Economic Impacts of Edge Effects Externalities on Land Use Decisions*

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Abstract

This paper examines the theoretical impacts of spatial externalities whose marginal impacts decline with distance, referred to as "edge effect externalities". A simple one dimensional model appropriate for analysis of policy measures and the potential for bargaining between affected agents is outlined, and the production impacts of this class of externalities are illustrated. Edge effect externalities create an incentive for the recipient to distance himself from the generator. Further, they imply that land use fragmentation will lead to non-linear declines in production possibilities. Due to the potential for asymmetric positive externalities between recipients, bargaining may be required to achieve the optimal arrangement, as well as allocation, of land uses.

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Introduction

Many land-use conflicts are characterized by impacts which are severe at the border between conflicting land uses, but decline in severity as distance from the offending land use increases. Examples include generation of noise, odors, and pollutants from industry into residential areas, spillovers of criminal activity from dangerous neighborhoods, degradation of habitat reserves due to surrounding development, and drift of agricultural pesticides into urban areas. This paper outlines the theoretical economic impacts of this class of land-use conflicts, which I refer to as "edge effect externalities".

Ecology, Ecosystems and Edge Effects The concept of an "edge effect" originated in the ecology literature. [12, 11, 6, 7, 10] The term refers to ecosystem degradation which occurs at the borders between differing habitat patches. A key feature of an edge effect is that degrading impacts, such as foreign plant species and predator migration, decline as the distance from the border increases. This feature implies that the arrangement and shape, as well as the total area distribution, of habitat patches become important for landscape management. Specifically, habitat fragmentation leads to non-linear declines in intact habitat.

Edge Effects in Economics Just as scale and pattern of habitat matter for species diversity and survival under ecological edge effects, under economic edge effects, scale and pattern of activity have implications for economic efficiency. In a landscape impacted by edge effect externalities, economic efficiency requires appropriate arrangement, as well as allocation, of land uses. Standard economic theory tells us that under externalities, market prices will not lead to the appropriate allocation of resources. The recognition of edge effect externalities leads to additional questions. First, how might free market landscape patterns deviate from optimality? Second, how successful might commonly implemented mitigations be at inducing both the optimal allocation and spatial arrangement of land uses?

Examples in Agriculture Conflicts in agriculture originating from incompatible production processes among growers are often appropriately characterized in terms of "edge effect externalities". California Central Valley examples reflect a range of institutional structures, liability rules, and mitigation measures. A conflict between cotton and olive growers over the possible spread of verticillium wilt has been successfully mitigated through a consensus agreement limiting cotton production to a specific region of Glenn County. Coordination of vineseed growers to ensure no cross-pollination is facilitated through centralized variety allocations by monopsonistic seed companies, crop-specific buffer zones mandated by seed companies, purity standards, and coordination over planting decisions by growers. Conflicts between rice and cotton growers over drift of rice herbicides which harm cotton have been addressed through buffer zone regulations and aerial spray restrictions, but these mitigations have been unsuccessful, and herbicides have been pulled from the market by legally liable chemical companies. Potential conflicts between organic and conventional producers are addressed through liability laws for pesticide drift, mandatory buffer zones for certified organic producers, the use of protective hedgerows, and strategic location by organic producers.

In general, three main policy tools are used to mitigate these spatial externalities: liability rules, mandatory buffer zones, and preferential zoning regulations. Negotiation between affected parties also plays an important role. In order to analyze the incentives created by these policy measures and the potential for successful negotiation, a theoretical framework is needed. This paper outlines a simple one dimensional model appropriate for preliminary analysis of policy measures. It then demonstrates production impacts of edge effect externalities in two dimensions, focusing on the non-linear negative production impacts of landscape fragmentation. Three important implications are emphasized. First, the externality creates an incentive for the recipient to distance himself from the generator. Second, ceteris paribus, economic efficiency requires spatial agglomeration (equivalent to minimal landscape fragmentation) of affected users. Third, incentives for affected users to agglomerate may be imperfect due to the possibility of mutual but asymmetric positive externalities.

