European Review of Agricultural Economics (2020) pp. 1–29
doi:10.1093/erae/jbz049
Advance Access Publication

Decentralisation of agri-environmental policy design

François Bareille[†,‡,§,*] **and Matteo Zavalloni**[‡]

[†]*INRA, UMR SMART-LERECO, Rennes, France;* [‡]*Department of Agricultural and Food Sciences, University of Bologna, Italy;* [§]*Economie Publique, INRA, Agro Paris Tech Université Paris-Saclay Thiverval-Grignon, France*

Received September 2018; final version accepted November 2019

Review coordinated by Jack Peerlings

Abstract

We theoretically examine the gains of the decentralisation of agri-environmental policy design. We consider a model with homogeneous regions and joint production of local and global public goods from agriculture. Assuming that governments are characterised by different agency costs and knowledge of the PG values, we evaluate whether decentralisation is a suitable strategy to improve the efficiency of agri-environmental payments. We find that partial decentralisation always improves the welfare. We apply our theoretical model to the case of abandoned wetlands in Brittany. We find that national governments are the most suitable to design agri-environmental policies. Our results contribute to reflections on future Common Agricultural Policy.

Keywords: Common Agricultural Policy reform, environmental federalism, public goods

JEL classification: Q18, Q28, H77

1. Introduction

Agriculture jointly produces private agricultural goods and environmental public goods (PGs), such as biodiversity, water quality or carbon sequestration (OECD, 2015). The impacts of PGs on the welfare of the population depend on the spatial distribution of their demand: the beneficiaries of global PGs are located all over the world, while local PGs benefit people in delimited areas around the provision locations.

The non-rival and non-excludable nature of environmental PGs justifies the intervention of a public regulator. This is the case in the European Union (EU), where farmers receive between 4 and 5 billion euros each year for

*Corresponding author: E-mail: francois.bareille@unibo.it

the provision of environmental PGs through the Agri-Environment-Climate Measures (AECMs) defined in the Common Agricultural Policy (CAP). Given their structure, design, objectives and budget, the AECMs are largely decided on and bargained over at the EU level (Beckmann, Eggers and Mettepenningen, 2009). While the subsidiarity principle ensures that agri-environmental programmes are locally formulated, they are still subject to the rules of the EU since their final approval remains up to the European Commission (EC) in agreement with articles 107 and 108 of the Treaty on the Functioning of the EU. Such centralised control has been criticised given the heterogeneity of benefits and costs of PG provision across the EU (Beckmann, Eggers and Mettepenningen, 2009; European Court of Auditors, 2011; Droste *et al.*, 2018). The EC addresses this issue in its proposal for the new CAP, claiming that each member state will have the flexibility to implement specific instruments tailored to their local needs (COM(2018) 392).

What is the level of government that should design and implement environmental policies? This issue is addressed by the economic literature on environmental federalism (Oates, 2001; Sigman, 2014; Harstad and Mideksa, 2017; Droste *et al.*, 2018). The basic features of this literature are that (i) the economy is structured in a federal system characterised by multiple hierarchical levels of governments, ranging from local to central ones and (ii) local governments can more efficiently target public spending, but (iii) local governments generate externalities to other jurisdictions and (iv) may face higher transaction costs than the central government. The main result of this literature is that interventions generating benefits contained within the boundaries of local jurisdictions present a high interest for decentralised intervention, while global environmental problems require central intervention (Tiebout and Houston, 1962). In particular, the Oates' decentralisation theorem states that, without interjurisdictional externalities and differentiated transaction costs between hierarchical governments, fiscal responsibilities should be decentralised (Oates, 1972). While addressing mainly the allocation of powers and functions at different levels of government, this literature also investigates other questions, such as the efficiency of the different instruments according to the governments in charge (Oates, 2001), the budgets and the intergovernmental vertical or horizontal transfers (Olson, 1969; Inman, 2003; Kumar and Managi, 2009; Droste *et al.*, 2018) or political economy issues linked to federalism (Besley and Coate, 2003; Lessmann and Markwardt, 2010). To our knowledge, the environmental federalism framework has not been applied to the agricultural sector, despite some specificities of agriculture that we present in the following paragraphs. Similarly, analysis of the efficiency of decentralised decision-making for agri-environmental issues is lacking in agricultural economics, the related literature focusing mainly on the role of transaction costs in agricultural policies (Beckmann, Eggers and Mettepenningen, 2009; Mettepenningen, Beckmann and Eggers, 2011; Weber, 2015).[1] Information on the efficiency of the decentralisation of agricultural policies is however crucial for the future CAP 2020 reform.

The objective of this paper is to theoretically determine the optimal level of government for the design of agri-environmental policies, in the case where (i) agriculture provides both local and global PGs, (ii) budget management is subject to transaction costs and (iii) the knowledge of local PG values improves with decentralisation. A numerical example based on wetland maintenance in Brittany (France) is used to illustrate the theoretical model.

We first develop atheoretical model in which different hierarchical governments are in charge of the design of agri-environmental payments. The model introduces some specific features of agricultural production and policy. First, we consider that the PG provision depends on agricultural land use. This implies, in contrast to most of the environmental federalism literature, that the suppliers of PGs are from not the public sector but the private sector (Harstad and Mideksa, 2017). Second, we consider that environmentally friendly land use produces both global and local PGs. The maintenance of wetlands contributes, for example, not only to biodiversity conservation (a global PG) but also to water filtration and thus water quality (a local PG). Third, we consider that the local PG values are heterogeneous across space within each region, a characteristic that has rarely been explicitly considered in the environmental federalism literature. For example, the benefit of water filtration of unpolluted water is null, while the benefits are positive for polluted water. The higher heterogeneity of local than global PG values is a usual feature of the literature on PG valuation (Johnston and Ramachandran, 2014; Logar and Brouwer, 2018), notably for agricultural and forest PGs (*e.g.* Czajkowski *et al.*, 2017). Fourth, we consider that hierarchical governments have different knowledge of the heterogeneity of the local PG values within each region. The easier access to information is a usual argument of the literature in favour of decentralisation (Oates, 1999). However, the environmental federalism literature usually considers that regions are heterogeneous in tastes (Tiebout, 1956) and does not integrate the different knowledge amongst the hierarchical governments of the heterogeneity of local PG values. Fifth, we consider that hierarchical governments face different agency costs when managing agri-environmental budgets. However, different from the usual assumption of economies of scale in public money management (Ahmad, 2006), we also consider the possibility of diseconomies of scale. Indeed, the literature on agri-environmental policies suggests that the centralised control of the CAP induces additional coordination costs between the regional and the central governments (Mettepenningen, Beckmann and Eggers, 2011; Weber, 2015). Sixth, we depart

1 Note that an exception is the unpublished work of Bougherara and Gaigné (2008), who focus on the competition between decentralized governments in the design of agri-environmental payments when residents are mobile, in the pure tradition of Tiebout (1956).

from Tiebout (1956) and consider that both suppliers and beneficiaries of PGs are immobile.

The results of the analysis indicate that the total amount of financed land decreases with decentralisation but that the amount of managed land increases amongst the most valuable areas; *i.e.* local governments reduce the global PG provision but improve the local PG provision. However, complete decentralisation is never optimal. We find that decentralisation would lead to a reduction of the total payments. Overall, our model suggests that partial decentralisation should lead to cost savings in agri-environmental payments and an increase in the efficiency of public intervention.

The numerical example displays the cut-off values and tipping points when regional, national or central governments are in charge of the design of agri-environmental payments. This section is constructed in two parts. We first rigorously apply our theoretical model using the parameters determined in Bareille, Couzier and Dupraz (2017). We find that the national decentralisation, as suggested in the EC proposal, would be the most efficient level of intervention, increasing the existing welfare by 66 per cent. We then take into account heterogenous costs and more heterogeneous PG benefits, which better represents reality. National decentralisation would increase the welfare by 435 per cent in this case.

The article is organised as follows. The next section presents the theoretical model. Section 3 is devoted to the empirical application. We discuss the theoretical and empirical results in the fourth section. Section 5 concludes the paper.

2. Theoretical analysis

2.1. Theoretical framework

Imagine an economy composed of a number of homogenous regions. Farmers in each region can manage land for agri-environmental purposes. Assume that this management jointly provides one global PG, whose value is homogenous over space, and one local PG, whose value is differentiated over space. Agri-environmental PGs are however costly to produce, and in the absence of regulatory intervention, farmers would not have any incentive to provide them. Assume that the public intervention is in the form of a land-based subsidy. There is a large literature examining the limits of such an instrument, *e.g.* due to transaction costs (Mettepenningen, Verspecht and Van Huylenbroeck, 2009) or to asymmetric information about opportunity costs (Gómez-Limón, Gutiérrez-Martín and Villanueva, 2019). Given this economic structure, the classical problem within the agricultural economics literature is to define the public intervention in such a way that the societal optimal land allocated to the PG is implemented by the farmers. However, this theoretical framework does not explicitly account for the structure and features of the different governments within the economy.

Drawing upon the literature on environmental federalism, we consider that any government level, in a continuum of hierarchical governments, from decentralised ones (the government of each region) to the central one (governing all regions), can design the land-based subsidy. The different hierarchical governments present advantages and/or disadvantages for financing PG provision. Here, we consider that these differences relate to (i) the informational advantage of the local PG value for the lower levels of governments, (ii) the spillover-internalisation advantage for the higher levels of governments and (iii) the different agency costs across the hierarchical governments. Given these differences, the problem is now to assess what level of payment each government level would set and to ultimately determine the optimal government level.

