#9818

An Analysis of Policy Alternatives for Pivotal Externalities

by

Marca J. Weinberg
Catherine L. Kling
James E. Wilen

February 14, 1991

AAEA, 1991

1991

Externalities

An Analysis of Policy Alternatives for Pivotal Externalities

This paper examines policy alternatives for pivotal externalities. A theoretical model of the welfare losses from non-optimal policies relative to the pareto optimum is examined. The magnitude of these costs are demonstrated with an example drawn from the agricultural drainage problem in California.

An Analysis of Policy Alternatives for Pivotal Externalities

The issue of how far back in the pollution stream one must look to define policy instruments that induce optimality has received limited attention in the literature. Bird (1987) defines a transferable externality as one for which the victim is able to shift the externality away from himself and on to another victim. He argued that recipients of transferable externalities would need to be compensated to prevent them from passing the externality on. Baumol and Oates responded that compensating victims might induce them to hold onto the externality when it would do less damage to another victim. They argued instead that a series of Pigouvian taxes was necessary to assure optimality: a tax on the original generator, as well as taxes on those who shift the externality.

A parallel line of inquiry concerning externalities defined as pivotal or intermediate has been developed by Wichelns, Holterman, and Weinberg. These externalities are essentially transferable, but, in addition, they are characterized by a change in the magnitude of the transaction costs associated with identifying and regulating the externality. With pivotal externalities, the victim, who may in turn shift (or pivot) the externality on to another victim is identifiable, but the original generator is not. In this case, policy instruments can be applied to the pivoter, but not to the original generator.

The agricultural drainage problem in California is an example of a pivotal externality. In this problem, farms located upslope in the pollution process contribute to the volume of effluent produced by downslope farms through laterally moving subsurface flows (Grismer and Woodring; Gilliom, et al.). Deep percolation of excess irrigation water applied on farms without tile drainage systems may be collected in the drainage systems of downslope farms who in turn discharge collected drain water into a waterway. The downslope farmer thus "pivots" the subsurface flows from a nonpoint source pollutant generated by upslope farmers into a point source pollutant.

The pivotal nature of the drainage externality is important for policy purposes since it may not be feasible to place a policy instrument on the upslope contributors of the externality. In this case, policies to deal with the drainage problem will be second best in nature and will, in general, not lead to a least cost solution to meeting drainage standards.

This paper presents a model of a pivotal externality, examines the welfare losses associated with two second best policy alternatives, and presents an empirical example to examine the possible magnitude of the welfare losses involved.

A Model of a Pivotal Externality

The implications of pivotal externalities in the context of the drainage problem are examined by adapting the model developed by Wichelns (1986). Two farms are considered, one of which (farm u) is located hydrologically upgradient of the other (farm d). Both farms have identical crop production functions, but the effluent produced by farm u enters the effluent function of farm d, rather than entering the social damage function directly.

The social objective is to maximize the sum of net returns to farms from crop production minus the social damages created by the production of drain water. That is the policy maker wishes to

$$Max \ \ p[f(x_u,z_u)+f(x_d,z_d)]-w(x_u+x_d)-r(z_u+z_d)-p_d g(x_d,z_d,h(x_u,z_u)), \tag{1}$$

where x_i is the quantity of the polluting input used by farmer i, i=u,d with price w, z_i is the quantity of an abating input with price r, p_d is the constant marginal social damage from the drainage, f(.) is the crop production function, g(.) is the downslope drainage production function, and h(.) is the subsurface drain flows produced by the upslope farmer. In this example, x_i may be thought of as water applications, while z_i represents improvements in irrigation technology or management.

Optimal taxes or other control instruments are required at all stages in the effluent production stream to induce competitive firms to generate a socially optimal amount of drain water. The optimal tax on drain water is p_d and the optimal tax on subsurface flows would be $p_d g_h$ (see Weinberg for details). Since the effluent produced upslope does not enter the social damage function directly, the optimal tax would be the marginal social damage of the effluent (p_d) weighted by the marginal contribution to effluent discharges from effluent produced upslope (subsurface flows).

