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common practice is to vary emission standards in line with this relation, allowing larger plants to pollute more than small ones so as to constrain every plant to emissions proportionally below the uncontrolled level. The standards are designed to force firms to adopt the more expensive control devices presently manufactured for each scale of output. This practice could be optimal economically in the special case where plants regardless of size are forced to equally high marginal costs of control and where damages from an extra pound of smoke are the same regardless of plant size. While the special case is probably never encountered exactly, the common practice is almost surely more optimal than setting standards invariant to scale.

For automobiles, the tax on leaded gasoline, requirement of catalytic mufflers, and emission standards or tests for cars, are examples of fuel input, control devices and emission policies. Limiting auto use in central business districts is an output policy, specifically restricting auto travel output.

The static case considered in this section provides a starting point for dynamic extensions in which policy costs are conceived as a present value. In view of incentives to move toward new factor combinations, enhanced inducements to discovery will lead to research and development responses to policies neglected in previous estimates of costs. Since substitutions depend on the wearing out of equipment, the optimal timing of pollution reduction depends on capital replacement decisions. Capital replacement analysis is needed for variances granted in judicial and administrative proceedings that allow delay in meeting standards. London laws banning coal in space heating provide examples of input policies with dynamic dimensions. Coal has been declining as a household fuel due to relative cost changes. Replacement of existing furnaces determines the timing. Part of the costs of reducing coal air pollutants is the present value of switching out of coal sooner rather than later.

Net Benefits

Best

The production functions considered so far have included equation (2) $y = y(z, q)$ explaining the output of commodities affected by pollution, equation (8) $x = x(u, f)$ explaining output of commodities whose production causes pollution and equation (11) $s = s(f, c)$ explaining pollution emissions. The system is completed by another production function

$$q_i = q_i(s_1, \ldots, s_n), \tag{17}$$

showing how pollution emissions are transformed into changes in the public good causing pollution damages. This function differs for air, water and solid wastes, and for pollutants within any one of the waste forms. It can indicate how treatment facilities affect q and how emissions s at one time affect the public good at later times. For the air pollution examples in this paper, (17) is an air dispersion model. As will be shown later, the effect of an emission s_j on air quality q_i within the same shed varies depending on the location of j and i.

If there is only one x and y producer each or if producers are identical with no locational differentiation within the shed, (17) reduces to $q = q(s)$. This equation can be used in expressions for y benefits such as (5) and (6) to replace q with s. One obtains benefits from y as a function of s which can be compared with the benefits from x as a function of s derived in the preceding section. In Figure 3, the y benefits as a function of s reach a maximum to the left of the maximum for the x good. Proceeding from the y maximum, the marginal y benefits are negative as s increases. The marginal y benefits with changed sign are marginal costs which may be plotted in the same quadrant as the marginal benefits from x. The marginal cost schedule is upward sloping and crosses the marginal benefit schedule for x still to the left of s_m. If the two marginal schedules are linear, the gain from moving from the free market situation s_m to the maximum net benefit point, say s^*, where the two marginal benefit schedules cross, is the area between the schedules or $-[b(y)_s^{s_m}]^2/2[b(y)_{ss}^s - b(x)_{ss}^s]$, where $b(y)_s^{s_m}$ is the y benefit from a unit increase in emissions at the free market level. The foregoing gain is the maximum potential gain from an environmental policy. Solving for the level of emissions where marginal benefits equal marginal costs and subtracting from free market emissions gives reduction in emissions necessary to achieve the maximum gain.

Absolutely inferior

If emissions are reduced beyond what is necessary to achieve the maximum gain, a level $\bar{s}$ will eventually be reached below which net benefits are less than at the free market level. With linearity, the critical emission reduction is twice the reduction necessary for maximum potential gain, or

$$s_m - \bar{s} = 2b(y)_s^{s_m}/[b(y)_{ss}^s - b(x)_{ss}^s], \tag{18}$$

that is, twice the marginal effect of emissions on y benefits at the free market level, divided by the sum of the slopes of the marginal schedules. Nonlinearities might increase negatively on the slope of the marginal benefits schedule for y at higher emissions and increasing marginal costs of control for x at lower emissions. Since the nonlinearities have opposite effects on s^* and $\bar{s}$, they could conceivably be offsetting. These considerations indicate information needed to eliminate policies, that may be put forth in the course of policy deliberations, which are worse than no policy.

