even endowed with property rights on this three groups, farmers concentrate on maximizing productive biota at the expense of the two others, simplifying the natural resource management issue to one single resource management. Destructive biota is eradicated with convenient techniques (pesticides, biocides) while resource biota is neglected according to the poor (but increasing) number of good environmental practices on land (conservation tillage technique for example). This simplification has generated the definition of agroecosystems - ecosystems that have been deliberately simplified by people for purpose of the production of specific goods of value to humans (Swift et al. 2004). These three sets of biota are not isolated but are correlated. The loss of resource biota when maximizing the productive biota may leave space to the destructive biota and thus reduces the productive biota. In reaction farmers may use techniques that eradicate the destructive biota but this will also negatively affect the resource biota that determine a part of the productive biota. The complexity of these interactions is being documented by biologists and the question

in the biodiversity conservation context is the role of the resource biota on the productive biota and in which proportion the resource biota conservation benefit to the productive biota. I present here some of these results.

Beare et al.(1997) propose a detailed review of the literature on the role of decomposer biota on soil biodiversity and agricultural intensification. This work illustrates the complexity of interactions that drives soil fertility: interactions among decomposers and between plants and microorganisms, influence of decomposers on soil properties (N transformations), influences of decomposers diversity on soil properties, influences of crop quality residues on decomposers density and diversity and on rates of residue decomposition but also influence of the mean by which crop residues are disposed on the size, the composition and the activity of soil biological communities and on rates of organic matter decomposition. These organisms participate in the soil organic matter synthesis and decomposition, but also regulate water infiltration and retention (Swift et al. 2004). Nevertheless, the function of this fauna, when identified, in the ecosystem is heavily ecosystem specific and species specific. It is an evidence that earthworms function of improving water infiltration is perceived as a damage for farmers cultivating rice (Joshi et al. 1999 in Swift 2004). Similarly, conversion of Amazonian rain forest to grassland lead to extinction of a native earthworm species, replaced by an exotic species that compact the soil and negatively affect pasture productivity (Chauvel et al. 1999 in Swift 2004).

Soil fauna is classified in three groups: microfauna (nematodes, protozoa) quite well known by biologists, mesofauna (mites, collembola) poorly known and macrofauna (earthworms, ants, termites, millipedes). Almost all are referenced as regulators of nutrient cycling by changing the decomposition processes that influence the release and retention of nutrients, they also enhance the efficiency of nutrient acquisition by plants. Each of the three groups plays its own role in the ecosystem but all contribute to soil fertility with different scales, directly or indirectly. Some studies (Tian 1997) suggest that promoting the colonization and activity of soil macrofauna may be important to restoring the decomposition function of degraded soils. Among macrofauna family, earthworms might be the most studied species (Darwin, Lavelle). It is known among biologists that many earthworms species contribute to nutrient cycling through the production of nutrient-rich casts. Their production is estimated around $50 - 100\text{kg}\text{ha}^{-1}$ in humid tropical pastures. It has also been shown that earthworms casts contain more organic carbon, total nitrogen, available phosphorus from which the casts are derived. The casts produced by the earthworms are rich in organic matter and the higher rates of mineralization found in these casts implicate and enhanced availability of nutrients (NH_4^+ and NO_3^-) to roots growing in this zone and to superficial roots which can absorb these nutrients after they leach from the litter layer (Anderson et al. 1983 in Fragoso 1997). In tropical grasslands around $25 - 150\text{kg}\text{ha}^{-1}$ of mineral nitrogen may be released annually by a species of earthworms (Lavelle et al. 1992). It is also estimated that $50\text{kg}\text{ha}^{-1}$ of mineral phosphorus could be released into the soil. Fragoso et al. also inform that "this nutrient may be rapidly assimilated by plants if released at a time when a nutrient sink is present and if not, may

be stored or made inaccessible to plant roots by leaching, surface runoff, soil erosion or others processes.” Nevertheless, whereas agricultural intensification reduces the diversity of organisms involved in nutrient cycling, there is no evidence that a higher diversity of these organisms can produce significant effects on decomposition and mineralisation processes (Swift et al. 2004). This illustrates the complexity and the mutualism existing among soil biodiversity, agro-ecosystem functions and agricultural practices.

The impacts of agricultural practices on soil biodiversity have also been studied but quantification of this impact is more rare. Beare et al. identify three factors associated with agricultural intensification: ”(1) an increase in the frequency and magnitude of perturbations that result from land-use change and site preparation (deforestation, burning, removal of residues), (2) a reduction in the quantity of organic resources returned to the soil; (3) the use of xenobiotic compounds such as industrial fertilizers and pesticides”. Land-use change consisting in converting native forest or grassland systems to arable cropping results in a decline of soil biodiversity (Cf. Table1)

Table 1: Effects of land use on soil biota of an Ultisol in Yurimaguas, Peru. (from Lavelle and Pashanasi 1989)

Land use	Number of taxonomic units	Population (number m^{-3}) ^a	Biomass ($g.m^{-2}$) ^a
Forestry			
Primary	41	4304 ± 933	53.9 ± 8.54
Secondary (15 years)	27	4099 ± 1828	24.1 ± 5.85
Crops			
High input maize	20	730 ± 221	3.1 ± 1.04
Low input rice	24	3683 ± 1059	8.5 ± 2.75
Traditional cassava	18	1197 ± 283	7.6 ± 3.26
Pastures			
Bracharia+Desmodium	27	922 ± 81	159.2 ± 16.4
Traditional (moist)	23	1768 ± 308	121.1 ± 20.8
Tradittional (dry)	20	2367 ± 453	82.3 ± 15.5
Fallows			
Centrosema (6 months)	22	1546 ± 253	111.9 ± 13.2
Kudzu	23	2214 ± 969	15.5 ± 6.2
Peach palm+kudzu	32	1858 ± 380	93.9 ± 25.2

