A double benefit of biodiversity in agriculture

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Abstract

The objective of this paper is to contribute to accounting for biodiversity goals in the design of agricultural policies. A bio-economic dynamic model is developed with a multi-scale perspective. It couples biodiversity dynamics, farming land-uses selected at the micro level and public policies at the macro level based on financial incentives for land-uses. The public decision maker provides optimal incentives respecting both biodiversity and budgetary constraints. These optimal policies are then analyzed through their private, public and total costs. The model is calibrated and applied to metropolitan France at the PRA ("petite région agricole") scale using common birds as biodiversity metrics. The study first shows that the efficiency curves display decreasing concavities for different biodiversity indicators pointing out the trade-off occuring between biodiversity and economic scores. However, the total and public costs suggest that accounting for biodiversity can generate a second benefit in terms of public incomes. It is argued how a regional redistribution of this public earning to the farmers could promote the acceptability of biodiversity goals in agricultural policies.

Keywords: Biodiversity, Land-use, Bio-economic modeling, Cost-effectiveness, Birds.

1. Introduction

In many European countries, a strong decline of biodiversity is observable in agricultural landscapes. This is especially documented for mammals in Flowerdew & Kirkwood (1997), for arthropods and plants in Sotherton & Self (2000) or for birds in Donald *et al.* (2001). Numerous studies (Chamberlain *et al.* 2000, Wretenberg *et al.* 2007) identify the changes in agricultural systems over the last decades and especially the intensification processes at play as major drivers of this erosion. Breeding bird populations are particularly vulnerable to global agricultural change (Jiguet *et al.* 2010, Krebs *et al.* 1999). Such a negative effect is due mainly to a degradation in habitat quality altering nesting success and survival (Benton *et al.* 2003). In this context, the European

Union has formally adopted the Farmland Bird Index (FBI) as an indicator of structural changes in biodiversity (Balmford *et al.* 2003).

A challenge to reach sustainability for agricultural land-use is therefore to reconcile farming production and farmland biodiversity. Usual approaches to achieve such multifunctional goals for farming rely on public policies (Pacini *et al.* 2004) or economic incentives (Drechsler *et al.* 2007, Mouysset *et al.* 2011). For Alavalapati *et al.* (2002) and Shi & Gill (2005), financial incentives are essential for convincing farmers to adopt eco-friendly activities. These policies modify the farmer's choices and thus impact both the habitat and the dynamics of biodiversity (Doherty *et al.* 1999, Holzkamper & Seppelt 2007, Rashford *et al.* 2008). In this perspective, many public policies including agri-environmental schemes have been proposed by decision makers. However, fifteen years after the initial implementation of such instruments at a large scale, their ability to enhance biodiversity remains controversial (Butler *et al.* 2009, Kleijn *et al.* 2006, Vickery *et al.* 2004). These policies face a variety of difficulties. From the ecological point of view, insufficient knowledge about the agro-ecological processes at play and the focus on a few emblematic species limits the results. From the economic point of view, limited acceptability by the farmers constitutes a major obstacle for the effectiveness of these policies. In this context, testing the efficiency of the different agricultural policy scenarios through quantitative methods and models is useful. The Cost-Benefit method (Boardman *et al.* (2005)) compares the costs and the benefits of a policy using monetary values. However, quantifying the economic benefits of an agricultural policy is particularly difficult for complex biodiversity (Diamond & Hausman 1994). The cost-Effectiveness analysis, which avoids monetary evaluation, appears as a relevant alternative. This method, based on optimization under constraint, leads to defining either the less expensive policy satisfying a biodiversity goal or the policy with the best biodiversity performance under budgetary constraint (Naidoo *et al.* 2006). Many authors (Drechsler *et al.* 2007, Polasky *et al.* 2008; 2005) using this method for agricultural policy issues exhibit a pareto-efficient frontier of optimal policies. As in Green *et al.* (2005) this frontier is generally concave pointing out a trade-off occuring between biodiversity and economic scores. In other words, it is possible to moderately improve biodiversity performance with limited income losses (Barraquand & Martinet 2011, Lewis *et al.* 2011, Polasky *et al.* 2005).

The objective of this paper is to contribute to accounting for biodiversity goals in the design of agricultural policies. More specificaly, cost-effective policies are designed and analyzed through different costs to identify potential ways to reduce the trade-off and improve the acceptability of such policies. The study relies on a spatio-temporal bio-economic model which articulates farming land-uses selected by rational agents, biodiversity community dynamics at micro (landscape) level and macro (typically national) financial incentives associated with land-uses. Public policies are computed at the macro scale through a cost-effectiveness method which maximizes a present value of incomes under different biodiversity targets and a budgetary constraint. Then the study focuses on the public and total social costs associated with each cost-effective policy as in Semaan *et al.* (2007). The method is applied to the metropolitan France case study. The calibration relies on a French time series of the abundance of 34 birds and 14 farming land-uses over the years 2001-2009 and 620 "small" regions (PRA) in metropolitan France. Two indicators, the Farmland Bird Index (FBI) which has been adopted by the European Union (Balmford *et al.* 2003), and the Community Trophic Index (CTI) which informs on a functional feature of the community (Mouysset *et al.* 2012, Pauly *et al.* 1998) capture the biodiversity scores. The study illustrates that the efficiency curves of the agricultural policies with biodiversity constraints have different qualitative shapes according to the ecological indicators. The analysis of the total and public costs shows that the integration of biodiversity goals is not detrimental to the whole society in the sense that it can generate a benefit in terms of public budget. In other words, the biodiversity-oriented policy yields a double benefit. We suggest that the redistribution of the induced earnings to the farmers could compensate their private loss and so increase their acceptance of biodiversity objectives in the design of agricultural policy. A first strategy is proposed through regional redistribution.

The paper is organized as follows. The second section describes the bio-economic model. The third section presents the case study. The fourth and fifth sections are respectively devoted to the results and their discussion.

2. The bio-economic modeling

As depicted by figure 1, the bio-economic model is composed of three compartements with a multi-scale pespective as in Mouysset *et al.* (2011): the public policy at the macro (national) scale interacts with the farming land-uses and biodiversity dynamics at the micro scale.

