Modeling Transactions Costs in a Regional Transferable Discharge Permit System for Phosphorus Runoff

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Abstract. This paper examines the construction and implementation of a regional transferable discharge permit system for phosphorus runoff from agricultural-related sources. The impact on behavior at the firm level is also examined. Results indicate that firms may respond to binding environmental constraints by both engaging in the trade of discharge permits and decreasing the output that can cause phosphorus runoff. The criticisms within the literature of building transferable discharge permit systems that ignore transactions costs are also addressed.

1. Introduction

In recent years the water pollution focus of state and federal environmental agencies, in conjunction with various environmental advocacy groups, has shifted from point sources to nonpoint sources. Point source pollution is pollution that is released into the environment from a specific identifiable point such as a smokestack or discharge pipe. Nonpoint source pollution, such as urban and agricultural runoff, has no specific identifiable point of discharge and can therefore be more difficult to correct. In fact the EPA stated in a recent report that pollution from nontraditional sources, i.e., nonpoint source pollution, is now the leading cause of impaired surface water bodies in the country (US EPA, 1996).

The impact of phosphorus runoff that emanates from poultry manure (litter) applications on cropland and pasture lands is believed to be responsible for a marked increase in the degradation of the quality of surface water bodies in the region of Northeast Oklahoma and Northwest Arkansas known as the Illinois River Basin. This particular region of the country, consisting of only five counties, is home to a relatively large poultry industry which raises 305 million broilers (chickens) per year,

or 21% of all broilers in both Oklahoma and Arkansas combined. This translates into approximately 415,500 tons of litter that must be properly disposed of. Not only does this region have a relatively high concentration of broiler production, but its share is growing. While total broiler production in Oklahoma and Arkansas has grown 20% over the past decade, the five county region has experienced a 41% increase in production since the 1997 Census of Agriculture (USDA 2007; Willett et al., 2000; Mitchell, 2001). An alternative way to show the extent of the problem is to consider that the phosphorus waste generated by the chicken litter in the region is equivalent to the waste generation of an additional 17.1 million people. This number is sizeable when one takes into account that the five-county region only has a population of approximately 500,000 people.

The presence of this industry and its impact on the regional environment has led to a concerted effort to find a solution to the problem of phosphorus runoff. For example, a phosphorus limit of 0.037 mg/l of water, which is generally considered to be the upper limit of phosphorus loadings which can maintain a semblance of environmental quality, was recently established. However, a regulatory or market process to actually enforce this standard was

never set up and, not surprisingly, the environmental standard is not currently met.

Environmental pollutants created by economic activity have usually been handled via direct regulation or taxes. Typically, the appropriate government entity has several options available to it, including prohibiting the use of a potentially polluting material, taxing the inputs that create the pollution, forcing firms to adopt some technology standard, taxing the emissions, or placing caps on the total amount of a pollutant that is allowed to enter the environment. Despite the success that methods such as these might have at reducing pollution, it is quite possible that the costs of implementing these regulatory measures are greater than the benefits to society from reducing the pollution.

For example, Luken and Clark (1991) found that EPA technology standards for air and water pollutants in the pulp and paper industry were inefficient at both an aggregate national level and at the regional level by imposing costs that were larger than benefits. Other regulations, such as Total Maximum Daily Load (TMDL) rules aimed at reducing bacteria and aquatic-life-use impairments, have also been found to be inefficient in the Opequon Watershed in Virgina. The benefit-cost ratios of these TMDL rules ranged from 0.1 to 0.3 depending upon the stringency of the standard (Borisova et al., 2008). Finally, Willet et al. (2006) estimated that 'command-and-control' reductions in poultry litter applications in the Illinois River Basin could shrink regional employment by over 15,000 and reduce regional value-added output by over half a billion dollars. Because of inefficient results such as these, there has been a move to try more market based approaches such as transferable discharge permit (TDP) trading (Hahn, 1994).

The use of TDP markets to reduce pollution at lowest cost is well known and understood in the literature. In theory, a TDP system is able to reach a given level of abatement at substantial cost savings over typical command-and-control policies by shifting the burden of abatement from all firms to firms with lower abatement costs (Tietenberg, 1980; Baumol and Oates, 1988). Although there has been much discussion in the literature about the potential drawbacks and implementation problems of a TDP market, such as transactions costs and defining emissions, permit systems have been applied in theory and successfully in practice to a variety of dilemmas. Some of these include hazardous waste (Opaluch and Kashmanian, 1985), biological oxygen demand (Eheart et al., 1987), water pollution (O'Neil

et al., 1983), and sulfur dioxide emissions from power plants (Schmalensee et al., 1998; Stavins, 1998).

The investigation of employing a permit system for phosphorus emissions in general has been undertaken in the literature as well. David et al. (1980) examined the problem of phosphorus loadings into Lake Michigan and found that a TDP system would be successful if some conditions to ensure permit market stability were met. Govindasamy and Cochran (1995b, 1998) appraised a TDP system specifically for poultry litter and compared the results with several other policy options including quantity restrictions on litter applications, taxes on litter, and taxes on land that has received litter applications. Although the taxes on litter and/or land may be easier to enforce and monitor, there is opposition to their use because of their effects on output, prices, profits, and the difficulty in determining the efficient tax rate. The authors discovered that the TDP was able to achieve the stated environmental goal at the lowest cost. They also found that the TDP, when measured against the previously stated alternative policy options, had the additional benefit of being easier to introduce to the stakeholders, reduced uncertainty and adjustment costs for impacted participants, and avoided the problem of industry change, economic growth, and inflation that would drive up taxes beyond their intended levels.

