BEBR

FACULTY WORKING PAPER NO. 1076

Taxes, Pollution and Optimal Abatement in an Urban Economy

Marvin Frankel

College of Commerce and Business Administration
Bureau of Economic and Business Research
University of Illinois, Urbana-Champaign

BEBR

FACULTY WORKING PAPER NO. 1076

College of Commerce and Business Administration

University of Illinois at Urbana-Champaign

September, 1984

Taxes, Pollution and Optimal Abatement in an Urban Economy

Marvin Frankel, Professor
Department of Economics

Abstract

A closed urban spatial model is used to examine the impact on consumer-renters and on absentee property owners of pollution abatement and alternative means of financing it. An explicit utility function and an explicit pollution- or amenity-distribution function are used, and all results are accordingly explicit. The incidence effects are developed for exogenously financed abatement and for its finance through an income tax and an excise tax. Note also is taken of the outcome with a property tax. The model also is used to consider optimal abatement from various vantage points. The results of consumer utility maximization under an income tax regimen are compared with those under an excise regimen, and both results are in turn compared with the outcome when a cost-benefit approach is applied.

Taxes, Pollution and Optimal
Abatement in an Urban Economy

by

Marvin Frankel*

I. Introduction

In assessing whether, or in what degree, to provide an environmental good, two propositions appear to command a measure of support. First, where a polluting source can be identified, such as a smoke-emitting factory or a noise-emitting airport, the "polluter pays" principle can properly be applied. Thus an excise tax might be levied on the good or service produced by the polluting source, or an emissions tax might be applied. The tax, by itself, can be expected to induce a reduction in emissions, and the tax revenues might be used to further reduce adverse environmental impacts or to compensate the affected parties. Second, where source identification is not possible, or where the issue is simply one of community improvement, like improving police services or city parks, the cost can properly be charged to those who gain from the improvement. In this case, an income or capitation tax or other charge might be levied on the benefitting parties.

It is recognized that it is not always easy to apply these principles and that ultimately the actions taken may cause inequities among the affected parties. Perhaps more important, behavioral changes consequent upon the provision of an environmental good and any charges therefore may cause portions of the costs and benefits to be shifted to third parties, with the ultimate incidence of effects differing significantly from the initial or proximate impacts.

This paper utilizes a closed-city urban spatial model (see for example, Polinsky and Shavell, 1976, Section 4) to examine two sets of issues arising from pollution and its abatement. First, it considers the distributional impacts of abatement itself and of alternative methods of financing it. Second, it develops optimal abatement outcomes both for alternative abatement-financing regimens and from a cost-benefit vantage point. The type of pollution considered is that having a defined pattern across the landspace, such as power-plant or factory emissions or noise emanating from an airport. However, the relevance of the analysis is not limited to pollution phenomena. Aspects of the discussion may be relevant for other public goods having the appropriate spatial characteristics. The model allows for assessment of impacts on distinct participant groups, renters and property owners, as well as on the polluting source. Primary consideration is given to an income tax and a commodity tax as means of financing abatement, while note is taken of a property tax as an alternative.

The choice for analytical purposes of a closed over an open city rests on two main grounds. First, in the short and medium run, all "cities" or residential communities are, as a practical matter, closed.[1] Decisions to change residence or neighborhood take time, and the period may be extended if there is uncertainty as to the permanence of a prompting amenity change. Moreover, movement into or out of an area may be inhibited by the special attachments that households often develop for place of residence or neighborhood, by occupational need that places a premium on a given residential location, and by transportation arrangements that make between-city moves costly. All such circumstances serve to limit residential adjustments in face of modest and even perhaps appreciable amenity changes, and make the closed city an appropriate object of attention. Second, the implications of amenity and related changes in an open city, with the utility levels of consumers exogenously given, are rather straightforward. The benefits and costs of such changes tend, through the migration of consumers and factors, to be translated into rental and property value charges, with associated benefits and burdens for property owners, leaving consumer-renters essentially untouched. In contrast, the effects of such changes in a closed city are less well understood.

It should be added that the intent of the paper is not to develop general results but to illustrate possible outcomes for an interesting class of cases.

II. The Basic Model

Let there be an island-like, elongated land mass devoted to residential dwellings. At one end is a disamenity source such as an airport emanating noise or a waste disposal site. The community occupying the land mass is self-contained, being separated from other communities by substantial transportation costs. A given number of persons or households resides in the community. The sites they occupy are rented, with the rental payments flowing to absentee landlords. Because the disamenity is most intense at its source, with its effects diminishing with distance, the amenity level rises with distance from the source.

We assume our population to be homogeneous in its tastes, including sensitivity to the disamenity. We assume also that our population has identical incomes. Let each consumer have a utility function of the form,[2]

(1) $U = (M+\delta)LZ$

and a budget constraint,

(1a) $P_M M + P_L L = y$

where M = quantity consumed (by each consumer) of a composite good

L = quantity consumed (by each consumer) of residential land

Z = index of amenity level at any location (and enjoyed by consumers at that location), in turn a function of distance from the disamenity source

P_M = price of the composite good

P_L = price per unit of land

y = income of the consumer

δ = a parameter, with $\delta \gtrless 0$

The utility function represents a compromise between what one might, on theoretical grounds, prefer and what is mathematically tractable. Because it allows for non-unitary income elasticities of demand, for a non-unitary price elasticity of demand for one of the goods, and for a non-zero cross-price elasticity for the other good, it has greater generality in the context of this paper than would a Cobb-Douglas function.