^a Value are mean ± SE

On the effects of agrochemical herbicides, on soil biodiversity, it has been shown that non-selective agrochemicals can be detrimental for long run soil management and maintaining soil fertility and that insecticides and herbicides reduce the density, the diversity and the biomass of earthworms (Reddy and Reddy 1994, Reddy et al., 1995). Nevertheless, the quantification of the role of soil fauna on soil fertility is poorly known and even less known is the effect of soil organisms on crop yields. Lavelle et al. have shown that

for the earthworm species they studied, this species enhanced maize yields. Gilot (1994) observed an increase of 18% and 12% in maize grain and stalk production respectively, when earthworm species was introduced into $1.28m^2$ microplots. But the survival rates of the species after the harvest was very low, which indicates a low robustness of the results. Hole et al. analyze the impact on biodiversity of agri-environmental schemes aim at promoting organic farming practices. Their conclusions are based on a comparative study of the literature on that field. They review the effect of organic farming on flora, soil microbes, invertebrates (earthworms, butterflies, spiders, beetles) and vertebrates (birds, mammals). They reveal that in almost all studies they refer to (76 studies), organic farming benefits to a larger abundance and/or species richness.

Coupling economic and biological model in soil fertility and conservation is not that evident to perform mainly because of "scales" differences and more precisely because of spatial scales differences. This is illustrated by Franklin (1993): "when discussing the implications of changes in soil biodiversity to ecosystem function it is important to identify the taxonomic resolution used to described diversity and the spatial scale at which diversity-function relationships are considered". Indeed, while economists deal with aggregate phenomena, biologists deal with micro plots (or laboratory chamber) and specific species or member of species. Aggregating biological results on biodiversity and agricultural production, only at the whole plot of the crop, or at the farm level will not satisfy the robustness of these results: there is a possibility that the functions and species change across space (Swift et al. 2004). Finally, while what matter for economists is the input productivity (resource biota) and how to derive soil conservation policies that could improve social welfare, biologists are at the step where they reference the fauna of the soil, understand their role, the interaction among soil organisms, the role of soil fauna and soil biodiversity on ecosystem functions, but also the impacts of farm management and land-use changes on this resource. It is recognized that "the effects of land-use change and agricultural intensification on biodiversity and associated functions are still poorly understood but conversion to agriculture almost always results in fewer species of both planned and associated biota with lower genetic variation and representing less functional groups" (Swift et al. 2004). Finally, biodiversity has a more complex scaling since it is referenced and analyzed at the plot levels but also should be considered at larger scales, i.e. at landscape levels, between-farm variability will define the landscape diversity. This landscape scale is not considered in this paper. For these reasons, I suggest not to calibrate a simulation model from biological results but I propose to estimate a structural model in a two step procedure to estimate the soil biota and agricultural practices interactions.

3 Natural resource exploitation by agriculture

3.1 The structural model

The space represents a heterogeneous land formed of different plots or fields indexed by c . Each plot characterizes a different land use and a different crop (wheat, maize, grassland,...). On this space is living the biotic resource (noted B) representing the resource biota discussed in the section two. This resource is a renewable resource whose evolution is described by a logistic form and is negatively affected by the agricultural effort, noted E exerted by the farmer on the land. This effort represents the use of chemical fertilizers and others pesticides and xenobiotic compounds. The damage produced by the effort takes the form of a shaefer function, $H_c(E_{ct}, B_{ct}) = \varphi_c B_{ct} E_{ct}$. The evolution of this resource is then:

$$\begin{aligned} B_{ct} &= B_{c,t-1} + B_{c,t-1} \left[r_c \left(1 - \frac{B_{c,t-1}}{\kappa_c} \right) \right] - H_c(E_{c,t-1}, B_{c,t-1}) \\ B_{c,t-1} &= B_{c,t-1} + B_{c,t-1} \left[r_c \left(1 - \frac{B_{c,t-1}}{\kappa_c} \right) \right] - \varphi_c B_{c,t-1} E_{c,t-1} \end{aligned} \quad (1)$$

where r_c is the intrinsic growth rate of the patch, κ_c is the carrying capacity of the patch and φ_c is a mortality coefficient due to E_{ct} in the shaefer function.

On economic part, the farmer uses two inputs for the production. The renewable resource, B and the agricultural effort, E . The production depends upon the agricultural effort in two opposed manners. The agricultural production Q_c on land c is then:

$$Q_c(B_{ct}, E_{ct}) = B_{ct} + \frac{1}{2} B_{ct}^2 + E_{ct} + \frac{1}{2} E_{ct}^2 + B_{ct} E_{ct} \quad (2)$$

3.2 Econometric estimations

3.2.1 The Data base

The data base is an unbalanced panel data of around a hundred french farmers over seven years, from 1995 to 2001. It is issued of the Farm Accountancy Data Network of the European Union (FADN). These 7650 farmers work in three different regions: Midi-Pyrénées for 38% of them, Pays de la Loire for 37% and Rhône-Alpes for about 25%. Table(2) summarizes descriptive statics for the studied land uses: wheat, maize, oil producing crops (Oil) and grassland (non permanent grasslands). The average farmer of this panel mostly devotes space firstly to wheat crop, grassland, maize and finally oil producing crop. There is a quite important dispersion in the data and significant regional differences for the land uses.

