(Forest) Land use impact on water quality

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Impact of the location of agricultural production on ecosystem services

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Motivations

- **The importance of forest lands in providing ES**
  - The role of the **forest in the supply of a number of goods and services** is recognized by the French policymakers since the Forest Orientation Law (2001)
  - This law reinforces the role of forest policies (with other policies in rural development), **to reduce the greenhouse effect, to preserve biological diversity, to protect soils**…
  - **Water purification** is one of the most important **ecological service provided by (forest) ecosystems** to humanity

Motivations

- **Effects on land uses on water quality**
  - **Under forest cover, nitrate levels are low**

Land cover	$[NO_3^-]$ in water in the soils at a depth of 1,10m in mg/l
Forests	2
Cut fields	19
Pastures	31
Temporary grassland	28
Winter wheat	46
Rape seed (*colza*)	62
Spring cereals	120
Maize as fodder crop (*maïs fourrage*)	126

  - Source : Benoit et al. 1997

  - **Similar results observed for various pollutants** (e.g., pesticides)

Motivations

- **The forest has a major positive impact on water quality**
  - **Some wooded formations clearly have a purification role** such as riparian, alluvial forests: the root system has a filtering role and trap nutritive elements (nitrogen, potassium, phosphorus) and some toxic elements
  - **Cultivated lands liberate five times more sediments** into the water course than wooden lands: the forest contributes to protecting land, favoring infiltration, and reducing rapid flow at the surface
  - **Forests generally limit sediment flow and thus turbidity**