2.1. The micro-economic model

Each region is represented by a standard agent. Agent income in region r at year t denoted by $Inc_r(t)$ relies on the expected gross margin per unit of scale $gm_{r,k}$, current proportions of the Utilized Agricultural Area (UAA) dedicated to the agricultural land-uses $A_{r,k}(t)$ and incentives τ_k (taxes with $\tau_k < 0$ or subsidies with $\tau_k > 0$) which takes form of a percentage of gross margins as follows:

$$Inc_r(t) = \sum_k gm_{r,k}.A_{r,k}(t).(1+\tau_k) \tag{1}$$

For each year t, the regional standard agents choose their agricultural land-uses $A_{r,k}(t)$ in order to maximize their income $Inc_r(t)$ according to capital and rigidity constraints.

$$\max_{A_{r,k}} Inc_r(t) = \max_{A_{r,k}} \sum_k gm_{r,k}.A_{r,k}(t).(1+\tau_k) \tag{2}$$

under the constraints

$$|A_{r,k}(t) - A_{r,k}(t-1)| \leq \varepsilon . A_{r,k}(t-1) \tag{3}$$

$$\sum_k A_{r,k}(t) = UAA_r(t_0) \tag{4}$$

The rigidity constraint (3) restricts the area that the farmer can modify at each time for each agricultural system k. The parameter ε captures change costs or inertia. The constraint (4) ensures that the total utilized agricultural area (UAA) is kept fixed.

2.2. The biodiversity model

The biodiversity model deals with a community of species instead of focusing on emblematic species. It is based on population dynamics with intra-specific competition depending on habitat and especially on farming land-use. A Beverton-Holt function is selected for sake of simplicity. It captures intra-specific competition through a carrying capacity parameter as follows:

$$N_{s,r}(t+1) = N_{s,r}(t).(1 + R_{s,r})\left(1 + \frac{N_{s,r}(t)}{M_{s,r}(t)}\right)^{-1} \tag{5}$$

where $N_{s,r}(t)$ stands for the abundance of species s in region r at year t. The $R_{s,r}$ coefficient corresponds to the intrinsic growth rate specific to a given species s in region r. The product $M_{s,k}(t) * R_{s,r}$ represents the carrying capacity of the habitat r and the value $M_{s,k}(t)$ captures the ability of the habitat r to host the species s. The habitat parameter $M_{s,r}(t)$ is assumed to depend on the farming land-uses $A_{r,k}(t)$ as follows:

$$M_{s,r}(t) = b_{s,r} + \sum_k a_{s,r,k}.A_{r,k}(t) \tag{6}$$

Consequently, the $a_{s,r}$ and $b_{s,r}$ coefficients, specific to each species, inform on how such species s responds to agricultural land-use k in a region r. The $b_{s,r}$ coefficient can be interpreted as the mean habitat coefficient for a species s in a region r and integrates other factors such as the proportion of forests or urban areas.

The indicators used to assess ecological performance are computed through the abundances $N_{s,r}(t)$ of the species at play. We denote the biodiversity index by $Biod$ without specifying it at this stage. Such formulation includes usual biodiversity indices such as species richness, simpson or trophic indices. In each region, it is defined as follows:

$$Biod_r(t) = h\big(N_{1,r}(t), \ldots, N_{S,r}(t)\big) \tag{7}$$

2.3. The public policy model

To analyze at macro scale the intertemporal economic performance, we use the net present value of incomes. The macro (national) income $Inc(t)$ depends on the micro (regional) incomes $Inc_r(t)$ and the superficy S_r of the UAA in every region r as follows

$$Inc(t) = \sum_r S_r \, . \, Inc_r(t) \tag{8}$$

The present value $PV(\tau)$ is defined as the intertemporal sum of the national incomes $Inc(t)$ associated with a discount rate ρ from the first year of the projection t_1 to the time horizon T.

$$PV(\tau) = \sum_{t=t_1}^{T} \rho^{t-t_1} \, . \, Inc(t) \tag{9}$$

This present value is contingent to the public incentives τ_k through relation (1). The decision maker at the macro scale selects the vector τ of the economic incentives τ_k, defined as percentages of the gross margins $gm_{r,k}$. The decision maker optimaly chooses taxes and/or subsidies for different agricultural land-uses k by maximizing the present value $PV(\tau)$ according to budgetary and biodiversity constraints:

$$\max_\tau PV(\tau) \tag{10}$$

under the constraints

$$Budg(t) \ \leq \ Budg(t_0) \tag{11}$$

$$Biod(T) \ \geq \ B_{lim} \tag{12}$$

The budgetary constraint (11) ensures that the public budget at each time t does not exceed the current budget at time t_0. The budget $Budg(t)$ is computed according to the different incentives τ_k as follows:

$$Budg(t) = \sum_r \sum_k S_r \, . \, gm_{r,k} \, . \, A_{r,k}(t) \, . \, \tau_k \tag{13}$$

The ecological target (12) is based on a conservation limit B_{lim} for the biodiversity goal imposed only at the temporal horizon T. Different values of B_{lim} can be tested between the maximal feasible biodiversity[1] $B_{lim} = B^*$ and the lowest value $B_{lim} = 0$.

The cost-effective incentives, optimal solutions of the problem (10)-(11)-(12), are denoted by

$$\tau^*(B_{lim}) = \underset{\tau \text{ admissible}}{\text{Argmax}} \quad PV(\tau) \tag{15}$$

[1]This maximum B^* is defined by a biodiversity maximisation under the budgetary constraint:

$$B^* \ = \max_{\left\{ \begin{array}{c} -1 \ \leq \ \tau_k \ \leq \ 1 \\ Budg(t) \ \leq \ Budg(t_0) \end{array} \right.} Biod(\tau) \tag{14}$$

2.4. Public, private and social biodiversity costs

The public policies induce two kinds of cost as proposed by Semaan *et al.* (2007): public and private costs. Analyzing such costs is helpful for evaluating the price of the different policies for the entire society and the weight dedicated to each part (public and private agents). The public cost denoted by $PuC(B_{lim})$ corresponds to the public budget of an optimal policy allocated to the agents at each time t. It depends on the biodiversity target B_{lim} as the budget is itself a function of the optimal incentives $\tau^*(B_{lim})$. The public cost reads as follows:

$$PuC(B_{lim}) = \sum_{t=t_1}^{T} \rho^{t-t_1} \,.\, Budg^*(t) \tag{16}$$

where $Budg^*$ stands for the cost-effective budget in the following sense:

$$Budg^*(t) = \sum_k S_r.gm_{r,k} \,.\, A_{r,k}(t).\tau^*(B_{lim}) \tag{17}$$

By contrast, the private cost $PrC(B_{lim})$, based on the loss of farmer income due to biodiversity requirements, is computed as the difference between the maximum feasible present value $PV(\tau^*(0))$ without a biodiversity target and the present value $PV(\tau^*(B_{lim}))$ under biodiversity goal B_{lim}:

$$PrC(B_{lim}) = PV(\tau^*(0)) - PV(\tau^*(B_{lim})) \tag{18}$$

The total social cost $SoC(B_{lim})$ is defined as the sum of the public and the private costs:

$$SoC(B_{lim}) = PuC(B_{lim}) + PrC(B_{lim}) \tag{19}$$

The question whether these costs are positive or not is decisive for the acceptability of biodiversity requirements and the adoption of eco-friendly agricultural policies.