The crop specific input expenditures in the chemical agricultural effort was not directly available from the FADN data base, only total expenditures (over all land uses) for mineral nitrogen and for biocides (insecticides, fungicides and herbicides) was reported. I then

Table 2: Descriptive statistics from the panel

Region	N	Mean	Std	Min	Median	Max
Grassland Area (ha)						
Pays de la Loire	2833	3068.7	2137.5	0	2911	19892
Midi-Pyrénées	2916	2640.5	3406.4	0	1670	27725
Rhône-Alpes	1901	3266.3	2838.9	0	2832	15163
All	7650	2954.6	2860.5	0	2531	27725
Wheat Area (ha)						
Pays de la Loire	2833	1492.3	1488.2	0	1080	12250
Midi-Pyrénées	2916	2121.0	2929.8	0	1072	28342
Rhône-Alpes	1901	951.1	1042.3	0	649	9349
All	7650	1597.5	2138.5	0	970	28342
Maize Area (ha)						
Pays de la Loire	2833	536.6	1713.3	0	0	23538
Midi-Pyrénées	2916	833.9	2086.2	0	0	22479
Rhône-Alpes	1901	815.1	1853.8	0	0	19521
All	7650	719.2	1902.3	0	0	23538
Oil-producing crops Area (ha)						
Pays de la Loire	2833	287.3	690.1	0	0	7200
Midi-Pyrénées	2916	1203.5	2154.5	0	0	22118
Rhône-Alpes	1901	219.4	497.1	0	0	3587
All	7650	619.7	1489.1	0	0	22118

Table 3: Descriptive statistics : chemical inputs use

Region	N	Mean	Std	Min	Median	Max
Mineral nitrogen, kg per ha of wheat						
Pays de la Loire	2833	27.1	11.8	0	26.6	110.6
Midi-Pyrénées	2916	25.2	15.6	0	24.2	193.2
Rhône-Alpes	1901	20.8	14.8	0	19.2	131.6
All	7650	24.8	14.3	0	24.2	193.2
Biocides, liter by treatment per ha of wheat						
Pays de la Loire	2600	0.031	0.03	0	0.029	0.40
Midi-Pyrénées	2565	0.037	0.11	0	0.017	3.31
Rhône-Alpes	1586	0.038	0.09	0	0.02	2.93
All	6751	0.035	0.08	0	0.02	3.31
Mineral Nitrogen, kg per ha of grassland						
Pays de la Loire	2833	6.3	2.7	0	6.2	25.7
Midi-Pyrénées	2916	4.5	2.8	0	4.3	35.1
Rhône-Alpes	1901	3.1	2.2	0	2.8	19.8
All	7650	4.8	2.9	0	4.65	35.1
Mineral Nitrogen, kg per ha of maize						
Pays de la Loire	2833	6.4	2.8	0	6.3	26.2
Midi-Pyrénées	2916	10.9	6.7	0	10.5	83.9
Rhône-Alpes	1901	7.9	5.7	0	7.3	50.5
All	7650	8.5	5.6	0	7.5	83.9
Biocides, liter by treatment per ha of maize						
Pays de la Loire	911	0.02	0.04	0	0.12	0.6
Midi-Pyrénées	1280	0.03	0.07	0	0.01	0.7
Rhône-Alpes	872	0.02	0.07	0	0.008	1.3
All	3063	0.03	0.08	0	0.02	3.31
Mineral nitrogen, kg per ha of Oil						
Pays de la Loire	2833	14.1	6.1	0	13.8	57.4
Midi-Pyrénées	2916	13.7	8.4	0	13.1	105.1
Rhône-Alpes	1901	10.7	7.6	0	9.9	67.9
All	7650	13.1	7.6	0	12.8	105.1
Biocides, liter by treatment per ha of Oil						
Pays de la Loire	699	0.08	0.11	0	0.04	1.17
Midi-Pyrénées	1320	0.05	0.14	0	0.02	2.81
Rhône-Alpes	467	0.08	0.15	0	0.05	1.93
All	2486	0.06	0.13	0	0.03	2.86

Table 4: Regional nitrogen and biocides shares

Region	Wheat		Maize		Oil-prod. crops		Grassland	
	Nitrogen	Biocides	Nitrogen	Biocides	Nitrogen	Biocides	Nitrogen	Biocides
Pays de la Loire	33.3%	22.2%	7.9%	5.8%	17.3%	15.8%	7.7%	NA
Midi-Pyrénées	29.3%	19.7%	12.7%	5.6%	15.9%	16.4%	5.3%	NA
Rhône-Alpes	30.8%	21.6%	11.8%	5.7%	15.9%	15.7%	4.6%	NA
All	31.2%	21.1%	10.7%	5.7%	16.4%	16%	6.0%	NA

Table 5: Land uses

	N	Percent
Wheat	6751	88.24%
Grassland	6384	83.45%
Maize	3063	40.03%
Oil seeds	2486	32.49%
Grassland or Wheat	7509	98.15%
Wheat or Maize	7025	91.83%
Wheat or Oil	6820	89.15%
Wheat or Maize or Oil	7043	92.06%
Wheat or Maize or Grassland	7639	99.85%
Wheat or Maize or Grassland or Oil	7648	99.97%
Grassland and Wheat	5626	73.54%
Wheat and Maize	2789	36.45%
Wheat and Maize and Grassland	2185	28.56%
Wheat and Maize and Oil	1429	18.67%
Wheat and Maize and Oil and Grassland	953	12.45%

cross the data base with the Agreste¹ regional data base from which I compute the shares of nitrogen and biocides spread over each type of land use for each of the three region, in 2001. Then, supposing that farmers behaviour in term of nitrogen use is uniform and reproduces regional decomposition of nitrogen use (unit per hectare) over the different crops, I compute the nitrogen quantity spread on each type of fields. For biocides shares, only the number of treatment was referenced in the Agreste base, so it has been supposed that the same number of treatment with biocides is delivered for all farmers and that farmers' behaviour reproduced regional decomposition of biocides treatment for each land use. This gives an approximation of crop specific fertilizers and biocides uses. Table3 and Table4 summarize the repartition of nitrogen and biocides over the different land inside a region². Biocides shares on grassland were not available since Agreste data base only references the share of grassland that have been treated. Over the three region, 85% of grassland has "never" been treated, 14% has been treated "sometimes to times" and 2% has been "yearly" treated.