In reality, it is difficult to implement this optimal tax policy. Effluent taxes are feasible only when both subsurface flows and collected drain water can be accurately measured. In the San Joaquin Valley, the volume and direction of subsurface flows can be estimated in local areas (Grismer and Woodring; Wichelns and Nelson), but the precise locations of origin are unknown. The costs of gathering this information regionally are likely to be prohibitive even if the task is physically possible. Therefore it is of interest to examine the implications of introducing policies that are not optimal, but may attain environmental objectives.

An Analysis of Second Best Policies

Marginal benefits and costs associated with the use of x in the upslope and downslope farms are illustrated in Figure 1. The downslope drainage function is assumed to be additively seperable in the upslope and downslope contributions. The upper left panel depicts net private marginal benefits and marginal social costs associated with the use of the polluting input by the upslope producer. The same relations are depicted in the lower right panel for the downslope producer. Net private marginal benefits are defined as $NMB_j = pf_x^j - w$, $i=u,d$, and are assumed (for diagramattic simplicity) independent of the level of the abating input.

The marginal social costs associated with downslope input use are the marginal social costs associated with a unit of effluent (p_d) weighted by the marginal effluent product of the input, i.e., $MSC_d = p_d g_{x_d}$. The upslope producer does not generate social damages directly; rather, the social costs associated with upslope input use arise as a result of the pivoting of subsurface flows into effluent (collected drain water) by the downslope producer. These are described by $MSC_u = p_d g_h h_{x_u}$. Marginal social costs are drawn flatter in the panel representing upslope activities than in the downslope panel since water on a field that overlies a drain system has a greater impact on collected drain water than water applied on a field upgradient but some distance away from the drains.

The upper right panel depicts effluent production isoquants. Effluent production is constant along each isoquant and isoquants further from the origin imply higher levels of effluent than those closer to the origin.

Farms in both areas will choose input use levels that drive net marginal benefits to zero in the absence of policy intervention. The level of effluent that will result from these input levels is g^0. Social welfare is the sum of the net gains from input use by downslope and upslope producers. Total private gain from input use is the area under the net private marginal benefit curves. Upslope gains are depicted as area (dc0 + bc0), while downslope gains are area (0eh + 0hi). Likewise, total social costs associated with input use are the areas under the marginal social cost curves, areas (abc + bc0) and (0hi + hij) for upslope and downslope activities, respectively. Net social welfare in the absence of policy intervention is

$$W^0 = (cd0 + 0eh) - (abc + hij) \,. \tag{2}$$

The socially optimal levels for each input are those that equate the net private marginal benefits and social marginal costs in each area (x_d^* and x_u^*), and the effluent level is g^* and net social welfare is

$$W^* = (cd0 + 0eh) \,. \tag{3}$$

The welfare *effects of policies that ignore the upslope* contribution can also be examined in this framework. Such policies will not affect the behavior of the upslope producer so input use upslope will remain at pre-policy levels. A Pigouvian tax (t_d) on the downslope producer set equal to the marginal social damages of the effluent (p_d) will result in the socially optimal level of downslope input usage and the level of effluent produced will be $\hat{g}$.

This effluent level is higher than the socially optimal level. Total net welfare is

$$W^t = (cd0 + 0eh) - (abc). \tag{4}$$

An alternate policy is a downslope discharge standard holding effluent levels at g^*. Net welfare is the same as with the Pigouvian tax (W^t) less an additional deadweight loss that is foregone welfare gains due to the tighter constraint on downslope activities. This deadweight loss is the difference between net benefits and social costs that result from a decrease in input use from x_d^* to x_d^s and is represented by area (fgh) in Figure 1. Total net welfare from a downslope discharge standard is

$$W^s = (cd0 + 0eh) - (abc + fgh) = W^t - fgh. \tag{5}$$

This result suggests that it will not be optimal to force the pivoter to restrict activities to compensate for effluent contributions by other producers.

