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AGRICULTURAL VERSUS URBAN INTERESTS IN GROUNDWATER QUALITY

by

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AGRICULTURAL VERSUS URBAN INTERESTS IN GROUNDWATER QUALITY

Concerns over water quality are playing an increasingly important role in agriculture throughout the United States, Europe and many other parts of the world. As progress has been made in curbing industrial and municipal emissions, agricultural sources are contributing growing shares of nutrients (nitrogen, phosphorus) and other pollutants such as pesticides and sediment. Population growth and the spread of urbanization increase the social costs of this pollution by increasing demand for recreation, fishery productivity and drinking, and thus demand for water in terms of both quality and quantity. As a result, urban and agricultural interests are increasingly in conflict over water.

Groundwater provides a good case in point. The quality of groundwater supplies has become a growing cause of concern throughout the United States. Surveys at the federal, state, and local levels (Office of Technology Assessment) indicate that many aquifers used for drinking water supplies contain chemicals that are documented or suspected human health hazards. Agriculture, in particular, has become a focus of concern over contamination of groundwater with nitrate and pesticides. A recent Environmental Protection Agency (EPA) survey found that 52 percent of community water system wells and 57 percent of rural domestic wells contained measurable amounts of nitrate, while 10 percent of community water system wells and 4 percent of rural domestic wells contained measurable amounts of pesticides (U.S. Environmental Protection Agency).

Groundwater is a critical source of drinking water in both rural and nonrural areas: Over 97 percent of rural drinking water comes from underground aquifers, while 50 percent of the U.S. population overall relies on groundwater (Office of Technology Assessment). Population growth in many areas has resulted in the conversion of many former rural areas to residential use.

Groundwater is the chief source of drinking water in these areas, as evidenced by the rapid growth of groundwater withdrawals in these areas (Aldrich). This increased reliance on groundwater has led to increased demand for nitrate- and pesticide-free water, which has led in turn to growing political pressure for curtailing leaching from agriculture, for example, via mandatory use of manure storage systems, more stringent restrictions on pesticide use and other regulations on agricultural production.

This emphasis on pollution control is somewhat one-sided. Since Coase, economists have understood that pollution problems exhibit joint dependence on the behaviors of emitters and receptors of pollution, that is, on polluter and pollution victims. Polluters can alter emissions by changing their production practices or by installing pollution control equipment. Victims can engage in averting behavior to reduce the level of damages suffered; moreover, the level of damage suffered will depend on the locational choices of victims. In general, it will be efficient for both parties to bear some of the cost of pollution, so that both will have incentives to reduce damages (Olson and Zeckhauser), although under certain conditions there may be nonconvexities that make it optimal to require only one party to bear the full cost (Shibata and Winrich, Oates).

This paper examines theoretically and empirically the potential roles of pollution control and mitigation by victims for the case of groundwater contamination, taking into account both efficiency and equity concerns. We begin with a simple model of the minimum cost allocation of effort between pollution control by farmers and mitigation by urban residents. We then examine the impacts of exogenous urbanization on this division of effort and on the total and marginal costs of managing agricultural pollution. We consider two types of urban growth, conversion of agricultural land to residential uses at existing population density and increases in population density with no changes in land use, a dichotomy that corresponds to recent growth control proposals. We then consider a simple financing scheme to implement the optimal mix of pollution control and mitigation in an equitable manner. We assume that the distribution of property rights to groundwater implies that farmers and the urban population should pay specific shares of the total cost of pollution control plus mitigation, and that those costs are defrayed from a central fund raised by levying per acre taxes on agricultural and residential land, a scheme corresponding to a form of political-economic equilibrium (Zusman) and which is also attractive on practical grounds. We examine the impacts of different patterns of growth on the rate of taxation of urban and agricultural land and discuss implications for further growth and political conflict.