2.5. Costs at regional scale

The different costs are computed at the micro scale in a similar way. The cost-effective budget $Budg_r * (t)$ is defined by

$$Budg_r^*(t) = \sum_k \mathrm{S_r} \,.\, \mathrm{gm_{r,k}} \,.\, \mathrm{A_{r,k}(t)} \,.\tau^*(\mathrm{B_{lim}}) \tag{20}$$

while the micro public cost $PuC_r(B_{lim})$ corresponds to

$$PuC_r(B_{lim}) = \sum_{t=t_1}^{T} \rho^{t-t_1} \,.\, Budg_r^*(t) \tag{21}$$

The micro (regional) private cost $PrC_r(B_{lim})$, based on the regional present value $PV_r(\tau)$, evaluates the loss of earnings due to the ecological objective

$$PrC_r(B_{lim}) = PV_r(\tau^*(0)) - PV_r(\tau^*(B_{lim})) \tag{22}$$

where

$$PV_r(\tau) = \sum_{t=t_1}^{T} \rho^{t-t_1} \, . \, Inc_r(t) \tag{23}$$

Finally the regional total social cost is the sum between the regional public and private costs:

$$SoC_r(B_{lim}) = PuC_r(B_{lim}) + PrC_r(B_{lim}) \tag{24}$$

3. The French case study

3.1. Context

We apply this bio-economic modeling framework to metropolitan France. France is split into 620 small agricultural regions (PRA for Petites Regions Agricoles). A PRA is part of a department (a major French administrative entity) which exhibits an agro-ecological homogeneity. This consistency from both the ecological and economic points of view makes the PRA the relevant regional scale for economic and biodiversity models. Ecological and economic data are available from 2001 to 2008 (t_0). The policy scenarios are tested between t_1 = 2009 and T = 2050. Selecting a shorter timeframe could consequently hide interesting long-term effects due to the inertia of the models.

3.2. Economic data

For agro-economic data, we use the French agro-economic classification OTEX (orientation technico-economique) developed by the French Farm Accounting Data Network (FADN)[2] and the Observatory of Rural Development (ODR)[3]. This organization distinguishes 14 classes of land-use named OTEX detailed in table 1. Each PRA is a specific combination of these OTEX. The surfaces dedicated to the 14 land-uses OTEX and the associated fiscal bases (tax return) used as a proxy of gross margins for the years 2001 to 2008 are available on the ODR website under a private request. Gross margin is an economic index broadly used in agricultural economics (Lien 2002). For accelerating the numerical computations, the public decision variables τ_k are restricted to only two incentives: the cereal incentive τ_{cop} is dedicated to arable lands (Otex (1) in table 1) and the grassland incentive τ_{grass} is applied to non-intensive grassland systems (Otex (4), (5), (6), (7) in table 1). The gross margins $gm_{r,k}(t)$ are computed as the temporal mean of the historical gross margins:

$$gm_{r,k} = \frac{1}{8} \sum_{t=2001}^{2008} gm_{r,k}(t) \tag{25}$$

The budgetary constraint is calibrated with the current French CAP budget.

[2] http://ec.europa.eu/agriculture/rica/
[3] https://esrcarto.supagro.inra.fr/intranet/

3.3. Biodiversity data

As regards biodiversity, we focus on common bird populations and related indicators (Gregory *et al.* 2004). Although the metric and the characterization of biodiversity remain an open debate (Millenium Ecosystem Assessment 2005), such a choice is justified for several reasons (Ormerod & Watkinson 2000): (i) Birds lie at a high level in the trophic food chains and thus capture the variations in the chains. (ii) Birds provide many ecological services, such as the regulation of rodent populations and pest control, thus justifying our interest in their conservation and viability (Sekercioglu *et al.* 2004). (iii) Their close vicinity to humans makes them a simple and comprehensive example of biodiversity for a large audience of citizens.

The STOC (French Bird Breeding Survey) database[4] provides information related to the bird abundances across the whole country. Abundance values for each species are available[5] for the period 2001-2008. Among the species monitored by this large-scale long-term survey, we selected 34 species which have been classified according to their habitat requirements at a Europe scale (European Bird Census Council 2007). Table 2 lists the 14 habitat generalist species and the 20 farmland specialist species used as a reference by the European Union (Gregory *et al.* 2004).

3.4. Model calibration

The agro-ecological parameters $R_{s,r}$, $a_{s,r,k}$ and $b_{s,r}$ introduced in equations (5)-(6) and the economic parameter ϵ of equation (3) are determined by a calibration based on a least square method. Hence are minimized errors between the observed outputs and the outputs derived from the model. The considered outputs of the model are the land-use values $A_{s,r,k}(t)$ for the economic model and the bird abundances $N_{s,r}(t)$ for the ecological model as detailed in Mouysset *et al.* (2012; 2011). The discount rate is set to $\rho = 4\%$.

3.5. Biodiversity indicators

The biodiversity indicators used in this study are the Farmland Bird Index (FBI) and the Community Trophic Index (CTI) both evaluated in final year $T = 2050$. The Farmland Bird Index has been adopted by the European Community as the official environmental index, especially to analyze structural changes in biodiversity (Balmford *et al.* 2003). The relevance of the FBI to reflect the response of farmland biodiversity to agricultural intensification has been shown

[4]See the Vigie-Nature website http://www2.mnhn.fr/vigie-nature/. Standardized monitoring of spring-breeding birds at 1747 $2 * 2\ km^2$ plots across the whole country. Details of the monitoring method and sampling design can be found in Jiguet (2009).

[5]For each species, a spatial interpolation of the abundance data is performed to obtain relative abundance values for each possible square in the country (Doxa *et al.* 2010). We then average the abundance values at the PRA scale.

in Doxa *et al.* (2010), Mouysset *et al.* (2012). We compute the FBI at the national scale with 20 farmland specialist species for each PRA:

$$FBI(t) = \prod_{s \,\in\, \text{Specialist}} \left(\frac{N_{s,nat}(t)}{N_{s,nat}(2008)} \right)^{1/20} \tag{26}$$

where $N_{s,nat}(t) = \sum_{r=1}^{620} N_{s,r}(t)$ stands for the total abundance of species s over the 620 PRA r.

The Community Trophic Index (CTI) informs on the average trophic level of a community as in Mouysset *et al.* (2012), Pauly *et al.* (1998). The CTI here integrates both the 14 generalist species and the 20 farmland specialist species (table 2). It is computed as the arithmetic mean of the exponential of the species trophic level[6] weighted by the relative abundances:

$$CTI_r(t) = \sum_s \frac{N_{s,r}(t)}{N_{tot,r}(t)} \,.\exp(STI_s) \tag{27}$$

where $N_{tot,r} = \sum_{s=1}^{34} N_{s,r}(t)$ represents the total abundance of birds in a PRA r. The exponential function is used to better contrast communities with or without bird individuals of the higher trophic levels as in Mouysset *et al.* (2012). This indicator classifies the communities with more granivorous species (e.g. low trophic level) compared to the communities with more insectivorous and carnivorous species (e.g. high trophic level).