Descriptive statistics in table(2) suggests a double censoring of the data: a first censoring occurs because farmers can specialize in only one of these land uses, for one or more than one year over the period and the second one originates from the restriction I impose by selecting agroecosystems: combinations of land uses. Table5 suggests that farmers practise land use rotation but a very few of them practise yearly multicrop-diversified land uses. Indeed about 89 to 99% of the farmers have alternated their land use with at least two different cover crops but much less of them practise different land uses at the same time, 12.4% of the farmer practise a fully³ diversified agriculture. Nevertheless, this panel is relatively environmentally diversified since 73% of farmers cultivate wheat associated with grassland at the same time.

3.2.2 Econometric procedure

Dynamic panel data allows to estimate the biological parameters of the model since it informs on the temporal evolution and on crop specific data that allow to control with agroecosystem (individual) specific effect. A two step estimation method is proposed. In a first step, the parameters of the law of motion of the natural resource are estimated a la Arellano et Bond and the predictions of this variable are used as a generated regressor in the second step to estimate the production function. Generalized Method of Moments is used to estimate the first step of the procedure.

3.2.3 Biological estimations: dynamic panel data

I consider different scenarii to estimate the dynamic of the resource. I will firstly studied the "island" case in which all plots are independent one another and where the resource

¹Agreste is a statistical organism of the french Ministère de l'agriculture et de la pêche.

²The sum of probabilities inside a region here is not one since non-wheat and non-grassland land uses are not presented.

³The four crops cultivated at the same time

habitat is fragmented. Secondly, I will connect and aggregate these habitats: wheat-maize, wheat-maize-oil, wheat-grassland.

As mentioned in the descriptive part censoring is present in the data. Sample selection in econometrics is highly documented since Heckman (1979) for cross section data. Sample selection correction in panel data is a quite recent issue. Some papers deals with this issue: Wooldridge(1995), Kyriazidou 1997, and Rochina-Barrachina (1999). But sample selection correction and dynamic panel data studies are really recent: Kyriazidou (2001), Hu (2001). In our case, we are interested in the identification of biological parameters and the prediction of a natural resource which is highly crop specific according to the biological literature on the as discussed in section 2. For this reason, sample selection issues can be set aside in this particular model. The estimated equation is then crop specific.

The low of motion of the natural resources of the soil c is described by equation 1:

$$B_{ct} = (1 + r_c)B_{c,t-1} - \frac{r_c}{\kappa_c}B_{c,t-1}^2 - \varphi_c B_{c,t-1}E_{c,t-1}$$

where B_{ct} is the natural resource of the soil c at time t , r_c is the natural growth rate of the resource on soil c , κ_c is the carrying capacity of the soil c and $E_{c,t-1}$ refers to the agricultural effort synthesized by the mineral nitrogen and biocides spread over soil c and φ_c is the mortality coefficient of the natural resource due to the agricultural effort.

Under this form, this equation is still not estimable since the data base does not contain the natural resource variable B but it contains information related to this variable. Indeed, it can be assumed that this resource is a function of the land on which the resource is living, function of its habitat. A simple form to formalize this relation is to take a linear function of the land⁴, then I can express the resource variable as:

$$B_{ct} = \theta_c L_{ct} \tag{3}$$

where L_{ct} is the land under land use c at time t . It is also supposed that θ_c is crop specific but time invariant.

Under this assumption, equation(1) rewrites as:

$$L_{ct} = (1 + r_c)L_{c,t-1} - \frac{r_c}{\kappa_c}\theta_c L_{c,t-1}^2 - \varphi_c L_{c,t-1}E_{c,t-1} \tag{4}$$

The crop specific econometric form of equation(4), for the agroecosystem or farm i is:

$$L_{it} = \beta L_{i,t-1} + \omega L_{i,t-1}^2 + \varphi L_{i,t-1}E_{i,t-1} + u_{it} \tag{5}$$

where

$$u_{it} = \alpha_i + \varepsilon_{it}$$

⁴Rosenzweig (2001) shows that at the scale of the whole earth and its major biogeographical provinces, the steady states in species diversity responds linearly to available area.

- Index i represents the farmer or the agroecosystem and index t the time.
- $\beta = 1 + r$ is expected to be larger than one, so that the natural growth rate $r = 1 - \beta$ is positive.
- $\omega = -\frac{r\theta}{\kappa}$, expected to be negative so that $\kappa = \frac{r\theta}{\omega}$.
- φ is expected to be negative to represent the damage caused by the chemical effort to the natural resource.
- α_i is the site or farmer or agroecosystem specific parameter for the considered land use.
- ε_{it} is the traditional error term, i.i.d $(0, \sigma^2)$.
- $L_{i,t-1}^2$ and $L_{i,t-1}E_{i,t-1}$ are exogeneous regressors.