A Simple Model of Land Use and Pollution

Consider the case of a region where agriculture generates a pollutant that is harmful to urban users, for example, nitrate in groundwater used for drinking water. Let all of the land in a region, A_T, be used either for agriculture or urban uses. Let A_F denote land used for agriculture, so that urban land is A_T-A_F. Let emissions of this pollutant be proportional to agricultural acreage, eA_F. Farmers can reduce emissions by engaging in pollution control, for example, storing manure and using it in place of chemical fertilizers, reducing chemical fertilizer applications, using time-release formulations of fertilizers, using cover crops during the off-season to soak up excess nutrients, and so on. Let the fraction of emissions controlled be denoted α, and let the total cost of controlling emissions by an amount $E = \alpha eA_F$ be a convex function $C(\alpha eA_F)$.. The convexity of the cost function captures diminishing marginal productivity of pollution control both at the farm and regional levels. On a single farm, the marginal cost of pollution control $C_E(\alpha e A_F)$ may be rising because reducing emissions by a larger amount requires larger investment in pollution control or impairs farm productivity more. At the regional level, the marginal cost of pollution control may be rising because achieving greater reductions in emissions requires controlling emissions on farms that emit less or have higher pollution control costs due to scale economies.

Let the urban population of the region be $P = \rho(A_T-A_F)$, where ρ is urban population density. Uncontrolled emissions from agriculture are $(1-\alpha)eA_F$. Assume that the pollutant is mixed uniformly in the environment, so that all urban users are affected equally by total emissions. Let the fraction of these uncontrolled emissions removed by mitigation efforts on the part of urban residents be β, and assume that the cost of these mitigation efforts is $K(\beta(1-\alpha)eA_F,\rho(A_T-A_F))$, a function of the amount of pollution removed, $B = \beta(1-\alpha)eA_F$, and the size of the urban population, $\rho(A_T-A_F)$. We assume that the marginal cost of mitigation, K_B, is positive and increasing ($K_B > 0$, $K_{BB} > 0$) and that mitigation exhibits increasing returns to population ($K_P > 0$, $K_{PP} > 0$, $K_{BP} < 0$). For example, mitigation may involve installing filtration systems or drilling new wells to obtain cleaner water, both of which have lower marginal costs with higher population because of high fixed costs.

Suppose that pollution control effort α and mitigation effort β are chosen to minimize the total cost of meeting a quality standard N such as the EPA standard for nitrate in drinking water. The regional optimization problem is:

$$\begin{aligned} \min \quad & C(\alpha e A_F) + K\big(\beta(1-\alpha)eA_F, \rho(A_T - A_F)\big) \\ s.t. \quad & (1-\beta)(1-\alpha)eA_F \le N. \end{aligned}$$

Assuming an interior solution, the necessary conditions can be written:

$$\begin{aligned} C_E - \beta K_B - (1-\beta)\lambda &= 0 \\ K_B - \lambda &= 0 \\ (1-\beta)(1-\alpha)eA_F &= N. \end{aligned}$$

The fact that λ, the (absolute value of the) shadow price of the pollution standard N, equals the marginal cost of mitigation effort K_B implies that the necessary conditions can be written in more simplified form as:

$$\begin{aligned} C_E - K_B &= 0 \\ K_B - \lambda &= 0 \\ (1-\beta)(1-\alpha)eA_F &= N. \end{aligned}$$

The first two of these conditions are the familiar requirements that (1) the marginal costs of pollution control and mitigation must be equal and (2) both must equal the marginal cost of the standard, λ.[1]

These necessary conditions are sufficient when:

$$\begin{aligned} e^2A_F^2C_{EE} + \beta^2e^2A_F^2K_{BB} &\ge 0 \\ (1-\alpha)^2e^2A_F^2K_{BB} &\ge 0 \\ \left(e^2A_F^2C_{EE} + \beta^2e^2A_F^2K_{BB}\right)(1-\alpha)^2e^2A_F^2K_{BB} - \beta^2(1-\alpha)^2e^4A_F^4K_{BB}^2 = (1-\alpha)^2e^4A_F^4C_{EE} &\ge 0, \end{aligned}$$

all of which hold when our assumptions about pollution control and mitigation technology are met.