Existing Literature Early urban economics literature examining continuous spatial externalities with diminishing marginal impacts is reviewed by Kanemoto. [8]. Model specifications are is consistent with my one dimensional approach, and models predict the emergence of possible buffer zones. However, separation of conflicting land uses is assumed, and only socially optimal outcomes are considered. Two important recent works on spatial externalities precede my research. Albers [1] examines optimal management decisions within a discrete spatial model consistent with the existence of edge effect externalities. Specifically, positive spillovers result in increased productivity in both cells when two adjacent cells are devoted to a compatible use. Consistent with expectations, when spatial externalities are accounted for, it is optimal to group habitat together and to group complementary land uses. Bockstael et al [3, 5] have conducted extensive empirical analysis striving to explain fragmented patterns of residential development in Maryland. They have included variables reflecting potential positive and negative spatial externalities in their models, explicitly accounting for distance impacts. Their results confirm the importance of positive and negative local spatial externalities: land values increase with the proportion of surrounding open space and pasture, and decrease with cropland and the amount of conflicting edges. Geoghean et al have begun to consider the impacts of landscape pattern on property values and have used landscape ecology statistics reflecting fragmentation and diversity in their empirical analysis. [5, 4] However, formal predictions as to the impact of landscape pattern on property values are not offered. Currently, a theoretical explanation of how spatial externalities, and in particular distance dependent externalities, can influence location decisions in a free market setting is absent from the literature. My work strives to provide that link.

Impacts in One Dimension

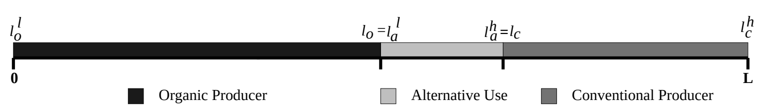

Figure 1: Firm Locations: Interior Solutions

A simple, one dimensional model is sufficient to illustrate some key results in an economy influenced by edge effect externalities. In this model, land available for production is represented by a line of length L. Three land uses are possible: organic agriculture, conventional agriculture, and an alternative use which could represent grazing land, forest cover, or some similar use. Organic production is negatively impacted by an externality generated by the conventional producer.[1] The magnitude of potential externality damage declines with increased distance from the conventional producer's border. The alternative use is assumed to be unaffected by any externality and to not positively or negatively impact marginal externality damage. The model assumes the market leads to the most efficient arrangement, if not allocation, of land uses, with the organic and conventional producer's sites separated by production of the alternative use.

Production Land is the single input to production. The conventional producer experiences decreasing returns to land as a factor of production, and the alternative use experiences constant returns to land. For the sake of clear illustration of key results, I assume the organic producer experiences constant returns to land as long as he is not impacted by the externality.[2] The results are generalizable to a case where the organic producer operates under diminishing returns and transportation costs influence land values.

Free-market and socially optimal outcomes are analyzed in a general equilibrium framework. This allows me to use very traditional methodology to illustrate deviations between the free market and socially optimal outcomes and to examine theoretical impacts of policy measures. This approach also has its limits, and in many cases a partial equilibrium approach may produce richer and more enlightening results.

For each producer, total production is found by integrating over the marginal productivity on all units of land occupied by that producer. The conventional producer occupies all land from l_c to L. Her production is given by:

$$C(l_c; L, \beta) = \int_{l_c}^{L} c(l; \beta)\, dl \tag{1}$$

where l represents an incremental land unit, $c(l; \beta)$ is the marginal product on a given unit of land, β is a vector of production parameters, and $c(l; \beta)$ is *increasing* with l, since a higher level of l implies a less land in production. An important note: I assume that land quality is homogeneous. Thus, given that her parcel is the economically optimal size, C is indifferent about which parcel of

[1]This example is stylized. It is certainly not the case that organic agriculture is always negatively impacted by surrounding conventional neighbors, or that conventional producers experience no negative externalities generated by organic neighbors.

[2]A realistic specification for both producers would probably include weak diminishing returns and fixed costs.

land on the line she occupies.