Waste interfaces

An illustration brings out the economics of the much discussed possibility that reduction of one externality may increase another. Suppose a choice is being made whether to get rid of garbage by incinerator or landfill. Direct costs per ton of garbage are $10 for incineration and $6 for landfill. To estimate external costs, suppose the volume to be handled of 500 tons per day, if incinerated, would result in 10 tons per day of particulate emissions. If damages from the particulates increase by $10,000 for each increase of one ton in daily particulate emissions, the external cost of the incinerator is $100,000 per year. Assuming a total of 125,000 tons are handled during a year, the external cost for incineration is $.80 per ton of garbage. A landfill will impose external costs on surrounding residences due to unsightliness, smell and noise. For this volume of waste, assume a landfill would impose an average property volume loss of $2,000 on 1,000 residences or $2 million capital loss which implies a yearly loss of perhaps $200,000. The external costs for landfill are then $1.60 per ton. Direct plus external costs per ton are $10.80 for incineration and $7.60 for landfill. The external costs do not reverse the ranking based on direct costs in this example, but, of course, they ought in other cases.

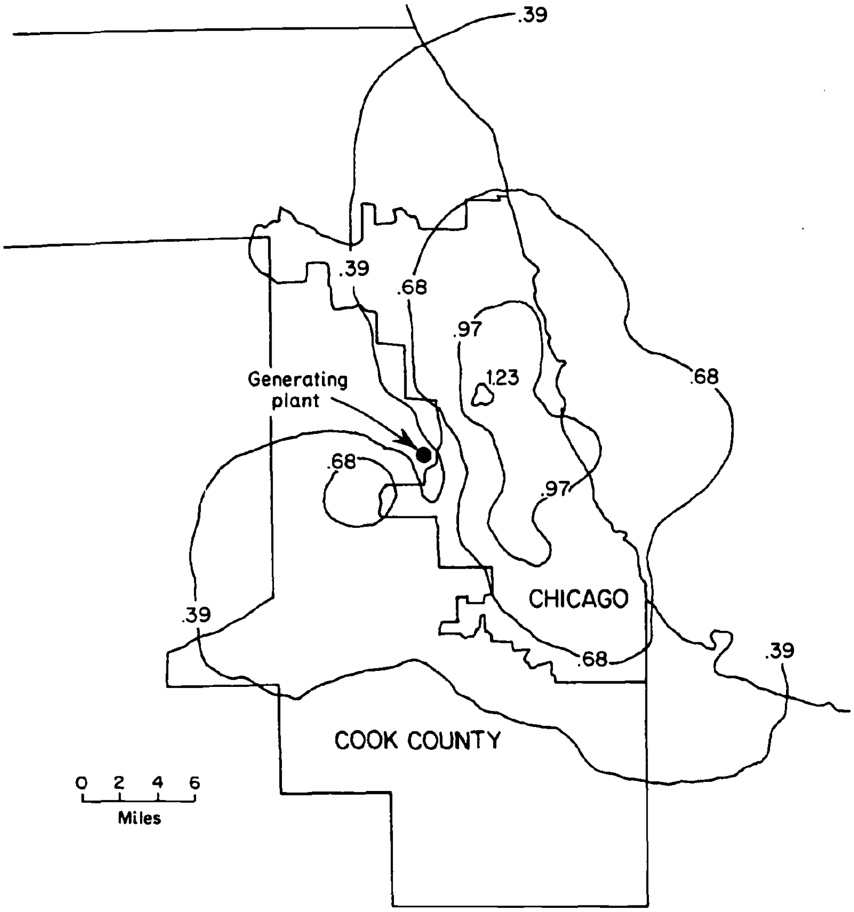
The landfill with external costs concentrated on a few residences in a vocal outlying community, might generate greater public opposition than the incinerator causing the landfill to be rejected in spite of its cost advantage. Requiring one payment for all compensation could make incentives of damagers and damagees coincide with incentives to maximize net benefits. If compensation of $2 million to surrounding property owners were required on opening the landfill (and likewise compensation to those damaged by air pollution were required if the incinerator were built) the external costs would be borne by those disposing of wastes. The damaged parties being fully compensated would lose their economic incentives for opposing the facilities.