National CTI is the arithmetic mean of the 620 regional CTI_r:

$$CTI(t) = \frac{1}{620}.\sum_r CTI_r(t) \tag{28}$$

4. Results

4.1. Efficiency curves

Figure 2 illustrates the bio-economic performance of the optimized present values under biodiversity and budgetary constraints. The red diamond corresponds to policy $\tau^*(0)$ without biodiversity constraint and the green plus in fig. 2(a) (cross in fig. 2(b) resp.) to the $\tau^*(FBI^*)$ policy ($\tau^*(CTI^*)$ resp.). The black plus (crosses resp.) represent the $\tau^*(FBI_{lim})$ policies (the $\tau^*(CTI_{lim})$ policies resp.). Their projection on the x-axis illustrates the level of the biodiversity constraint B_{lim} and their projection on the y-axis shows the associated present value $PV(\tau^*)$. We observe two efficiency curves which are both decreasing but with different shapes. The curve obtained with the FBI constraint in fig. 2(a) is almost linear. Hence, the increase of the FBI constraint leads to regular losses on the economic indicator. By contrast, the curve obtained

[6] See in Mouysset *et al.* (2012) for the Species Trophic Indices

with the CTI constraint in fig. 2(b) displays a concavity especially strong for the large biodiversity level B_{lim}. Hence the increase of the CTI constraint has limited impact on the economic indicators for CTI levels lower than 6.43. After this threshold, the economic loss becomes major.

4.2. Optimal public incentives

Tables 3 and 4 depict the optimal incentives with increasing biodiversity goals. For both ecological indices, we observe a decrease of the cereal subsidies τ_{cop} with biodiversity objective B_{lim}. In particular, for the strongest biodiversity targets, the incentive becomes a tax. In contrast, the incentive for extensive grasslands τ_{grass} remains globally stable with a high value except for the policy with the more stringent CTI constraint namely CTI^*. Globally, these observations highlight the need to promote extensive grassland at the expense of crops to satisfy biodiversity objectives. According to the selected ecological indicator, this pattern is more or less emphasized.

Figure 3 illustrates the proportions of UAA dedicated to the extensive grassland systems for the three extreme policies: the $\tau^*(0)$ policy in figure 3(a), the $\tau^*(FBI^*)$ policy in figure 3(b) and the $\tau^*(CTI^*)$ policy in figure 3(c). The $\tau^*(FBI^*)$ strategy promotes the grassland activities through an increase of PRA with important grassland proportions. The $\tau^*(CTI^*)$ incentives induce a developement of PRA with moderate grassland proportions on contrary to the $\tau^*(0)$ option where the rate of intermediate PRA declines.

4.3. National costs

The figure 4 plots the total social costs $SoC(B_{lim})$ by detailing the public $PuC(B_{lim})$ (in red) and the private $PrC(B_{lim})$ (in blue) costs for the different optimal solutions. The dotted lines on the left correspond to the $\tau^*(0)$ policy (without biodiversity) and on the right to the $\tau^*(B^*)$ policy (biodiversity oriented). We observe that the total social cost is similar to the FBI or CTI constraints. Morever it is globally steady although we note a slight decrease for the highest CTI constraints. Figure 4 highlights the fact that the repartition between public and pivate costs changes in the same way as FBI and CTI indicators when the ecological requirement is more demanding: the public cost decreases while the private cost increases. These patterns are more contrasted with the CTI index than with the FBI.

4.4. Regional costs

Figure 5 details the regional total social costs $SoC_r(B_{lim})$ at the regional scale for several public policies $\tau^*(B_{lim})$. Figure 5(a) stands for the $\tau^*(0)$ policy (without a biodiversity target). Figures 5(b), 5(c), 5(d) and 5(e) represent several $\tau^*(FBI_{lim})$ policies with two intermediate B_{lim} for each biodiversity indicator. Finally, figures 5(f) and 5(g) depict the $\tau^*(B^*)$ policies. A complete pie-chart represents the maximum regional total costs (i.e. $2,5$ millions Euros). We observe that the regional social total costs are also very stable among the optimal policies. In other words, the biodiversity constraint does not affect the social cost, even at the micro level. We also note that the repartition of the national cost is not equally distributed between the regions.

Figure 6 presents the distribution of the regional total social costs $SoC_r(B_{lim})$ between the regional public costs $PuC_r(B_{lim})$ (in red) and the regional private costs $PrC_r(B_{lim})$ (in blue) . According to the equation (18), there is no private biodiversity costs for the $\tau^*(0)$ policy. So we start directly with the $\tau^*(FBI_{lim})$ policies with two medium B_{lim} for each indicator. Pink represents negative public costs, where taxes exceed subsidies. Pale blue represents negative private costs, i.e. the regional farmer income is larger than under the $\tau^*(0)$ policy without a biodiversity requirement. Finally, strong grey (pale grey, white resp.) regions which have very stationary (intermediary stationary, instable resp.) costs among the cost-effective strategies.

We observe that the policies affect the regions differently. But the patterns are similar for the two indicators and all the regions: when the biodiversity constraint is more stringent, the public cost decreases and the private cost increases. As suggested by figure 4, there is a strong complementarity between the two costs: regions where the public cost strongly decreases are those where the private cost strongly grows. Typically, the four regions (in white on figure 6) which have a historically strong specialization in arable lands are the most affected by "green" policies. Hence, for the strongest biodiversity targets, they generate a public benefit.

5. Discussion

5.1. The bio-economic trade-off

The bio-economic model developed in this study leads to the design of optimal policies with respect to budgetary and biodiversity constraints. The optimal strategies maximize the aggregated intertemporal farming income or equivalently minimize the (global) private cost under a biodiversity target with a non-increasing budget. The cost-effective analysis of the policies with different objectives of biodiversity provides bio-economic efficiency curves. As stressed by figure 2 for the tested biodiversity indicators, the bio-economic trade-off is strictly negative. This suggests that integrating biodiversity goals in agricultural policies entails a loss of earnings for farmers as in Barraquand & Martinet (2011), Drechsler *et al.* (2007), Lewis *et al.* (2011), Polasky *et al.* (2005).