Empirical Estimates of the Effects of Policy Alternatives

In this section, the welfare losses of the second best tax and standard policies described above compared to the first best tax solution are estimated for the pivotal externality of agricultural irrigation drainage. A non-linear programming model combined with a hydrologic model of the region was developed to predict changes in farmer decision making and effluent production in response to policy alternatives. Crop production functions for cotton, melons, tomatoes, and wheat, an irrigation technology cost function, and a drainage production function are included in the model (see Weinberg for a complete description of the model). Drainage reductions may occur in this model in three ways: (1) water applications can be reduced *ceteris paribus*, resulting in yield reductions as well as reductions in drainage; (2) water applications can be reduced in conjunction with improvements in irrigation technology and managerial practices to avoid yield reductions; and, (3) cropping patterns can be adjusted in favor of crops with relatively low marginal effluent (drain water) products. The irrigation technology cost function is included to model increases in production costs that will be incurred when farmers improve irrigation systems. To examine the empirical implications of the pivotal externality on drainage policies, a hypothetical example is constructed wherein 50% of the water percolating below the root zone in the upslope region moves laterally and enters the drains of a downslope farmer.

The first best solution to achieving an environmental objective is examined by maximizing the sum of net returns to land and management in both areas subject to a constraint on total collected drain water. When examining second best policies, subsurface flows are assumed to be exogenous to the downslope farmer and net returns to land and management are maximized for each area independently.

Table 1 presents the base case (pre-policy) results of the simulation indicating the number of acres planted in each of the crops, amount of inputs used, yield, and net revenues for both the upslope and downslope farmer. Subsurface flows entering downslope drains contribute 0.26 acre-feet (34%) of the 0.77 acre-feet of drain water collected per acre in the downslope area when no drainage policies are implemented. The target drainage reduction goal is a 30% decrease in collected drain water from the study area

(California, 1987). Three policy options are examined. The optimal solution is to regulate both upslope and downslope contributions. Crop returns are reduced by $7 per acre in the downslope area and by $6 per acre in the upslope area in the optimal solution to the drain water reduction goal (see Table 1). Subsurface flows are reduced by 36% from base levels at the optimum because only a portion of subsurface flows entering a drained area are collected in drainage systems.

The second policy, a tax on the downslope effluent only, provides the downslope farmer with correct signals regarding the social costs of production activities. The downslope farmer faces a drain water tax of $130 per acre-foot of collected drain water. The upslope farmer is not affected by the drain water tax and subsurface flows are not reduced. However, the consequences of ignoring the subsurface contribution are that the 30% drain water reduction goal is not achieved (collected drain water is reduced by only 22%).

Under the second best effluent tax policy, crop returns received by the downslope farmer decline by $7 per acre (see Figure 2); both crop returns and net returns remain at base levels for the upslope farmer. Average crop returns are actually higher with the drain water tax than in the optimal solution, but the social costs of the drain water are also greater. The fiscal cost of the tax policy is $77 per acre and is borne completely by the downslope farmer.

An alternative (second best) policy is a standard imposed on the downslope farmer that mandates the optimal level of drain water discharge. Upslope farmers are not affected by a drain water standard requiring a 30% reduction in collected drain water, as was the case with the drain tax. However, unlike the drain tax, the behavior of the downslope farmer <u>is</u> modified as a consequence of the subsurface flows when a drain water standard is imposed. The upslope contribution is exogenous to downslope farmers and must be subtracted from the drain water volume standard to determine the volume of drain water that may be generated by on-farm irrigations. Crop returns are $11 per acre less for downslope farmers than in the optimal solution.