Substituting (1a) into (1) and maximizing utility gives demand functions for each of the two goods,

(2) $$M = \frac{y - P_M\delta}{2P_M}$$

(2a) $$L = \frac{y + P_M\delta}{2P_L}$$

Substituting these demand functions back into the utility function, treating utility as a constant and solving for P_L gives:

(3) $$P_L = \frac{Z(y + P_M\delta)^2}{4UP_M}$$

Note that the amenity level, Z, varies with the consumer's distance, X, from the disamenity source. With this in mind, expression (3) may be interpreted as describing a family of bid-price contours over the land space (Rosen, 1974, p. 38; Polinsky and Shavell, 1976, p. 122). Along each contour, differential prices serve to equalize utility across locations differing in their respective amenity levels. The contour that comes ultimately to prevail, and the utility level associated with it, depends on the aggregate number of consumers competing for the limited supply of land. Let there be N consumers, or renters, seeking shelter in the limited land space. Then we may write

(4) $$\int_0^{\overline{X}} D(X)w\,dX = N$$

where $\overline{X}$ = a parameter denoting distance from the disamenity source to the terminal point of the land space or island

D = population density, or persons per acre (which varies with the price of land and, in turn, with distance from the source)

w = width of the land space or island, taken equal to unit distance, e.g., one mile

The left side of (4) sums the residents over the available land space. This number must equal the total who bid for that space, or the population of the area. Population density may be expressed as

(4a) $$D(X) = \frac{1}{L(X)}$$

That is, density equals the reciprocal of land consumed per capita, with both in turn dependent on distance from the disamenity source. Substituting (3) into (2a) and the resulting expression for L(X) into (4a) gives,

(4b) $$D(X) = \frac{(y+P_M\delta)Z(X)}{2P_M U}$$

Now let the amenity function, Z(X), be described by the diffusion or propogation function,

(4c) $$Z = j + gX$$

where j = the amenity level at the source of the disamenity, i.e., where X = 0

$g > 0$ = a propogation coefficient indicating the increase in the amenity level as one moves away from the source

The parameter j may be understood as $j = a - c$, where "a" represents the amenity level in the absence of the disamenity and c represents the amenity loss at the source of the disamenity, with $a > c > 0$. Thus, a decline in the intensity of the disamenity at the source, as through abatement, would serve to shift the amenity function upwards. The left panel of Figure 1, showing contours m_1 and m_2, illustrates such a shift.

Substituting (4c) into (4b) and the result, in turn, into (4) gives

(4d) $$\int_0^{\overline{X}} \frac{(y+P_M\delta)(j+gX)wdX}{2P_M U} = N$$

and performing the integration yields

(4e) $$\frac{(y+P_M\delta)(2j\overline{X}+g\overline{X}^2)}{4P_M U} = N$$

Solving for the equilibrium utility level yields

(4f) $$U = \frac{(y+P_M\delta)(2j\overline{X}+g\overline{X}^2)}{4P_M N}$$

Equation (4f) expresses the equilibrium utility level and substituting it into (3) gives the equilibrium rent contour:

(5) $$P_L = \frac{(y+P_M\delta)(j+gX)N}{(2j\overline{X}+g\overline{X}^2)}$$

This contour is linear in X and rises over the land space as distance from the disamenity source increases. Such a contour is illustrated in the right panel of Figure 1 by the curves designated η_1 and η_2. The differential prices displayed along the contour reflect differential land quality as determined by the disamenity. Land more distant from the source enjoys a higher amenity level and thus commands higher rents.

III. Costless Abatement

Consider the case in which partial abatement occurs by means that reduce the intensity of the disamenity at the source. The effect will be an increase in the parameter j in the amenity function and a resultant upward shift in the function, as from the curve m_1 to the curve m_2 in the left panel of Figure 1. Suppose further, as a reference case, that the abatement is costless or, if not, is financed by an external governmental source. How will the benefits of this abatement be distributed?

The shift in the amenity function will prompt an adjustment in the rent contour. In the present instance, the contour will rotate clockwise, with the post-abatement contour intersecting the pre-abatement contour from above. Rents for properties to the left of the intersection thus rise, while those to the right of the intersection decline.[3] In the right panel of Figure 1, the curves η_1 and η_2 represent respectively the pre-and post-abatement contours. An intuitive explanation for this outcome is that properties close to the source have become relatively more attractive with abatement, while more distant properties have lost some of the relative advantages they previously enjoyed (see Polinsky and Shavell, 1975, p. 103, Frankel, 1985).