In this paper we will examine the establishment and consequences of a regional TDP system for phosphorus runoff at the farm level that emanates from poultry litter applications to crop land and will seek to fill a gap in the literature concerning how firms might alter their behavior under a TDP regime. Although the model design is derived from the perspective of a poultry grower in the Illinois River Basin, it is quite malleable towards studying other pollution problems. For instance, the Chesapeake Bay area and Lake Okeechobee in Florida suffer from water quality problems created by excessive nitrogen and/or phosphorus runoff from local farms and animal operations (Shuyler et al, 1995; Boucher et al., 1994). Past attempts to implement restrictions on nutrient loadings, such as TMDL rules, have proved ineffective in improving the issue. Therefore, other methods, such as a regional-based TDP, could prove more successful and cost effective. It should be noted that our purpose is not to digress into a complete explanation of the structural relationships that are present in the poultry industry— there are other works in the literature that will accomplish this (Knoeber and Thurman, 1994; Vukina and Foster, 1996; Mitchell, 2001). Nevertheless, a

brief explanation of the poultry industry will prove valuable to the reader in understanding the proceeding sections of the paper and how the implementation of the TDP system will affect the firm.

1.1. Primer on general poultry industry operations

The poultry industry is highly integrated and essentially consists of integrators, such as Tyson Foods or ConAgra, and growers. The integrators contract the raising (growing out) of chickens, turkey, and other fowl to local growers who raise poultry in chicken houses where the floors are lined with litter which consists mostly of shredded bark. The integrators provide the grower with technical support, medication, feed, and chicks which are grown out to market weight.   The integrator-grower contract specifies that the integrator retains ownership of the birds and that the grower will feed and house the birds, remove and dispose of deceased birds in the flock, and apply medication as necessary.   The grower is paid a standard price for each pound of chicken he provides for the integrator plus a bonus, or loss, depending upon his performance relative to other growers in the area who have contracted with the same company. Typically, this bonus is a function of the settlement cost per pound of broiler raised where the settlement cost depends upon the conversion of feed into actual broiler weight.

Once the broilers have been marketed, the grower is left with the responsibility of cleaning out the chicken houses and disposing of the litter, which the grower owns. Most poultry growers farm their own crops to augment their income and, since litter is a valuable source of nutrients such as nitrogen and phosphorus (Govindasamy and Cochran, 1995a; Xu and Prato, 1995), it is economically feasible for growers to lay litter on their crops and pasturelands[1]. Typically growers lay litter on their land to meet their crop's nitrogen needs, resulting in excess phosphorus applications which can than become available for runoff into surface waters[2] causing eutrophication which creates a foul smell for drinking water, reduces oxygen levels leading to a greater probability of fish kills, and leads to losses of

water recreation tourism dollars (Robinson, Sharpley, and Smith, 1994). It has been suggested that nitrogen and phosphorus concentrations as low as 0.3 mg/L and 0.01mg/L, respectively, are the critical values for advanced eutrophication (Pote, 1997).

Table 1 provides some further specific background information on industry operations within the Illinois River Basin region and throughout the states of Arkansas and Oklahoma. It should be noted that the information in Table 1 represents the broiler industry only and does not reflect other related poultry operations such as turkeys, laying hens for egg production, geese, etc., which also have a sizeable presence in the region. The data on the number of farms and broilers raised is from the 2007 USDA Census of Agriculture, while the average live-weight of a broiler in 2007, 5.52 pounds, was used to convert this number to tons of live weight (Watt Poultry USA, 2011). As one can see from the table, the Illinois River Basin region contributes significantly to the states' broiler industry, with the region supplying 31% of Oklahoma's and 19% of Arkansas' broiler output. Not only is total broiler output high in the region, but the size of poultry operations in the region is high compared to the rest of the states. Broiler farms in the region of study are on average 35% larger than broiler farms located in other parts of the states.[3]

2. A theoretical model of a permit trading system

We begin our model by examining a single farm and assuming that the grower is a profit maximizer who raises broilers, *B*, and crops, *Y*. Broilers are raised with labor (*L*) and capital, where capital is defined as the size of the poultry operation (*S*), so that *B* is dependent upon the production function *g(L,S)*. The production of broilers produces litter which is spread on crop fields as a fertilizer and soil amendment. Since the litter contains phosphorus, runoff from the fields causes phosphorus pollution. Phosphorus runoff above a given environmental constraint must be abated.   This can take many forms including the physical storage of litter in silos, planting and maintaining riparian buffers, or similar measures that have some positive, i.e., nonzero, cost

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[1] These crops tend to be "low dollar" crops and consist mostly of hay which is baled for cattle feed. Since the return from these crops is very low, in some instances less than $7 per acre, it is not economically feasible to add commercial fertilizer.

[2] Although high nitrate levels are a problem in some watersheds, this is not the case here, and therefore they have been deleted from further analysis.

[3] This size differential becomes even more acute if one excludes Cherokee County, OK from the analysis. In this case regional broiler farms are 56% larger than the combined two state average and 75% larger than the Oklahoma-only average.

Table 1. Operational data on broiler farms in the Illinois River basin.

