An Examination of the External Costs of Nitrogen in Agriculture

Roberto Mosheim and Marc Ribaudo

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Background

The overuse of nitrogen fertilizer primarily by large scale agriculture has polluted streams and lakes, and, in turn, coastal waters around the world. One consequence is the contamination of drinking water sources relied on by millions of consumers.

Nitrogen is toxic to human health. Clean Water Act regulations require that drinking water supplied by public utilities contain less than 10 ppm of nitrogen. Water utilities in regions with high nitrogen concentrations must install expensive treatment systems to meet the nitrogen limit. This necessity creates an externality from agricultural production.

This poster seeks to estimate the cost to utilities of abating nitrogen coming from agriculture.

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* The views expressed are the authors and should not be attributed to the Economic Research Service or the U.S. Department of Agriculture.

DATA

The analysis uses the most recent survey conducted by the American Water Works Association where information on water quantity as well as public water system characteristics and distributed water quality were gathered at the same time (1996). Estimates of the proportion of the cost of nitrogen abatement that can be attributed to agricultural sources come from results of the SPARROW model [Smith el al. (1997)] which allocates nitrogen in raw water to manure, crop, atmospheric and point sources.

Table 1 Summary Statistics and Definitions

Definition (unit) Variable	Mean (Std. Dev.)	Definition (unit) Variable	Mean (Std. Dev.)
Variable Cost (in $) *VC*	$ 8,479,039 (13,477,167)	Chemicals Price (in $ per pound) w_3	0.2 (0.0)
Annual Water Production (in millions of gallons) *y*	14,449 (23,498)	Capital (residual rate of return) *K*	$ 145,916,037 (217,806,925)
Annual Salary (in $) w_1	$34,353 ($11,538)	System Type (1 = Distribution and waste water, 0 = Otherwise) *dww*	0.54 (0.50)
Nitrogen Abatement (difference of raw-finished nitrates in water) (in mg/liter) *N*	0.98 (4.04)	Network Density (population served/length of distribution main) *netd*	1,176 (5,608)
Electricity Price (in $ per kilowatt hour) w_2	$0.05 ($0.01)	Organizational Type (1 = public, 0= otherwise) *public*	0.87 (0.34)

2. Econometric Specification and Estimation

$$\ln\left(\frac{VC}{w_3}\right)_i = \hat{b}_o + \hat{a}_1 \ln y_i + \hat{a}_2 \ln N_i + \hat{b}_1 \ln\left(\frac{w_1}{w_3}\right)_i + \hat{b}_2 \ln\left(\frac{w_2}{w_3}\right)_i + \hat{h} \ln K_i + e_i$$

0.2	0.7***	0.07 **	0.6***	0.4**	0.2**
(0.1)	(9.6)	(2.0)	(5.2)	(1.9)	(2.3)

where $e_i = v_i + u_i$ is a composite error term

where random component, v_i : iid $N(m_v, s_n^2)$, is assumed normal heteroskedastic

where $\ln s_v^2 = \hat{d}_o + \hat{d}_1 dww + \hat{d}_2 public$

-2.6	2.8***	0.9
(0.6)	(2.8)	(1.2)

and inefficiency component, u_i : iid $N^+(m_u, s_u^2)$, is assumed half normal where

$\ln s_u^2 = \hat{d}_o + \hat{d}_1 netd + \hat{d}_2 public$

-5.0	-0.009***	5.2
(-1.3)	-(2.3)	(1.4)

and v_i and u_i are independent each other and of the regressors [Battese and Coelli (1995)]. Statistical significance: ** 5%, *** 1%.

3. Derivation of Shadow Cost of Nitrogen Abatement and Discussion.

$$\widehat{VC} = \exp\left(\ln\left(\frac{\widehat{VC}}{w_3} \right) \right) \times w_3 . \tag{2}$$

$$SC_N = \frac{\partial \widehat{VC}}{\partial N} = \widehat{VC} * \frac{\hat{h}}{N} . \tag{3}$$

The estimated variable cost function meets most of the theoretical regularity conditions, i.e. it is monotonically increasing in desirable output as well as in variable inputs. The only case in which the desirable theoretical properties of inputs are not met is in the case of capital which in a variable cost function setting should be negative. The explanation resides in overcapitalization of water utilities—a phenomenon widely observed for regulated utility firms of all kinds. Homogeneity in the cost function is imposed by dividing both input prices and variable costs by price of chemicals. Consistent with the literature on undesirable outputs, the presence of an undesirable byproduct in a production process, in this case nitrogen, implies a higher cost to the utility which it then abates either to meet regulation or more generally to reduce risk to customers. As to the exogenous effects, network density has a negative effect on variable costs as expected. Whether the water system is categorized as a public system is not significant but important it is important to include for projection purposes (observations are mostly public).

The shadow marginal cost of nitrogen abatement is derived in equation (3) by taking the derivative of (2), estimated variable cost, which in turn was derived by taking the exponential of (1). From equation (3) various additional derivations can be made:

shadow marginal cost by millions gallons, $\partial \hat{V} / \partial N$ $/ y$; estimated shadow total variable cost of nitrogen abatement (*SVC*), $\partial \hat{V} / \partial N \times N$, and *SVC* per millions of gallons of water produced ($\partial \hat{V} / \partial N \times N$)/ y .

Table 2 Shadow Costs for Nitrogen Abatement by Level of Abatement
(Agriculture Contribution Percentage in Squared Brackets)

Nitrogen Abatement (NA) (Raw-finished nitrates in water in mg/liter) (Number of observations in parenthesis [observations for agriculture in squared brackets])	Shadow Cost of Nitrogen Abatement (SC_N) $\partial \hat{V} / \partial N$ (Total Shadow Cost of abatement in \$ per mg/liter of N [% agriculture])	SC_N per millions of gallons of water produced ($\partial \hat{V} / \partial N$)/ y [% agriculture]	Estimated Shadow Total Variable Cost of Nitrogen Abatement (SVC) $\partial \hat{V} / \partial N \times N$ [% agriculture]	SVC per millions of gallons of water produced ($\partial \hat{V} / \partial N \times N$)/ y [% agriculture]
NA <= 0.03 (9),[9]	$ 1.98e+07 [21%]	$ 1,932 [33%]	$399,498 [19%]	$ 37.85 [34%]
NA > 0.03 and NA <= 0.1 (9), [9]	$ 5,390,286 [28%]	$ 777 [29%]	$353164 [28%]	$ 48.69 [26%]
NA > 0.1 and NA <= 0.32 (12), [12]	$ 6,894,246 [33%]	$ 239 [38%]	$1,017,424 [29%]	$ 39.22 [40%]
NA > 0.32 and NA <= 0.42 (8), [8]	$ 915,191 [52%]	$ 107 [53%]	$ 364,898 [52%]	$ 42.60 [56%]
NA > 0.42 (10), [10]	$ 245,765. [53%]	$ 67 [56%]	$ 200,978 [43%]	$ 53.73 [45%]

The results from the above derivations are presented in table 2. This table cross tabulates these derived results by abatement levels. The most important set of results are contained in the second column. The shadow costs decrease with system size pointing to scale economies in nitrogen abatement efforts. Future work will extend this analysis to a meta-frontier framework.

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