The organic producer's production possibilities will depend on the location of C's extensive margin, since marginal productivity will vary with distance from this margin, $\bar{l}_c$. Initially, I assume a linear externality impact which does not depend on C's scale of production. The following marginal damage function is used:

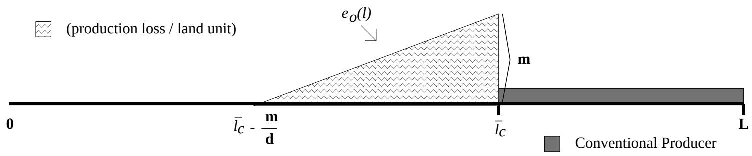

Figure 2: The Marginal Externality Damage Function

$$e_o(l) : \left\{ \begin{array}{l} 0 \mid l < \bar{l}_c - \frac{m}{d} \\ m - d(\bar{l}_c - l) \mid l \in (\bar{l}_c - \frac{m}{d}, \bar{l}_c) \end{array} \right\} \qquad (2)$$

where $\bar{l}_c$ is the fixed extensive margin of the conventional producer, d is the *dispersal rate*, m is the *maximal damage* from the externality, and $\bar{l}_c - \frac{m}{d}$ is the l intercept, where the externality impact is zero.[3]

O's marginal production possibilities, given the location of C's extensive margin $\bar{l}_c$, will be equal to the constant marginal product α less the externality damage.

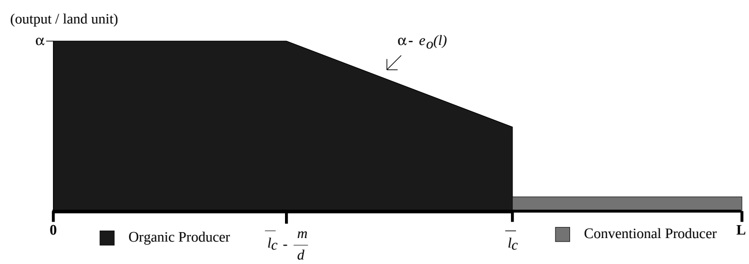

Figure 3: O's Potential Marginal Product

Given a choice of extensive margin l_o, O's total production, can be found by integrating the functions over the region of no externality damage and the region in which O is close enough to C to experience externality damage:

$$O(l_o; \bar{l}_c, m, d) = \int_0^{\bar{l}_c - \frac{m}{d}} \alpha \, dl + \int_{\bar{l}_c - \frac{m}{d}}^{l_o} \alpha - e_o(l) \, dl \qquad (3)$$

$$= (\alpha - m + d\bar{l}_c)l_o - \frac{d}{2}{l_o}^2 + m\bar{l}_c - \frac{d}{2}{\bar{l}_c}^2 - \frac{m^2}{2d} \quad \text{(using equation 2)} \qquad (4)$$

Notice that if O could choose the

[3] Since the marginal damage does not depend on A's location or scale of production, A does not appear in either figure 2 or 3.

lower bound of the first integrand, he would choose to back up production farther, increasing his production in the constant returns to land range. However, he is bound by the length of the line. Thus, he is not indifferent about where his production is located – he will locate as far away from C as possible. Note also that O's production function is now concave in l for sufficiently large values: the externality has imposed diminishing returns to land as a factor of production. Formally,

$$\frac{\partial^2 O}{\partial l^2} = -d < 0 \mid l \in (\bar{l}_c - \frac{m}{d}, l_o)$$

The free-market outcome Each producer is assumed to maximize profits equal to total revenue less total land costs, taking market prices (p_c, p_a, p_o, p_l) and the other producers' location choices as given. Profit maximization conditions for the conventional producer and the alternative use are standard. C and A will set the marginal revenue from production equal to the price of land. Their decisions will be independent of the extensive margin choice of other actors. However, for O, externality damage and therefore marginal productivity depends directly on distance from $\bar{l}_c$. O's optimal solution is therefore a function of C's choice of extensive margin.