	Benton (AR)	Washington (AR)	Adair (OK)	Cherokee (OK)	Delaware (OK)	State of Arkansas	State of Oklahoma
Farms (broilers only)	202	168	35	8	72	2,485	636
Number of Broilers (thds.)	116,599	112,332	26,638	1,650	47,971	1,171,556	242,228
Average Farm Size (number of broilers)	577,226	668,646	761,087	206,256	666,276	471,451	380,862
Average Farm Live-Weight (tons)	1,593	1,845	2,101	569	1,839	1,301	1,051
Average Farm Litter Generated (tons)	929	1,077	1,225	332	1,073	759	613
Average Farm Phosphorus Generated (tons)	23	27	31	8	27	19	15

to the farm[4]. Alternatively, the phosphorus pollution can be permitted via the use of the grower's initial endowment of permits from the regulatory body plus the net amount of permits purchased in the open market. Finally, in a vein similar to Tschirhart (1984) we assume that there are transactions costs in obtaining permits. Although the market price for a permit is h, the actual price paid by the buyer for the permit, including the transactions costs, is h^+. Consequently, the existence of these transactions costs reduces the actual amount received by the seller to h^-. Not only does this type of analysis address criticisms from the literature concerning the exclusion of transactions costs in forming permit trading markets, but it helps to ensure that growers will not engage in buying and selling permits at the same time since to do so would reduce profits[5]. We can state the grower's profit maximization problem as follows:

$$\pi = P_B B + P_Y Y - nL - rS - aW - eA - h^+ T^D + h^- T^S \qquad (1)$$

where

B = the number of broilers raised
P_B = the price growers receive for broilers
Y = the amount of crops raised

P_Y = the price growers receive for crops
n = the wage rate
r = capital cost
a = the cost of spreading litter on crops
W = the amount of litter spread on crops
e = the cost of one unit of abatement
A = the amount of abatement undertaken by the grower
h^+ = the true price paid for a phosphorus permit
T^D = the number of permits demanded by the grower from the market
h^- = the true price received for selling a phosphorus permit and
T^S = the number of permits supplied by the grower to the market.

The reader should note that the existence of transactions costs imply that $h^+ > h > h^-$, where h is the permit price. The production of broilers depends upon labor and the size of poultry operations, so that

$$B = g(L,S). \qquad (2)$$

The production of litter depends upon the number of broilers raised, so that

$$W = W(B). \qquad (3)$$

and the production of nitrogen depends upon litter production, yielding

$$N = N(W). \qquad (4)$$

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[4] There has been some discussion about shipping the litter to other regions. However, since the agronomic value of the litter is relatively low, and the transportation costs are relatively high, such a policy is not feasible (Mitchell, 2001).

[5] A component of these transactions costs include the cost of monitoring and measuring the amount of runoff that occurs. Of course, this is likely to be stochastic based upon conditions such as the amount of rainfall, crop type, etc. Our thanks to an anonymous referee for this suggestion.

There are also the following production relations and constraints:

$$Y = F(N,M) \qquad (5)$$

$$R(W) = M + f(g(L,S),A) \qquad (6)$$

$$f(g(L,S),A) \leq T^E + T^D - T^S. \qquad (7)$$

Equation (5) states that crop production is a function of nitrogen, N, and phosphorus, M, that is taken up by crops. Equation (6) is a balance constraint which shows the amount of phosphorus generated from litter, $R(W)$, will either be used by the crops, M, or will become available for runoff which is represented by the function $f(g(L,S),A)$.

It should be noted that the crop's use of the phosphorus does not necessarily have to occur instantly. We allow for the 'storage' of phosphorus in the soil to be used by crops at a later time. This 'storage' however does not negate the fact that a unit of phosphorus will either be used by the crops at some point in time or will be available for runoff. It does not alter our balance constraint. An alternative way to see this is to view the amount of phosphorus that is present in the soil as a 'stock', whereas this analysis is concerned with the 'flow' of phosphorus. Some of this 'flow' can be used to replenish and/or augment the 'stock' of phosphorus in the soil while the remaining portion of the 'flow' will run off and enter the hydrological system. Further examination of equation (6) shows that the amount of runoff is related to the amount of broilers raised and the amount of abatement undertaken by the grower.

Although the exact amount of phosphorus runoff is likely to be stochastic in nature, the potential amount of phosphorus runoff is substantial. Litter contains nitrogen and phosphorus in a 1:1 relationship, but this ratio can be as high as 1:3 or even 1:4 depending upon the cleanout frequency of the poultry houses (Zhang, Johnson, and Fram, 2000; Daniels et al., 1998; Xu and Prato, 1995). The data in Table 1 on the average amount of phosphorus generated per farm was created under the most conservative restrictions and can therefore be seen as a lower bound of the amount of phosphorus produced in the Illinois River Basin region. However, the crops grown in the region use nitrogen relative to phosphorus in a 2.5:1 or even 4:1 ratio[6]. Since growers primarily

lay litter based on the crop's nitrogen needs and not their phosphorus needs, it is not necessary to represent nitrogen runoff in equation (4).

Finally, equation (7) states that runoff cannot exceed the net amount of permits owned by the grower. Here T^E is the grower's initial endowment of permits and can be thought of as the maximum amount of phosphorus runoff that will be allowed if the grower does not purchase or sell any permits.