However, according to the biodiversity indicator, the shape of the efficiency curve slightly differs (fig. 2). The curves displayed in the litterature (Barraquand & Martinet 2011, Polasky *et al.* 2005) are concave with a change of slope for high levels of the ecological score. We recover this pattern for the Community Trophic Index. In this context, it is so possible to moderately improve the CTI without strong private costs for farming. The strongest biodiversity requirements imply a major decrease in farmer incomes. Such a change is explained by a switch in the incentives (as exhibited in tab. 4): the strongest CTI goals impose a change in the optimum incentive set with smaller subsidies As regards the FBI, the trade-off is clearly more linear. This is explained by the improvement of the FBI with a continous decrease of crop incentives (as detailed in tab. 3). With the second shape, it is not possible to improve the biodiversity performance, even moderatly, without strongly affecting the farmers. The diversity of these efficiency curves stresses the difficulty in selecting a policy among the optimal ones and a bio-economic pattern.

5.2. A second dividend of policies with biodiversity goals

The first dividend of policies with biodiversity goals is obviously the improvment of biodiversity performance. But public and social costs give insight into a second dividend. First, it turns out that the total cost does not rise in response to biodiversity requirements. This suggests that biodiversity is not penalizing for the overall (macro) economic performance. Second, such an assertion is reinforced with the study of the public cost. We observe that, for both biodiversity indicators, the increase of biodiversity objectives leads to a decrease of the farming public budget. Therefore, it is possible to improve biodiversity performance without altering the public budget. In other words, the policies with demanding biodiversity goals yield a budgetary benefit which can be interpreted as a second dividend. This budgetary margin could be redistributed to the agents (farmers) in order to improve their private income. By reducing their private cost, their acceptability for adopting biodiversity goals in agricultural policies should be favored.

5.3. Regional redistribution of the second dividend

However, this financial redistribution of the public margin questions the equity between the agents, or the spatial scale of the redistribution. The regional analysis of the different costs provides a first answer to the second dividend redistribution. Indeed, the study shows that the stability of the total cost with respect to the biodiversity target also occurs at the regional scale. The policies do not affect all the regions with the same intensity but a gain between public and private costs is obtained for each region. As the regions with private losses are also those where the public cost decreases, a first redistribution mechanism emerges at the regional scale.

5.4. Perspectives and limitations

The objective of this study is to examine to role played by biodiversity goals on agricultural policies and symetrically to help conservation biology to take socio-economic issues into account. In this vein, ecological-economic modeling is a fruitful framework to bring together social and natural sciences in order to tackle biodiversity management issues (Cooke *et al.* 2009) especially within an agro-ecological and terrestrial context. By stylizing the agro-ecological system, this kind of modeling leads to both improvements in understanding and reinforcement of decison-making supports by fostering the policy effectiveness. The integration of dynamics and spatialization of the processes taken into account stresses the relevance of their use. Moreover, the relative simplicity of the initial mechanisms underlying the model together with its multi-scale perspective should make it easily transferable to other case-studies and other biodiversity taxa.

However, the results presented in this paper should be viewed as suggestive rather than predictive elements. Some improvements could have a positive impact on the design of relevant policies and should be integrated in future developments. Taking into account more explicit spatial processes within the bio-economic model should reinforce the derived assertions. For example, accounting for the level of landscape fragmentation which affects both biodiversity dynamics (Tscharntke *et al.* 2005) and agricultural land-use policies (Hartig & Drechsler 2009, Polasky *et al.* 2008) should be a fruitful task. From the economic point of view, it would be accurate to account for price mechanisms. Typically, future profitabilities of agricultural activites can vary according to the influence of fuel prices or technical progress. Finally, allowing for dynamic incentives instead of fixed incentives could be a relevant way to improve the effectiveness of agricultural strategies as in Hartig & Drechsler (2009).

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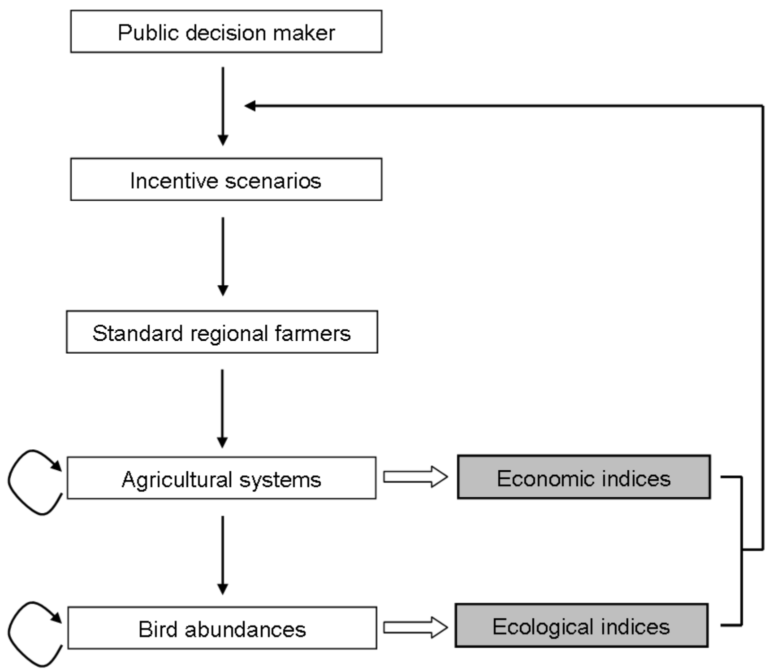
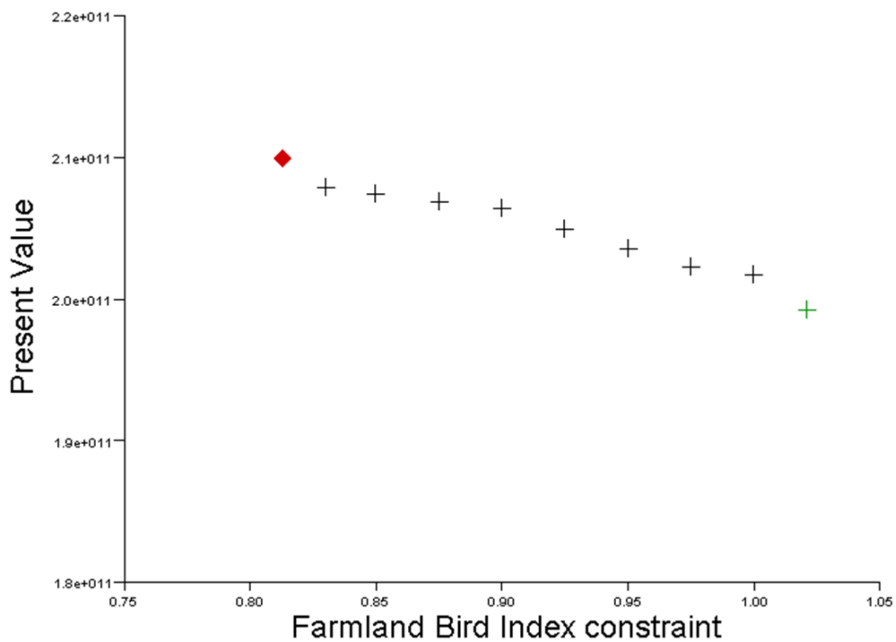
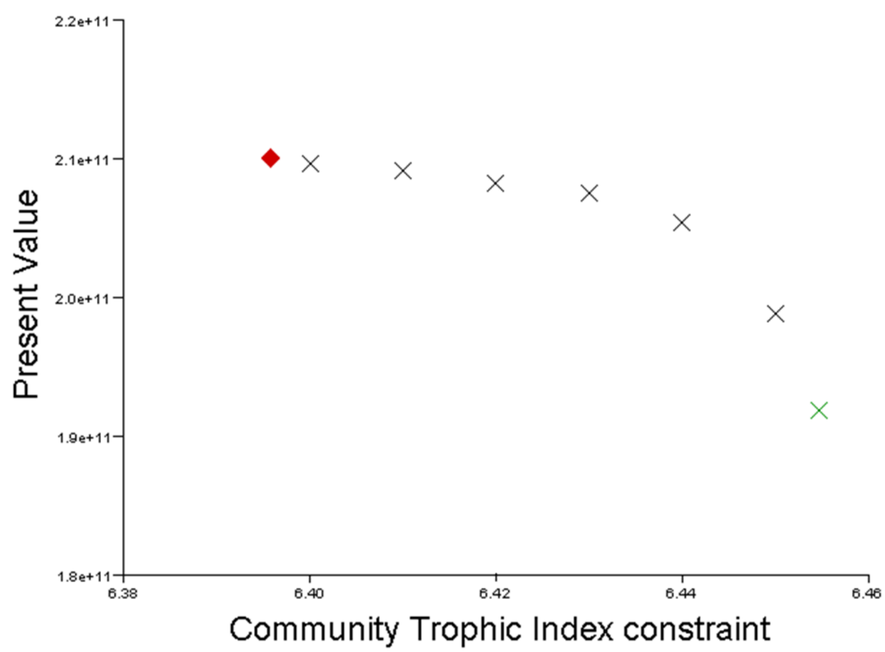