We endogenously identify the optimal level of governmental intervention in three steps. First, the farmers respond to the chosen agri-environmental payments by allocating the land to PG provision. Second, the governments of different levels maximise the utility of the regions under their responsibility by determining the optimal agri-environmental payments and agri-environmental budget based on their characteristics (different information about the PG values and different transaction costs). The budget is thus endogenously assessed by the responsible governments in our analysis. An alternative mechanism could have been to model transfers from the centralised to the decentralised governments (Ring, 2008; Kumar and Managi, 2009; Droste *et al.*, 2018). However, while these top-down transfers exist in the case of the CAP, the centralised budget of the CAP is alsobuilt from national contributions. Our budget-rising assumption should be seen as a simplifying assumption. It is also used in Bougherara and Gaigné (2008), for example. Third, the optimal level of the governments in charge of the design of the agri-environmental payments is determined by maximising the welfare of the whole economy given the subsidies the different governments offered to the farmers.

In the current CAP framework, the agri-environmental policy is characterised as follows: (i) the agri-environmental budget comes from the contributions of the different environmental regions and (ii) each European region expresses its local needs, but (iii) the EU determines *in fine* the design of the agri-environmental payments and (iv) regional or national governments cannot offer additional or alternative agri-environmental payments (article 107 of the Treaty on the Functioning of the European Union states that regional subsidies to private companies, including farms, are not allowed). This setting matches the fully centralised case of our model. Our model provides a framework to examine the potential decentralisation of agri-environmental policy, as proposed in the future CAP reform.

The mathematical description of the model follows.

2.2. Model description

2.2.1. *Supply and demand of agricultural public goods.* Assume that there are $R \geq 2$ homogenous regions with no mobility of inhabitants amongst them. In each region, there is an agricultural sector consisting of two farmers $i \in \{1; 2\}$. Each farmer can allocate area X_i to PG provision, up to $X_i \leq L_i$. Area X_i can be productive land that jointly provides PGs, such as permanent grassland, or unproductive land, such as buffer strips. We consider that these areas support the joint production of local and global PGs. For example, the conservation of permanent grassland increases water quality through filtration (a local PG) but also acts as a carbon sink, thus contributing to climate stability (a global PG). The allocation of land to PGs entails a marginally increasing cost cX_i that we can interpret as the opportunity costs of environmentally friendly land (*e.g.* Barrett, 1994). Without loss of generality, we consider that the farmers face homogeneous costs.[2]

The provision of local and global PGs delivers benefits to each region. We assume that the preferences for local and global PGs are linear in the land allocated to PG. This assumption simplifies the strategic interactions among governments and allows us to focus on the specificities of the hierarchical governments (see Section 2.2.3). We consider that the global PG value is captured by the whole economy and that its value is homogenous. The marginal benefit derived by the inhabitants of one region from the provision of global PG is $w > 0$. The local PG benefits are captured within the region where the production occurs, but its value is heterogeneously produced by the farmers: farmer 1 produces a local PG of value v_1, while farmer 2 produces a local PG of value v_2, with $v_1 > v_2 \geq 0$. Thus, X_1 is the most valuable land in terms of PG in any region. Without loss of generality, we assume that $v_2 = 0$, and we simply call $v_1 = v$. Altogether, the benefits B obtained by each region from PG provision are determined by

$$B = \sum_i v_i \cdot X_i + \sum_i w \cdot X_i + (R-1) \cdot \sum_i w \cdot X_i \quad (1)$$

where the first term represents the benefits of the local PG in a given region, the second term represents the benefits derived by the global PG provided in the region and the third term is the benefits of the global PG provided by the other regions in the economy. Note that, as the regions are homogenous, the benefits are identical for each region. We thus do not index the benefits B.

2.2.2. *Farmers' reaction.* From the point of view of the farmers, the provision of PG is simply a cost, and the farmers would not provide any PG in the absence of policy intervention.[3] If a subsidy $p_{i,s}$ is offered to farmer i by a given government level s responsible for managing the agri-environmental schemes, the farmers' objective becomes:

$$\max_{X_i} \Pi_i = p_{i,s} \cdot X_i - \frac{1}{2} \cdot c \cdot X_i^2 \quad (2)$$

2 Heterogeneous costs for the two farmers would only marginally change our results, which are primarily driven by the differences between the hierarchical governments (see Section 2.2.3). We examine the impact of the assumption of homogeneous costs in Section 3.

3 Environmental lands are sometimes productive lands whose profitability depends on input and output prices or fixed input dotation. We assume that these features are captured within the cost parameter c. Our simplifying representation of the agricultural technology allows us to focus on the role of the governments.

Note that the payment can be differentiated by farmers, which is something already known in the literature to increase the efficiency of land-based subsidies compared to homogenous subsidies (Latacz-Lohmann and Van der Hamsvoort, 1997; Perino and Talavera, 2013). The results of such a maximisation are a response $\hat{X}_i\left(p_{i,s}\right)$ that describes the farmers' land-use choices as a function of the agri-environmental subsidies.

2.2.3. *Public intervention.* We assume that the payment $p_{i,s}$ can be set by the different hierarchical governments, from the regional to the central ones, but that a single level of government is in charge of the agri-environmental policy. Call S the number of regions that are under control of a given government level s. For example, the centralised government is in charge of $S = R$ regions, while the maximum degree of decentralisation entails that agri-environmental policies are managed by the government level in charge of $S = 1$ region. In the first case, there is a single government, while in the second case, they are R governments. Because the regions are homogenous, there are R/S governments in the economy for any degree of centralisation. Any government level decides on the payment levels offered to the farmers accounting for the welfare of the population of the S regions under its responsibility, given the information it has regarding the values of the local PG, the benefits derived from the global PG and the costs related to the budget management. In the following section, we describe these elements in more detail.

First, we consider that the hierarchical governments have different knowledge of the local PG values (Oates, 1999).[4] In particular, we assume that the precision of the knowledge of the heterogeneity of the local PG values decreases linearly with centralisation. We assume that the expected values of the local PGs for a government of size S are $\dot{v}_1(S) = \theta(S)\cdot v_1 + (1-\theta(S))\cdot v_2 = \theta(S)\cdot v$ and $\dot{v}_2(S) = \theta(S)\cdot v_2 + (1-\theta(S))\cdot v_1 = (1-\theta(S))\cdot v$, and where $\theta(S)$ is defined as:

$$\theta(S) = 1 - \frac{S-1}{2\cdot(R-1)} \tag{3}$$

The value of $\theta(S)$ increases with decentralisation (decreases with S). It is equal to 1 in the case of complete decentralisation and 0.5 in case of complete centralisation. That is, the regional governments perfectly know the distribution of the local PG values, while the central government is ignorant of its heterogeneity and cannot distinguish between the local PG values produced by the two farmers. Furthermore, this implies that the different hierarchical governments have similar information on the average local PG value but different information on the variance of local PG values. There is thus an informational advantage for lower levels of government. This is an original

4 Note that we implicitly assume that there is perfect knowledge on the supply side, whatever the level of the government in charge. This assumption is supported by the availability of the database on agricultural production across Europe. For example, the Farm Accountancy Data Network is available for governments at all hierarchical levels.

feature of our analysis. The literature usually assumes heterogeneous taste between regions but homogenous value of the PG inside each region.

Second, governments may face different agency costs $\tau(S)$ for managing agri-environmental payments. The literature on fiscal federalism considers that public money management presents economies of scale due to, *e.g.* the economies on the public agents' payroll (Ahmad, 2006). However, Crémer, Estache and Seabright (1996) highlighted that the central government can also face higher transaction costs than the regional government when the central government spends resources to obtain information on local conditions. This material compilation appears in the CAP structure, where regional agencies coordinate with the EC to provide information on the farmers' opportunity costs of PG provision (Beckmann, Eggers and Mettepenningen, 2009; Mettepenningen, Beckmann and Eggers, 2011). The parameter $\tau(S)$ captures both the economies of scale and the coordination costs, which have both been observed in the literature on the efficiency of agri-environmental payments (Falconer, Dupraz and Whitby, 2001; Weber, 2015).[5] Depending on the amplitude of these two strengths, $\tau(S)$ can be either increasing or decreasing in S. The integration of both economies of scale and coordination costs is an original feature of our analysis.

Moreover, the governments in charge of agri-environmental policy must constitute their agri-environmental budget. We assume that the governmental budgets come from the income taxation of the S regions under their responsibility (at rate t). The total regional income Y is exogenous and corresponds to the sum of the incomes of all the households living in one region. Income taxes can lead to distortion within the economy, *e.g.* on the functioning of the labour market, and thus lead to deadweight losses for the economy. We do not model such a market and exogenously integrate the distortion by considering it proportional to the total raised taxes (at a rate k—see, *e.g.* Gilbert and Picard, 1996). An income taxation puts the tax pressure on households rather than on producers (*e.g.* through taxes on public bads).

Given these assumptions, a government of size S maximises the utility function U_s by choosing the agri-environmental payments in the S governed regions, given its knowledge on the PG values, the incurred transaction costs and farmers' response to the payments $\hat{X}_i\left(p_{i,s}\right)$. The utility function U_s equals the difference between the benefits defined in relation (1) and the deadweight losses induced by the total tax incomes:[6]

$$\begin{aligned}
&\max_{p_{i,s}} U_s = S \cdot \sum_i \hat{X}_i\left(p_{i,s}\right) \cdot \left[\dot{v}_i(S) + w(S)\right] + (R - S) \cdot w(S) \cdot \sum_i \overline{X}_i\left(\overline{p}_{i,s}\right) - k \cdot t \cdot Y \cdot S \\
&s.t.\, S \cdot \left(\sum_i \hat{X}_i\left(p_{i,s}\right) \cdot p_{i,s} + \tau(S)\right) = t \cdot Y \cdot S
\end{aligned} \quad (4)$$

5 Falconer et al. (2001) measured economies of scale in transaction costs in the English agricultural administration, but Weber (2015) found that more than 50 per cent of the transaction costs are due to coordination between the EC, national and regional governments.