What are the welfare implications of this case for renters and property owners? Consider a household at location X_θ, the intersection of the two rent contours. The rent at this location does not change with abatement, and the consumer experiences a simple utility increase from the reduction in the disamenity. Since price differences are utility-equalizing, all other households along the contour η_2 enjoy the same level of utility as the household at X_θ and with abatement experience the same net increase in utility as it does. For these other households, the net utility gain is a combination of abatement benefits and price changes. Households to the left of the intersection enjoy relatively large (subjective) abatement benefits that are partially offset by price increases, while households to the right of the intersection experience smaller (subjective) abatement benefits that are augmented by price reductions.[4] For the landlord or property owners, as distinct from the renter, the effects of abatement are mixed. Properties to the left of X_θ, whose rents rise, rise in value while those to the right of X_θ fall in value. Note, however, that the aggregate of rents paid by renters and received by property owners is the same after abatement as before. This is so because the demand for land by each consumer, as expressed in (2a), exhibits unitary elasticity. While abatement thus leaves property owners as a group as well off as before, it causes a redistribution of income and wealth among them.[5]

Two things are worth stressing about these distribution effects. First, it is not possible through abatement to bring differential benefits to renters. No matter what abatement scheme might be adopted--for example one to give greater physical relief to those close to the disamenity source than to those more remotely situated--land prices will respond in a way that causes all households to benefit equally. Second, the consequences for property owners are not consistent with any plausible distributional ethic. One might reasonably want or expect this group to share in, or perhaps be the exclusive recipients of, abatement benefits. But the results in the present case do not fulfill any such expectation.

IV. Financing Abatement

If abatement is not costless to the community, but instead must be financed by it, the net benefits realized by renters and property owners, and the distribution of benefits between the two groups, will change, with the outcome dependent on the type of financing employed. The discussion that immediately follows considers the impacts of the major financing alternatives. The scenario we envisage is one in which the imposition of a tax does not cause a leakage of income from the community and a consequent change in pre-tax income. This outcome may be assured in various ways. But let us simply suppose that whatever the type of tax applied, the proceeds are used within the community, as may be needed, to offset any decline in after-tax outlays and reemploy, say in the supply of abatement services, resources that might otherwise be displaced. Thus income or sales tax revenues might be used to reallocate resources from the composite good, whose production might be thought of as the polluting source, to the supply of abatement services.

With the foregoing caveat in mind, each of the financing alternatives may be incorporated into the model described above. With identical incomes for consumers, the levy of an income tax becomes a capitation tax and can be represented as a simple deduction from before-tax income. Accordingly, in the several expressions previously presented, the parameter y may be replaced by $(y-A)$, where A is the amount of the capitation tax. An excise tax on the composite good may be treated as having two components, one representing the amount by which the price of the composite good is increased and the other representing the amount by which, at the margin, producer's surplus is decreased. Then we may write

$$(6) \qquad T = E + S$$

where T is the tax per unit and E and S denote respectively each of the two above components. Note that in the case of constant marginal costs, S = 0 and the full amount of the tax will be passed through to consumers in an adjustment of the price of the composite good.

It may be helpful in understanding the discussion that follows to note also the price elasticity of demand for the composite good. From (2),

$$(7) \qquad \eta_M = \frac{-y}{y - P_M \delta}$$

If $\delta = 0$, the special Cobb-Douglas case, $\eta_M = -1$. $\delta > 0$ yields the case of relatively elastic demand, and $\delta < 0$ gives the case of relatively inelastic demand. It may also be helpful to point out that the equilibrium quantity of land rented by any consumer, in contrast to the equilibrium price paid for it, is independent of both income and the price of the composite good. Substituting expression (5), which gives equilibrium land price, into expression (2) showing the demand for land, results in

$$(7a) \qquad L = \frac{2j\bar{X} + g\bar{X}^2}{2(j+gX)N}$$

Hence an income tax, which reduces y, or an excise tax, which raises P_M, will not alter the quantity of land taken by a consumer.[6]

A. The Effects of an Income Tax

In considering an income tax, let us first treat the case where the composite good is supplied under conditions of constant marginal cost. In the absence of any taxes, the aggregate expenditure for rent by any consumer can be obtained by multiplying (2a) by P_L to get

$$P_L L = \frac{y + P_M \delta}{2} \qquad (7b)$$

If an income tax in amount A is levied, aggregate expenditure is instead

$$(P_L L)_A = \frac{(y-A) + P_M \delta}{2} \qquad (7c)$$

Although the demand curve for the composite good shifts to the left in response to the income tax, the price of the composite good, P_M, is unaffected by the tax under conditions of constant marginal cost, and subtracting (7c) from (7b) yields

$$P_L L - (P_L L)_A = \frac{A}{2} \qquad (7d)$$

That is, the consumer's expenditure on rent declines by half the amount of the tax. Since the quantity of land he consumes is unaffected by the tax, it follows that this part of the tax is passed to and borne by landowners. It also follows that the other half of the tax must be paid from reduced expenditures on, and reduced consumption of, the composite good (see expression (2)). Thus, the consumer-renter, while enjoying the benefits of abatement, bears only half the tax that finances it.