By construction, the lagged variable $L_{i,t-1}$ is correlated with the residual since the farm specific component (α_i) of the error term (u_{it}) is correlated with the residual term (ε_{it}). One way to get ride of this endogeneity is to write the model in first differences, to eliminate the farm specific parameter.

$$L_{it} - L_{i,t-1} = \beta(L_{i,t-1} - L_{i,t-2}) + \omega(L_{i,t-1}^2 - L_{i,t-2}^2) + \varphi(L_{i,t-1}E_{i,t-1} - L_{i,t-2}E_{i,t-2}) + (\varepsilon_{it} - \varepsilon_{i,t-1})$$

$$\Leftrightarrow \Delta L_{it} = \beta\Delta L_{i,t-1} + \omega\Delta L_{i,t-1}^2 + \varphi\Delta(L_{i,t-1}E_{i,t-1}) + \Delta\varepsilon_{it} \quad (6)$$

where Δ is the first difference operator. This form solves the problem of endogeneity due to the farm specific effect but does not solve the second source of endogeneity arising from correlation between $\Delta L_{i,t-1}$ and $\Delta\varepsilon_{it}$. To correct for this endogeneity, Arellano and Bond propose to use $m = T(T-1)/2$ moment conditions ($T = 7$):

$$E[L_{is}\Delta\varepsilon_{it}] = 0 \quad (7)$$

for $s = 0, \dots, t-2$ and $t = 2, \dots, T$

The dependent variable lagged twice or more, is a valid instrument to correct for endogeneity. The dynamic unbalanced panel data estimation matches the Arellano-Bond estimation (1991). This estimator is based on Generalized Method of Moment to correct for the double endogeneity appearing in equation(5).

These m moment conditions are valid under the hypothesis that:

- For all i, ε_{it} is uncorrelated with with L_{i0} .
- For all i, ε_{it} is uncorrelated with α_i , for all t .
- For all i , the ε_{it} 's are mutually uncorrelated.

Finally, moment conditions described by equation(7) hold if the error terms are not serially correlated, at order 1 and at order 2. Indeed, as noted by Arellano and Bond, "the consistency of the GMM estimators hinges heavily upon the assumption that $E(\Delta\varepsilon_{it}\Delta\varepsilon_{i,t-2}) = 0$ ", no order 2 serial correlation. This serial correlation of order 2 is rejected by the data for all the estimated equations. The order 1 non serial correlation hypothesis deals with the hypothesis of heteroskedasticity and will affect the efficiency of the GMM estimators.

On the question of identification of parameters related to the biological model, the $\Delta L_{i,t-1}E_{i,t-1}$ parameter represents the mortality due to the use of chemical fertilizers, the natural rate of growth (r) of the resource is one minus the $\Delta L_{i,t-1}$ parameter but as long as θ is unknown carrying capacity κ can not be identified, only the ration of θ over κ is identified thanks to the $\Delta L_{i,t-1}^2$ and the value of r .

Table6 presents the "island" biodiversity estimations and shows that the test of over-identifying restrictions (Sargan test) rejects the model specification only for the oil seeds habitat, the lowest used single practice. It appears that all significant parameters are of expected sign and that the growth rate of the resource can be identified with the $\Delta L_{i,t-1}$ parameter and is positive.

Focusing on the impact of the chemical inputs on the resource, mineral nitrogen (N) always significantly affects negatively the resource but the biocides input (P) has no significant direct effects on the resource⁵. Nevertheless, a test of nested model suggests to prefer the extended model with biocides (M2) to the restricted model (M1) although the biocides effect is not directly significant⁶.

Table7 presents the connected habitat and the main result is that the test of over-identifying restrictions reject the model specification for the full cash crop resource habitat (wheat, maize and oil seeds) and for the "Wheat - Maize" habitat at the 10% level. The test does not reject the model specification when grassland is introduced in the habitat. In that case, the effect of mineral nitrogen (N) and biocides (P) is the lowest of the different lands. It also appears that the mineral nitrogen effect becomes smaller when more crops are introduced in the rotation ("Wheat or Maize" and "Wheat or Maize or Oil seeds").

General lessons from the dynamic estimations, based on the model specification tests are that the natural resource estimations should be studied crop specifically, habitat by habitat instead of describing the resource as a global one and that considering an aggregate habitat lowers the negative effect of chemical inputs on the resource. This confirms the biological results suggesting the importance of scaling in the examination of ecosystems functions. The data also confirms, that a logistic form can describe the evolution of a natural resource and that the parameters of the equation have a significant effect and these effects are of expected sign.

From these estimations,the predicted value of the land use can be computed and be

⁵This may comes from the low information available to construct this variable and hypothesis used as explained in section 4.1

⁶This is the bias of omitted variable

used as a generated regressor in the production equation. The generated regressor is given by equation6 modified:

$$\widehat{L}_{it} = L_{i,t-1} + \widehat{\beta}\Delta L_{i,t-1} + \widehat{\omega}\Delta L_{i,t-1}^2 + \widehat{\varphi}\Delta L_{i,t-1}E_{i,t-1} \quad (8)$$