We assume that the production functions for broilers and crops have the typical form: g_L, g_S, F_N, $F_M > 0$ and g_{LL}, g_{SS}, F_{NN}, $F_{MM} < 0$ in that increases in labor and size will increase the number of broilers produced but at a decreasing rate. Similarly, increases in nitrogen and phosphorous applications will increase crop yields but, like labor and size, are also subject to diminishing returns. Litter production increases as broiler production increases, but at a constant rate yielding: W_g, N_W, $R_W > 0$ and W_{gg}, N_{WW}, $R_{WW} = 0$. In other words, as you double the number of broilers, you double the amount of litter generated. Lastly, pollution is an increasing function of broiler production and a decreasing function of abatement so that $f_g > 0$, $f_{gg} > 0$ and $f_A < 0$, $f_{AA} < 0$. We hypothesize that pollution increases at an increasing rate relative to the production of broilers. We base this on the carrying capacity for phosphorus in the soil. As the number of broilers increases, there will be a corresponding increase in the production of litter. As this additional litter is laid on the soil, some of it will be absorbed by the soil and some will be subject runoff. As the amount of phosphorus already present in the soil increases relative to its carrying capacity, larger percentages of additional phosphorus from additional applications will be subject to runoff since the ability of the soil to absorb and hold additional phosphorus is being diminished. We are also assuming that increases in abatement will lead to decreases in pollution, but that this additional abatement is also subject to diminishing returns.

2.1. Case 1: a binding pollution constraint with abatement choices only

We shall begin our analysis of pollution constraints, abatement, and tradeable permits by examining the grower's decisions under a base case

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[6] If we assume that the nitrogen:phosphorus ratio of litter is 1:4 and that crops in the area need nitrogen relative to phosphorus in a 4:1 ratio, laying litter on the soil to meet a crop's need of 1 unit of nitrogen means that there will be an additional 15 units of

phosphorus that will be unnecessary. Once the storage capacity of the soil for phosphorus is met, all of these 15 units will now be subject to runoff. Current soil tests show phosphorus levels of over 300 pounds of phosphorus per acre, but the regional crop needs vary between 80 to 120 pounds of phosphorus per acre (Mitchell, 2001).

scenario. Under this scenario the firm's only option is to abate. As stated earlier, this abatement can take many forms, including riparian buffers, litter storage, etc. The grower's problem is now to maximize equation (1) subject to the constraints of equations (2) through (7), with T^D and T^S set equal to zero, and λ_1, λ_2, θ, α_1, ϕ, and α_2 as the respective multipliers. The first order conditions of interest are listed below:

$$B: P_B - \lambda_1 + \lambda_2 W_B \leq 0 \tag{8}$$

$$Y: P_Y - \alpha_1 \leq 0 \tag{9}$$

$$L: -n + \lambda_1 g_L + \phi f_g g_L - \alpha_2 f_g g_L \leq 0 \tag{10}$$

$$S: -r + \lambda_1 g_S + \phi f_g g_S - \alpha_2 f_g g_S \leq 0 \tag{11}$$

$$W: -a - \lambda_2 - \phi R_W + \theta N_W \leq 0 \tag{12}$$

$$A: -e + \phi f_A - \alpha_2 f_A \leq 0 \tag{13}$$

$$M: \phi + \alpha_1 F_M \leq 0 \tag{14}$$

$$N: -\theta + \alpha_1 F_M \leq 0 \tag{15}$$

Substitution and rearranging yields the following relationships for L and S:

$$L: g_L[P_B + (P_Y F_N + P_Y F_M R_W - a)W_B - P_Y F_M f_g]$$
$$= n + \alpha_2 f_g g_L \tag{16}$$

$$S: g_S[P_B + (P_Y F_N + P_Y F_M R_W - a)W_B - P_Y F_M f_g]$$
$$= r + \alpha_2 f_g g_S. \tag{17}$$

We can interpret the left hand side as being the value of the marginal product from L or S. The term in parentheses within the bracket tells us the VMP of litter to crop output, i.e., its agronomic value, less its spread costs, which are a dollars. Recall that the production of broilers produces litter which also has some agronomic value for the crops. The nitrogen from the litter supplements crop(s) output by the amount F_N which can then be sold at price P_Y. Therefore, $P_Y F_N$ is the value of the increased crop output from the increased nitrogen application which comes from additional litter applications of W_B. A similar analysis of the agronomic value from phosphorus is represented by the term $P_Y F_M R_W$. The third bracketed term on the left hand side is the loss of value from phosphorus runoff and warrants some additional explanation.

Recall that $f(g(L,S),A)$ is our pollution production function. Therefore, $f_g g_S$ tells us the increase in phosphorus runoff when S increases[7]. The value of that runoff, i.e., the increase in crop output that the lost nutrients *could* have produced had the firm engaged in some activity to prevent the nutrients from being allowed to runoff, is $P_Y F_M f_g g_S$. For clarification, consider the problem as follows. Suppose that the grower knows that the crops planted will need 100 pounds of phosphorus. However, some amount of this phosphorus will run off. Therefore, if the grower wants to ensure that 100 pounds of phosphorus will remain in the soil for crop uptake after runoff, he must lay more than 100 pounds of phosphorus, e.g., 110 pounds of phosphorus, and costs subsequently increase. Alternatively, the grower could lay the required 100 pounds of phosphorus and engage in some abatement activity to ensure that none of the laid phosphorus is available for runoff. In short, the last term on the left hand side simply reflects the decreased value of crop production when phosphorus is allowed to become runoff.[8]

The first term on the right hand side is simply the marginal cost of L or S. We can use the envelope theorem to give an interpretation to α_2 as the marginal profit of allowing an additional unit of phosphorus in runoff. Therefore, the second term on the right hand side is the marginal profit from a change in emissions (phosphorus) as S or L changes. Let us consider S for the moment. Equation (17) states that in equilibrium the firm uses S to the point where the VMP from the last unit of S equals the sum of marginal cost of that unit of S plus the marginal profit loss from increased emissions (see Appendix).