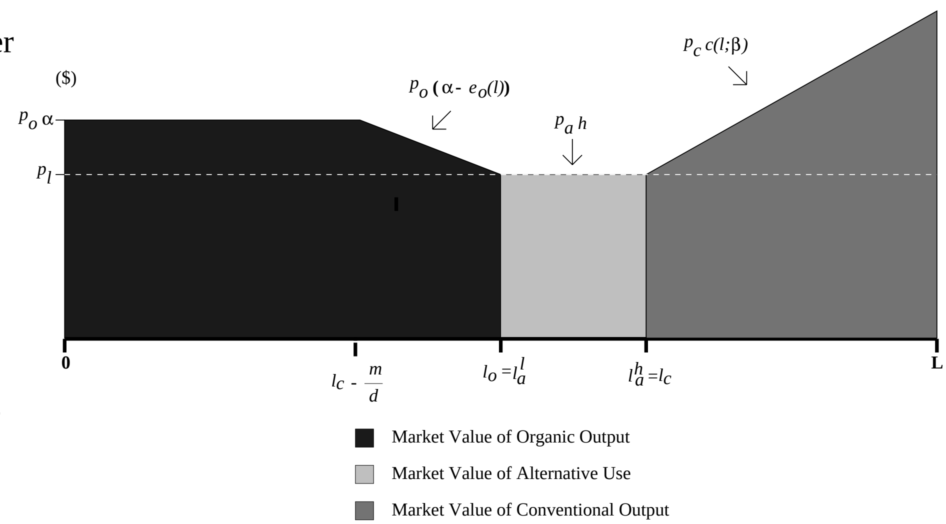

Figure 4: The Free-Market Outcome

The solution to O's f.o.c., given the linear externality from (2), can be characterized in terms of an optimal distance from C:

$$l_o^* = \underbrace{\frac{p_o(\alpha - m) - p_l}{p_o d}}_{B} + \bar{l}_c = B + \bar{l}_c \tag{5}$$

where $B \leq 0$ holds. This solution distance, which could be viewed as a buffer left in the alternative use, is decreasing in own price and d and is increasing in m and the price of land.

In order to close the model, a representative consumer is assumed to own land inputs, receive profits from the sale of products, and choose consumption of the three goods. The general equilibrium outcome will be driven by assumptions imposed on the consumer's utility function. The outcome I illustrate here is based on utility function assumptions which lead to interior solutions for all three goods.

The first-order conditions can be combined to characterized the equilibrium through the following free market conditions:

$$\frac{\partial U}{\partial O}\ \frac{\partial O}{\partial l_o^*} = -\frac{\partial U}{\partial A}\ \frac{\partial A}{\partial l_a^{l*}} = \frac{\partial U}{\partial A}\ \frac{\partial A}{\partial l_a^{h*}} = -\frac{\partial U}{\partial C}\ \frac{\partial C}{\partial l_c^*} \tag{6}$$

The value of an additional unit of the organic good, given the conventional producer's location, is equated to the value of the last unit of production of the alternative use and conventional good.

The Social Optimum Using the first-order conditions from maximization of the utility of the representative consumer subject to production and land input constraints, the general equilibrium social optimum can be characterized by the following equations:[4]

$$\frac{\partial U}{\partial O}\frac{\partial O}{\partial l_o} = -\frac{\partial U}{\partial A}\frac{\partial A}{\partial l_a^l} = \frac{\partial U}{\partial A}\frac{\partial A}{\partial l_a^h} = -\frac{\partial U}{\partial O}\frac{\partial O}{\partial l_c} - \frac{\partial U}{\partial C}\frac{\partial C}{\partial l_c} \tag{7}$$

These conditions can be reduced to obtain:

$$\frac{\partial U}{\partial O}\,(\frac{\partial O}{\partial l_o} + \frac{\partial O}{\partial l_c}) = -\frac{\partial U}{\partial C}\ \frac{\partial C}{\partial l_c} \tag{8}$$

implying that the marginal social value of an additional unit of production of the organic good should be equal to the marginal social value of production of an additional unit of the conventional good. To clarify the economic intuition behind this condition, note that in this specific example the net productivity effect of reducing C's land use by one unit and allowing one more unit of O's

[4] The assumptions on production and utility discussed above ensure interior solutions.