For landlords whose properties are relatively close to the source, the shifting effect serves at least partially to offset the benefits gained from abatement itself and the clockwise rotation of the contour that serves to raise their rents. For landlords with more distant properties, the result of shifting is to compound the loss experienced from abatement and the rotation-induced rent decline. The shifting effect is in fact more severe for the latter group. For while each consumer passes the same absolute amount of tax back to the landlord in the form of lower rents, the more distant consumer, because he faces higher land prices and consumes less land, passes back more on a per acre basis. That is, for the more distant properties, shifting brings a larger decline in rent per acre. This is shown in the right panel of Figure 1 by the dashed contour η_3, which not only lies below η_2, but has a shallower slope.[7]

If marginal cost for the composite good is rising, rather than constant, the leftward shift in demand in response to the income tax will cause P_M to decline. Then the difference between aggregate expenditures on rent before levy of the tax and aggregate expenditures after levy of the tax is

$$(7e) \qquad P_L L - (P_L L)_A = \frac{A + \delta(P_{M_1} - P_{M_2})}{2}$$

where P_{M_1} is the before tax price of the composite good and P_{M_2} the after tax price, with $P_{M_1} > P_{M_2}$. If $\delta = 0$, the outcome in the land market is the same as in the case of constant marginal cost, with half the tax, or $\frac{A}{2}$, passed back to the landlord. If $\delta > 0$, more than half the tax will be passed back, and if $\delta < 0$, less than half the tax will be passed back. The remainder of the tax comes from consumers, as reflected in reduced purchases and consumption of M, and from the suppliers of M, through reduced producers surplus.

There are thus three components to the outcome of this rising marginal cost scenario: a "beneficiaries pay" component, in the form of the burden borne by consumer-renters; a "polluters pay" component, if we think of the suppliers of M as the polluting source; and an "innocents pay" component in the burden passed back to the landlords who, in the aggregate, gain no benefit from the abatement that is being financed. One might not ordinarily expect the latter two components to arise from an income tax on consumers. The more steeply marginal costs rise, the smaller will be the fall in the consumption of M and hence the loss to consumers, and the larger will be the burden on producers.

B. The Effects of an Excise Tax

Again let us consider first the case of constant marginal cost in the supply of the composite good. With an excise (but no income) tax, price will rise by the amount of the tax. The difference between the consumer's aggregate outlays on rent before levy of the tax and his aggregate outlays after levy of the tax is given by (7e) with A = 0, or

$$P_L L - (P_L L)_T = \frac{\delta(P_{M_1} - P_{M_2})}{2} \qquad \text{(7f)}$$

where now $P_{M_1} < P_{M_2}$. If $\delta = 0$, the consumer spends the same amount for rent after the tax as before. The implication of this Cobb-Douglas case is that none of the tax burden is passed through to the landlord. From (7), $\delta = 0$ implies also unitary elasticity of demand for M. Expenditures on M gross of the excise are the same as outlays before the levy. After-tax outlays thus decline, along with the quantity of M taken, and in this way consumer-renters bear the whole of tax burden.

If $\delta > 0$, the amount spent by the consumer on rent rises following the excise levy, and landlords benefit from the tax. Land and the composite good are in this case substitutes. In the right panel of Figure 1, the rent contour would shift from η_2--the post-abatement pre-tax contour to η_4. At the same time gross outlays on M fall, implying elastic demand for the composite good (see expression (7)). The consumer ends up paying the full amount of the tax, acquires less of the composite good, and pays more rent. If $\delta < 0$, rent payments decline, and part of the tax burden is thus passed through to landlords. At the same time, gross outlays on M rise--the case of relatively inelastic demand--with the remainder of the tax burden borne by consumers through reduced consumption of M. Note that a lower tax rate will suffice in this case to raise a given amount of revenue than when $\delta > 0$, since with inelastic demand purchases of M decline by less.

The conclusions are essentially unchanged when the composite good is produced under conditions of increasing cost. Now, however, a part of the tax burden will be borne by suppliers through a reduction in producers surplus. Also, P_M will rise by less, given the amount of the excise, than in the constant cost case. One implication of this is that the impact on landlords, whether favorable or unfavorable, will be reduced. Another is that a smaller excise will be needed than in the constant cost case to raise a given amount of revenue, since sales of the composite good will decline by less.

Under restricted conditions, this analysis of the effects of an excise tax applies also to an emissions tax. The restrictions are first that emissions be proportional to output of the composite good, second that the increment of amenity improvement arising from the tax-induced reduction in output be considered as already reflected in the rotation of the bid-rent contour, and third that the tax not induce the suppliers of M to undertake yet further abatement actions. But even when these restrictions do not fully hold, the analysis still serves to indicate the general direction of the expected effects. What it mainly neglects are the potential emissions-reducing responses by suppliers in an effort to minimize their taxes. To the extent that such responses are successful, marginal costs will rise by less than would otherwise occur.

To summarize briefly, with an income tax, a share of the resulting burden will always be passed through to landlords. The remainder of the burden will be borne by renter-consumers through their purchases of the composite good, or with rising marginal costs it will be shared with producers of that good. With an excise tax on the composite good, landlords may benefit, be injured or be unaffected. The remaining burden of the tax will be carried by consumer-renters or, with rising marginal costs, it will be shared with producers of the composite good. Meanwhile, on the environmental side, consumers are beneficiaries of the abatement that taxes finance. In contrast, the outcome for landlords is mixed since, apart from the shifting effects, abatement induces a rise in rents for properties located toward the source and a decline for those further out.