What if the pollution constraint represented in equation (7) is non-binding for the firm? The Kuhn-Tucker conditions state that α_2 will be equal to zero. In this case, the firm is faced with the usual profit maximizing decision problem of equating the VMP from S to the marginal cost of S, i.e., capital cost. The firm's choice of S can be seen in Figure 1 where the firm uses S^* units of capital when the pollution constraint is non-binding. Now assume that the pollution constraint becomes binding on the firm. This could be because of a regional regulation that has imposed a limit on the amount of phosphorus, such

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[7] Similarly, $f_g g_L$ shows the increase in phosphorus runoff when the firm employs an increase in labor.

[8] Since nitrogen runoff is not a problem in this region, it is not necessary to represent nitrogen runoff and the subsequent decrease in crop output. However, there are many regions of the country where nitrogen runoff is an issue and this model could easily be generalized to take account of this fact. A region that has experienced significant nitrogen runoff from nitrogen fertilizer applications on crops is the Chesapeake Bay.

as T^E_1, that is allowed to enter the watershed and the firm will exceed that limit with its current use of S^* units of S. At this point, α_2 is no longer equal to zero, and the firm must respond by decreasing its use of S to only S_1 units under pollution constraint T^E_1 or S_2 units of S under the more restrictive pollution constraint of T^E_2.

An alternative explanation to α_2 can be seen by taking the total differential of equation (7) which is the pollution constraint, and recalling that under this scenario that $T^D = T^S = 0$, we have

$$f_g g_L \, dL + f_g g_S \, dS + f_A \, dA = dT^E. \tag{18}$$

Setting $dL = dT^E = 0$ and rearranging yields

$$f_g g_S \, dS = - f_A \, dA \tag{19}$$

so that

$$dA/dS = - f_g g_S / f_A \ > 0 \tag{20}$$

since $f_A < 0$. Equation (20) shows the relationship between abatement and poultry operation size for any given pollution standard, T^E. Once the firm has used enough S so that it emits enough runoff to make the pollution standard binding, all additional (potential) pollution from an increase in S, or L for

that matter, must be fully abated at some positive nonzero cost to the firm.

We are now in a position to interpret the last term in equation (17) in a third alternative manner as the marginal cost of abating the additional pollution produced, $f_g g_S$, when S increases. Furthermore, since additional pollution requires additional units of abatement, and the marginal effectiveness of abatement is decreasing, the cost of abatement is increasing at an increasing rate. To see that this is true, assume that the pollution standard is systematically tightened. Figures 1 and 2 assume that the firm does not change the size of operations, S^*, as the pollution constraint is imposed and is tightened. The result of the tighter standards, from being nonbinding to T^E_1 to T^E_2, are to increase the required level of abatement from zero to A_1 to A_2, resulting in increasing marginal abatement costs of MAC_1 and MAC_2 respectively. Figure 1 shows these increases in marginal abatement costs as the vertical distance from r to $r + \alpha_2 f_g g_S$ for various levels of the environmental constraint. Therefore, if the environmental standard is represented by T^E_2, at S^* the firm is increasing revenues by r, but costs are increasing by MAC_2, so profits are falling by $MAC_2 - r$. This result is inefficient.
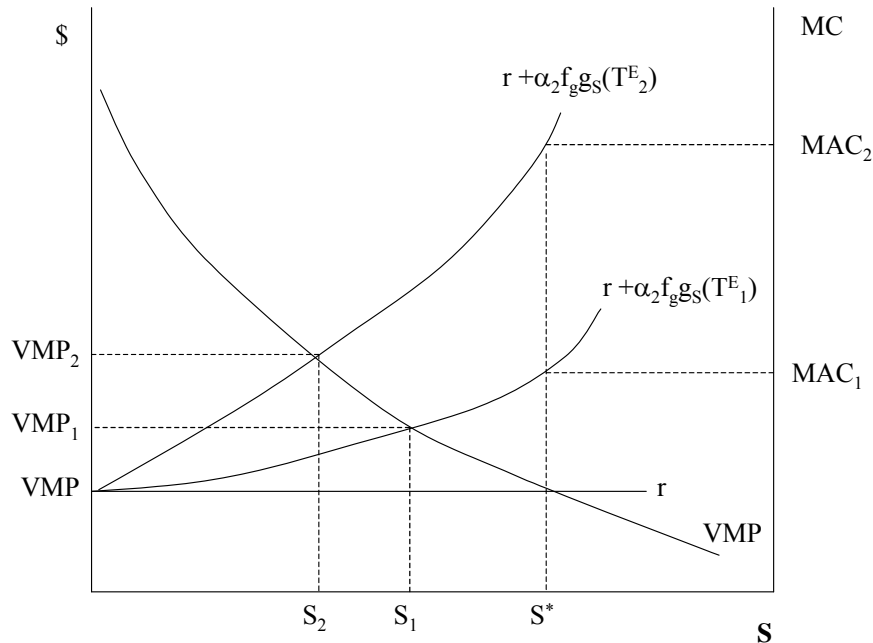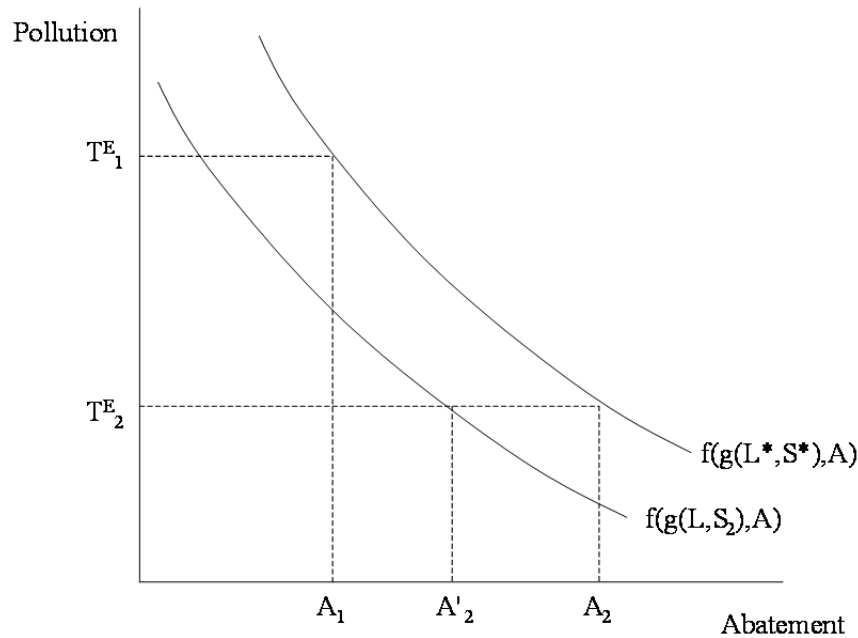