production is:

$$\frac{\partial O}{\partial l_o} + \frac{\partial O}{\partial l_c} = (\alpha - e_o(l_o)) + e_o(l_o) = \alpha$$

which is simply an additional unit of production possible for O free from the externality. [5]

Substituting this result into (8), production of the two goods will be balanced when:

$$\frac{\partial U}{\partial O}(\alpha) = -\frac{\partial U}{\partial C}\,\frac{\partial C}{\partial l_c} \tag{9}$$

Note that the benefits of shifting the externality generation point and thus granting O an additional unit of production free of externality damage are balanced against the benefits of an additional unit of production by C. In contrast, in the free market situation, the value of production at each producer's extensive margin is balanced.

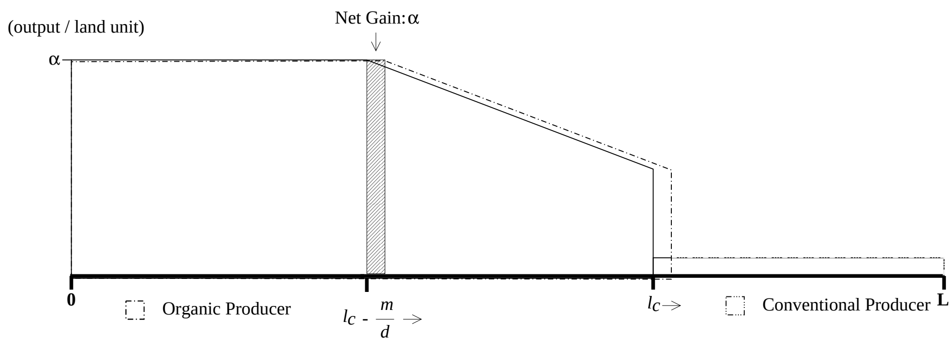

Figure 5: Production Gain by a Reduction in C's Scale

Land Allocation Implications Consistent with standard results for general equilibrium solutions in economies characterized by externalities [2], the amount of land occupied by the organic producer under the social optimum is larger than under the free market solution, and the amount of land occupied by the conventional producer is smaller. Further, the socially optimal amount of land devoted to the alternative use is larger than in the free market. This implies that first, if the alternative use is viewed as a buffer zone, the socially optimal buffer zone is larger than the free market buffer. Second, it follows that the total externality damage experienced by O is smaller under the social optimum, since the organic producer is farther from the conventional producer.

[5] Again, A does not appear in the diagram because A does not impact the production result.

Impacts in two dimensions

A one dimensional model is insufficient to illustrate the potential production impacts of edge effect externalities. In general, the externality will result in increasing average product in land for the recipient, since as he occupies more land, a smaller proportion of his land is impacted by the externality. In two dimensions, average product will vary with parcel shape, the number of parcels, and the distribution of land between parcels, as well as with division of land between generators and recipients.

A set of simple, stylized examples illustrates the production possibility impacts in two dimensions. Available land is represented by a square, with no negative production impacts occurring at its edges. Parcels occupied by recipients originate at corners. For mathematical simplicity, the externality damage is represented by a fixed loss at the recipient's border – no positive production is possible within one unit of the generating border. This representation is consistent with a mandatory buffer. The production impacts of a marginally declining production loss would be similar. Finally, the marginal productivity of each unit of productive land is normalized to one.[6]

As intact habitat will vary with the degree of landscape fragmentation under ecological edge effects, production possibilities will vary with fragmentation under edge effect externalities. Parcel shape, the number of parcels, and the distribution of land within parcels collectively represent different possible dimensions of "fragmentation" of land use. Landscape ecologists have developed numerous statistics and indices to measure fragmentation [9]. For purposes of illustration, three fairly simple statistics that concisely demonstrate variation of production possibilities in each dimension are presented. These measures are a height/width ratio for parcels, the number of parcels, and a normalized concentration index:

$$CI = \frac{\sum_{i=1}^{n} \left(\frac{1}{n}\right)^2}{\sum_{i=1}^{n} \left(\frac{A_i}{TA}\right)^2} \tag{10}$$

where n is the total number of contiguous parcels, A_i is the area of a given parcel, and TA is the total land area. The measure has a maximum of one when each parcel has equal area. The

[6] Without the externality, the production possibilities frontier would be a straight line due to the assumption of constant returns to land.

numerator is the value for the Herfindahl index if each parcel had equal area; the denominator is the Herfindahl for the particular parcel configuration, calculated using the share of total land area for each parcel. The measure is designed to reflect inequality in area distribution, independent of the number of separate parcels.