The regional cost of this inefficiency is offset somewhat by higher crop returns in the upslope area with this policy compared with the optimal solution. Average returns decline by only $3 per acre. The optimal drain water volume is achieved with the standard and the $3 per acre difference in returns is the efficiency cost of the second-best policy.

Discussion

Implementing a policy that motivates the optimal solution to a pivotal externality requires that both upslope and downslope contributions be accurately observed. In lieu of this information, policy makers may be tempted to implement control measures at the known source of the effluent (the downslope farmer). The welfare consequences associated with these second best policies are examined in this paper from both a theoretical and an empirical perspective.

The results of the theoretical section suggest that a Pigouvian tax assessed on drain water collected by the downslope farmer will generate less social loss relative to the optimum than will a standard on the downslope farmer set at the optimal level.

The empirical results support this contention, but suggest that the difference in efficiency benefits among policy alternatives may be small. Average crop returns under the Pigouvian tax alternative are $3 per acre higher than those realized under the optimal solution to the 30% drainage reduction objective and are $6 per acre greater than when a drain standard is imposed. However, collected drain water is reduced by only 20% with the Pigouvian drain water tax. The efficiency costs of the second best method for achieving the 30% decrease in collected drain water is $3 per acre. This figure is likely to be well below the cost of determining the volume and origin of subsurface flows necessary to implement an optimal policy solution.

The results presented in this paper help to focus on the important tradeoffs between transaction costs and economic efficiency inherent in policy choice. The volume of drain water collected in drainage sumps is much easier and less costly to measure than the contribution from the upslope farmer. The costs of obtaining the information necessary to institute a first best policy, such as a Pigouvian tax on both the upslope and downslope producers, may exceed the efficiency gains from doing so. Policies that do not directly address the upslope contribution will be desirable in this case.

Income distribution issues also are highlighted in this analysis since downslope farmers are worse off with second best policies (relative to the first best policies), while upslope farmers do better in the second best environment than in the first best solution.