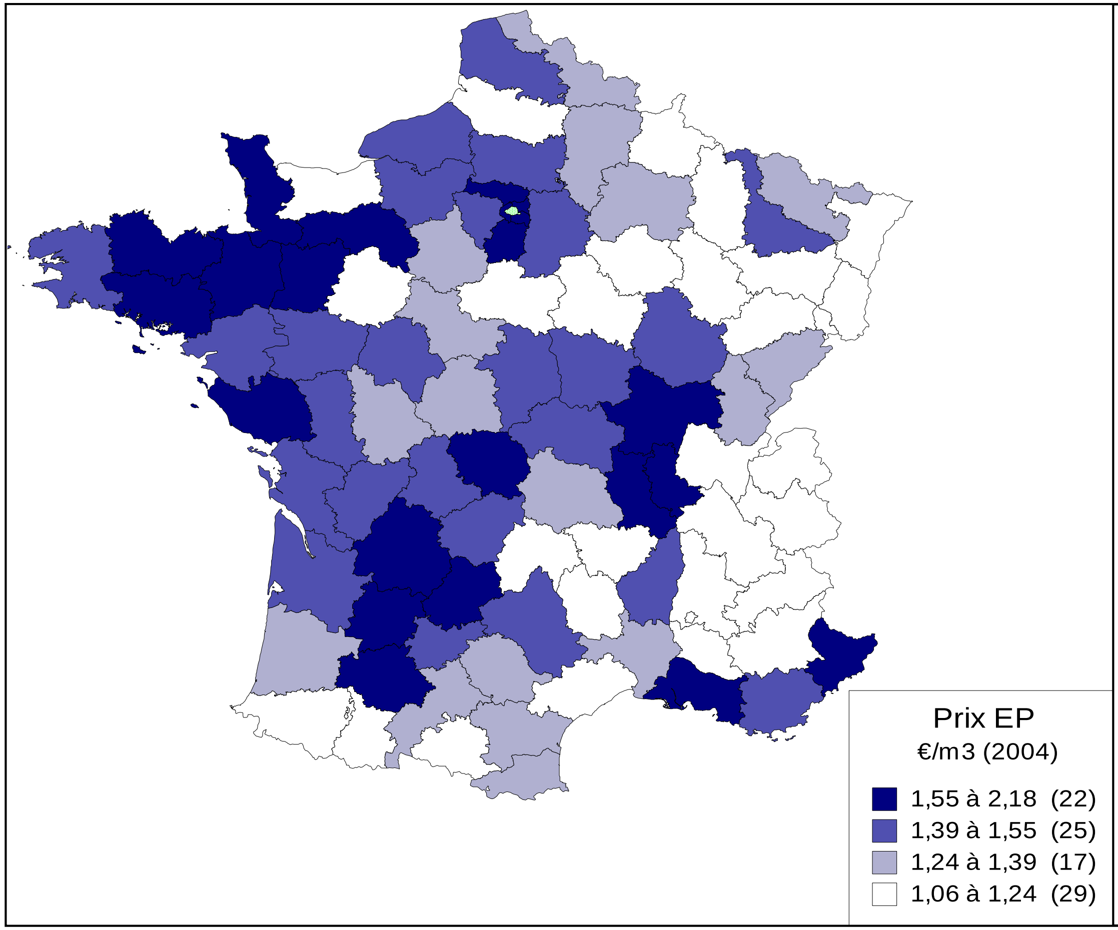
Motivations

- **Influence of forest management on water quality**
  - **Land management in forests is less intensive** than for agriculture and interventions are less frequent
  - **Very limited use of chemicals is made in forest areas**: agro-pharmaceutical products and fertilizers are rarely used
  - **Disturbances in the forest cover**, especially clear cutting, can lead to increase nitrate concentrations in drained water

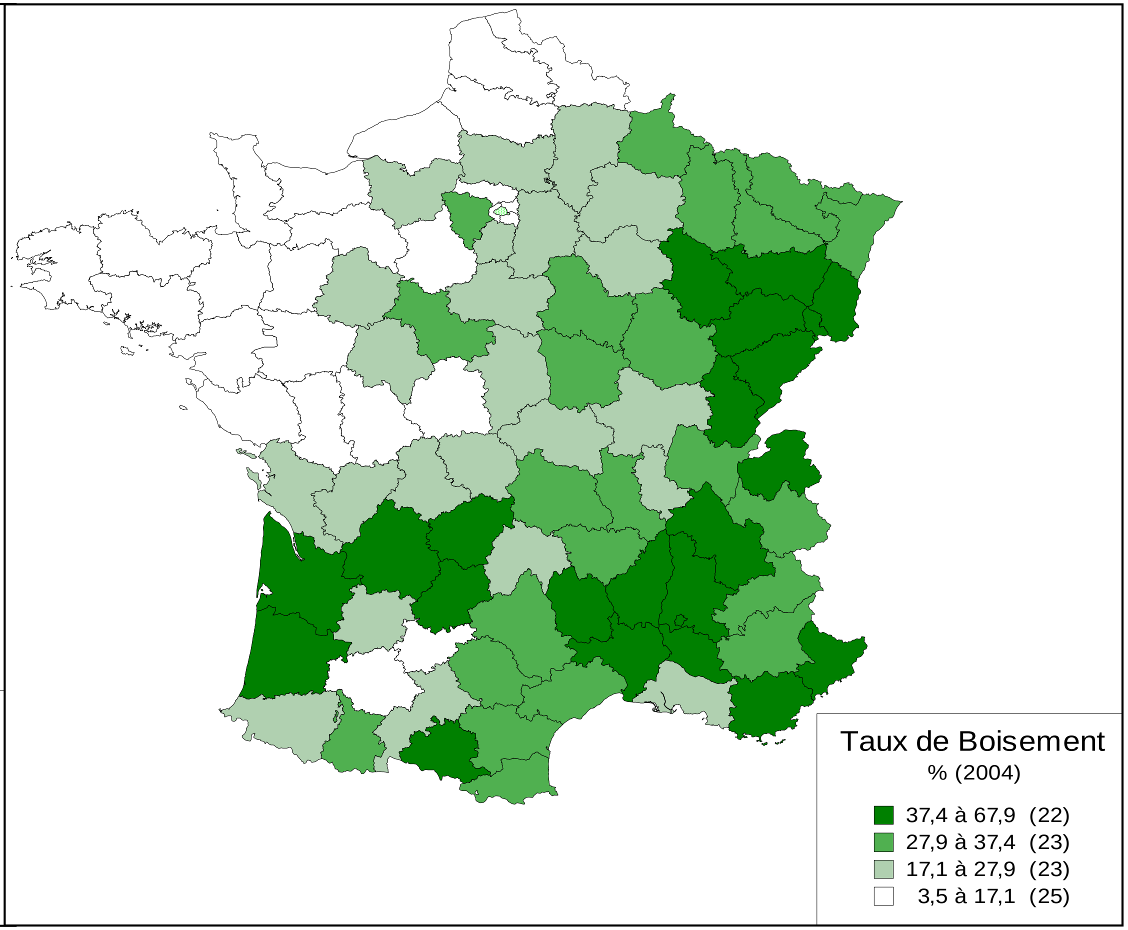
Motivations

- **Land uses have an impact on water quality and on costs of drinking water production**
  - **Forest land use is associated with the protection of water resources** from contamination and the **reduced cost of drinking water supply** (Abildtrup and Strange 2000, Willis 2002, Ernst 2004, Freeman et al. 2008)
  - Raw water from catchment areas (for drinking water purpose) with **a large portion of forests is of higher quality than that of agricultural, urban or industrial landscapes**
  - Hence **reducing the need for treatment of drinking water** and, as a result, the associated **costs and prices of drinking water supply**