Urban Growth and the Division of Effort between Agriculture and the Urban Population

Consider the impact of urbanization on the optimal division of effort between pollution control in agriculture and mitigation conducted by the urban population. We distinguish two types of urban growth. The first, extensive growth, we characterize by examining conversion of agricultural land to urban uses holding population density constant. This corresponds to growth patterns where agricultural land is zoned for low density residential development. The second, intensive growth, we characterize by examining increases in population density holding agricultural land use constant. This corresponds to a situation where growth is restricted to existing urban corridors, and agricultural land is zoned to prohibit its conversion to residential use.

This dichotomy springs from current debates over land use planning in areas like the Northeastern United States. In Maryland, for example, agricultural land in the Baltimore-Washington corridor is being converted to urban uses at a relatively rapid rate. Existing zoning regulations favor low-density development, which results in extensive growth. Recently, the governor of the state proposed a new land use planning framework in which the state would pre-empt local control and restrict urban growth to specific corridors. This new framework would channel development into intensive growth patterns.

It is straightforward to show the following:

Proposition 1. Conversion of agricultural land to urban uses will result in an increase (decrease) in pollution control in agriculture if it reduces the marginal cost of pollution control more quickly (slowly) than the marginal cost of mitigation. Mitigation by urban users will increase (decrease) if population growth makes the marginal cost of mitigation rise more slowly (quickly) than the marginal cost of pollution control in agriculture.

Proof. Differentiating the simplified system of necessary conditions totally and using Cramer's rule yields:

$$\frac{\partial\alpha}{\partial A_F} = \Delta^{-1}(1-\alpha)eA_F(\alpha eC_{EE} + \rho K_{BP} - (1-\alpha)eK_{BB})$$
$$\frac{\partial\beta}{\partial A_F} = \Delta^{-1}(1-\beta)eA_F(eC_{EE} + \rho K_{BP})$$

where $\Delta = -(1-\alpha)eA_F[C_{EE} + K_{BB}] < 0$.

Consider first the impact of conversion of agricultural land on pollution control effort α. A reduction in agricultural land reduces emissions from agriculture and thus the marginal cost of pollution control in agriculture by αeC_{EE}. It has two effects on the marginal cost of mitigation by urban residents: (1) a direct decrease of $(1-\alpha)eK_{BB}$ and (2) a decrease of ρK_{BP} due to the increase in the urban population. If the reduction in the marginal cost of pollution control is greater, then pollution control will increase, and vice versa.

Mitigation by urban residents, on the other hand, will increase whenever the decrease in the marginal cost of pollution control in agriculture, eC_{EE}, is greater than the decrease in marginal mitigation cost due to the increase in the urban population, ρK_{BP}. This means that three different situations can occur. First, the decrease in the marginal cost of pollution control may be greater than both the total decrease in marginal mitigation cost and the decrease in marginal mitigation cost due to increased population, i.e., $\alpha eC_{EE} > (1-\alpha)eK_{BB} - \rho K_{BP} > -\alpha\rho K_{BP}$. In this case, conversion of agricultural land to urban uses will lead to an increase in pollution control in agriculture and a decrease in mitigation by urban users. Second, the decrease in the marginal cost of pollution control may be less than both the total decrease in marginal mitigation cost and the decrease in marginal mitigation cost due to increased population, i.e., $(1-\alpha)eK_{BB} - \rho K_{BP} > -\alpha\rho K_{BP} > \alpha e C_{EE}$. In this case, conversion of agricultural land to urban uses will lead to an decrease in pollution control in agriculture and a increase in mitigation by urban users. Third, the decrease in the marginal cost of pollution control may be less than the total decrease in marginal mitigation cost but greater than the decrease in marginal mitigation cost due to increased population, i.e., $(1-\alpha)eK_{BB} - \rho K_{BP} > \alpha e C_{EE} > -\alpha\rho K_{BP}$. In this case, conversion of agricultural land to urban uses will lead to decreases in both pollution control in agriculture and in mitigation by urban users. In the first two cases, the reduction in agricultural land leads to reductions in emissions that alter the comparative advantage of pollution control vis-a-vis mitigation. In the third case, the reduction in emissions of the pollutant is sufficiently large to permit meeting the environmental quality standard N with an overall reduction in both types of effort.