Figure 1: Bio-economic model coupling. The decision maker determines an incentive scenario according to a bio-economic optimization. The farmers choose their agricultural systems by maximizing their income under technical constraints. These choices affect the habitat and the bird communities.

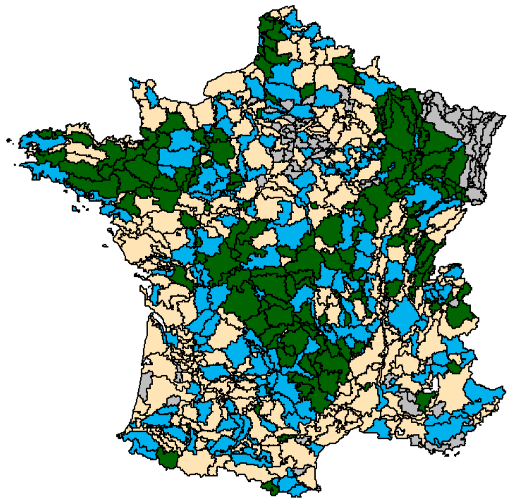


(a)

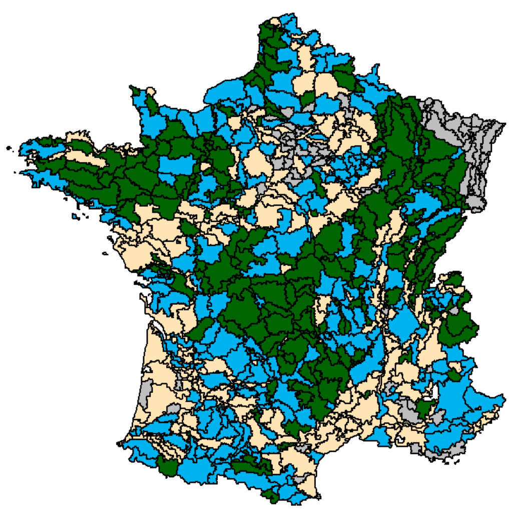


(b)

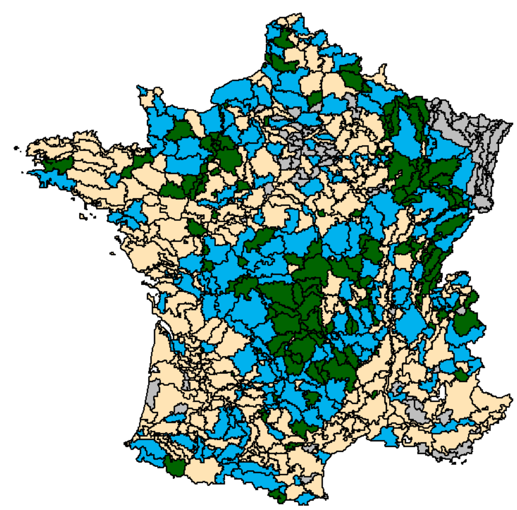
Figure 2: Optimal present values $PV(\tau^*(B_{lim})$ with respect to the biodiversity constraint B_{lim}. In (a) with the $FBI(2050)$ biodiversity indicator and in (b) with the $CTI(2050)$ biodiversity indicator. The extreme policies $\tau^*(0)$ and $\tau^*(B^*)$ are in red and green respectively.