Figure 1. The optimal value of size for the firm.

Figure 2. Abatement choice with various environmental constraints.

However, there is more than one way for the firm to change its behavior to meet the environmental standard. It can also "abate" pollution by reducing S which would subsequently reduce broiler output and pollution. Figures 1 and 2 give a graphical example of this process. Initially, the environmental standard is T^E_1 and the firm buys A_1 units of abatement to meet the standard. When the constraint is tightened to T^E_2, the firm must increase its purchases of abatement to A_2. Alternatively, the firm can reduces its use of S to S_2 and simply increase its abatement purchases to A'_2. The "cost" to the grower of decreasing S is the reduction in profits from producing fewer broilers for market; however, the grower "saves" in abatement costs since he no longer needs to purchase $A_2 - A'_2$ units of abatement. The grower will continue to engage in reductions in S and increases in A to meet the environmental standard until their effect on marginal profits is equated.

Figure 1 shows these the tradeoff between these choices much more clearly. The left axis is the VMP from S and the right axis is the marginal cost of S and marginal abatement costs. Initially, with a nonbinding pollution constraint, the firm choose S^*. However, when the pollution constraint becomes binding, the firm experiences increases in marginal abatement costs. These marginal abatement costs are increasing at an increasing rate as S grows larger. When the pollution constraint is implemented and then tightened to T^E_1, the firm engages in

purchasing some abatement and reducing S to S_1 at the same time and continues to do so till the reduction in the VMP from reducing S is equal to the increase in marginal abatement costs.

2.2 Case 2: a binding pollution constraint with abatement and permit trading

For the second case, we consider a binding pollution constraint where the firm now has the option of purchasing permits in lieu of abatement or of selling permits and engaging in abatement. Once again, the regulator has set the pollution limit at T^E_1 and the firm is able to purchase permits at the price of h^+ if it wishes to exceed the environmental standard. Similarly, the firm may sell permits at the price of h^- and reduce pollution subsequently by abating or reducing output. The question before us now is how will the option of purchasing/selling permits change the grower's previous decisions?

The grower will once again maximize equation (1) subject to the constraints in equations (2) through (7) with the same respective multipliers. This time however, T^D and T^S are not equal to zero. The relevant first order conditions are identical to those listed under case 1 with the following additions:

$$T^D: \ -h^+ + \alpha_2 \leq 0 \tag{21}$$

$$T^S: \ h^- - \alpha_2 \leq 0 \tag{22}$$

Noting that $h^+ = \alpha_2$ from equation (21) and rearranging equation (17) yields the following for S and a similar equation for L:

$$S:\ g_S[P_B + (P_Y F_N + P_Y F_M R_W - a)W_B - P_Y F_M f_g]$$
$$= r +\ h^+ f_g g_S. \tag{23}$$

The first three terms on the left hand side have the same interpretation as in case 1. The last term on the right hand side shows the cost to the grower of buying permits to abate the additional pollution created when S increases. Note that these costs are increasing in S. As S increases, broiler output expands at a decreasing rate but pollution runoff increases at an increasing rate; therefore, the amount of permits (or abatement) necessary for the firm to purchase to stay compliant with the environmental standard is increasing at an increasing rate. Since the firm has the option of engaging in abatement activities to reduce pollution to the environmental standard or to allow runoff beyond the environmental standard to occur so long as permits have been purchased, how does the firm decide which activity to engage in? The short answer is that it equates the marginal costs of each activity, i.e., purchases permits up until the point where the permit price is equal to the marginal cost of additional abatement.

By rearranging equation (13) we see that the relationship between permit price and abatement cost can be expressed as[9]

$$h^+ = [-e - P_Y F_M f_A] / f_A\ > 0. \tag{24}$$

The bracketed term on the right hand side is the "net cost" of abatement activities. Recall that litter has agronomic benefits in that it provides nutrients for crops and thus increases crop yield. The value of this increased yield is $P_Y F_M$, and the term f_A shows the amount of nutrients that do not run off when the grower engages in some abatement activity. Therefore, when the grower chooses to abate runoff, he incurs a cost of e per unit of abatement but increases revenue from crops by $P_Y F_M f_A$. If the grower was to choose to purchase a permit to allow runoff, he incurs the cost of both the permit and the loss of the possible increased yield that the nutrients in the runoff could have produced. Nevertheless, recall that as litter applications increase, the increased yield from the nutrients is increasing at a decreasing

rate. Therefore, at some level of nutrient saturation within the soil, the value of additional nutrient applications falls to zero meaning that the term $P_Y F_M f_A$ is also approaching zero. When this occurs, we are left with equation (25)

$$h^+ = -e/f_A\ > 0. \tag{25}$$

Equation (25) states that the firm will purchase permits and engage in abatement activities until the marginal cost of permit purchases is equated to the marginal costs of abatement per unit of reduced pollution. This choice is shown in Figure 3. Initially, the firm purchases A_1 units of abatement when the environmental standard is T^{E_1}. Permit purchases allow the firm to be in compliance while only employing A'_1 units of abatement. The increase in cost to the grower of purchasing T^D units of permits is offset by cost savings in abatement purchase reductions, $A_1 - A'_1$.