C. Other Kinds of Taxes

Two other types of taxes, if imposed, would cause the entire tax burden to be carried by landlords. One is a simple property tax. The levy of such a tax would not affect the supply of land and hence would not alter the equilibrium bid-rent contour. Thus net rents would simply decline to the detriment of landlords. A tax on gross rentals would produce a similar result. The equilibrium set of bid-rents would not be affected. Rather renters would now find themselves making a part of their rent payment to the government and the remainder to landlords. In neither of these cases would there be any effects on the price of the composite good or the quantity taken of it.[8]

V. The Optimal Amount of Abatement

There are multiple vantage points from which to consider the question, how much abatement, or improvement in the amenity level, should be chosen? One such vantage point is simple utility maximization for the consumer, given both the benefits from amenity improvement and the behavior of prices, including their response to any taxes that might be levied.[9] Let us refer to this approach as the full equilibrium approach and consider the outcomes when an income tax, and alternately an excise tax, are levied. We shall assume throughout that the composite good is supplied under conditions of constant marginal cost.

Let the cost of achieving any amenity level be given by the function,

$$(8) \qquad j = j_0 + vW$$

where,

j = the amenity level at the disamenity source

j_0 = the amenity level at the source in the absence of abatement outlays

v = a parameter denoting environmental improvement per dollar of abatement outlays

W = dollar outlays on abatement

If an income tax is contemplated, W/N will be the capitation charge, or charge per consumer necessary to cover any expenditures on abatement. Expression (4f), which gives the equilibrium utility level, may now be rewritten to incorporate both abatement costs and the associated capitation charge:

$$(8a) \qquad U = \frac{(y - \frac{W}{N} + P_M\delta)[2\bar{X}(j_0+vW)+g\bar{X}^2]}{4P_MN}$$

Differentiating this expression with respect to W, setting the result equal to zero and solving for W yields:

$$(8b) \qquad W = \frac{2vN(y+P_M\delta)-(2j_0+g\bar{X})}{4v}$$

With W determined, j and hence Z are also determined.

This solution is utility-maximizing for every consumer, since each consumer is located on the same utility-equalizing rent contour. It is also a solution that recognizes the consumer's opportunity to shift a part of the tax burden to the landowner and hence one that does not recognize abatement's full cost. It is tempting to conclude that if rents were internalized, say through an arrangement in which consumers collectively owned the land and shared the rent proceeds, the utility-maximizing level of abatement would be lower. But the conclusion would be incorrect. With rent sharing, the consumer's cost of abatement would rise. But so also would his income, and with it his demand for abatement. In the model employed here, the two forces are offsetting, and the utility-maximizing level of abatement outlays does not change.[10]

Suppose that instead of an income tax, abatement is to be paid for by an excise tax on the composite good. To avoid mathematical complications, we consider here only the case where $\delta = 0$. Expression (4f) may now be written,

$$(8c) \qquad U = \frac{y(2j\bar{X}+g\bar{X}^2)}{4P_M N}$$

With an excise, P_M will rise by the amount of the tax. The per unit tax needed to recover expenditures on abatement of W is $\frac{W}{NM}$, and the new price P_2, in relation to the old price P_1 may be expressed as

$$(8d) \qquad P_{M_2} = P_{M_1} + \frac{W}{NM_2}$$

From expression (2), the demand for M, we have

(8e) $M_2 = \frac{y}{2P_{M_2}}$

Substituting (8e) into (8d) and simplifying gives

(8f) $P_{M_2} = \frac{NyP_{M_1}}{Ny-2W}$

The last expression indicates the post-tax price of M when that good is being sold in its equilibrium quantity. It may be substituted, along with expression (8), into (8c) above (letting $P_M = P_{M_2}$) and utility maximized as before to get

(8g) $W = \frac{vNy - (2j_0+g\overline{X})}{4v}$

Comparing this expression with (8b) (with $\delta = 0$), it is clear that the consumer chooses lower abatement expenditures when he is to pay for them through a goods tax rather than an income tax. A plausible explanation for this outcome is that the excise tax carries an excess burden. But that has not been demonstrated.

A second vantage point from which to consider the question of optimal outlays for abatement[11] is that of cost-benefit analysis. Cost-benefit methods comprise a potpourri of tools and techniques, but within our problem context common elements would include the effort to determine consumers' collective marginal willingness to pay for environmental improvement, an assessment of the costs of such improvement, and through the equating of marginal costs to marginal willingness to pay, the choice of an optimal level of outlays.