(a) $B_{lim} = 0$ target

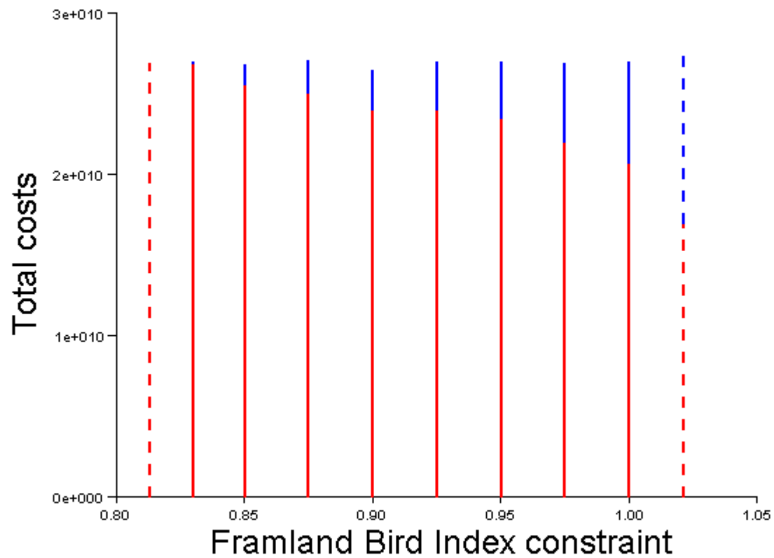


(b) FBI^{*} target

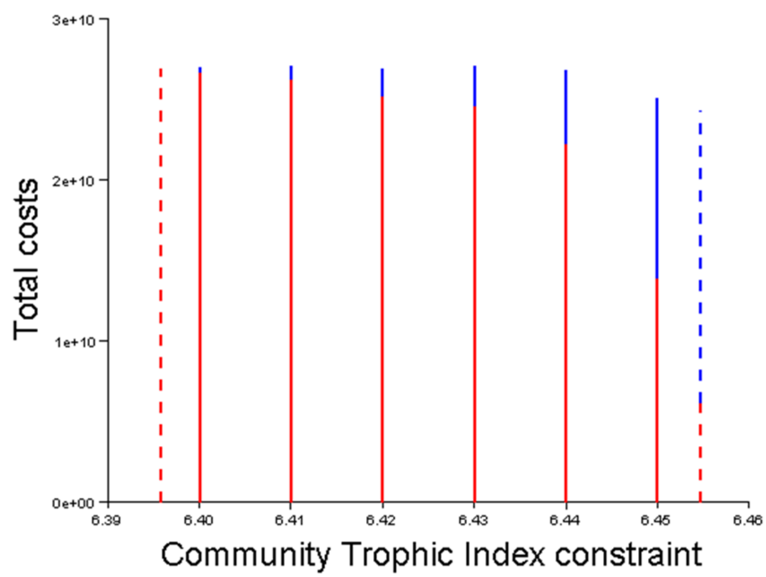


(c) CTI^{*} target

Figure 3: Proportions of the non-intensive grassland land-use (OTEX) ($\sum_{k=4}^{7} \frac{A_{r,k}(2050)}{UAA_r}$) at the PRA scale for optimal policies under several biodiversity targets B_{lim}. In green: 100-45%, in blue: 45-10%, in yellow: 10-0%.

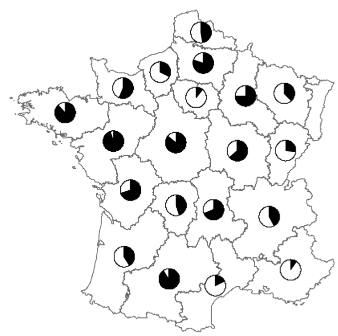


(a) $FBI(2050)$ as biodiversity index

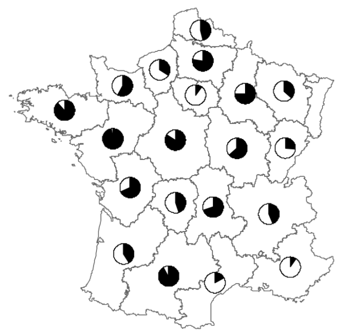


(b) $CTI(2050)$ as biodiversity index

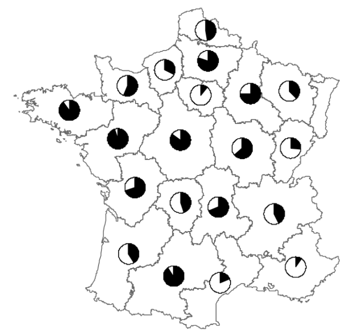
Figure 4: Total social costs $SoC(B_{lim})$ separated between the public costs $PuC(B_{lim})$ in red and the private costs $PrC(B_{lim})$ in blue for different biodiversity targets B_{lim}. Dashed lines stand for the extreme cases $B_{lim} = 0$ on the left and $B_{lim} = B^*$ on the right.