6 Note that the total agri-environmental payments are not considered a cost for the government because farmers benefit from them. Such payments should rather be considered transfers from the households to the farmers.

where $\overline{X}_i\left(\overline{p}_{i,s}\right)$ represents the subsidised land in the other *R-S* regions, whose levels do not depend on the considered government. The outcome of the maximisation problem is the level of the payments offered to the farmers $\hat{p}_{i,s}$ from any given government level and the resulting land allocation to PG $\hat{X}_i(S)$. Note that each government level accounts for the global PG a value such as $w(S) = w \cdot S$; *i.e.* it integrates only the benefits received from and for the *S* regions under its responsibility, free-riding on the PG contribution of the other regions. This implies that only the central government can internalise the entire value of global PGs, while lower hierarchical governments generate externalities to regions that are not under their control. As classically shown in the literature on environmental federalism, there is thus a spillover-internalisation advantage for higher levels of government.

2.2.4. *Optimal government level.* The optimal size of the governments in charge of the design of agri-environmental payments is determined by maximising the welfare of the entire economy, which depends on the agri-environmental payments that each government of size *S* offers to farmers in the regions under its control. Thus, the optimal government size S^* is the solution to

$$\max_S W(S) = R \cdot \left[(v + w \cdot R) \cdot \hat{X}_1(S) + w \cdot R \cdot \hat{X}_2(S)\right] \\ -k \cdot \left(\hat{X}_1(S) \cdot \hat{p}_{1,s}(S) + \hat{X}_2(S) \cdot \hat{p}_{2,s}(S) + \tau(S)\right) \qquad (5)$$

With respect to equation (4), equation (5) is characterised by perfect knowledge on the value of the local PG and a whole internalisation of the global PG benefits, while it is constrained by the choice on the payment levels (and land allocations) that depends on the government level. Indeed, as the land devoted to PG provision depends on the level of centralisation, the welfare function depends only on the size *S* of the governments in charge of the design of the agri-environmental policy. To underline the role of the different sources of inefficiencies of public intervention across hierarchical governments, we solve this problem by assuming null transaction costs in a first step. We consider the case where $\tau(S) \neq 0$ in a second step.

2.3. Results

2.3.1. *Determination of the optimal payments for a government of size S.* The first step of the problem is to determine the response of the farmers in terms of land for PG production X_i, given the offered agri-environmental payments. The optimal allocation of land is determined by solving the first-order conditions (FOC) of relation (2). Under the assumption that the land constraint is not binding, the FOC of (2) on X_i yields $\hat{X}_i\left(\hat{p}_{i,s}\right) = \frac{\hat{p}_{i,s}}{c}$. The farmers allocate land to PG provision, such as the cost of the last unit of land devoted to PG production, which equals the agri-environmental payment. An increase in the payments leads to an increase in the land devoted to PG provision.

In the second step, the government of size S maximises (4) by choosing agri-environmental payments. Integrating the farmers' response, the FOC on $\hat{p}_{1,s}$ and $\hat{p}_{2,s}$ leads to:

$$\hat{p}_{1,s}(S) = \frac{\dot{v}_1(S) + w(S)}{2 \cdot k} \tag{6}$$

$$\hat{p}_{2,s}(S) = \frac{\dot{v}_2(S) + w(S)}{2 \cdot k} \tag{7}$$

The payments are set such that the marginal costs of taxation (in the case of X_1: $2 \cdot k \cdot \hat{p}_{1,s}(S)$) equal the expected marginal benefits (in the case of X_1 and a government of size S: $\dot{v}_1(S) + w(S)$). Introducing these payments back to the farmers' maximisation programme (2) leads to the optimal land allocations:

$$\hat{X}_1(S) = \frac{\dot{v}_1(S) + w(S)}{2 \cdot k \cdot c} \tag{8}$$

$$\hat{X}_2(S) = \frac{\dot{v}_2(S) + w(S)}{2 \cdot k \cdot c} \tag{9}$$

The land allocated to PG provision X_i thus depends on the level of centralisation. The derivatives of (8) and (9) with respect to S show that the levels of PG provision increase when v and w increase but decrease when the cost parameters k and c increase. One can also verify that X_1 increases with S if $\frac{1}{2} \cdot v < (R-1) \cdot w$ but decreases otherwise. Note that the term $(R-1) \cdot w$ is the global PG value captured outside the region where production occurs. In other words, it represents the externalities generated by one unit of managed land in one region to the other regions. The term $v/2$ represents the average value of local PGs under the two types of land. It also represents the marginal value attributed by the central government to the local PG due to information loss.

Proposition 1. *The lands allocated to PG provision depends on the level of centralisation. The level of the less valuable lands X_2 increases with centralisation due to the conjugate actions of information loss on local PG values and better integration of the global PG value. The level of the most valuable lands X_1 increases with centralisation if the externalities generated by the other regions are lower than the average value of the local PG but decreases otherwise.*

Furthermore, one can note that the addition of relations (8) and (9) leads to:

$$\hat{X}_1(S) + \hat{X}_2(S) = \frac{v + 2 \cdot w \cdot S}{2 \cdot k \cdot c} \tag{10}$$

Since the derivative of (10) relative to S is positive, the total amount of financed lands $X_1 + X_2$ decreases with decentralisation. Indeed, the regional governments would use their information to support relatively more the most valuable lands X_1. However, the last unit of financed X_1 under decentralisation entails more costs for the farmers than the last unit of land under centralisation. This means that decentralised governments offer higher payments for the most valuable land, even if this reduces the total amount of financed land. Together with Proposition 1, this feature leads to the following proposition:

Proposition 2. *The total amount of financed land decreases under decentralisation to the profit of the most valuable lands* (X_1).

2.3.2. *Optimal size of the governments.* We first assume null transaction costs. As the level of land devoted to PG provision depends on the level of centralisation, the welfare function depends only on the size S of the governments in charge of the design of the agri-environmental policy. The FOC of relation (5) relative to S leads to (computations available in Appendix A):

$$S^* = \frac{4 \cdot R \cdot (R-1)^2 \cdot w^2 + v^2}{4 \cdot (R-1)^2 \cdot w^2 + v^2} \tag{11}$$

Relation (11) highlights that the optimal size of the government intervention S^* is independent of the farmers' cost parameter c and the deadweight loss rate k. This feature is driven by our assumptions of homogeneous costs between farmers and undifferentiated agency costs between hierarchical governments (see Proposition 5).

Given (11), complete decentralisation $S^* = 1$ arises in the single case when $w = 0$ (or $R = 1$), and complete centralisation $S^* = R$ arises when $v = 0$. As mentioned before, we rule out (by definition) these two extreme cases given the complexity of PG provision by agriculture. Thus, it is never optimal to have complete centralisation, as in the ongoing CAP, or complete decentralisation.

In addition, the derivatives of S^* relative to local and global PG values highlight that the decentralised strategies are more suitable when the heterogeneity of local PG (v) increases, while centralised governments are more suitable when the global PG value (w) increases.[7] The analysis of these derivatives indicates that the relative strengths of centralisation (when w increases) are greater than the strengths of decentralisation (when v increases) if $w > 1$, *i.e.* when the whole global PG value wR is higher than the number of regions.

Proposition 3. *Complete centralisation and complete decentralisation are never optimal when agriculture produces both local and global PGs. The optimal size of government S^* increases with the value of the global PG, while it decreases with the value of the local PG. The amplitudes of the strengths towards centralisation or decentralisation depend on the global PG value: the strengths are higher for centralisation in the cases where the global PG value is higher than the numbers of regions, while otherwise, the strengths are higher for decentralisation.*

7 Indeed, because we have $v > 0$, $w > 0$, and $R \geq 2$, the derivatives verify: $\frac{\partial S^*}{\partial v} = -8 \cdot (R-1)^3 \cdot v \cdot w^2 / \left(4 \cdot (R-1)^2 + w^2 + v^2\right)^2 < 0$ and $\frac{\partial S^*}{\partial w} = 8 \cdot (R-1)^3 \cdot v^2 \cdot w^2 / \left(4 \cdot (R-1)^2 \cdot w^2 + v^2\right)^2 > 0$

The choice between centralised or decentralised provision involves a basic trade-off between the gains from the internalisation of spillovers under centralisation and the greater sensitivity of local outputs to heterogeneous conditions under decentralisation (Oates, 2005). The higher the global PG value is, the greater the interest is in centralisation. The higher the heterogeneity of the local PG value is, the greater the interest is in decentralisation. Our Proposition 3 is consistent with the Oates' decentralisation theorem (1972), although the local PG is heterogeneous within each region and not between each region.

In Figure 1, we depict the optimal size of the government S^* (y-axis) for different values of v (x-axis) and w (z-axis) under an economy composed of $R=10$, $R=50$, $R=100$ and $R=200$ homogenous regions. Figure 1 shows that the higher the number of regions R, the higher the need for centralisation is. The slope of the curves in Figure 1 underlines, in line with Proposition 3, that the strengths towards centralisation are higher when the whole global PG value is higher than the number of regions. Figure 1 also underlines that a high heterogeneity in the local PG values is required for decentralisation.