Similar analysis can show the firm's choice if it decides to sell permits. Equation (25) is modified to become

$$h^- = -e/f_A\ > 0, \tag{26}$$

which states that the firm sells permits until the marginal revenue of permit sales equals the marginal costs of abatement per unit of reduced pollution. Once again, this is shown in Figure 3 where the firm's permit sales indicate an increase in abatement purchases to A''_1 to remain in compliance with the environmental standard. The increased cost of additional abatement purchases is offset by the revenue the firm receives from selling permits on the open market.

What effect would permit purchases have on the optimal size of poultry operations? The analysis is identical to that between the firm's abatement choices and S that was examined in case 1. Since successive increases in S translate into increases in pollution at an increasing rate, the firm's pattern of permit purchases must also increase at an increasing rate in order to avoid violating the environmental standard set by the regulator. Through a reexamination of Figure 1, and by replacing α_2 with h^+, we see that the firm will also decrease its operation size in a manner like it did when it was faced with only using abatement to remain compliant with the environmental standard.

How does the firm respond to an increase in the price of broilers? With the price growers receive for raising broilers increasing, they will expand output

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[9] Recall from equation (A3) in the appendix that
$\alpha_2 = [-e - P_Y F_M f_A] / f_A$. However, equation (21) implies that
$h^+ = \alpha_2$, which leads to the statement of equation (24).

and hire more labor and capital. The increase in profits that the firm is able to realize by increasing output will be hindered somewhat by the increase in pollution treatment costs that the firm must now pay. Consider Figure 3, which shows the increase in abatement the firm must purchase when L and S increase to L_2 and S_2. Recall that if the firm sells permits it must buy $A''_1 - A_1$ units of abatement and if it buys permits it can reduce abatement purchases by $A_1 - A'_1$ units. As output expands, pollution increases and the costs of either abatement or permits will be increasing at an increasing rate. Once again,

the firm will be in equilibrium where the VMP from expanding output equates to the increased marginal pollution control costs the firm must pay from the expansion in output, regardless of whether these pollution control costs are from abatement or permit purchases. When the firm expands output and sells permits it must now purchase $A''_2 - A_2$ units of abatement, a larger amount of abatement for the same amount of permits sold, $T^E_1 - T^S$, than when output was it its reduced level.
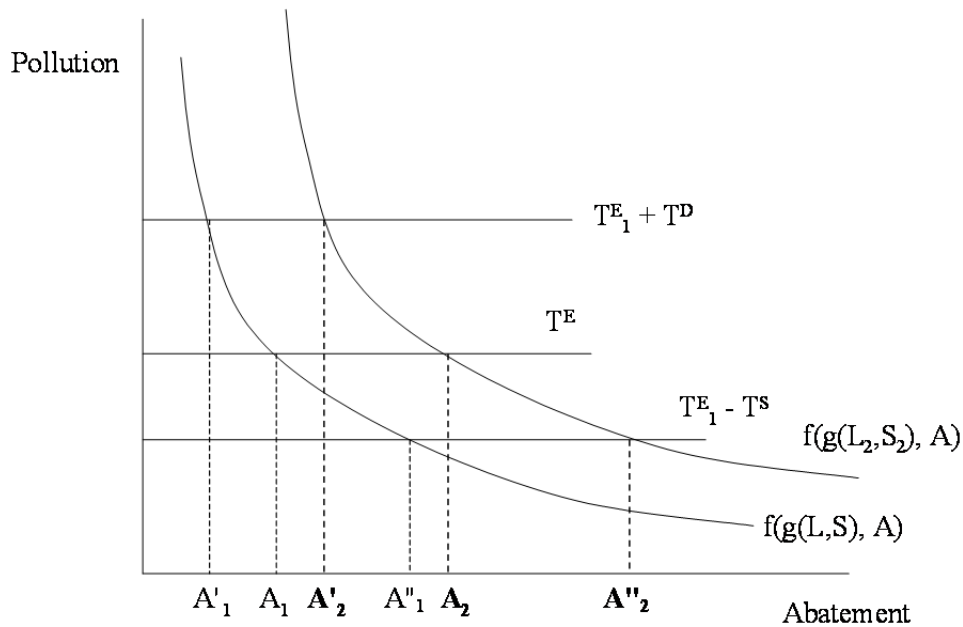

Figure 3. Abatement choices and permit transactions.

3. Implementation and caveats

There are several caveats that should be taken into account when developing and implementing this model within the Illinois River Basin or within other watersheds such as Chesapeake Bay. Probably the most important is that the region under study crosses a political boundary. Therefore, any economic solution will also have to have a political solution. This is evidenced by the long legal history between Oklahoma and Arkansas. For example, in the late 1980s and early 1990s, the state of Oklahoma sued the state of Arkansas over municipal wastewater discharges into the Illinois River that were originating in Arkansas. In 1992, the Supreme Court ruled in favor of Arkansas and stated that Oklahoma's water quality standards had to be met at the state line but not before the state line. Since this time, there has been continued discussion between differ-

ent stakeholders from Oklahoma and Arkansas on a variety of issues including at what level to set a phosphorus standard. This has ranged at different times from 0.01 mg/l to as high as 0.05 mg/l.