Table 6: Arellano-Bond estimation results for single crops

Variables ^a	Grassland		Wheat		Maize		Oil prod. crop	
	M1	M2	M1	M2	M1	M2	M1	M2
constant	64.243** (7.11)	64.243** (7.11)	7.91 (7.00)	7.96 (6.77)	95.24 (15.18)	93.99** (14.96)	71.63** (19.05)	67.96** (18.84)
$\Delta L_{i,t-1}$	1.177** (0.346)	1.177** (0.346)	1.620** (0.487)	1.60** (0.48)	1.128** (0.26)	1.13** (0.25)	1.19** (0.31)	1.20** (0.31)
$\Delta L_{i,t-1}^2$	-0.000142** (0.000038)	-0.000142** (0.000038)	-0.00028** (0.00007)	-0.00028** (0.00007)	-0.00022** (0.00007)	-0.00022** (0.00007)	-0.0003** (0.00006)	-0.0003** (0.00006)
$\Delta L_{i,t-1} N_{i,t-1}$	-0.84** (0.37)	-0.84** (0.37)	-0.93** (0.33)	-0.92** (0.32)	-3.55** (0.85)	-3.58** (0.84)	-2.73** (0.90)	-2.83** (0.9)
$\Delta L_{i,t-1} P_{i,t-1}$	-	-	-	0.163 (1.15)	-	2.98 (4.34)	-	2.33 (2.21)
Tests^b								
Sargan test: $\chi^2(14)$	Test Statistic 12.6 (0.5)	12.6 (0.5)	Test Statistic 17.6 (0.22)	17.75 (0.21)	17.52 (0.22)	17.14 (0.24)	66.62 (0.00)	65.89 (0.00)
Average Autocovariance of order 1	-2.4 (0.01)	-2.4 (0.01)	-3.8 (0.00)	-3.8 (0.00)	-3.38 (0.00)	-3.45 (0.00)	-1.41 (0.00)	-1.42 (0.15)
Average Autocovariance of order 2	0.72 (0.47)	0.72 (0.47)	0.18 (0.85)	0.17 (0.86)	0.27 (0.78)	0.27 (0.78)	-0.69 (0.48)	-0.74 (0.46)
Wald test ($\chi^2(3)$)	15.8	15.8	20.1	$\chi^2(4)=21.15$	26.06	26.06	95.23	94.31
Panel								
Number of obs	3089	3089	2979	2979	1199	1199	646	646
Number of group	944	944	947	947	462	462	273	273

** and * : parameters significant at 95% and 90% confidence levels, respectively.

^aN stands for Nitrogen and P stands for biocides.

^b: p-value in parentheses.

Table 7: Arellano-Bond estimation results for connected habitat Rotations

Variables ^a	Wheat or Maize		Wheat or Grassland		Wheat or Maize or Oil	
	M1	M2	M1	M2	M1	M2
constant	22.79** (6.9)	22.07** (7.67)	36.04** (12.76)	35.6** (12.73)	13.03 (8.17)	13.05 (8.11)
$\Delta L_{i,t-1}$	1.36** (0.45)	1.38** (0.44)	1.5** (0.38)	1.5** (0.38)	1.76** (0.66)	1.74** (0.65)
$\Delta L_{i,t-1}^2$	-0.00026** (0.00006)	-0.00027** (0.00006)	-0.00012** (0.00002)	-0.00012** (0.00003)	-0.00035** (0.00001)	-0.00035** (0.00001)
$\Delta L_{i,t-1} N_{i,t-1}$	-0.45** (0.14)	-0.46** (0.14)	-0.15** (0.05)	-0.15** (0.05)	-0.32** (0.11)	-0.31** (0.11)
$\Delta L_{i,t-1} P_{i,t-1}$	- (0.14)	0.88 (0.72)	- (0.05)	0.46 (1.15)	- (0.11)	0.04 (0.65)
Tests^b						
Sargan test: chi2(14)	Test Statistic 22.1 (0.076)	21.75 (0.08)	Test Statistic 16.05 (0.31)	16.05 (0.31)	36.88 (0.00)	37.55 (0.00)
Average Autocovariance of order 1	-3.12 (0.00)	-3.25 (0.00)	-3.46 (0.00)	-3.48 (0.00)	-1.95 (0.05)	-1.94 (0.05)
Average Autocovariance of order 2	0.38 (0.70)	0.39 (0.69)	1.21 (0.22)	1.20 (0.22)	0.81 (0.41)	0.79 (0.42)
Wald test (chi2(3))	81.17	chi2(4)=84.56	19.6	chi2(4)=19.92	50.15	chi2(4)=73.39
Panel						
Number of obs	2972	2972	3303	3303	2808	2808
Number of group	941	941	1014	1014	895	895

** and * : parameters significant at 95% and 90% confidence levels, respectively.

^aN stands for Nitrogen and P stands for biocides.

^b: p-value in parentheses.

3.2.4 Production function estimation

The production is supposed to fit a quadratic form as a function of the soil biotic resource (B) estimated in step 1 and the level of chemical inputs [$E = (N, P)$] used on that land:

$$Q(B_{it}, E_{it}) = \psi_0 + \psi_{1B} B_{it} + 0.5\psi_{2B} B_{it}^2 + \psi_{1E} E_{it} + 0.5\psi_{2E} E_{it}^2 + \psi_{BE} B_{it} E_{it} \quad (9)$$

Under the assumption stated by equation(3), then one can rewrite the production function as

$$Q(\theta\widehat{L}_{it}, E_{it}) = \psi_0 + \psi_{1B} \theta\widehat{L}_{it} + 0.5\psi_{2B} (\theta\widehat{L}_{it})^2 + \psi_{1E} E_{it} + 0.5\psi_{2E} E_{it}^2 + \psi_{BE} \theta\widehat{L}_{it} E_{it}$$

$$Q(\theta\widehat{L}_{it}, E_{it}) = \psi_0 + \psi_{1L} \widehat{L}_{it} + 0.5\psi_{2L} \widehat{L}_{it}^2 + \psi_{1E} E_{it} + 0.5\psi_{2E} E_{it}^2 + \psi_{LE} \widehat{L}_{it} E_{it} \quad (10)$$

with $\psi_{1L} = \theta\psi_{2B}$, $\psi_{2L} = \theta^2\psi_{2B}$ and $\psi_{LE} = \theta\psi_{BE}$

Identification issues have been checked and the order condition is verified: the number of exogenous variables excluded of step 2 equation is at least equal to the number of included endogenous variables minus one. Indeed, the three explanatory variables of step 1 equation are for date $t - 1$ and are excluded of step 2 equation which has three endogenous explanatory variables.