Figure 1 Welfare effects of policy alternatives for pivotal externalities

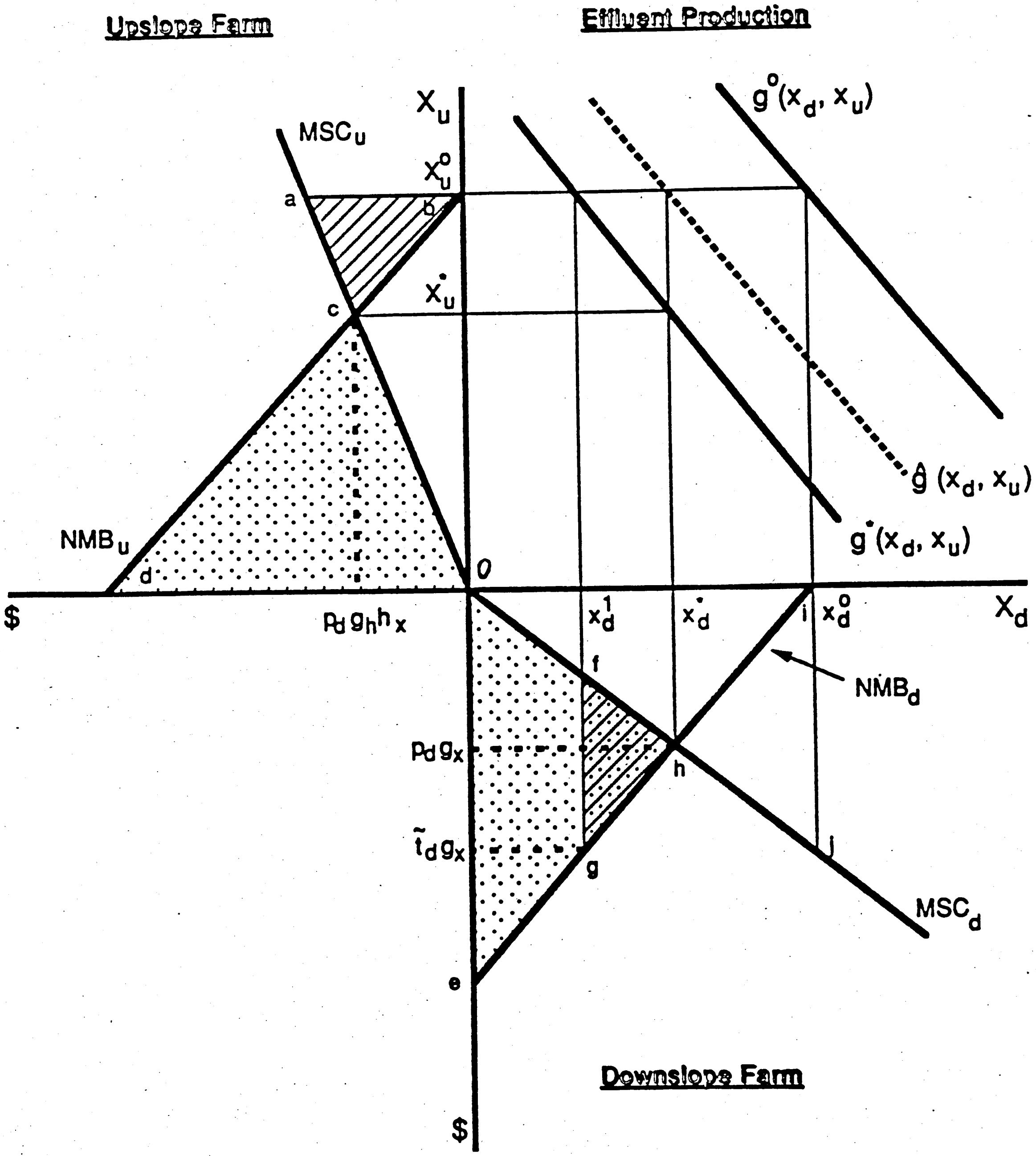
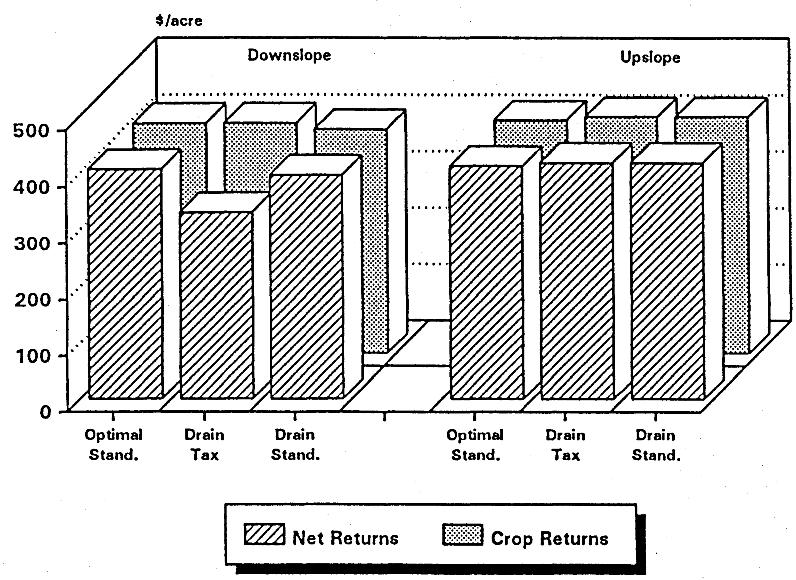


Table 1. Base case results and predicted policy response in the presence of a pivotal externality