A corollary to the political boundary problem is the location of the broiler farms. Recall from Table 1 that 75% of the broilers are being raised in Arkansas. Therefore, it is Arkansas growers that will bear the largest brunt of this policy. The average Arkansas grower will either have to reduce size or purchase permits to remain in compliance with the environmental standard. Previous research has suggested that Arkansas' regional economy could see a reduction of between 1 and 6% depending upon the strength of the environment constraint. This is in contrast to a one-half to 1% decline in the overall regional economy in Oklahoma (Willett et. al., 2006). Uneven economic impacts such as this can be a

difficult sell to stakeholders, but these economic changes can be mitigated if the regional economy is able to diversify. Of course, it can be difficult and time consuming to alter labor skills and established capital. In short, although regional economic diversification might provide a long run solution, it is unlikely to occur in the short run.

A final problem worth noting is actually measuring the farm-level emissions. In order for a TDP program to work, the market participants have to be able to measure their emissions and the regulatory agency has to be able to monitor compliance. In this region this could take many forms, including testing soils for the levels of phosphorus (STP) and basing permit trading on a given STP standard. Therefore, in order to have an STP higher than the standard, the grower would have to purchase permits. However, it is possible for STP to vary within many parts of a field. Therefore multiple tests in multiple locations would have to be performed. This would of course raise transactions costs and increase uncertainty making the TDP less viable in meeting its goal of increasing efficiency. On the other hand, although the soil in the Illinois River Basin is not perfectly homogeneous, and therefore could contain fields that would be capable of storing more phosphorus before runoff occurs, it is somewhat homogeneous. Therefore, the regulator could sacrifice some 'economic efficiency' for 'operational efficiency' and have fewer STP observations.[10]

An alternative to testing and monitoring soil or water conditions is to base the TDP system on the number of broilers themselves. Once again, this might lead to the sacrifice of a perfectly efficient theoretical result. However, the relationship between the number of broilers raised and the amount of litter generated is fairly well known. Therefore, reductions in the number of broilers raised should lead to reductions in the amount of litter generated and hence laid on the soil. The regulatory agency could easily implement a limit on the number of broilers raised and allow growers who wanted to exceed the limit to purchase permits or allow growers to sell permits if they wanted to reduce their size.

Contrary to popular opinion, it is fairly easy to 'count your chickens' and base the TDP on the chicken count.

4. Conclusions

The economic benefits of using transferable discharge permits to control pollution from both point source and nonpoint sources has been understood in the literature for some time. The application of permit theory to real world pollution problems is also increasing as many of the obstacles in establishing and monitoring a permit market are becoming easier to solve. This paper has investigated a farm-level establishment of a permit market for phosphorus runoff that is derived from applications of poultry litter to aid in cropping activities.

The firm's optimal choice of poultry operation size was determined under a base case scenario where the firm only has the option to abate. Once the firm reaches a size where the environmental standard becomes binding, all additional pollution must be abated. However, due to the decreasing effectiveness of additional abatement units, marginal abatement cost will be increasing. These increasing marginal abatement costs might act as a limit on firm size. Furthermore, it was shown that firm may respond to an increasingly strict environmental standard not by merely increasing abatement but by reducing output as well.

The introduction of a tradeable permit system yielded similar results. Once the level of generated pollution was equal to the environmental standard, all additional pollution either had to be abated or permitted. The grower will buy permits until the permit price is equated to the marginal costs of abatement. Once again, since increases is S result in more pollution that must be abated or permitted at an increasing cost, there will be some limits to firm size. The grower's behavior when the environmental standard was tightened was identical to his choice when the firm could only abate; the grower would reduce the size of poultry operations and hence output. How much output, and hence firm size, will be reduced depends upon the strength of the environmental standard.

Acknowledgements

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[10] Standard economic theory dictates that efficiency occurs when the marginal benefits of an action equal the marginal costs of an action. However, oftentimes there is a problem of information. Market participants might not know exactly what the marginal benefits and marginal costs of additional action are. Therefore, they need to collect additional information on these additional costs and benefits. Of course, collecting more information is itself costly; therefore, it might be 'cheaper' to make a less-than-fully-informed decision than a fully-informed decision.

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Appendix

By rearranging equations (9) and (14) and through substitution we can see that

$$P_Y = \alpha_1 \tag{A1}$$

$$\phi = -P_Y F_M \tag{A2}$$

Therefore, equation (13) can be written as

$$\alpha_2 = [-e - P_Y F_M f_A] / f_A \tag{A3}$$

and substituting the value for α_2 into (17) we arrive at

$$g_s[P_B + (P_Y F_N + P_Y F_M R_W - a)W_B - P_Y F_M f_g] = r + [[-e - P_Y F_M f_A] / f_A] f_g g_s \tag{A4}$$

$$= r - (e f_g g_S) / f_A - (P_Y F_M f_A f_g g_S) / f_A \tag{A5}$$

and noting that the f_A's cancel in the last term and that the remaining portion of the last term cancels out on the right hand side yields

$$= r - (e f_g g_S) / f_A. \tag{A6}$$

However, $f_A < 0$ making the last term appear positive as it does in equation (17).