Uniformity Losses

Within a metropolitan area, identical polluters cause different damages. Figure 4 shows SO_2 changes within the Chicago area that would result from a new power plant. The damages from the plant depend on densities of activity along each isopleth. Locating the plant differently would

Figure 4

Increase in SO_2 Levels from a New Generating Plant ($\mu g/M^3$)



change the isopleths leading to different damages. In outlying low density areas, the damages would be smaller.

Imposing uniform restrictions on emissions regardless of location imposes identical control on different externalities. All the current policies mentioned in the section on pollution control costs have this defect. Control may result in positive net benefits for some sources, while for other sources emissions are restricted below $\bar{s}$ with control costing more than worth. If quantitative restrictions are to be used, a case can be made for administrative or court regulation set case by case according to damages, rather than having a uniform emission standard. A uniform tax on emissions also imposes identical incentives on different externalities. To avoid the uniformity losses, the tax rate on emissions should vary at different points in the city. Salable emission rights also encounter the problem. If sales of rights to emit were allowed unrestricted within the metropolitan area, their trading value would tend to be the same as the tax necessary to attain the same level of emissions. With salable emission rights, *transfer fees* or *rebates* might be desirable equal to differences in damages caused by a change in the location of emissions.

Uniformity losses could be restricted by establishing zones within cities, within which uniform incentives would be imposed. Zoning could avoid a failure, possible under the foregoing policies, to find gains from eliminating pollution from some areas altogether. Joe Reid has emphasized the implications of nonconvexities, indicating a formal case for zoning to exclude some types of pollution altogether if the marginal damages are decreasing rather than increasing. The stability conditions are then violated, and the market—or policies trying to correct the market marginally—may find a local polluting optimum where net benefits are less than with no pollution. The normal concave situation of increasing marginal damages probably applies to materials damages and health. The convexity argument applies to esthetic and recreational uses of land, whereby a little bit of blight is sufficient to reduce drastically the benefits and with further blight not having much effect after the initial impact.

None of the policies mentioned so far avoids the free rider problems of getting people to bid either for reduced pollution or for the generation of knowledge about health and other adverse effects of pollution. Schemes have been proposed, so far at an abstract level, for including people to reveal their preferences for a public good by making the supply curve facing them be the actual supply curve less other people's bids (Clarke, Tideman). These schemes face the same problems connected with nonuniformities as do other policies.

The issue of losses from uniformity extends beyond spatial variation within one metropolitan area. When the wind is blowing and the weather is mild, reducing demand for fuels for heating, the marginal damage caused by a given level of emissions may be small, in contrast to great damages in still, cold weather, and even greater damages during an inversion. If a single emission standard must be observed at all times, as most plans require, different external costs are being treated alike over time as well as over space. Emergency measures required during episodes are a step in the direction of recognizing uniformity losses.

Administrative costs and regulatory behavior partly determine how much uniformity should be imposed, but the benefits and costs being considered in this paper also influence the choice. Because there are costs of varying the level of emissions, particularly if plants must be shut down for temporary periods, the maximization of net benefits does not call for instantaneous adjustment of emissions to every change in external costs.

The uniformity issue is particularly severe for automobiles in view of the variability in their emission damages with weather and traffic. While the costs of instantaneous adjustments appear prohibitive, the current legislative approach aiming to require the same control at all times everywhere maximizes uniformity losses. Preliminary results by Richard Zerbe suggest promise for varying standards by area and other intermediate strategies.

Location of Industry in Different Parts of the Country

Applying the same emission standard everywhere in the nation carries uniformity losses to a maximum. Costs for areas where emissions are reduced below $\overline{s}$ could exceed gains for areas of positive net benefits. If an industry's production costs are not very different among locations, shifts toward areas of low damage may be cheaper than relying solely on control in place. One of the least costly ways to reduce pollution losses could be to induce a different locational pattern. At odds with this idea is current legislation, which aims to freeze location. Standards for new plants are the same everywhere and are more stringent than for existing plants, impeding even normal locational adjustment.