As discussed in the biological section and confirmed in the estimations in step one, the soil biota is a dynamic and site specific phenomena. In that sense, the fluctuation of the resource over time and space should be accounted for when estimating the agricultural production. This biological considerations are verified in this panel since the Hausman tests in Table8 suggest to use fixed effects estimator and thus to treat the specific individual effects as a parameter of interest in the model. This function is then estimated with fixed effect panel data estimation that uses time variation within each cross section (within estimator). It amounts to apply OLS the following equation:

$$\begin{aligned} Q_{it}(\theta\widehat{L}_{it}, E_{it}) - Q_{i.}(\theta\widehat{L}_{i.}, E_{i.}) &= \psi_{1L} [\widehat{L}_{it} - \widehat{L}_{i.}] + 0.5\psi_{2L} [\widehat{L}_{it}^2 - \widehat{L}_{i.}^2] \\ &+ \psi_{1E} [E_{it} - E_{i.}] + 0.5\psi_{2E} [E_{it}^2 - E_{i.}^2] + \psi_{LE} [\widehat{L}_{it} E_{it} - \widehat{L}_{i.} E_{i.}] + u_{it} - u_{i.} \end{aligned}$$

with $u_{it} = \alpha_i + \varepsilon_{it}$, $E_{i.} = \frac{1}{T} \sum_{t=1}^T E_{it}$ and $L_{i.} = \frac{1}{T} \sum_{t=1}^T L_{it}$

This then amounts to estimate:

$$WQ = W\widehat{L}\psi_{1L} + W\widehat{L}^2\psi_{2L} + WE\psi_{1E} + WE^2\psi_{2E} + W\widehat{L}E\psi_{LE} + Wu \quad (11)$$

where $W_{(NT \times NT)} = I_N \otimes \left[I_T - \frac{J_T}{T} \right]$ is the within operator which computes the vector of fluctuations around mean, where J_T is a (T x T) matrix of ones. The effort variable E is

represented by the level of nitrogen (N) and the level of biocides (P).

The studied farmer population from Pays de la Loire, Midi-Pyrénées et Rhône-Alpes is characterized by preferences for mixed land uses, since about three quarter of them mix wheat and grassland (Table5). Nevertheless, grassland is not a cash crop so that data on the production of that land use is poorly referenced⁷. Indeed, 83% of the farmers have allocated space to grassland but only about 14% of them have sold direct production from grassland, this amounts to about 11% of the farmers that dedicated land to grassland and sold direct production of that land. Thus, because of the lack of data on the production of grassland, I do not estimate this production and concentrate on the estimation of the production of cash crops sold on the market.

Results show that not all productive agroecosystems are dependent upon the resource living in that habitat and the role of the resource is different in each part of this agroecosystem (in each crop) since the parameters associated to \hat{L} are different from one crop to the other. All the productions are significantly dependent upon the level of mineral nitrogen. The signs of the effects of the inputs indicate that the production function is well behaved and concave for the wheat production. The effect of the pesticide input on the production is not significant and not always of expected sign. One could conjecture a significant positive effect of the pesticides but as pesticides are not used to increase the growth of the plant as nitrogen does but are used to avoid treat to the plant, to avoid a loss of production due to the abundance of pests. Nevertheless, these results should be interpreted with caution since censoring in the second step estimations is not accounted for. The bias may be small for the wheat and non continuous wheat-maize rotation since respectively 88% and 91% of the farmers produced this cash crops but the bias may be important for maize since only 40% of the farmers cultivate maize.

The sign of the cross variable does not allow to state commonly to both land uses the relationship between the two or three inputs since the sign of the cross products changes among land uses, except for the cross product formed by the nitrogen and the pesticides inputs but all are not significant.

Focusing on the production of wheat with pesticides (M2 model) all cross products are significant. It then appears that mineral nitrogen and resource are complement as well as nitrogen and pesticides and that the resource and the pesticides are substitute inputs. The complementarity of mineral nitrogen and pesticides in the production process comes from the fact that they are not used in the same goal, the latter is used to control the pests and the former to improve the growth of the plant. The complementarity of the nitrogen and the soil species deals with the nutrient cycle since some species of the soil

⁷This land can be use for cattle grazing, for beekeeping or for landscape value

fix mineral nitrogen, this avoid nitrogen leaching and nitrogen immobilization⁸ so that it improves the efficiency of nitrogen acquisition by the plant. Finally, the substitutability of pesticides and resource biota may involve the negative effect of pesticides to the non targeted species. Indeed, less pesticides in the soil favors the growth of the resource which affects positively the production so that pesticides and resource biota are expected and found to be substitutes.

⁸Nitrogen immobilization characterizes the process by which mineral nitrogen become organic nitrogen useless for the growth of the plant unless this organic nitrogen become mineral nitrogen during a mineralization process.

Table 8: Quadratic production function
Single agroecosystem
Wheat production **Maize production**
Maize OR Wheat prod