One key indicator for the design of agri-environmental instruments is the amount of spending entailed by the policy. In our case, this spending corresponds to the total payments from governments and thus from households to farmers. These payments depend on the level of centralisation, as suggested by Proposition 1. Using relations (6)–(9), we find that the total payment $T(S)$ is

$$T(S) = \frac{1}{4 \cdot k^2 \cdot c} \cdot \left[\left(1 - \frac{S-1}{R-1}\right) \cdot v^2 + 2 \cdot w^2 \cdot S^2 + 2 \cdot w \cdot v \cdot S \right] \tag{12}$$

One can verify that the total payments decrease with centralisation when $v \in]0; (R-1+\sqrt{R^2-3}) \cdot w]$ but increase otherwise (see Appendix B). When this condition is verified, the total payments are minimised when S reaches the threshold $\overline{S} = [v^2 - 2 \cdot (R-1) \cdot w \cdot v]/[2 \cdot (R-1) \cdot w^2]$ (see Appendix B). Given that the number of regions is higher than two, the condition $v \in]0; (R-1+\sqrt{R^2-3}) \cdot w]$ implies that the total payments to farmers decrease only if the local PG value is relatively low compared to the global PG value. Indeed, one can note that the upper boundary of this condition is lower than $2wR$, *i.e.* is lower than two times the whole global PG value. Given the distribution of the values of local and global PG v and wR in the literature (Johnston and Ramachandran, 2014; Logar and Brouwer, 2018), this condition seems to be rarely reached in the real world. We will illustrate this point in the empirical section in the case of the maintenance of agricultural wetlands, where the PG valuation of Bareille, Couzier and Dupraz (2017) suggests that $v \approx 10 \cdot w \cdot R$.

Proposition 4. *The total payments to farmers always increase with the degree of centralisation when the heterogeneity of the local PG (v) within the considered region is higher than $(R-1+\sqrt{R^2-3}) \cdot w$, i.e. approximately two times the global PG value. Otherwise, in the case whenv $\in]0; (R-1+\sqrt{R^2-3}) \cdot w]$, the total payments decrease with increasing centralisation until S reaches the threshold $\overline{S}$ and then increase. The total payments are the lowest when $S = \overline{S}$.*

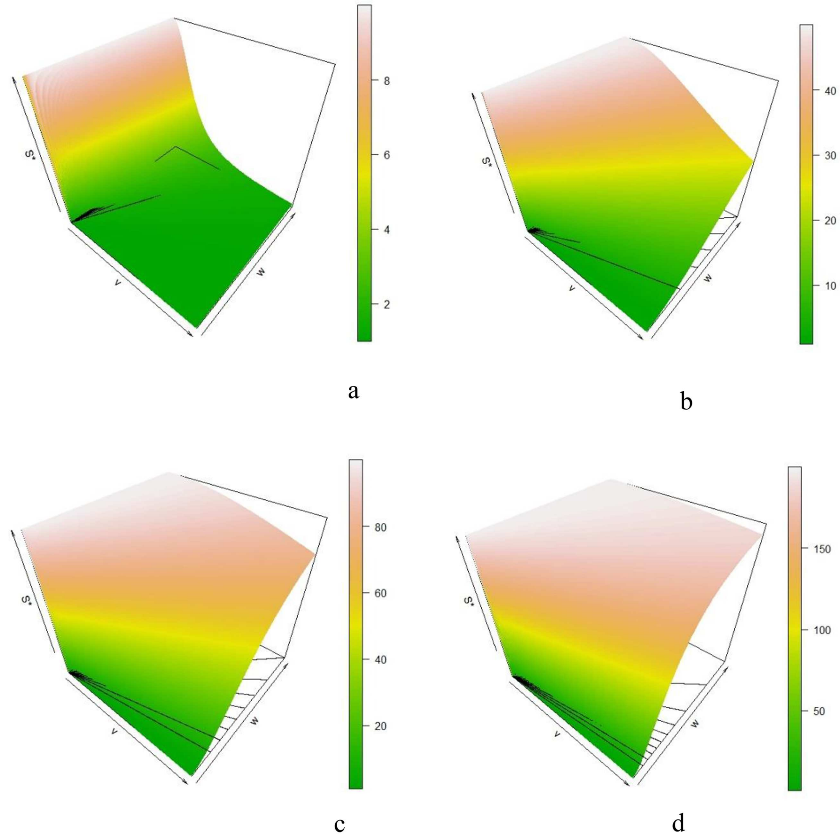

Fig. 1. The optimal size of the governments for an economy composed of (a) 10 regions, (b) 50 regions, (c) 100 regions and (d) 200 regions (*source*: authors' own computations). *Note*: In the figures, $v \in [0; 2000]$ and $w \in [0, 20]$.

This result is consistent with some empirical results on the 'race to the bottom' mechanism, where local governments tend to lower taxes and public spending compared to central governments (Busemeyer, 2008). While this phenomenon appears only in some public sectors (Arends, 2017), our analysis suggests that it should theoretically occur within the agricultural sector. Proposition 4 also suggests that farmers should be opposed to the decentralisation of the design of agri-environmental policy. Finally, taken together, Propositions 2 and 4 suggest that decentralised governments designing agri-environmental payments should do 'better with less' (Benassy-Quere, Gobalraja and Trannoy, 2007; Busemeyer, 2008). In other words, the efficiency of agri-environmental payments should increase with decentralisation.

We now turn to the case where the hierarchical governments present different agency costs, *i.e.* when $\tau(S) \neq 0$. Similar to relation (11), we reach

(see Appendix C)

$$S^{*} = \frac{4 \cdot R \cdot (R-1)^2 \cdot w^2 + v^2 - 2 \cdot c \cdot k^2 \cdot (R-1)^2 \cdot \tau'(S)}{4 \cdot (R-1)^2 \cdot w^2 + v^2} \tag{13}$$

where $\tau'(S)$ represents the derivative of the transaction cost with respect to S. Relation (13) suggests that the transaction costs impact the optimal level of decentralisation. If the transaction costs decrease with the size of the government, as supposed by the environmental federalism literature, the optimal size of the governments is higher than that determined in (11). If the transaction costs increase with S, as supposed by the literature on the transaction costs of agri- environmental policies, the optimal size of the government is lower than that determined in (11). The consideration of transaction costs introduces the parameter cost of PG supply into the optimal size of the government. Following the assumption that $\tau'(S) < 0$, the higher the farmers' opportunity cost parameter c is, the higher the interest in centralisation is. The same appears for the deadweight loss rate k induced by the taxation of regional incomes.

Proposition 5. *The features of the supply side and the deadweight losses impact the optimal degree of centralisation only in the case of differentiated transaction costs amongst governments.*

3. Numerical application: abandonment of wetlands in Brittany

3.1. Provision of public goods from agricultural wetlands of the Odet watershed

To show the implications of our theoretical model in a real setting, we parameterise a numerical example to the case of wetland abandonment in the Odet watershed (Brittany, France—Figure 2). The Odet watershed is a territory of 724 km^2, representing 2.64 per cent of the region of Brittany (Figure 2). The territory consists of 27 municipalities and presents a density of 174 inhabitants/km^2. The main city of the watershed is Quimper, the third largest city of Brittany. Eight watercourses cross the watershed and group within the Odet coastal river. Agricultural wetlands represent 5.1 per cent of the watershed area.

Wetland management is a good empirical counterpart to our theoretical model because managing wetlands incurs opportunity costs to the farmers but increases both local (water quality) and global (biodiversity habitat) PG provision.[8] Bareille, Couzier and Dupraz (2017) estimated a conservative value

8 Although the Odet watershed is not a NUTS2 region, we consider that the watershed represents a credible counterpart to our theoretical regions. This simplification makes sense because the benefits of the local PG (here, water quality) are captured inside the watershed, and regional government representatives are part of the local agencies that are in charge of improving water quality in the watershed. We consider that the global PG value is captured by all EU inhabitants.

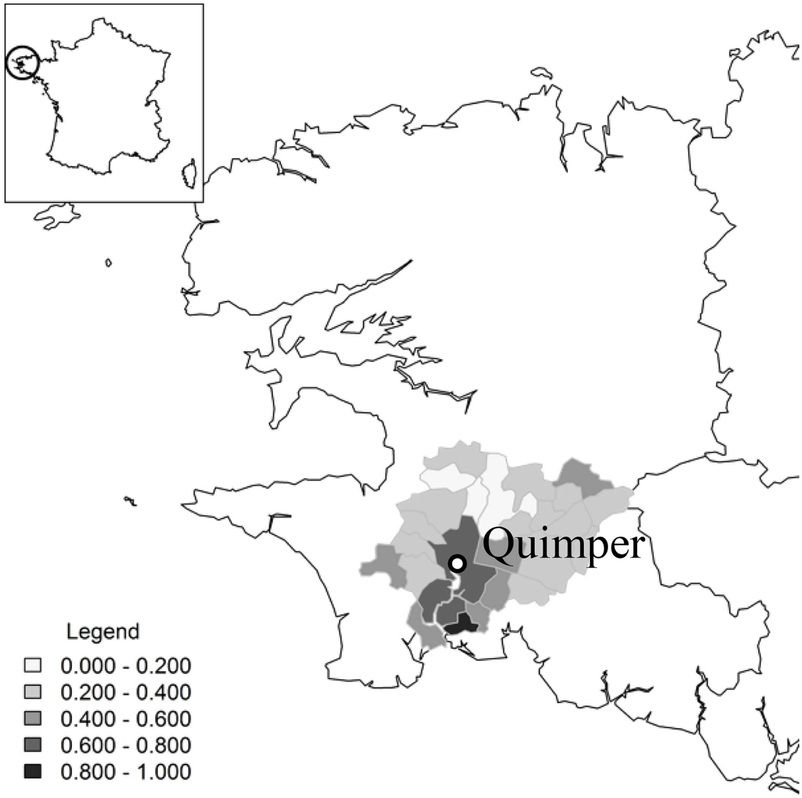

Fig. 2. Wetland abandonment rate in the Odet watershed (*source*: Bareille, Couzier and Dupraz, 2017).