Motivations



Drinking water price (2004 ; €/m³ ; IFEN SCEES)



Proportion of land area covered by forest (2004 ; % ; SCEES)

Simple correlation or causality?

Literature

- Many scientific (mainly hydrological) works on the relationship between forest (and other land uses) and water quality
- A short literature in economics
  - Impacts of alternative land uses on watershed health (Hascic and Wu, 2006; Langpap et al., 2008).
  - Still very few on ***the value of forests in supplying drinking water*** (Núñez et al. 2006, Biao et al. 2010, Elias et al. 2013)
- Vincent et al. (2015) claimed the first econometric analysis on the effect of forests on water treatment costs
  - BUT…

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Literature

- A new approach developed by a LEF team from 2009
  - Objective: estimate the economic value of the ecological service provided by land uses (especially, forest areas) on quality of raw water used for drinking water supply
  - Hypothesis: If land use affects raw water, then we can identify this impact in the process of drinking water supply:

    Raw water is transformed into drinking water with costs
  - Method: estimate a (complete) cost model for drinking water supply by taking the impact of land uses on raw water into account

Literature

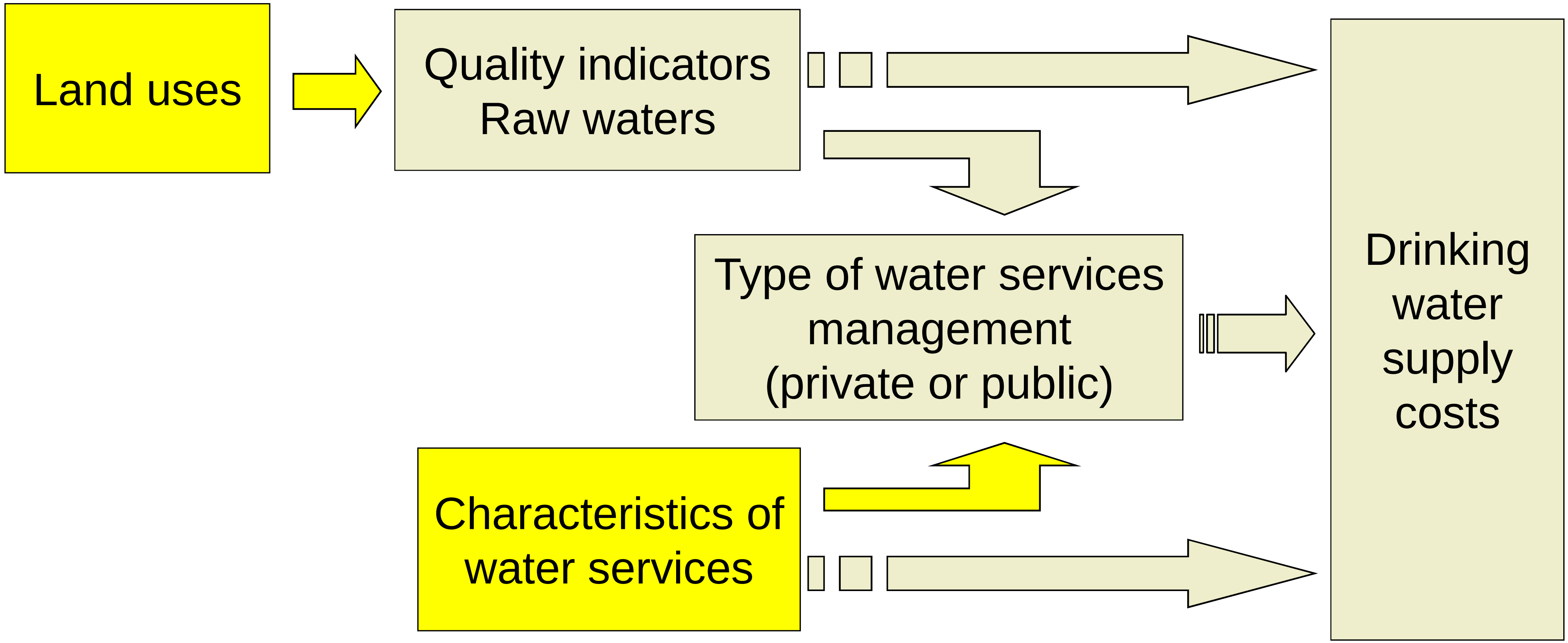
- A new approach from LEF
  - Fiquepron J., Garcia S., Stenger A. (2013). Land use impact on water quality: Valuing forest services in terms of the water supply sector. ***Journal of Environmental Management***, 126, 113-121
  - Abildtrup, J., Garcia S., Stenger A. (2013). The effect of forest land use on the cost of drinking water supply: A spatial econometric analysis. ***Ecological Economics***, 92, 126-136
  - Abildtrup J., Garcia S., Kéré E. (2015). Land use and drinking water supply: A sample selection model with spatial dependence. ***Revue d'Économie Régionale et Urbaine***, 1/2015 (mai), 321-342
  - Abildtrup J., Garcia S., Le Gallo J., Ndiaye Y. (Ongoing work).

