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Land use impact on water quality: Valuing forest services in terms of the water supply sector

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ABSTRACT

The aim of this paper is to quantify the impact of the forest on raw water quality within the framework of other land uses. On the basis of measurements of quality parameters that were identified as being the most problematic (i.e., pesticides and nitrates), we modeled how water quality is influenced by land uses. In order to assess the benefits provided by the forest in terms of improved water quality, we used variations of drinking water prices that were determined by the operating costs of water supply services (WSS). Given the variability of links between forests and water quality, we chose to cover all of France using data observed in each administrative department (France is divided into 95 *départements*), including a description of WSS and information on land uses. We designed a model that describes the impact of land uses on water quality, as well as the operation of WSS and prices. This bioeconomic model was estimated by the generalized method of moments (GMM) to account for endogeneity and heteroscedasticity issues. We showed that the forest has a positive effect on raw water quality compared to other land uses, with an indirect impact on water prices, making them lower for consumers.

1. Introduction

The purpose of this article is to quantify the impact of the forest on the quality of water and its economic value. Forests have an extensive root network and a great ability to generate porous and filtering soils. Recycling, especially of nitrogen, is important. Under forest cover, nitrate levels are low (Jussy et al., 2002) and similar results are also observed for various pollutants (e.g., pesticides). Our hypothesis is that raw water from catchment areas with a large portion of forests is of higher quality, thus reducing the need for treatment of drinking water and, as a result, the associated prices of drinking water supply. In contrast, runoff from agricultural lands is the main cause of water pollution (Hascic and Wu, 2006), and nitrification is greater in an agricultural environment. The presence of agricultural land in the area surrounding the water supply service (WSS) may thus lead to sophisticated and costly treatments.

While considerable research has been devoted to quantifying the physical extent of the impact of the forest on water quality, few studies have attempted to estimate the economic value of the impact of forests on the quality and still fewer on the value of forests in supplying water for human consumption (Núñez et al., 2006; Biao et al., 2010; Abildtrup et al., 2013). Forest land use is normally associated with the protection of water resources from contamination and the reduced cost of drinking water supply (Abildtrup and Strange, 2000; Willis, 2002; Ernst et al., 2004). The relative impacts of alternative land uses on water quality have already been studied (Hascic and Wu, 2006; Langpap et al., 2008). The objective of such studies was to analyze how water quality affects watershed ecosystem health at different spatial scales and whether land-use changes exacerbate these impacts. Whereas the impacts in those studies are estimated from variations in terms of quality indicators and the number of species at risk, our article seeks to measure the effect of land uses on water quality indicators (for drinking water uses) and on the price of water supply. The objective *in fine* is to estimate the economic value of the ecological service provided by forests on the quality of raw water used for drinking water supply.

The French Forest Orientation Law (*Law no. 2001-602, 9/7/2001*) recently recognized the role of the forest in the supply of a number of non-market services, including protection of water. Moreover, with the application in France of the Water Framework Directive (*Directive, 2000/60/CE*), actors involved in the water sector are now aware of the importance of protection and prevention for water resources intended for drinking water. Although it does not explicitly mention forest areas, the Water and Aquatic Environment

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Law (*Law no. 2006-1772 30/12/2006*) opens up many possibilities in terms of collaboration with and contributions by forest owners related to the forest service associated with water quality. A look at some of the big cities in the world (e.g., New York) well illustrates that the links between forest and water are real issues underlying the success of public policies on water quality and water prices (Johnson et al., 2000).

The objective of our study is to assess the role of land uses, and more specifically of the forest on the quality of drinking water and its price at the national level. The interest of this approach is to estimate whether this role is significant throughout the French territory, without being restricted to local effects that could challenge the transfer of results. This approach might be complemented by more detailed analysis at the scale of watersheds, as undertaken in the Vosges department by Abildtrup et al. (2013). Nevertheless at this scale, the richness of data is much lower and it is difficult to gather a sample of representative watersheds at the national level. While there are studies on the scale of water catchments, they are based on catchments inclined to encounter problems. However this implies a sample bias, with watersheds predominantly covered by very little forest. Local features and observation levels as well are both limiting factors when transferring results from one site to another (Ranger et al., 2007; Gove et al., 2001; Kiersch and Tognetti, 2002).