Proposition 2. Restricting urban growth to existing urban areas will result in decreased pollution control in agriculture and increased mitigation by urban residents.

Proof. Differentiating the simplified system of necessary conditions totally and using Cramer's rule yields:

$$\frac{\partial\alpha}{\partial\rho} = -\Delta^{-1}(A_T-A_F)(1-\alpha)eA_FK_{BP} \leq 0$$
$$\frac{\partial\beta}{\partial\rho} = \Delta^{-1}(A_T-A_F)(1-\beta)eA_FK_{BP} \geq 0.$$

Intuitively, an increase in population density decreases the marginal cost of mitigation by urban residents while leaving the marginal cost of pollution control unaffected. As a result, mitigation effort must increase, while pollution control effort falls.

Together, propositions 1 and 2 indicate that different patterns of growth (and, by implication, different growth control policies) can have very different implications for least cost pollution control strategies. Zoning regulations that favor low density development may increase emphasis on either pollution control or mitigation. If they lead to large enough reductions in emissions, they may even permit reductions in both pollution control and mitigation. Strategies that seek to channel urban growth into a few restricted areas, and thus increase density, will lead to a greater emphasis on mitigation and reduced emphasis on pollution control.

Urban Growth and the Total Cost of Pollution Management

These two different approaches to growth control also have different consequences in terms of the total and marginal costs of pollution management, that is, the total and marginal costs of pollution control in agriculture plus mitigation by urban users. They thus have different implications for public finance and government budgets.

It is straightforward to show the following.

Proposition 3. Conversion of agricultural land to urban uses will increase (decrease) the total cost of pollution management if the direct reduction in the costs of pollution control and mitigation due to lower emissions are less (greater) than the increase in mitigation cost due to higher population.

Proof. Differentiating the total cost of pollution management $C(\alpha^* eA_F)+K(\beta^*(1-\alpha^*)eA_F,\rho(A_T-A_F))$ using the envelope theorem yields:

$$\frac{\partial(C+K)}{\partial A_F} = \alpha e C_E + \beta(1-\alpha)eK_B - \rho K_P.$$

Converting an acre of agricultural land to urban uses has two effects. First, it reduces emissions by e and thus the cost of pollution control by αeC_E and the cost of mitigation by $\beta(1-\alpha)eK_B$. Second, it increases need for mitigation because of urban growth, thereby increasing the cost of mitigation by ρK_P. If the cost reduction due to lower emissions is greater, then the total cost of pollution management will fall, and vice versa.

Proposition 4. Restricting urban growth to existing areas will increase the total cost of pollution management.

Proof. Differentiating the total cost of pollution management using the envelope theorem yields:

$$\frac{\partial(C+K)}{\partial \rho} = (A_T-A_F)K_P > 0.$$

The increase in the size of the urban population increases the need for mitigation and thus its cost. But because agricultural land remains constant, emissions and thus the costs of pollution control, pollution control effort α and the level uncontrolled emissions $\beta(1-\alpha)eA_F$ remain the same. As a result, the total cost of pollution management C+K rises.

Taken together, Propositions 3 and 4 imply that growth control policies will affect expenditures on pollution management in different ways. Restricting urban growth to existing urban areas will necessarily result in greater expenditures on pollution management, while permitting conversion of agricultural land to urban uses, i.e., low density development, may allow expenditures on pollution management to fall. High density development increases the need for