Drinking water supply (DWS)

- DWS covers all operations from resource extraction to customer tap. Several functions with specific costs:
  - Production and treatment: resource extraction (groundwater or surface water) and purification (disinfection, filtering, softening)
  - Transfer and stocking in water tanks and towers and
  - Pressurization of water (gravity or pump-operated system)
  - Distribution to users by distribution mains and service lines
- **Trade-off between treatment costs and distribution costs**, according to water availability and quality
- The sole **analysis of treatment costs could be fake**

A Production approach…

- A bioeconomic model



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…Combined with a preference approach

- We estimate welfare changes for the water drinkers
  - We measure the impact of land use changes on water price
  - And determine the value of one ha of afforested land from the water invoice

Appli 1: Fiquepron et al. (2013)

- System of simultaneous equations
  - Quality equations

X : Characteristics of service

Z : Land uses

$$Pesti = \gamma 0 + \gamma x\ X + \gamma z\ Z + \varepsilon_{Pesti}$$

$$NO3 = \delta 0 + \delta x\ X + \delta z\ Z + \varepsilon_{NO3}$$

  - Price equation

$$Price = \alpha 0 + \alpha x\ X + \alpha z\ Z + \alpha 2\ Pesti + \alpha 3\ NO3 + \alpha 4\ DSP + \varepsilon p$$

  - Management type equation (DSP)

$$DSP = \beta 0 + \beta x\ X + \beta z\ Z + \beta 1\ Pesti + \beta 2\ NO3 + \varepsilon d$$

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Empirical strategy

- Econometric analysis
  - National study – at the French administrative department level

  Sample : 93 administrative departments (without Paris et Corse)

  - The econometric estimation method

  Estimation of the system of simultaneous equations by GMM

Results

- Estimation results

Variable to be explained	Explanatory Variable	Impact
Pesticides	% Forest land use	- - -
	% permanent grassland	- - -
	% cereal, oilseeds, protein crops	+ + +
	% vine, arboriculture, market gardening	+ + +
	% underground resources	- - -
Nitrates	% Forest land use	- - -
	% permanent grassland	- - -
	% cereal, oilseeds, protein crops	+ + +
	% vine, arboriculture, market gardening	- - -
	% mountain area	- - -
	Number of pigs per ha	+ + +
	% underground resources	+ + +

Results

- Estimation results

Variable to be explained	Explanatory Variable	Impact
Management type (% private management)	Delivered drinking water volume	+ + +
	Population density	+ +
	Water recharge	- - -
	Maximal Population	+ + +
	Pesticides	+ +
Drinking water price	Length of water network	+ + +
	% groundwater	- - -
	Management type	+ + +
	Nitrates	+ +

Results

- Simulation of land use changes

Scenario : substitution forests → mains crops

Change of land uses	Variation / total surface	Surface
% forests	+ 5pts (from 28% to 33%)	+ 2675901 ha
% crops	- 5pts (from 32,5% to 27,5%)	- 2675901 ha

Nitrates	- 2,5 mg/l
Pesticides	- 3,7 pts of outflows to treat

Price	- 0,02 €/m3

Savings on water bill for domestic users	77 million € per year
	29 €/ha/year

Appli 2: Abildtrup et al. (2013)