While prominent in classic externality discussions (Coase, Pigou) spatial considerations have not been fully resolved partly because of need to more adequately consider land. The usual conclusion that a quantitative restriction, tax or salable right have the same effects on a producer is valid only if he stays in business at the same location. Consider the bid for an industrial site by a polluter. He will have higher profits with a quantitative restriction on emissions requiring no payments, than he will with necessity to pay an emissions tax, even though the two forms of control induce the same emissions reduction if he produces at the site. With the quantitative restriction he can bid more for the site and is more likely to bid out competing users. To foster optimum allocation, it appears his tax payments should equal total damages imposed making his bid correctly reflect x-benefits less y-losses. In deciding where to locate, externalities will then be internalized.

One pitfall to avoid is levying only a marginal tax rate. If an emission tax rate is made equal to marginal damages caused by a pound of pollutant, the total tax paid will equal total damages only if marginal and average damages are equal. If the idea is correct that marginal tends to be above average damages, the tax collected would be greater than total damages calling for a lump sum rebate. Under any policy, there may be a difference between marginal payments for emissions and the damages caused. As another example, under an emission standard marginal payments are zero. A general rule is to make lump sum rebate (or tax) equal to the difference between the sum of marginal payments and the total damages caused.

Payments by polluters should be coupled either with no compensation to those damaged (Baumol) or more equitably one payment for all compensated. As applied to land values, with no compensation, external costs will cause negative windfalls to owners of land on which external costs are borne, and taxpayers will gain the proceeds of the tax. With compensation, there need be no such wealth transfer. The present value of the damages is transferred from polluters to owners of affected land exactly offsetting the loss in sale value of their land due to the damages. Note that compensation is not related marginally to damages and is to be paid to land owners, not land users. If frequent compensation is expected and if land owners can manage to have excessive losses incurred on which to base the compensations, the expectation of compensations might conceivably induce nonoptimal use of land on which damages occur. However, the idea of deciding land use for expected compensation ignoring market revenues seems somewhat far fetched, and the practice would be limited by abilities of outside adjudicators to verify gross cases of excessive losses.

With agreement that the foregoing norms would induce optimal adjustment to pollution, estimates of costs of departures from them could be made. This requires comparing locational differences in costs of polluting production with differences in damages, a job in which little progress has yet been made.

Conclusion

Any environmental policy instrument reduces pollution damages through some combination of reducing emission producing inputs, installing pollution control devices, reducing product output or changing the location of activities. This paper has examined benefits and costs for these dimensions. Instead of seeking a single best instrument the approach has been to compare alternatives, recognizing that resource allocation is not the sole consideration in environmental policy. Yet the very reason for concern with the environment is to correct resource allocation failures. Resource allocation is more important in environmental policy than in many other policy areas.

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COMMENT

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It is common knowledge that the best level of pollution occurs when the marginal damage of pollution offsets the marginal cost of an action which reduces pollution. This rule can be characterized either graphically or mathematically. The first sections of George Tolley's paper provide us with an original treatment of some thorny conceptual issues involved in identifying these functions.

It is also true that goods or bads, as the case may be, have a space and time dimension. Carrots from the San Joaquin valley differ in a fundamental economic sense from carrots from Chicago, and the economic value of a given environmental quality level in New York City only fortuitously is the same as the level in the desert region of Utah. Therefore, most would agree that a uniform air or water quality standard is not likely to make economic sense. The fourth and fifth sections of the paper discuss the effects of uniformity, those heavy-handed environmental policies which fail to recognize the spatial and temporal characteristics of bads.

The necessary ingredients for evaluating alternative environmental policies are benefit and cost functions. In too many publications, empirical benefit functions capture the value of changes in environmental quality by looking only at changes in the total expenditures of variable factors. Such estimates are conceptually biased, since changes in environmental quality impinge on the value of producers' and consumers' surpluses, necessary elements in the true estimate of net benefits. For plausible values of the elasticities of demand and supply the bias is shown to be significant. Tolley's main contribution here is to treat households as firms after the fashion of Becker.