of 330€/Ha for the PGs provided by agricultural wetlands, with 300€/Ha for the local PG (*i.e.* water quality) and 30€/Ha for the global PG (*i.e.* biodiversity habitat). The low productivity of agricultural wetlands encourages farmers to abandon their wetlands. In this context, farmers managing wetlands receive a payment of 120€/ha, thanks to the AECM 'Herbe_13' defined in Measure 10 of the 2014–2020 Rural Development Program for Brittany. The subsided areas should respect the maximum animal density of 1.4 unit/ha, a maximal nitrogen fertilisation and the interdiction of pesticides and tillage. Despite these payments, wetland abandonment remains an issue. Bareille, Couzier and Dupraz (2017) determined that 46 per cent of the agricultural wetlands were abandoned in Brittany. In particular, 1,800 Ha of agricultural wetlands were abandoned in the Odet watershed (Figure 2).

Based on a realistic parametrisation of the theoretical model, we compare the welfare emerging from the Odet watershed landscape under the control of regional (Brittany), national (France) and central (EU) governments. In a first set of simulations (hereafter referred to as the 'homogeneous farmers' case), we group the municipalities into two groups (upstream and downstream), and we assume, as in the theoretical model, homogenous opportunity costs across the two groups of farmers. The PG values are taken from Bareille, Couzier and Dupraz (2017). Given the high uncertainty on several parameter levels, we run a sensitivity analysis on both the global PG value and the transaction costs. In the second case (hereafter referred to as the 'heterogeneous farmers' case), we account for heterogenous opportunity costs and more heterogeneous PG benefits to reproduce the real level of wetland abandonment.[9] The details of the calibration are provided in Appendix D. The optimisation problem is solved using the GAMS software.

3.2. Results

3.2.1. *Homogeneous farmers.* Table 1 presents the results of the empirical model, in the case of homogeneous farmers, when the agri-environmental payments are designed by (i) the European government (complete centralisation), (ii) the regional government (complete decentralisation) and (iii) the national government (partial decentralisation). We here assume no differences in the agency costs (*i.e.* the theoretical case of null transaction costs). The results follow the theoretical analysis: decentralisation of the CAP increases the welfare compared to the actual centralised situation. We find that the optimal level of decentralisation is the national level, resulting in a 66 per cent increase in welfare with respect to the full centralisation case. As the theoretical model suggests, in the absence of any additional transaction costs, complete decentralisation is not the optimal choice. As expected, even if the aggregate level of abandonment increases with decentralisation, the gains from decentralisation are due to a decrease in the abandonment of the most valuable lands, *i.e.* the upstream wetlands. This shift is due to a reorientation of the subsidies towards the upstream wetlands (Table 1). The results of the regional and national governments in Table 1 are close because the parameters $\theta(S)$ are almost equal in the two cases: equal to 1 for the regional government and 0.979 for the national government.[10]

Table 1. Summary of results on the Odet watershed for homogenous farmers

	Regional government	National government	European government
Welfare (1,000,000 €)	160.51	160.64	96.71
Payment level (€, upstream)	68.60	67.43	41.15
Payment level (€, downstream)	0.02	1.79	41.15
Abandonment rate (%, average)	0.77	0.77	0.73

9 Indeed, the calibration in the case of central intervention with homogeneous payments of 120€/Ha (as in the existing case) allows us to reproduce the real levels of wetland abandonment across the municipalities of the watershed (see Appendix D).

10 There are 281 and 13 NUTS2 regions in Europe and France, respectively. As a result, the parameter $\theta(S)$ for the French government is equal to $1 - \frac{13-1}{2\cdot(281-1)} \approx 0.979$.

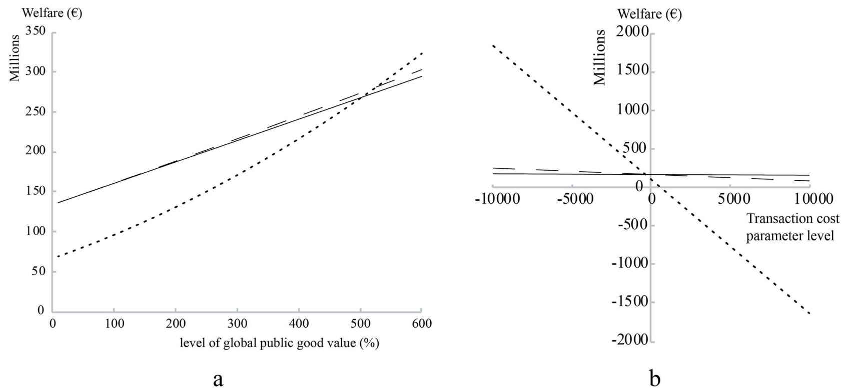

Fig. 3. Welfare for (a) different values of the global PG (as a per cent of the original welfare) and (b) different transaction costs under the regional (solid line), the national (dashed line) and the central governments (dotted line).

The interest of decentralisation must be further evaluated to observe whether such a result holds in the presence of transaction costs. The relative value of the two types of PG is also a major driver of the results. The small difference between complete decentralisation and partial decentralisation is due to the relatively high value of the local PG with respect to the value of the global PG. We provide a sensitivity analysis on these two points in the next paragraph.

For the sensitivity analysis on the global PG value, we modify the value by multiplying *w* by a coefficient of $0.1 \leq a \leq 6$ with 0.1 steps. These increases represent different environmental practices, *e.g.* a practice that mainly provides a global PG, such as no-tillage. Figure 3a shows the welfare effects emerging from such a sensitivity analysis in the cases of the three different governments. We find that, even when the global PG value decreases by 75 per cent, the national government remains the best level of intervention. The regional government is thus favourable only when the targeted environmental practice produces very low global PG. Figure 3a also shows that the EU government would become the best level of intervention if the global PG increased by more than 520 per cent. Thus, the EC should continue to target practices that are of high interest for global PG provision. In particular, central intervention would still be required for Natura 2000 areas or for agricultural policy targeting climate change mitigation.

The sensitivity analysis on the transaction costs shows how these are major determinants of the optimal level of decentralisation. Indeed, in the case of economies of scale, the EU undoubtedly represents the most efficient government level, but this rapidly changes as opportunity costs increase. Welfare under regional and national governments is less sensitive to changes in transaction costs. The results for the regional and national governments remain close in Figure 3b because, despite the additional transaction costs,

Table 2. Summary of results on the Odet watershed for heterogeneous farmers

	Regional government	National government	European government
Welfare (1,000,000 €)	126.72	127.54	29.34
Payment level (€, average)	43.21	45.30	89.69
Payment level (std/average)	0.95	0.92	0.79
Total expenditures (€)	175,128	189,114	664,328
Abandonment rate (%, average)	0.77	0.76	0.50
Abandonment rate (std/average)	0.23	0.25	0.78

the French government governs only 4.6 per cent of all the European regions.

3.2.2. *Heterogeneous farmers.* Table 2 presents the results of the empirical model in the case of the heterogeneous farmers and more heterogeneous local PG values (see Appendix D).[11] We again find that the best level of decentralisation of the CAP is the national level. National and regional governments increase the welfare by 435 and 432 per cent, respectively, compared to the European government. As expected, we find that the payments from the decentralised governments decrease sharply: they represent 26 per cent (28 per cent) of the centralised payments when the regional (national) government is in charge. As a consequence, the share of wetland abandonment increases with decentralisation. The evolution of abandoned wetlands is, however, heterogeneous across municipalities, *e.g.* the abandonment rate decreases in the eight upstream municipalities closest to Quimper (see maps in Appendix E). This is due to an increase in the heterogeneity of the payments across the municipalities: the coefficient of variation of the agri-environmental payments increases with decentralisation (Table 2). Our results show that decentralised governments choose to reduce their agri-environmental budget and finance the most valuable lands. Overall, our results suggest that the decentralisation of agri-environmental payments represents an option worth exploring, either partially or totally.

4. Discussion

4.1. Theoretical section

By integrating the complexity of PG provision from agriculture within an environmental federalism framework, this paper provides some theoretical

11 Note that, as Sections 3.2.1 and 3.2.2 represent two distinct realities, the results of Table 2 are not comparable with the results of Table 1.

background for the potential assessment of the decentralisation of the design of agri-environmental payments. Such an issue is becoming a crucial feature of the future of the CAP (COM(2018) 392). Our theoretical model is based on two main assumptions related to the advantages and disadvantages of different levels of government, namely, the different knowledge on PG values and the different agency costs. These two concepts are part of the second-generation theories on fiscal federalism (Oates, 2005). One original contribution of our paper is the consideration that the local PG values are heterogeneous inside each region and that hierarchical governments have different knowledge of the value distribution. Additionally, we depart from the standard assumption that agency costs include only economies of scale by considering additional coordination costs.