The consumer's marginal willingness to pay for environmental improvement--call it his MWTPZ--is defined as his marginal rate of substitution between Z and his income, y. (See, e.g., Diamond and Tolley, 1982, pp. 12-13.) This can be derived directly from the utility function, as expressed in (1), and the demand functions (2) and (2a).

$$\text{(8j)} \qquad MWTPZ = \frac{y + P_M\delta}{2Z}$$

This function expresses the implicit demand for Z and tells us Z's implicit price, P_Z. Substituting for Z, we may write for any consumer at any location X

$$\text{(8k)} \qquad P_Z = \frac{y + P_M\delta}{2(j+gX)}$$

This equation tells us the consumer's marginal willingness to pay for environmental improvement in terms of the amenity level at the source, j. To obtain aggregate willingness to pay, one must sum over the individual demand functions, such as (8k). This entails two steps. First, the demand expression must be weighted by population density, since density varies across the landspace with the changing price of land. Second, the weighted demands at successive locations must be added up. Performing these two steps[12] yields the aggregate MWTPZ, or P_Z^*, for all consumers:

$$\text{(8n)} \qquad P_Z^* = \frac{N(y+P_M\delta)}{(2j+g\overline{X})}$$

Looking now at the cost side, we may rewrite (8) to get for expenditures on or total cost of abatement,

$$\text{(8o)} \qquad W = \frac{j-j_0}{v}$$

so that marginal cost--the cost of abatement that adds one unit to j (and with a linear amenity function, to every other location), is

(8p) $$MC_j = \frac{1}{v}$$

Equating MC_j to P_Z^* and solving for the optimal j yields

(8q) $$j = \frac{vN(y+P_M\delta) - g\overline{X}}{2}$$

and substituting into (10o) gives

(8r) $$W = \frac{vN(y+P_M\delta) - (2j_0+g\overline{X})}{2v}$$

A direct comparison of the cost-benefit result in (8r) with the earlier full-equilibrium utility-maximizing income tax case, as shown by (8b), can now be made. The latter prescribes greater expenditures on abatement than does the former. That the two should differ is perhaps not surprising, for the cost-benefit procedure does not allow for the equilibrating adjustments in a closed city that abatement sets in motion.[13] It thus offers an incorrect prescription for consumer optimization.

The cost-benefit approach, when applied in the closed-city setting, is misleading in two related and noteworthy respects. First, it implies that individual consumers at different locations will benefit unequally from abatement, since they have different MWTPZ's. But the equilibrium process is such that the opposite occurs. Each benefits equally. Second, the approach implies that the collective or aggregate benefit for consumers at any one location will be the same as the collective benefit at any other location, since the aggregate

MWTPZ's are the same across locations. But the equilibrating process brings about a different outcome. Aggregate benefits at locations near to the source, where P_L is low and hence density is low, are lower than aggregate benefits at more distant locations, where P_L and density are high. Thus, representations that might be made to individual consumers on the basis of cost-benefit findings, pursuant to a proposed abatement action, would be falsified by the resulting outcomes.

It should be added that the cost-benefit approach has nothing useful to say to property owners, since their rents do not respond to abatement in a manner consistent, from location to location, with consumers' MWTPZ's. Moreover, as noted earlier, abatement itself does not bring any change in aggregate property values, while the charge for abatement through an income tax reduces that value.[14]

Footnotes

*University of Illinois at Urbana-Champaign. I am indebted to Jan K. Brueckner for helpful counsel on many points.

[1]The term "city" is intended in an analytically appropriate sense. A city as conventionally defined may be too heterogeneous an entity for our purposes (Abelsen, 1979, pp. 12-13).

[2]A more general form would be $U = [(M+\delta)LZ]^{\alpha}$, where $\alpha > 0$. All the results obtained in the paper would hold also for this more general form.

[3]The effect of a change in source intensity on the rent contour can be determined by evaluating expression (5) as follows:

$$(5a)\qquad \frac{\partial P_L}{\partial j} = \frac{(y+P_M\delta)(g\overline{X}^2-2gX\overline{X})N}{(2j\overline{X}+g\overline{X}^2)^2}$$

All terms on the right are positive except $(g\overline{X}^2-2gX\overline{X})$. When $X = 0$, the latter term (and hence (5a)), is positive, and when $X = \overline{X}$ it is negative. Recalling that abatement entails an increase in j, this implies clockwise rotation. The intersection of the pre- and post-abatement contours occurs when the derivative is zero and hence where $g\overline{X}^2 = 2gX\overline{X}$ or $X = \frac{\overline{X}}{2}$.

[4]This is true notwithstanding that with a linear amenity function, all consumers experience the same absolute increase in the amenity index, Z.

[5]Obviously in this situation the change (of zero) in aggregate property value cannot serve as a measure of the benefits of abatement. This result is consistent with the findings of others. (See, for example, Polinsky and Shavell, 1976, Section 4, Pines and Weiss, 1976, pp. 6-7, and Freeman, 1979, Ch. 6.) The result is not dependent on the assumption of absentee landownership and would not be changed by the internalization of rents.

[6]This conclusion does not hold for an open city. The levy of a tax temporarily reduces the utility of residents in the city. If the city is open, out-migration will occur and with it, ultimately, a change in land consumption by renters at all locations.