Turning next to loss functions, the analysis begins with single product profit maximization in an environment where pollution occurs but voluntary regulation is ruled out. The first point of departure assumes a control policy on emissions. Since the control policy is restrictive—otherwise why have it?—benefits are reduced compared to the unregulated market outcome, reduced by the marginal cost of control. Labels may be misleading. The focus is on the production of conventional goods in combination with bads. Forcing firms to produce less bads increases their costs, referred to in the text as change in benefits. It should be emphasized that the author is not here discussing what is commonly referred to in the literature as the benefit or damage reduction function.

The regulator's second policy alternative involves the choice of a level of control inputs. It is exemplified by the prescription: Use secondary treatment in the case of water quality management. For any given level of control input, the optimal level of the pollution intensive input will be greater in the second policy relative to the first unless it is in a world of fixed factor proportions. As long as factor substitution is technically feasible, policy two is second best, involving greater private costs for any given initial level.

A third policy requires regulating the level of the pollution intensive input, while the fourth policy entails controlling emissions by using a final output level.

Emission regulation is superior to all other policies because the entrepreneur is left with more choice. He can select best values for x, f, c, and u whereas with the remaining policies, one of the first three variables is exogenously determined. Tolley proves that policy three, restricting pollution intensive inputs, is superior to the output restriction policy four after assuming a constant marginal benefit (loss) function and a specific form for the emission relation (11). The same conclusion holds much more generally. The policy which has the flattest marginal benefit function (3) is best. Therefore, if the fuel restriction policy is better than restricting output,

$$b(x)_{ss}^{\bar{f}}/b(x)_{ss}^{\bar{x}} < 1,$$

where $b(x)_{ss}$ is the slope of the marginal benefit function. Since

$$b(x)_{ss}^{\bar{f}} = (1/S_f^2)(M/M_{ff}), \tag{15f}$$

$$b(x)_{ss}^{\bar{x}} = (1/S_f^2)(M_{xx}/M_{xf})(M/M_{xf}), \tag{15x}$$

using the original notation, then

$$b(x)_{ss}^{\bar{f}}/b(x)_{ss}^{\bar{x}} = \frac{M_{xf}^2}{M_{ff}M_{xx}} < 1$$

or

$$M_{ff}M_{xx} - M_{xf}^2 > 0.$$

One can show that this expression indeed is positive by computing its value from the determinant exhibited above (11) in the original paper. The only requirement is that the production function is concave.

Regrettably, a complete general ranking does not seem possible since the virtues of the fuel policy (3) relative to the fixed control expenditures policy (2) depend on the choice of elasticities and parameter values.

The last pages of Tolley's paper discuss some of the problems which arise when a uniform policy is applied to an area or time period in which the net benefit function varies. Uniformity of pollution policy is expensive because no longer are there incentives to make intertemporal production adjustments or substitutions from a region of high opportunity cost to one of low opportunity cost of pollution.

Zoning and salable rights are additional tools available to policy makers. As the author rightly emphasizes, if the rights are not well-defined in space, the rights will be distributed inappropriately unless exchange involving spatial transfer is accompanied by a charge which reflects spatial opportunity cost differences.

This section offers fertile ground for other investigators to till. To cite one example, suppose meteorology was a fine-tuned science enabling us to predict weather with certainty. Suppose weather changes affect the net benefit pollution function and policy-makers had chosen a policy of charging for emissions. What is the optimal rate of price change? Surely econo-

Some may wish to argue that Tolley cast his net in too modest an arc. I would argue that even artificially simple but sound approaches are meritorious because they place in bold perspective crucial relationships which may change only in degree when a more encompassing model is developed. Understanding of the complex generally proceeds from a deep appreciation of the less complex to which this paper is a contribution.

Tolley is engaged in a substantial research project on environmental quality. This paper probably can be regarded as an interim report in which the author spells out the analytical framework of the larger study. Some of the topics are better developed than others, leaving the reader with an impression of rugged terrain rather than a polished surface. Nevertheless, the paper is a provocative and original contribution to the literature on environmental quality and bears the imprint of an insightful innovative mind. With this paper as openers, I'd bet heavily on the final study.