Our results show that total or partial decentralisation could improve the welfare of the whole economy. We find that the benefits of decentralisation increase as the heterogeneity of local PG values increases and as the global PG values decrease. Indeed, on the one hand, better knowledge of the heterogeneity of local PG values allows decentralised governments to better target payments. On the other hand, the total amount of financed land decreases under decentralisation, as the global PG benefits are not fully internalised. An increase in the global PG value leads to higher externalities in the case of decentralised design of agri-environmental payments. These results are consistent with the Oates' decentralisation theorem (1972) within a given jurisdiction. We find that, in most cases, local governments can do 'more with less' (Busemeyer, 2008), by reducing the total spending and concentrating payments on the most valuable lands. This is a major result given the sensitivity of this question for European stakeholders. In particular, this suggests that European farmers would be harmed, on average, by a decentralisation of the agri-environmental policy, confirming the results from the survey of Beckmann, Eggers and Mettepenningen (2009). The fact that total spending is primarily reduced through the reduced payments on the least valuable lands suggests that decentralisation should increase the efficiency of agri-environmental payments. We find that the optimal level of governmental intervention depends on the farmers' opportunity costs and the deadweight losses only when hierarchical governments face different agency costs (due to economies of scale and coordination costs). To our knowledge, no study has estimated these two types of transaction costs together. This gap in the literature is a large drawback to studying the efficiency of the decentralisation of agri-environmental payments, as already emphasised by Beckmann, Eggers and Mettepenningen (2009) and Mettepenningen, Beckmann and Eggers (2011). Our sensitivity analysis on agency costs illustrates this lack of information.

Our theoretical results are, however, subject to some limitations. First, we have considered that all hierarchical governments have the same knowledge on the farmers' opportunity costs. We have assumed that this feature is justified in the case of the CAP due to the flows of information from regional agencies to the EC.

Second, we have considered that both firms and residents are immobile, while the literature on environmental federalism considers that firms and/or residents are mobile. We justify our choice regarding farmers' immobility given the lower sensitivity of farmers' labour to short-term changes: farmers' mobility occurs in the long term when farmers start their business, leave agriculture or retire (Bougherara and Gaigné, 2008). Additionally, given the small shares of the agri-environmental budget in the total and regional budgets, it is unlikely that residents move to avoid an increase in agri-environmental tax.

Third, we have assumed that the PGs enter linearly within the benefit function (1). This simplifying assumption prevents the analysis of any strategic interaction or competition amongst the different governments. The consideration of alternative functional forms with marginally decreasing benefits would have led to less contrasted results. In particular, the benefits of decentralisation would have decreased due to the 'race to the bottom' mechanism (Busemeyer, 2008).

Fourth, we have made restrictive simplifications with the reality of European agri-environmental budget and payments. For example, we have assumed that decentralised governments could raise their own agri-environmental budget. However, for the time being, all states/regions contribute to the European budget proportionally to their wealth and development levels, and the European budget is then split between the European objectives (including the agri-environmental budget). A second restrictive simplification is that we have not considered that the states and the regional governments/agencies co-financed the agri-environmental payments. The European agri-environmental budget is thus characterised by both horizontal and vertical transfers. One can even consider that the agri-environmental budget is exogenous and thus that the type of decentralisation that we have explored with an endogenous agri-environmental budget is not the type explored by the EC for the following CAP reform. In this case, an alternative reform could be to perform higher vertical transfers. This reform could lead to fiscal competition between regional governments, notably if regions have heterogeneous PG preferences. We do not consider such competition here, but future studies could investigate this possibility.

4.2. Numerical section

Our numerical application illustrates the potential gains from the future CAP reform. In the case of agricultural wetlands facing a risk of abandonment, the land allocations resulting from decentralisation always improve welfare compared to the current centralised case. It appears that the national government, as suggested in the CAP reform, is the best level of decentralisation. Further decentralisation would, however, decrease the welfare compared to national intervention, although regional decentralisation would decrease the welfare reached by the national government by only 0.63 per cent. We also find that decentralisation would decrease the agri-environmental budget by

300–400 per cent. In any case, national decentralisation in the spirit of the EC's proposal COM(2018) 392 is of interest for the retained PG values. Our sensitivity analysis confirmed that such decentralisation would be beneficial even if PG values increase by a sensible percentage *ceteris paribus*.

Our results are subject to some limitations. First, wetland abandonment is a specific example where agricultural management increases both local and global PG provision. We can imagine cases where payments would improve the provision of one type of PG but decrease the provision of the other. Such a context could lead to competition between hierarchical governments, which is non-existent in our case. Second, the results depend on the valuation of the considered PGs, which are subject to their own limitations (Bareille, Couzier and Dupraz, 2017). Our spatialisation of the local PG values in the second case is also based on rough assumptions from the distance-decay literature, which can affect our welfare quantification.

5. Conclusion and policy recommendations

In this paper, we provide a framework to examine the gains of the decentralisation of the design of agri-environmental payments. We apply the principles of environmental federalism to the specificities of agri-environmental policy: (i) environmentally friendly land-use produces both local and global PGs, (ii) the value of local PG is more heterogeneous across space than the value of the global PG is, (iii) hierarchical governments have different knowledge of the heterogeneity of the local PG value within each region and (iv) hierarchical governments present different agency costs.

Given the assumptions of the model, the theoretical analysis shows that the efficiency of agri-environmental payments should increase with decentralisation due to (i) a reduction of the total payments from society to farmers and related deadweight losses and (ii) a reorientation of the payments to the lands with the highest local PG value. The savings would be realised by decreasing the payments over the least valuable lands. Our results suggest that a representative farmer would be harmed by a decentralisation of the agri-environmental policy. The optimal level of decentralisation decreases as the heterogeneity of the local PG values increases and as the global PG values decrease. However, complete decentralisation is never optimal. Our numerical analysis provides insights into the magnitude of the gains of decentralisation in the illustrative case of wetland abandonment. Overall, the decentralisation of the agri-environmental policy at the national scale appears to be the most suitable reform. Our example suggests that national decentralisation would increase welfare by 66–435 per cent.

Our results provide some suggestions for the future reform of the CAP. First, the theoretical model, albeit simple, suggests that setting a CAP characterised by higher freedom for decentralised governments to design agri-environmental payments is a strategy worth exploring. In particular, a CAP reform giving higher flexibility to the decentralised governments to set their own agri-environmental payments and priorities, by, *e.g.* decreasing the power of the

EC in the context of articles 107 and 108 of the Treaty on the Functioning of the European Union, seems promising. Second, our results are in line with the EC proposal COM(2018) 392: a partial decentralisation at the national level seems to be a compromise that can balance the trade-offs between more precise knowledge of local needs and the internalisation of global PGs. However, our results suggest that the EC should continue to design agri-environmental payments targeting practices that provide mostly global benefits (rather than local benefits). For example, the EC should remain in charge of the financing of agricultural practices whose main benefits are to conserve biodiversity or reduce carbon emissions.

Note that a reformulation of the European legislative context may, however, not be required to implement these recommendations; the utilisation of the '*de minimis*' agricultural subsidies may be sufficient (Langlais, 2019). These subsidies, introduced in the regulation n°1998/2006 (2006) and generalised to the agricultural sector in the regulation n°1408/2013 (2013) for the 2014–2020 period, state that regional governments can subsidise firms without any approval of the EC if the total amount of subsidies does not exceed €15,000 per firm for three consecutive years.[12] Taking our illustrating case of agricultural wetlands in Brittany, the average area of wetlands is approximately 5 Ha per farm (Bareille, Couzier and Dupraz, 2017), while the simulated payments reach a maximum of 218€/Ha in our numerical exercise. The limit of '*de minimis*' subsidies would not be reached in this case. Given the amounts per hectare of most of the agri-environmental subsidies, this threshold should not be a constraint.

These propositions could be deepened by the modification of some features of our analysis. In particular, future works could study strategic interactions between regions and different hierarchical governments of heterogeneous size in a more decentralised context (Epple and Nechyba, 2004). A proper assessment of agri-environmental policy decentralisation should probably take into account the political economy aspects of such a reform (Besley and Coate, 2003), as local political phenomena would gain importance. Such questions are of interest for the analysis of the decentralisation of agri-environmental payments.

Acknowledgements

The authors are grateful to the three referees for their valuable suggestions on the manuscript. The authors would like to thank Pierre Dupraz, Carl Gaigné and Davide Viaggi for their helpful suggestions on earlier drafts of the paper. This research was funded by the EU's Horizon 2020 program under grant agreement n°633838 (PROVIDE project, http://www.provide-project.eu/). This work does not necessarily reflect the view of the EU and in no way anticipates the Commission's future policy.

12 Note that, in the case of farms run by several associates, the limit of "de minimis" subsidies is 15,000€ multiplied by the number of associates.

References

Ahmad, E. (2006). *Handbook of Fiscal Federalism*. Northampton, USA: Edward Elgar Publishing.

Arends, H. (2017). More with less? Fiscal decentralisation, public health spending and health sector performance. *Swiss Political Science Review* 23: 144–174.

Bareille, F., Couzier, J. and Dupraz, P. (2017). *Delivrable D4.2.—Report on Valuation Results: Demand-side Valuation Results—Annex 4—PROVIDE H2020 Project "PROVIding Smart DElivery of Public Goods by EU Agriculture and Forestry", Grant Agreement No. 633838*. Cordoba, Spain: University of Cordoba.

Barrett, S. (1994). Self-enforcing international environmental agreements. *Oxford Economic Papers New Series* 46: 878–894.

Beckmann, V., Eggers, J. and Mettepenningen, E. (2009). Deciding how to decide on agri-environmental schemes: the political economy of subsidiarity, decentralisation and participation in the European Union. *Journal of Environmental Planning and Management* 52: 689–716.