[7]Starrett (1981) explores in a quite general framework the conditions under which public good improvements and their tax-based financing would be capitalized into land values. Using his terminology, the tax cases presented in the present paper involve

"internal capitalization," with rent changes occurring through the "internal margin." See also Heurin (1981) who considers how, in an open locale or city, land values respond to a public improvements financed by an income tax.

[8]These results resemble what one might suspect in an open city where consumers' utility levels are exogenous. See Polinsky and Rubinfeld (1978). The complexity of their model allows for a variety of interactions, so that a one-for-one translation of a property tax into reduced land values does not occur.

[9]In this approach, as elsewhere in the paper, rent payments are treated as flowing to absentee landlords. A more global approach would involve optimization on the assumption that rents stay within the closed city and are shared by its consumers.

[10]Internalization is accomplished by 1) multiplying expression (5) by L to obtain the rent paid by any consumer, 2) recognizing that a consumer's income includes as a component a share of aggregate rent, 3) aggregating over all consumers to obtain an expression for aggregate rent, 4) solving for aggregate rent, and 5) incorporating the result into expression (8a). Internalization yields an expression for consumer utility equal to the right side of (8a) multiplied by 2. Abatement is now more costly to consumers, since tax shifting reduces their own incomes. At the same time, the interactive effects between rent contour movements and income changes are offsetting with regard to choice of an abatement level, and optimization yields the same result as shown in (8b).

[11]There is yet another vantage point--a variant on the utility maximization procedure just discussed--from which to view the matter. Consumers will not ordinarily be aware of how land rents might change following abatement, or of how prices might change following the levy of a tax. Such changes are, after all, the outcomes of economy-wide forces that are difficult to perceive. Consumers are more likely to believe that rents will be unaffected, or little affected, by abatement actions and that any income or excise taxes that are levied will be borne by them. It is of interest therefore to ask what level of abatement consumers will choose, given their essential ignorance about how market adjustment forces will operate. This situation can be explored with the aid of expression (3), since it does not reflect the equilibrating forces contained in (4f). Treating P_L as constant, making appropriate substitutions, and optimizing on W yields the following results for the consumer's optimal choice of abatement expenditures for the respective cases of an income tax and (with $\delta = 0$) an excise tax:

$$(8h) \qquad W = \frac{vN(y+P_M\delta) - 2(j_0+gX)}{3v}$$

$$(8i) \qquad W = \frac{vNy - 2(j_0+gX)}{4v}$$

In contrast to the respective full equilibrium cases shown in (8b) and (8g), the amount of abatement chosen by the consumer is now seen to depend on his location, X. Those more remote from the source and enjoying higher amenity levels will prefer lower values for W. This outcome is conditioned by the fact that the consumer now does not recognize either the rotation of the rent contour with abatement or the tax-induced shifting of the contour. Also, the consumer will generally choose less abatement when he fails to anticipate the market adjustment process and treats P_L as constant.

[12] Expression (4a) defines density. Substituting (2a), the consumer's demand for land, into (4a), the expression for density, and then (5), the equilibrium price of land into the result, yields population density D at any location X:

$$(8\ell) \qquad D = \frac{2N(j+gX)}{2j\overline{X} + g\overline{X}^2}$$

Multiplying (8k) by (8ℓ) gives

$$(8m) \qquad D \cdot P_Z = \frac{N(y+P_M\delta)}{(2j\overline{X}+g\overline{X}^2)}$$

This equation expresses the total of the MWPTZs for any location X. An interesting feature of the expression is its independence of X. That is, the total MWTPZ for any one location is the same as for any other. By integrating (8m) with respect to X across the length of the landspace, from X = 0 to X = $\overline{X}$, we obtain expression (8n) in the text.

[13] These adjustments, as reflected in (8b), include the shifting of a part of the income tax burden from renters to absentee landowners, and one might surmise that this factor contributes to the disparity between the two outcomes. However, as discussed earlier, the internalization of rents, with consumers sharing equally in the aggregate of rent proceeds, does not alter the full-equilibrium result.

[14] In an open city setting, the utility of renters is fixed by multi-city or economy-wide forces (Polinsky and Shavell, 1976, p. 123), and it is property owners who benefit from abatement through resultant higher land prices. The cost-benefit approach fares better in this

setting in two basic ways. First, through reliance on the MWTPZ, it accurately anticipates the effects of abatement on property values. Second, as a corollary, its prescription for optimal abatement in any city or locale corresponds to the abatement level that maximizes property values in that locale. Both of these points can be demonstrated using an open city version of the model employed in this paper. These issues have been treated by others using variant approaches. (E.g., Brueckner, 1983, Polinsky and Shavell, 1976, and Starrett, 1981.)

References

1. Abelson, Peter W., "Property Prices and the Value of Amenities," Journal of Environmental Economics and Management, March 1980, 6, 11-28.

2. Brueckner, Jan K., "Property Value Maximization and Public Sector Efficiency," Journal of Urban Economics, July 1983, 14, 1-15.

3. Diamond, Douglas B., Jr. and Tolley, George S., "The Economic Roles of Urban Amenities," in Diamond, D. B. and Tolley, G. S., eds., The Economics of Urban Amenities, Academic Press, 1982, Ch. 1, 3-54.