- (Positive or negative) externalities between WSS arising from characteristics of neighborhood WSS
  - The costs of water supply may be influenced by **local competition for scarce local water resource**s :

If quantity and quality are low, the WSS can decide to use other water resources further (even in another WSS), consequently increasing scarcity and water supply costs for neighboring WSS

  - **Technical spillovers** may occur as a result of knowledge diffusion or the sharing of input factors:

and have an impact on the organization of WSS: grouping of municipalities, extension of delegation

Spatial issues

- **Spatial heterogeneity** can be explained by the proximity of WSS that exhibit the same conditions of operation due to geographical, topographical factors or even the extraction of water in the same aquifer
- **WSS area and land uses generally do not match**. The impact of land uses on service costs should thus be measured by taking both land distribution on the WSS and on its neighbors into account.

Economic model

- **The costs of supplying drinking water to users** can be described by the cost function:

$$C_i = C(W_i, q_i, X_i, \varepsilon_{ci}; W_{n(j)}, q_{n(j)}, X_{n(j)}, \varepsilon_{cn(j)})$$

  - The service i, the neighboring services $n(j)$
  - Y: delivered water volume, X : characteristics of the WSS
  - q : quality of raw water supposed to dependant on land uses L:

$$q(L_i, \varepsilon_{qi}; L_{n(j)}, \varepsilon_{qn(j)})$$

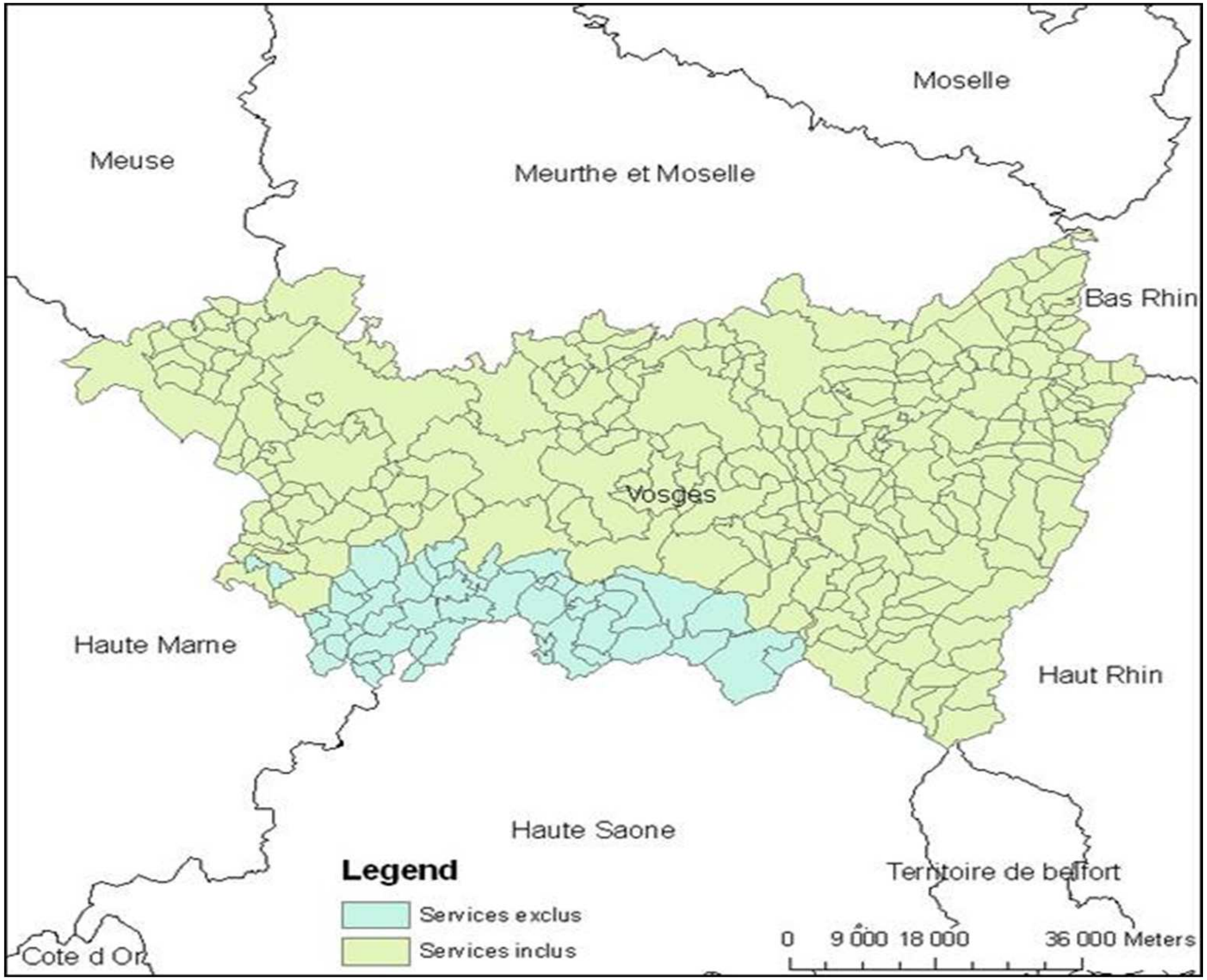
- **The pricing model** is:

$$P = AC\left(W_i, L_i, X_i, \varepsilon_i; W_{n(j)}, L_{n(j)}, X_{n(j)}, \varepsilon_{n(j)}\right) + R$$

  - AC : average cost of drinking water supply
  - P: water price, R : private operator rent

Data

Sample: 515 communes, which form 283 WSS with 1070 water intakes



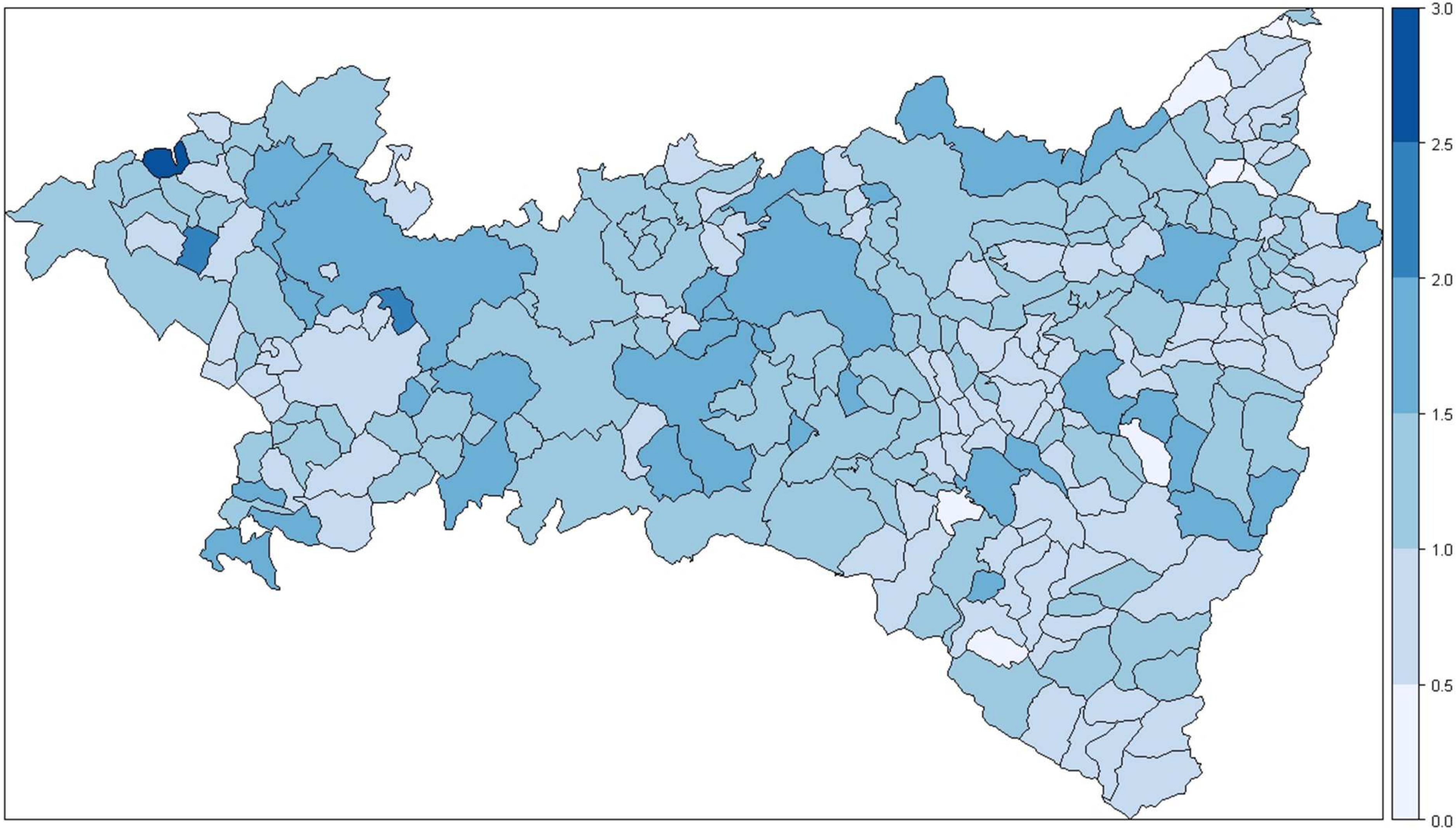
- 51 WSS depending on another water basin have missing information
- 232 WSS in the sample
- 21 WSS privately operated (only 9%)