Benassy-Quere, A., Gobalraja, N. and Trannoy, A. (2007). Tax and public input competition. *Economic Policy* 22: 386–430.

Besley, T. and Coate, S. (2003). Centralized versus decentralized provision of local public goods: a political economy approach. *Journal of Public Economics* 87: 2611–2637.

Bougherara, D. and Gaigné, C. (2008). On the efficiency of decentralized conservation policy. In: Is Decentralization of Agri-Environmental Policy Welfare Enhancing? Program for Environmental and Resource Economics Seminar, 06 May 2008, Urbana-Champaign, USA.

Busemeyer, M. R. (2008). The impact of fiscal decentralisation on education and other types of spending. *Swiss Political Science Review* 14: 451–481.

Cavailhès, J. and Wavresky, P. (2003). Urban influences on periurban farmland prices. *European Review of Agricultural Economics* 30: 333–357.

Crémer, J., Estache, A. and Seabright, P. (1996). Decentralizing public services: what can we learn from the theory of the firm? *Revue d'Economie Politique* 106: 37–60.

Czajkowski, M., Budziński, W., Campbell, D. et al. (2017). Spatial heterogeneity of willingness to pay for forest management. *Environmental and Resource Economics* 68: 705–727.

Droste, N., Becker, C., Ring, I. et al. (2018). Decentralization effects in ecological fiscal transfers: a Bayesian structural time series analysis for Portugal. *Environmental and Resource Economics* 71: 1027–1051.

Epple, D. and Nechyba, T. (2004). Fiscal decentralization. In *Handbook of Regional and Urban Economics*, Vol. 4. Amsterdam, Netherlands: Elsevier, 2423–2480.

European Court of Auditors (2011). Is Agri-environmental support well designed and managed? Luxembourg: European Court of Auditors. Special Report No. 7. ISSN 1831-0834.

Falconer, K., Dupraz, P. and Whitby, M. (2001). An investigation of policy administrative costs using panel data for the English environmentally sensitive areas. *Journal of Agricultural Economics* 52: 83–103.

Gilbert, G. and Picard, P. (1996). Incentives and optimal size of local jurisdictions. *European Economic Review* 40: 19–41.

Gómez-Limón, J. A., Gutiérrez-Martín, C. and Villanueva, A. J. (2019). Optimal design of agri-environmental schemes under asymmetric information for improving farmland biodiversity. *Journal of Agricultural Economics* 70: 153–177.

Harstad, B. and Mideksa, T. K. (2017). Conservation contracts and political regimes. *The Review of Economic Studies* 84: 1708–1734.

Inman, R. P. (2003). Transfers and bailouts: enforcing local fiscal discipline with lessons from US federalism. In *Fiscal Decentralization and the Challenge of Hard Budget Constraints*, Massachusetts London, England: The MIT Press Cambridge, 45–47.

Johnston, R. J. and Ramachandran, M. (2014). Modeling spatial patchiness and hot spots in stated preference willingness to pay. *Environmental and Resource Economics* 59: 363–387.

Kumar, S. and Managi, S. (2009). Compensation for environmental services and intergovernmental fiscal transfers: the case of India. *Ecological Economics* 68: 3052–3059.

Langlais, A. (2019). *L'agriculture et les paiements pour services environnementaux. Quels questionnements juridiques?*. Rennes, France: PUR, 447.

Latacz-Lohmann, U. and Van der Hamsvoort, C. (1997). Auctioning conservation contracts: a theoretical analysis and an application. *American Journal of Agricultural Economics* 79: 407–418.

Lessmann, C. and Markwardt, G. (2010). One size fits all? Decentralization, corruption, and the monitoring of bureaucrats. *World Development* 38: 631–646.

Logar, I. and Brouwer, R. (2018). Substitution effects and spatial preference heterogeneity in single-and multiple-site choice experiments. *Land Economics* 94: 302–322.

Mettepenningen, E., Verspecht, A. and Van Huylenbroeck, G. (2009). Measuring private transaction costs of European agri-environmental schemes. *Journal of Environmental Planning and Management* 52: 649–667.

Mettepenningen, E., Beckmann, V. and Eggers, J. (2011). Public transaction costs of agri-environmental schemes and their determinants—analysing stakeholders' involvement and perceptions. *Ecological Economics* 70: 641–650.

Oates, W. E. (2001). *A Reconsideration of Environmental Federalism*. Washington, DC: Resources for the Future Washington.

Oates, W. E. (1999). An essay on fiscal federalism. *Journal of Economic Literature* 37: 1120–1149.

Oates, W. E. (2005). Toward a second-generation theory of fiscal federalism. *International Tax and Public Finance* 12: 349–373.

Oates, W. E. (1972). *Fiscal Federalism*. Cheltenha, UK: Edward Elgar Publishing.

OECD. (2015). *Public Goods and Externalities Agri-environmental Policy Measures in Selected OECD Countries*. Paris, France: OECD Publishing.

Olson, M. J. (1969). The principle of "fiscal equivalence": the division of responsibilities among different levels of government. *American Economic Review* 59: 479–487.

Pate, J. and Loomis, J. (1997). The effect of distance on willingness to pay values: a case study of wetlands and salmon in California. *Ecological Economics* 20: 199–207.

Perino, G. and Talavera, O. (2013). The benefits of spatially differentiated regulation: the response to acid rain by US states prior to the acid rain program. *American Journal of Agricultural Economics* 96: 108–123.

Ring, I. (2008). Integrating local ecological services into intergovernmental fiscal transfers: the case of the ecological ICMS in Brazil. *Land use policy*, 25(4), 485–497.

Sigman, H. (2014). Decentralization and environmental quality: an international analysis of water pollution levels and variation. *Land Economics* 90: 114–130.

Tiebout, C. M. (1956). A pure theory of local expenditures. *Journal of Political Economy* 64: 416–424.

Tiebout, C. M. and Houston, D. B. (1962). Metropolitan finance reconsidered: budget functions and multi-level governments. *The Review of Economics and Statistics* 44: 412–417.

Weber, A. (2015). Implementing EU co-financed agri-environmental schemes: effects on administrative transaction costs in a regional grassland extensification scheme. *Land Use Policy* 42: 183–193.

Appendix A: Proof of Proposition 3

Noting that $\frac{\partial \dot{v}_1(S)}{\partial S} = -\frac{v}{2\cdot(R-1)}$ and $\frac{\partial \dot{v}_2(S)}{\partial S} = \frac{v}{2\cdot(R-1)}$, the FOC of welfare (5) according to the size of the governments S is:

$$\frac{\partial W(S)}{\partial S} = \frac{R}{2\cdot k\cdot c}\cdot\left[\begin{array}{l}\left(-\frac{1}{2}\cdot\frac{v}{R-1}+w\right)\cdot(v+w\cdot R)+\left(\frac{1}{2}\cdot\frac{v}{R-1}+w\right)\cdot w\cdot R\\ -\left[\left(-\frac{1}{2}\cdot\frac{v}{R-1}+w\right)\cdot\left(\left(1-\frac{1}{2}\cdot\frac{S-1}{R-1}\right)\cdot v+w\cdot S\right)\right.\\ \left.+\left(\frac{1}{2}\cdot\frac{v}{R-1}+w\right)\cdot\left(\frac{1}{2}\cdot\frac{S-1}{R-1}\cdot v+w\cdot S\right)\right]\end{array}\right]=0$$

which is equivalent to:

$$\left(-\frac{1}{2}\cdot\frac{v}{R-1}+w\right)\cdot\left(v+w\cdot R-\left(1-\frac{1}{2}\cdot\frac{S-1}{R-1}\right)\cdot v-w\cdot S\right)$$
$$+\left(\frac{1}{2}\cdot\frac{v}{R-1}+w\right)\cdot\left(w\cdot R-\frac{1}{2}\cdot\frac{S-1}{R-1}\cdot v-w\cdot S\right)=0$$

The successive factorisation and developments of the relationship lead to the following:

$$-\frac{1}{2}\cdot\frac{S-1}{(R-1)^2}\cdot v^2+2\cdot w^2\cdot(R-S)=0$$

Multiplying this last expression by $(R-1)^2$ leads to

$$4\cdot R\cdot w^2\cdot(R-1)^2+v^2=S\cdot\left(4\cdot w^2\cdot(R-1)^2+v^2\right)$$

which is equivalent to relation (11), leading to Proposition 3.

Appendix B: Proof of Proposition 4

The derivative of $T(S)$ in relation (12) relative to S leads to

$$\frac{\partial T(S)}{\partial S}>0 \iff S>\frac{v^2-2\cdot(R-1)\cdot w\cdot v}{2\cdot(R-1)\cdot w^2}$$

The total payments increase with the degree of centralisation once S exceeds threshold $\overline{S}=\left[v^2-2\cdot(R-1)\cdot w\cdot v\right]/\left[2\cdot(R-1)\cdot w^2\right]$. This threshold can be positive or negative. After examining the properties of the trinomial $v^2-2\cdot(R-1)\cdot$

$w \cdot v - 2 \cdot (R-1) \cdot w^2 = 0$, we conclude that $\overline{S}$ is higher than 1 (*i.e.* the most local government) when $v \in [(R-1-\sqrt{R^2-3}) \cdot w; (R-1+\sqrt{R^2-3}) \cdot w]$, *i.e.* in the case where $v \in]0; (R-1+\sqrt{R^2-3}) \cdot w]$ given that $v > 0$ and $R \geq 2$. Otherwise, the threshold is negative, and the total payments from society to the farmers always increase with the degree of centralisation.