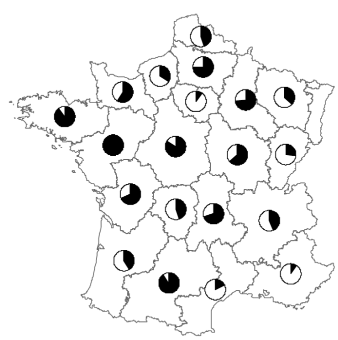
(a) $B_{lim} = 0$



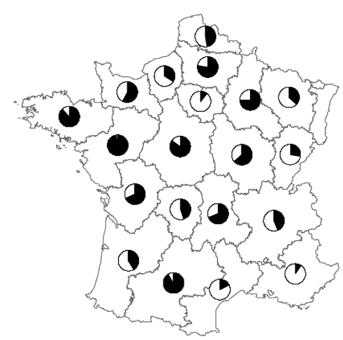
(b) $FBI_{lim} = 0.85$



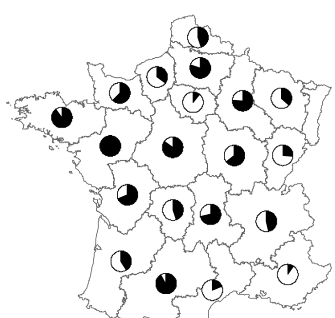
(c) $CTI_{lim} = 6.40$



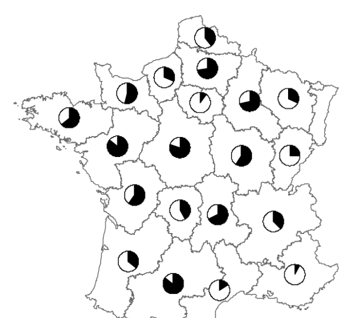
(d) $FBI_{lim} = 0.925$



(e) $CTI_{lim} = 6.43$

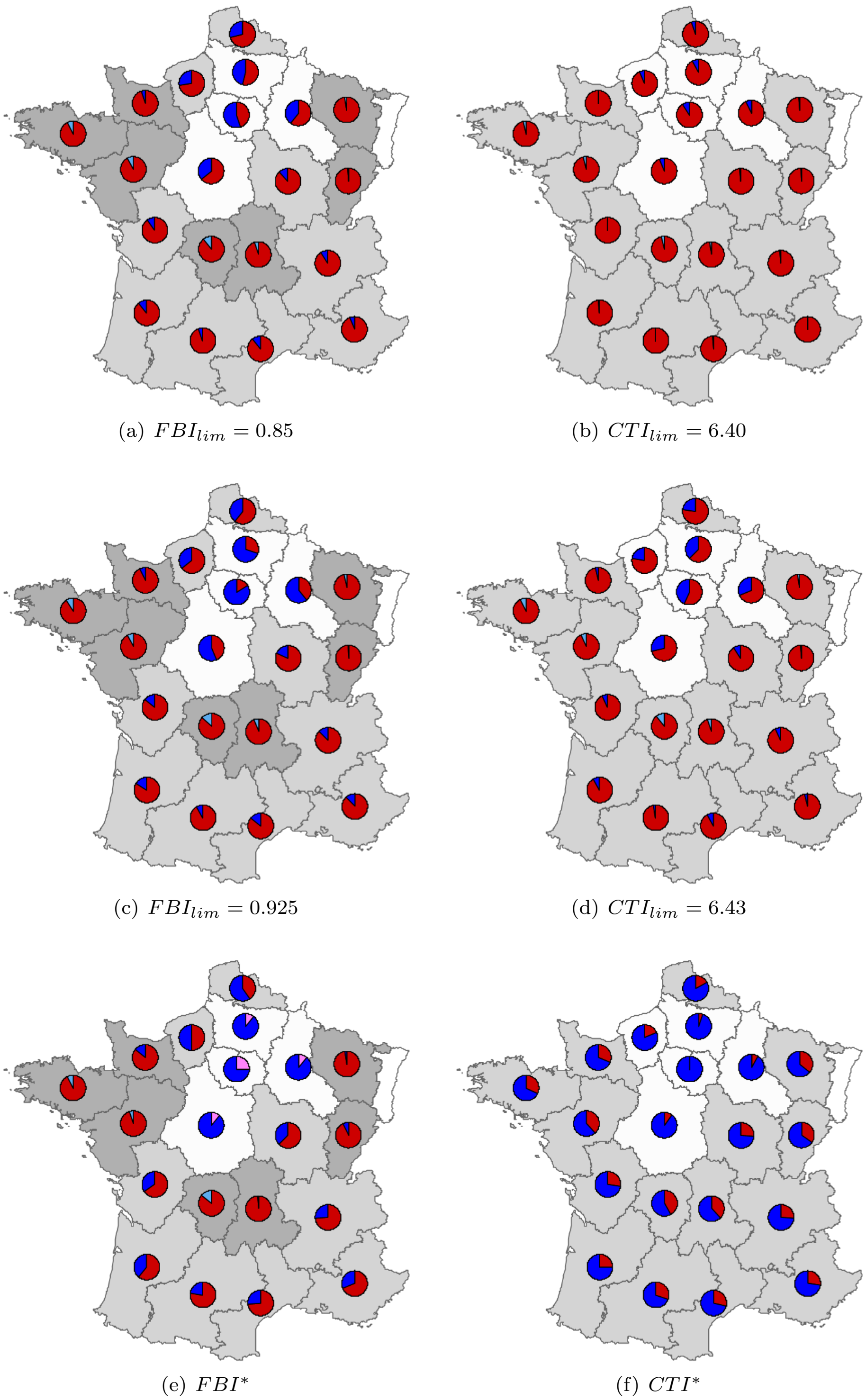


(f) FBI^{*}



(g) CTI^{*}

Figure 5: Regional total social costs $SoC_r(B_{lim})$ in black under several biodiversity targets B_{lim}. On the left the FBI and on the right the CTI for the biodiversity index.



(a) $FBI_{lim} = 0.85$

(b) $CTI_{lim} = 6.40$

(c) $FBI_{lim} = 0.925$

(d) $CTI_{lim} = 6.43$

(e) FBI^*

(f) CTI^*

Figure 6: Regional public $PuC_r(B_{lim})$ (in red) and private $PrC_r(B_{lim})$ (in blue) costs under several biodiversity targets B_{lim}. Pink stands for negative public costs and pale blue negative private costs. Grey (resp. pale grey, white) regions present stable (resp. intermediary stable, instable) costs.

The 14 land-uses (OTEX) k
(1) Cereal, Oleaginous, Proteaginous (COP)
(2) Variegated crops
(3) Intensive bovine livestock breeding
(4) Medium bovine livestock breeding
(5) Extensive bovine livestock breeding
(6) Mixed crop-livestock farming with herbivorous management
(7) Other herbivorous livestock breeding
(8) Mixed crop-livestock farming with granivorous management
(9) Mixed crop-livestock farming with other management
(10) Granivorous livestock breeding
(11) Permanent farming
(12) Flower farming
(13) Viticulture
(14) Others associations

Table 1: List of the 14 farming land-uses (OTEX)

20 farmland bird species	14 generalist bird species
(1) Buzzard *Buteo buteo*	(1) Blackbird *Turdus merula*
(2) Cirl Bunting *Emberiza cirlus*	(2) Blackcap *Sylvia atricapilla*
(3) Corn Bunting *Emberiza calandra*	(3) Blue Tit *Parus caeruleus*
(4) Grey Partridge *Perdix perdix*	(4) Carrion crow *Corvus corone*
(5) Hoopoe *Upupa epops*	(5) Chaffinch *Fringilla coelebs*
(6) Kestrel *Falco tinnunculus*	(6) Cuckoo *Cuculus canorus*
(7) Lapwing *Vanellus vanellus*	(7) Dunnock *Prunella modularis*
(8) Linnet *Carduelis cannabina*	(8) Great Tit *Parus major*
(9) Meadow Pipit *Anthus pratensis*	(9) Green Woodpecker *Picus viridis*
(10) Quail *Coturnix coturnix*	(10) Golden oriole *Oriolus oriolus*
(11) Red-backed Shrike *Lanius collurio*	(11) Jay *Garrulus glandarius*
(12) Red-legged Partridge *Alectoris rufa*	(12) Melodius Warbler *Hippolais polyglotta*
(13) Rook *Corvus frugilegus*	(13) Nightingale *Luscinia megarhynchos*
(14) Skylark *Alauda arvensis*	(14) Wood Pigeon *Columba palumbus*
(15) Stonechat *Saxicola torquatus*	
(16) Whinchat *Saxicola rubetra*	
(17) Whitethroat *Sylvia communis*	
(18) Wood Lark *Lullula arborea*	
(19) Yellowhammer *Emberiza citrinella*	
(20) Yellow Wagtail *Motacilla flava*	

Table 2: List of the 20 farmland and 14 generalist bird species *s*

FBI_{lim}	0	0.825	0.85	0.875	0.9	0.925	0.95	0.975	1	FBI*
τ^*_{cop}	0.47	0.27	0.23	0.23	0.14	0.02	-0.06	-0.19	-0.25	-0.54
τ^*_{grass}	0.52	0.58	0.59	0.58	0.61	0.62	0.61	0.62	0.62	0.63

Table 3: Optimal cereal incentives τ^*_{cop} and grassland incentives τ^*_{grass} for different biodiversity targets B_{lim} using the FBI as biodiversity index.

CTI_{lim}	0	6.40	6.41	6.42	6.43	6.44	6.45	CTI*
τ^*_{cop}	0.47	0.42	0.37	0.33	0.23	0.20	0.34	-0.02
τ^*_{grass}	0.52	0.54	0.56	0.56	0.59	0.54	0.23	0.23

Table 4: Optimal cereal incentives τ^*_{cop} and grassland incentives τ^*_{grass} for different biodiversity targets B_{lim} using the CTI as biodiversity index.