Variables ^a	Wheat production		Maize production		Connected agroecosystem	
	M1	M2	M1	M2	M1	M2
Constant	111.6** (26.7)	91.57** (32.65)	124.65** (44.46)	220.55** (100.14)	235.94** (31.70)	215.25** (37.92)
\hat{L}	3.94** (1.92)	3.95** (1.87)	6.48 (6.24)	5.76 (6.55)	6.13** (2.53)	4.69 * (2.53)
\hat{L}^2	-0.29** (0.85)	-0.16** (0.08)	0.27 (0.46)	-0.07 (0.49)	-0.059 (0.12)	-0.162 (0.12)
N	0.89** (-0.09)	0.78** (0.09)	6.08** (0.48)	5.74** (0.56)	0.649** (0.064)	0.654** (0.067)
N ²	-0.00034** (0.00012)	-0.0013** (0.00014)	-0.0039** (0.0005)	-0.004** (0.0005)	-0.00005** (0.000024)	-0.000079** (0.000026)
P	-	0.32 (0.75)	-	-3.45 (7.53)	0.707 (0.724)	0.707 (0.724)
P ²	-	-0.011** (0.002)	-	-0.16 (0.17)	-0.015** (0.003)	-0.015** (0.003)
\hat{L} x N	0.00716** (0.0036)	0.008** (0.0037)	-0.0393** (0.015)	-0.03* (0.016)	-0.0039** (0.0017)	-0.005* (0.0018)
\hat{L} x P	-	-0.051** (0.21)	-	0.19 (0.17)	0.060 (0.023)	0.060 (0.023)
P x N	-	0.008** (0.0007)	-	0.006 (0.009)	0.00046 (0.0003)	0.00046 (0.0003)
R ² within	0.183	0.242	0.2986	0.3047	0.1599	0.1696
R ² between	0.676	0.682	0.6404	0.6213	0.6783	0.7143
R ² overall	0.585	0.615	0.5725	0.5554	0.6230	0.6625
Specification test						
Individual effect	F(920,1912)=6.3 p-value=0.00	F(919, 1908)=5.7 p-value=0.00	F(451, 687)=5.7 p-value=0.00	F(449, 682)=5.3 p-value=0.00	F(919, 1930)=10.9 p-value=0.00	F(919, 1926)=9.75 p-value=0.00
Global validity	F(5,1912) =85.7 p-value=0.00	F(9,1908)=67.9 p-value=0.00	F(5,687)=58.4 p-value=0.00	F(9,682)=33.21 p-value=0.00	F(5,1930)=73.4 p-value=0.00	F(5,1926)=43.71 p-value=0.00
Hausman test	chi2(5)= 196.9	chi2(9)=198.7	chi2(5)=129.6	chi2(9)=133.6	chi2(5)=262.1	chi2(9)=273.4
Corr(μ_i, X)	0.48	0.5	0.0814	0.1272	0.608	0.6267
Rho ^c	0.767	0.77	0.7221	0.7361	0.8797	0.8691
# of observation	2838	2838	1141	1141	2855	2855
# of group	921	921	450	450	920	920

** : parameters significant at 95% confidence levels.

^a:N stands for Nitrogen and P stands for biocides and std in parentheses.

^c: fraction of variance due to the individual specific effect.

4 Conclusion

The paper presents an empirical analysis of the interactions of soil resource biota and agricultural production. The model is based on biological results on agricultural intensification and soil biodiversity that describes the way farmers influences the biotic resource of the soil and the way this biotic resource influences the productivity of the agroecosystem. Nevertheless, these interactions between farmers and its natural resources is being documented by scientists and rarely quantified. A consensus among scientists is that the resource biota is heavily site specific such as its functions and its role in the agroecosystem. But quantification of these effects which is of interest for the implementation of an efficient natural resource conservation policy, seems to be confronted to the complexity of the ecosystem functioning. I then propose a simple econometric procedure to estimate the relationship between farmers' production and the biotic resource of the soil and it also gives the possibility to test empirically whether biological results are supported with economic data base.

A two step econometric procedures has been proposed to estimate these interactions. This has been possible with a panel data base that allows to account for the unobserved heterogeneity and the site specific effect and allows to estimate a dynamic phenomenon of natural resource evolution. Under the hypothesis that the stock of the resource biota is a linear function of its habitat, the resource biota evolution is estimated in step one as depending one past levels and on mortality caused by the xenobiotic compounds used by farmers. In the second step these resource biota is used as a generated regressor to estimate production functions of different agroecosystems.

The model was estimated using a sample of french producers, for the period 1995-2001 and considers wheat, maize, oil producing crop and grassland. Some different agroecosystems have been studied: island agroecosystems formed of one these four single crops, and connected agroecosystems: wheat and maize, wheat and grassland, wheat and maize and oil producing crop.

The validity of structural model was checked using the Sargan over-identifying restrictions statistics. This specification was not rejected for the island study and rejected for some connected agroecosystems, all expect when grassland is introduced in the agroecosystem. This then suggests that soil natural resource has to be studied crop specifically as it is also claimed by Franklin (1993):"when discussing the implications of changes in soil biodiversity to ecosystem function it is important to identify the taxonomic resolution used to described diversity and the spatial scale at which diversity-function relationships are considered". Step one results also isolates and quantify the significant and negative impact of chemical fertilizers uses on the resource biota. Step two estimations quantifies the magnitude of the effect on the production of the resource biota and the chemical input uses. It then informs that the production is significantly dependent upon the use of mineral nitrogen and upon the resource biota for the production of wheat and the wheat-maize land use. Nevertheless these results have to be interpreted with caution since the second

step estimation does not control for censoring in the data which is more present in the last two ecosystems.

Finally, interpretations of the relationship between inputs recover biological results on the cycle of nutrient and on relation between destructive and resource biota. This approach could be used to simulate the effect of natural resource conservation policies such as agri-environmental schemes aiming at reducing the level of nitrogen in the soil and/or at encouraging the adoption of prairies or similarly conserved areas since it provides estimations of the magnitude of the interactions terms between soil resource biota and agricultural practices. The modelisation of the resource biota allows to give a thinner estimation of the effect a policy aiming at reducing the level of nitrogen in the soil and estimation of the cost for farmers of such a policy since empirical results suggest that a reduction of nitrogen will be partly compensated by an increase in the level of the resource which affects positively the production. Roughly speaking, a reduction of chemical fertilizers will improve the quality of the soil which improve the production.

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