		Base Results		Optimal Solution		Second–best Policies: Drain Tax		Second–best Policies: Standard	
		D	U	D	U	D	U	D	U
Cotton									
Acres	[% total]	67%	65%	82%	82%	82%	65%	82%	65%
Applied Water	[feet]	3.31	3.34	3.12	3.11	3.12	3.34	3.02	3.34
Irrig. Efficiency	[%]	74%	73%	82%	80%	82%	73%	85%	73%
Irrig. System Costs	[$/acre]	93.54	91.95	125.4	115.58	125.4	91.95	138.1	91.95
Yield	[tons/acre]	0.72	0.72	0.73	0.73	0.73	0.72	0.73	0.72
Melons									
Acres	[% total]	15%	17%	0%	0%	0%	17%	0%	17%
Applied Water	[feet]	1.98	1.99	0	0	0	1.99	0	1.99
Irrig. Efficiency	[%]	65%	64%	0%	0%	0%	64%	0%	64%
Irrig. System Costs	[$/acre]	57.71	56.77	0	0	0	56.77	0	56.77
Yield	[tons/acre]	8.48	8.48	0	0	0	8.48	0	8.48
Tomatoes									
Acres	[% total]	8%	8%	8%	8%	8%	8%	8%	8%
Applied Water	[feet]	3.38	3.41	3.08	3.15	3.08	3.41	2.98	3.41
Irrig. Efficiency	[%]	74%	74%	82%	80%	82%	74%	85%	74%
Irrig. System Costs	[$/acre]	95.37	93.59	123.83	116.81	123.83	93.59	136.24	93.59
Yield	[tons/acre]	33.48	33.48	33.48	33.48	33.48	33.48	33.48	33.48
Wheat									
Acres	[% total]	10%	10%	10%	10%	10%	10%	10%	10%
Applied Water	[feet]	2.18	2.18	1.94	1.99	1.94	2.18	1.86	2.18
Irrig. Efficiency	[%]	73%	72%	82%	80%	82%	72%	85%	72%
Irrig. System Costs	[$/acre]	71.67	70.22	93.99	88.6	93.99	70.22	103.37	70.22
Yield	[tons/acre]	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13
Coll. Drain Water	[af/dr. acre]	0.77	na	0.54	na	0.60	na	0.54	na
Subsurface Flows	[af/acre]	0.26		0.17		0.26		0.26	
Crop Returns	[$/acre]	415	419	408	413	408	419	397	419
Net Returns	[$/acre]	415	419	408	413	331	419	397	419
Ave. Crop Returns	[$/acre]	417		410		413		407	

Note: D and U designations refer to downslope and upslope farmers, respectively

Figure 2. Crop returns and net returns under first-best and second-best policy alternatives for drainage reduction



References

Baumol, W.J. and W.E. Oates. The Theory of Environmental Policy. Cambridge: Cambridge University Press. 1988.

Bird, P.J.N. "The Transferability and Depletability of Externalities." Journal of Environmental Economics and Management. 14(1987):54-57.

Holterman, S. "Alternative Tax Systems to Correct for Externalities, and the Efficiency of Paying Compensation."Economica. 43(1976):1-16.

Gilliom, R.J. and others. "Preliminary Assessment of Sources, Distribution, and Mobility of Selenium in the San Joaquin Valley, California." U.S. Department of the Interior. U.S. Geological Survey. Water-Resources Investigations Report 88-4186. Sacramento, California. 1989.

Grismer, M.E. and R.C. Woodring. "Assessment of Lateral Groundwater Flows in the San Joaquin Valley. " California Agriculture. 41(1987):22-23.

Weinberg, M.J. "Economic Incentives for the Control of Agricultural Non-point Source Water Pollution." Unpublished Ph.D. Dissertation, University of California, Davis, 1991.

Wichelns, D. "Economic Impacts of Salinity: Farm-Level Effects and Regional Analysis." Unpublished Ph.D. Dissertation, University of California, Davis, 1986.

Wichelns, D. and D. Nelson. "An Empirical Model of Irrigation and the Volume of Water Collected in Subsurface Drains." Agricultural Water Management. 16(1989):293-308.