Data

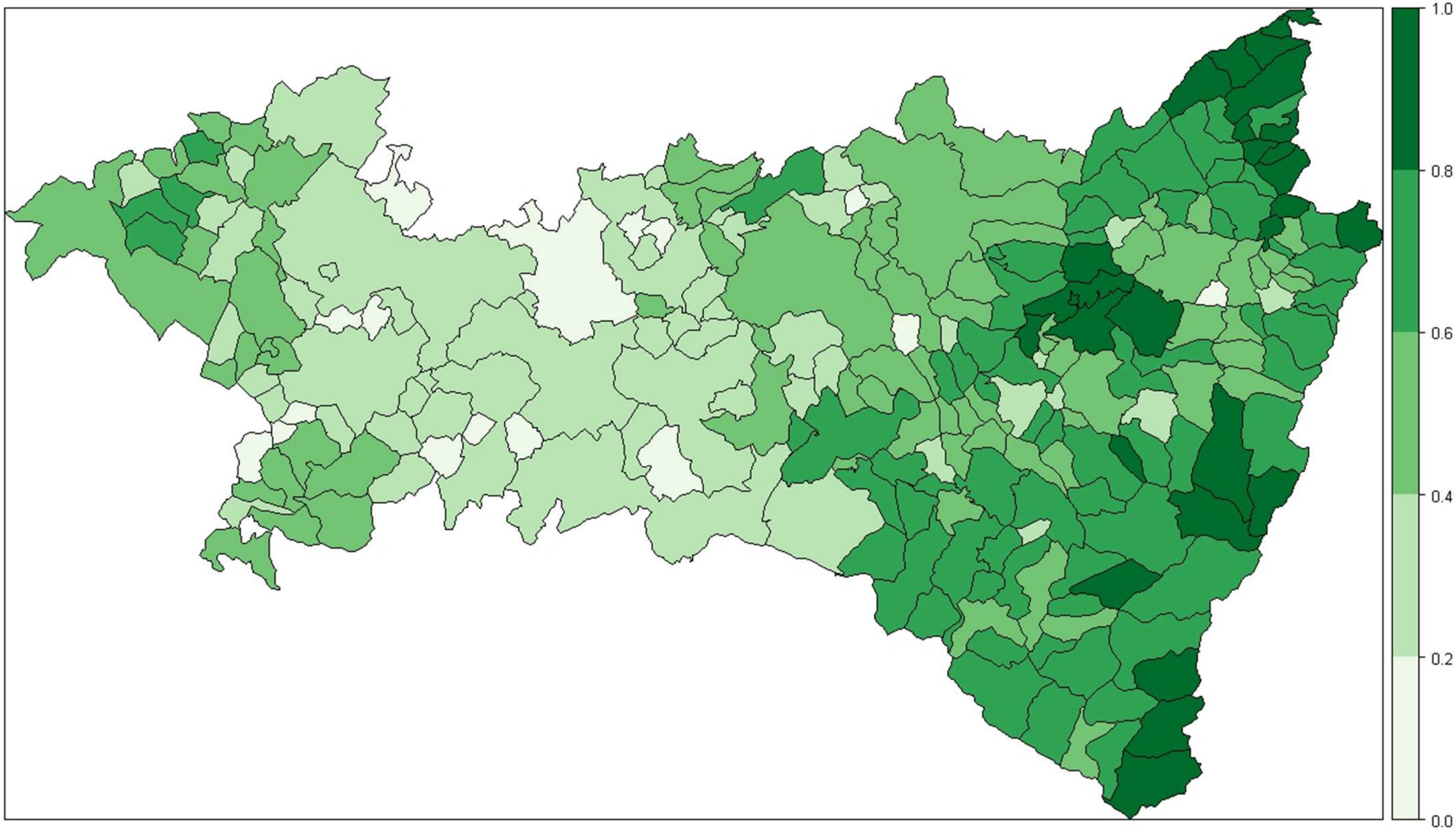
- PRICE: average drinking water price (composed of a fixed charge and a marginal price) for a consumption of 120 m3, without VAT
- MUNICIP: number of municipalities served by the WSS
- USER: number of users served by the WSS
- Number of intakes (INTAKE) and type: DRILL (deep), WELL (less), SOURCE (surface)
- ALT-DIF: Difference of altitudes between WSS and intake
- Land uses (in %): FOREST, AGRI, URBAN, OTHER