We have thus conducted our study with departmental data from a rich dataset but highly aggregated. It is the best way to achieve results that are representative at national level. Effects assessed at the national level could inspire public policy, knowing that the aggregation of data at the national level would tend to limit the effects of land use on water quality. Given the variability of the links between the forest and water quality, we decided to cover all of France using data observed in the different administrative departments. We therefore collected both data related to water supply management and data on land use and land cover, including the proportion of woodland at the department level. The hypothesis of our model is that land uses have a direct affect on raw water quality and an indirect effect on the price of water. The main results show an expected positive effect of the forest on water quality with respect to other land uses, i.e., departments with a relatively high proportion of forest cover have better water quality and lower water prices.

In order to understand land use impact on water price and quality, we present some elements in the following section on the links between forest and water, focusing on the qualitative aspect of water, followed by the economic model and the estimation results.

2. Links between the forest and water quality

The influence of the forest on the quality of the water resource is all the more important in that it constitutes one of the main types of land cover, at least in temperate zones like France, where the metropolitan afforestation rate is 28.5% (Agreste, 2004). This influence of the forest can be distinguished between effects related to the existence of forests and those related to forest management, a distinction that was notably made in a reference document produced by the US Forest Service (Brown and Binkley, 1994). Forest management requires different types of operations such as creating stands, cleanings, successive thinnings and timber transport that can cause considerable disturbance to the soil, depending on the precautions taken while the work is carried out. Forest management is not neutral in terms of water quality, but many factors tend to attenuate harmful effects, particularly the fact that human interventions are less frequent in this sector than in agriculture.

Land management in forests is less intensive than for agriculture, and interventions are less frequent due to the long-term rotations in forests. The use of chemicals in forest areas is very limited. Agropharmaceutical products and fertilizers are rarely used. Regarding the effect of the type of forest stand on nitrate losses, results can also be seen as somewhat contradictory in the literature. And mixing species, especially broadleaved and conifers, may lessen the disadvantages of some mono-specific stands such as plantations made up solely of spruce (Knoke et al., 2008).

Compared to other types of land uses, the forest differentiates itself by its high level of aerial development, its extensive root network and its ability to generate porous and filtering soils. The efficient functioning of biological cycles in forest stands optimizes the use of nutritional elements from the soil (Ranger et al., 1995), making it possible to obtain a large biologic production, often from poor soils, and strongly limiting mineral element leakage out of the soil/plant system. Recycling, especially of nitrogen, is important in forests. Nitrate levels are therefore low under forest cover (Gundersen, 2007). Vittel, a small town in eastern France, is a good example since it subsidizes agriculture to reduce chemical inputs and purchases forested land around the private catchment area for the purpose of improving water quality. Under the forest cover on the plain near Vittel, infiltration waters alone do not exceed 2 mg/l of nitrates (Benoît and Papy, 1997), whereas the quantity of nitrates on agricultural land is significantly higher (Table 1). This trend can be verified at the catchment area level. An afforestation rate of 30% in agricultural watersheds should be enough to produce water with a nitrate content lower than the norms for drinking water in Europe (50 mg/l) (Benoît et al., 2002).

Compared with other land uses such as urbanization or arable land, the forest generates lower runoff coefficients (Adhikari et al., 2002; Sikka and Selvi, 2005). Cultivated land releases more than five times more sediment into the watercourse than wooded areas, whereas wooded areas have a tendency to occupy the most uneven areas (Brown and Binkley, 1994). Thus, the forest contributes to protecting the land, tending to favor infiltration and reducing rapid flow at the surface. The forest generally makes it possible to limit sediment flow and turbidity.

Some wooded formations clearly have a purification role: riparian forests, alluvial forests and hedged farmland are cases in point. The root systems of riparian forests and alluvial forests have a filtering role and trap nutritive elements (nitrogen, potassium, phosphorus) as well as some toxic elements (Broadmeadow and Nisbet, 2004). However, it should be mentioned that these conditions, which are ideal for denitrification, are not specific to the forest. Grassland can also offer very favorable conditions. Hedges and other linear wooded areas constitute effective filters as well.

3. Empirical approach

The approach used to process the data was based on an estimation of a simultaneous equations model that included one equation related to water price, two equations related to raw water quality via pesticide and nitrate indicators, and one equation related to water supply service (WSS) management regime.

Table 1
Nitrate levels in water collected by porous-cup lysimeters at a depth of 1.10 m under different types of land cover in Lorraine.

Land cover	$[NO_3^-]$ in water at a depth of 1.10 m in mg/l
Forests	2
Cut fields	19
Pastures	31
Temporary grassland	28
Winter wheat	46
Rape seed	62
Spring cereals	120
Maize as a fodder crop	126

Source: Benoît and Papy, 1997.