Appendix C: Proof of Proposition 5

The FOC of welfare (5) according to the size of the governments is:

$$\frac{\partial W(S)}{\partial S} = \frac{R}{2 \cdot k \cdot c} \cdot \begin{bmatrix} \left(-\frac{1}{2} \cdot \frac{v}{R-1} + w\right) \cdot (v + w \cdot R) + \left(\frac{1}{2} \cdot \frac{v}{R-1} + w\right) w \cdot R \\ -\left[\left(-\frac{1}{2} \cdot \frac{v}{R-1} + w\right) \cdot \left(\left(1 - \frac{1}{2} \cdot \frac{S-1}{R-1}\right) \cdot v + w \cdot S\right) \right. \\ \left. + \left(\frac{1}{2} \cdot \frac{v}{R-1} + w\right) \cdot \left(\frac{1}{2} \cdot \frac{S-1}{R-1} \cdot v + w \cdot S\right) + 2 \cdot k^2 \cdot c \cdot \tau\text{'}(S) \right] \end{bmatrix} = 0$$

which is equivalent to:

$$\left(-\frac{1}{2} \cdot \frac{v}{R-1} + w\right) \cdot \left(v + w \cdot R - \left(1 - \frac{1}{2} \cdot \frac{S-1}{R-1}\right) \cdot v - w \cdot S\right)$$
$$+ \left(\frac{1}{2} \cdot \frac{v}{R-1} + w\right) \cdot \left(w \cdot R - \frac{1}{2} \cdot \frac{S-1}{R-1} \cdot v - w \cdot S\right) - k^2 \cdot c \cdot \tau\text{'}(S) = 0$$

The successive factorisation and developments of the relationship lead to the following:

$$\left(-\frac{1}{2} \cdot \frac{S-1}{(R-1)^2} \cdot v^2\right) + 2 \cdot w^2 \cdot (R-S) - k^2 \cdot c \cdot \tau\text{'}(S) = 0$$

Multiplying this last expression by $(R-1)^2$ leads to

$$4 \cdot R \cdot w^2 \cdot (R-1)^2 + v^2 - 2 \cdot k^2 \cdot c \cdot \tau\text{'}(S) = S \cdot \left(4 \cdot w^2 \cdot (R-1)^2 + v^2\right)$$

which is equivalent to relation (13), leading to Proposition 5.

Appendix D: Calibration and functional forms

Calibration of the supply side

In the ‘homogeneous farmers’ case, we calibrate the cost parameter of wetland management from the current observed aggregate level of wetland management X^0 and the Herbe_13 homogenous agri-environmental payment p^0 of 120€. Following the farmers’ FOC of (2), the cost parameters are given by $c = p^0/X^0$. The definition of such homogenous costs prevents us from reproducing the municipal abandonment levels in Figure 2 and allows us to reach only the aggregate level of abandonment. As in the theoretical exercise, we consider that all hierarchical governments are aware of this opportunity cost.

In the ‘heterogeneous farmers’ case, we take into account the heterogeneity of the opportunity costs of managing wetlands across the municipalities. These costs

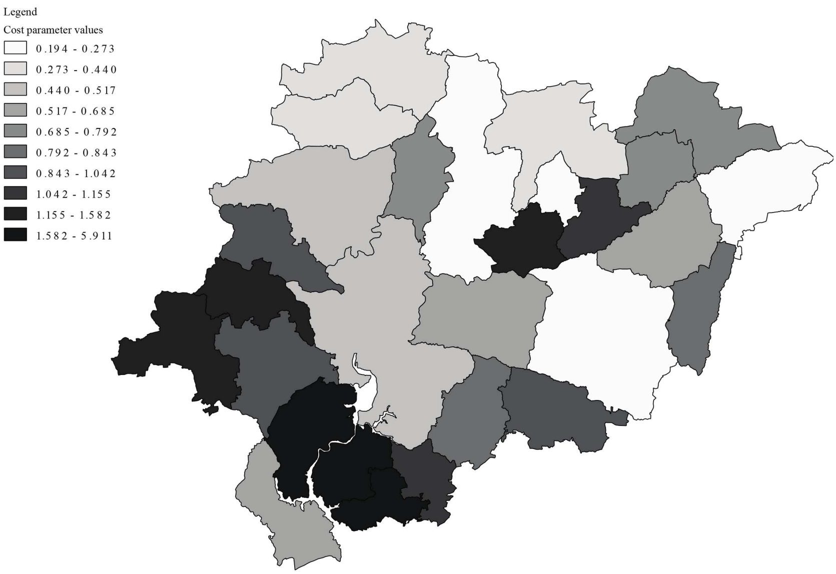

Fig. A1. Map of the calibrated cost parameters (*source*: authors' own computation).

are indeed heterogeneous because they depend on local conditions (*e.g.* features of the land market). We calibrate the municipal cost parameter c_i of wetland management from the current observed levels of managed wetland X_i^0 ($i \in [1; 27]$, see Figure 2) and the agri-environmental payment p^0. The cost parameters are given by $c_i = p^0/X_i^0$ (see Figure A1. for the calibrated values). This procedure leads to cost parameters whose levels decrease with decreasing distance to the seacoast, which is consistent with the usual results on the functioning of land markets (Cavailhès and Wavresky, 2003). We consider that all hierarchical governments are aware of this heterogeneity in the opportunity costs.

D.2. Calibration of the demand side

In the 'homogeneous farmers' case, we set the value of the wetlands in a dichotomous way: if the wetland is located upstream of Quimper, the value of the local PG (water filtration) it provides is equal to the value determined in Bareille, Couzier and Dupraz (2017), *i.e.* $v = 300€/\text{Ha}$; if the wetland is located downstream of Quimper, the value of the local PG (water filtration) it provides is null. This calibration is supported by the fact that Quimper concentrates most of the consumption of the domestic watershed but also that the water treatment plant of the watershed is located in Quimper. Thus, the wetlands located downstream of Quimper do not provide any local benefits to the population. There are 10 and 17 municipalities located downstream and upstream of Quimper, respectively.

In the second case, we integrate the heterogeneity of the local PG across the watershed in a more in-depth way by considering that the value of water filtration is heterogeneous for upstream municipalities. Indeed, given the hydrology of the watershed, the closest wetland to the water treatment plant is the one that filters the highest volume of water, *i.e.* the one with the highest value. One can thus assume that the value of water filtration decreases with the distance from Quimper. This assumption is supported by the literature that displays a distance decay in the willingness-to-pay for PGs: the value of the local PG decreases with the distance between the household and the locality where the local PG is provided (see Pate and Loomis, 1997 for an application on wetlands). Therefore, we write the utility of the watershed as follows:

$$U_{\text{water shed}} = \int_0^{d} \left(\mathbf{1} \frac{v_{\text{water}}}{d_i} + w \right) X_i dd_i$$

where d_i is the distance in kilometres between the centroid of the municipality i and the centroid of Quimper, $\overline{d}$ is the distance between Quimper and the farthest municipality and $\mathbf{1}$ is an indicator function taking the value 1 (respectively 0) for municipalities located upstream (respectively downstream) of Quimper. Hence, all the wetlands of one municipality have the same value, which depends only on d_i. We parametrise v_{water} using the non-spatialised values of Bareille, Couzier and Dupraz (2017), such that

$$v_{\text{water}} = 300 \cdot 17 / \sum_{i=1}^{17} \frac{1}{d_i}$$

This ensures a similar average value of the local PG in the cases of homogeneous and heterogeneous farmers.

In the two cases, we have for all wetlands $w \cdot R = 30€/\text{Ha}$. Given that there are $R = 281$ regions in the EU, Proposition 4 implies that the total payments should always increase with marginal centralisation in cases where $v \notin [0; 60]$, which is the case here.

Finally, the source of public money is based on an income tax on the inhabitants of the Odet watershed. We calibrate the parameter k to 2.1871 such that the generated landscape in the heterogeneous farmers case represents exactly the existing municipal abandonment rates under the existing homogeneous AECMs (Figure 2). This implies that each 1€ spent for agri-environmental payment incurs 1.1871€ of deadweight loss in the examined watershed.

The mathematical formulation of the ‘homogeneous farmers’ case is identical to our theoretical model. The single mechanism at play that may differ in our empirical analysis is the role of the farmers’ land constraint. The increase in the number of farmers, from 2 to 27, does not play any role in this first step, as our dichotomous segregation of wetlands between upstream and downstream creates two groups of farms with identical characteristics, as in our theoretical part. In the heterogeneous farmers case, we differ from our theoretical analysis with respect to the specification of heterogeneous costs and the functional form for the heterogeneity of local PGs.

Appendix E. Maps of wetland abandonment rates under different levels of government

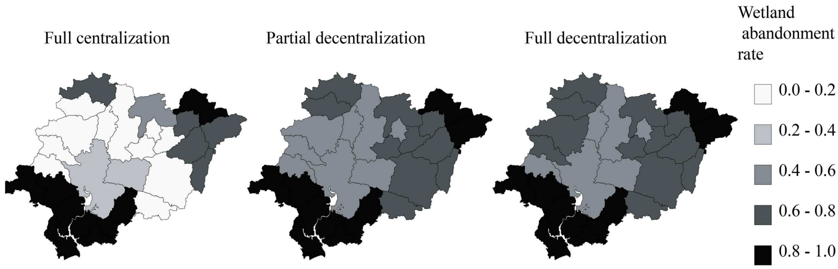

Fig. A2. Results of simulations under the control of the regional, national and EU governments (rows) with $\tau = 0$ (*source*: authors' own computation).