4. Frankel, Marvin, "Amenity Changes, Property Values and Hedonic Prices in a Closed City," Journal of Environmental Economics and Management, forthcoming.

5. Freeman, A. Myrick, III, The Benefits of Environmental Improvement, Resources for the Future, Baltimore, 1979.

6. Heurin, Donald R., "Local Income Taxation in an Urban Area," Journal of Urban Economics, Nov. 1981, 10, 323-37.

7. Pines, David and Weiss, Yoram, "Land Improvement Projects and Land Values," Journal of Urban Economics, Jan. 1976, 3, 1-13.

8. Polinsky, A. Mitchell and Rubinfeld, Daniel L., "Property Values and the Benefits of Environmental Improvements: Theory and Measurement," in Wingo, Lowden and Evans, Alan, Public Economics and the Quality of Life, Johns Hopkins Press, 1977, Ch. 8, 154-80.

9. Polinsky, A. Mitchell and Shavell, Steven, "The Air Pollution and Property Value Debate," The Review of Economics and Statistics, February 1975, 57, 100-104.

10. ______________, "Amenities and Property Values in a Model of an Urban Area," Journal of Public Economics, Jan.-Feb. 1976, 5, 119-29.

11. Rosen, Sherwin, "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition," Journal of Political Economy, January 1974, 82, 34-55.

12. Starrett, David A., "Land Value Capitalization in Local Public Finance," Journal of Political Economy, April 1981, 89, 306-27.

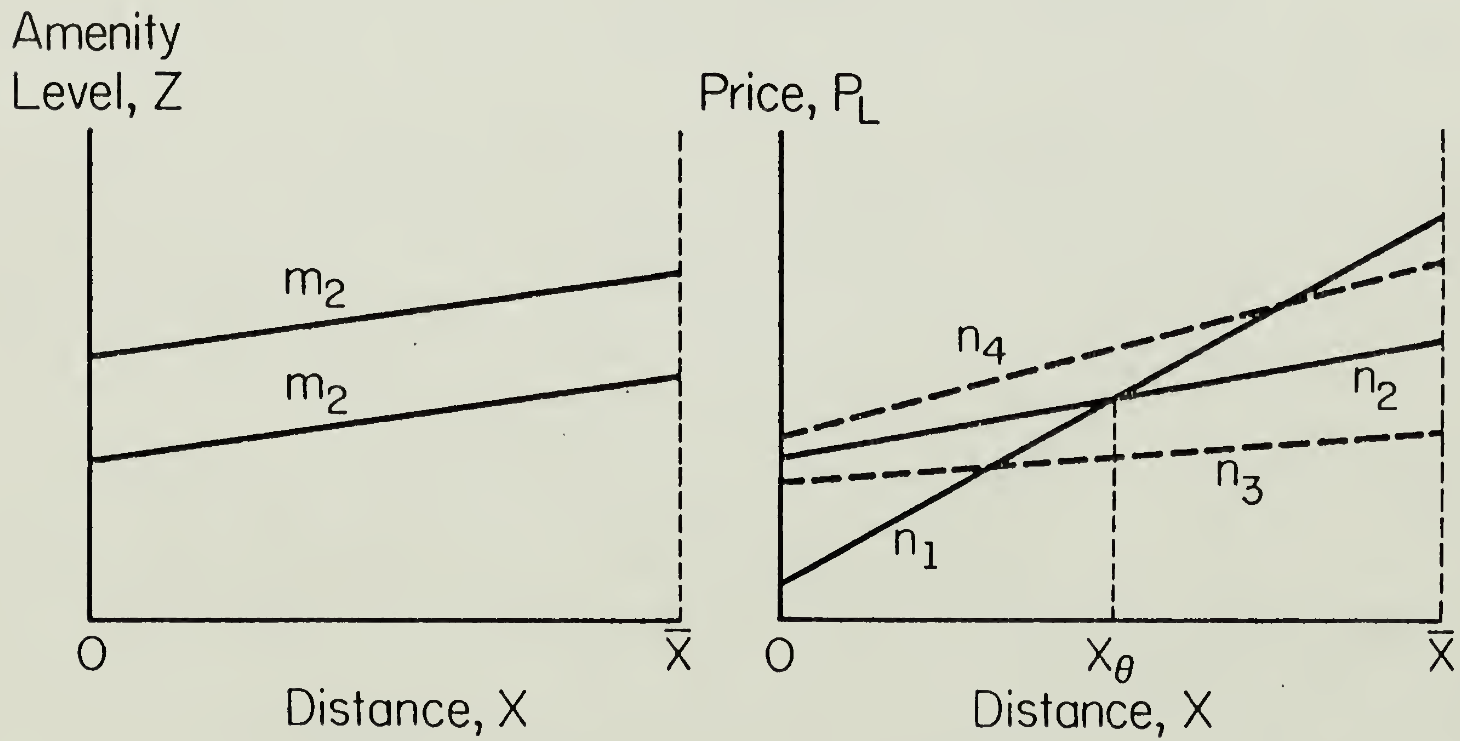

Figure 1: Amenity Functions and Rent Contours