  Total = 100%
- DELEG = 1 if privately operated

Spatial distribution of water prices



Spatial distribution of forest



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Spatial econometric model

- W : a spatial weights matrix to define the dependence between the individual observations
  - Based on neighbourhood contiguity, distance between centroids
- Several spatial econometric models:

$$P = X\beta + L\gamma + W_1 Z\delta + \varepsilon$$

with:

$$\varepsilon = \lambda W_2 \varepsilon + u$$

- Econometric method (Fingleton and Le Gallo, 2008):
  - 2SLS (multi-step) estimation method

Estimation results

Variable	Estimate (Std. Error)	Estimate (Std. Error)
	2SLS	Spatial 2SLS
(Intercept)	1.8843*	2.8562**
WATER (in log)	-0.5471**	-0.4708**
USER (in log)	0.6091**	0.4441**
DENSITY (in log)	-0.1978***	-0.1118*
DELEG	0.4866***	0.4510***
MUNICIP	0.0220	0.0216*
DELEG x MUNICIP	-0.0241	-0.0268*
INTAKE	0.0070	0.0084
FOREST	-0.9502***	-0.7059***
URBAN	0.0763	-0.0268
OTHER	-0.8201**	-0.6529**
FOREST_lag	--	-0.8405*
URBAN_lag	--	8.1980*
OTHER_lag	--	-1.3144
WATER_lag (in log)	--	0.0489*
λ	--	0.2557**

Note: ***: significant at 1%, **: at 5%, *: at 10%.

Estimation results

Variable	Estimate (Std. Error)
	Spatial 2SLS
(Intercept)	1.7141*
WATER (in log)	-0.3707**
USER (in log)	0.3504**
DENSITY (in log)	-0.1020*
DELEG	0.4307***
MUNICIP	0.0216*
DELEG x MUNICIP	-0.0231
INTAKE	0.0078
FOREST	0.0202
URBAN	0.5567
AGRI	0.6871**
FOREST_lag	-1.1049**
URBAN_lag	9.6119*
AGRI_lag	-1.2841
WATER_lag (in log)	0.0399*

Note: ***: significant at 1%, **: at 5%, *: at 10%.

Estimation results

Average value estimates of forests in supplying water for human consumption (in €)

	No spatial	AGRI as reference	OTHER as reference
Direct impact	-0.0095	-0.0071[a]	0[b]
Indirect impact	--	-0.0084	-0.0110
Total impact	-0.0095	-0.0155	-0.0110
Direct value of 1ha	85.08	63.20	0
Indirect value of 1ha	--	75.25	98.93
Total value of 1ha	85.08	138.46	98.93

Note: Values are computed for an average WSS: average water price = €1.08 per m3, average delivered drinking water volume = 104,676 m3, average WSS area = 2165 ha, average proportion of forest lands.

[a] From estimation results, an increase of one point in the proportion of forest (for an equivalent decrease of the proportion of agricultural lands) would imply a decrease of €0.0071 of the water price per m3.

[b] Non significant value.

Conclusions

- A valuation method for water quality service of forests
- A significant impact of forest land use on water costs
- And a value of the ecological service provided by forests significantly different from zero
- A (relative) value of service different according to different land uses
- Importance to deal with the complete costs of DWS
- Importance of taking spatial issues into account:
  - Forest lands and water supply areas do not match together
  - Spatial spillovers from the water market valuation method

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Merci

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