In figure 6, the amount of land area occupied by the externality recipient (the sum of the light gray and black areas) in each graph is constant. "Average Product" in this example is simply the proportion of land held by the externality recipient which goes to productive use.

Production possibilities (expressed by average product) are decreasing in height to width ratio, decreasing in the number of parcels, and increasing in concentration. There is an inverse relationship between productivity and edge per unit area. The landscape configuration which minimizes edge per unit area also maximizes production possibilities. The broad implication is that edge per unit area can be used as an empirical proxy for average productivity. However, in order to understand the sources of possible efficiency loss, measures reflecting each potential dimension of fragmentation must also be examined.

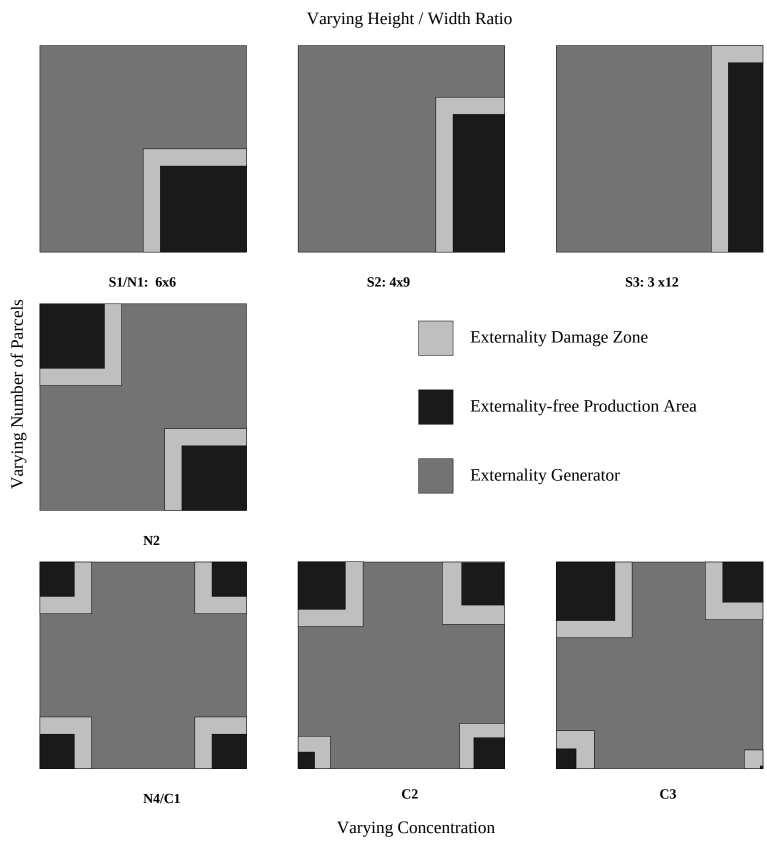

Figure 6: Varying Parcel Configurations

Graph	Average Product	Edge/Area	Height/Width	Num. Parcels	Adj. Herfindahl
S1/N1	0.7	0.67	1	1	1
S2	0.67	0.72	2.25	1	1
S3	0.61	0.83	4	1	1
N2	0.58	0.94	1	2	1
N4/C1	0.44	1.34	1	4	1
C2	0.46	1.3	1	4	0.83
C3	0.5	1.2	1	4	0.64

Multiple Recipient Implications

Since the average externality damage to O declines as the amount of land occupied by O increases, it is advantageous for O to occupy one contiguous parcel. Imagine a case where there are two organic producers and one conventional producer active in the economy. It should be most economically efficient to group the organic producers together. Initial intuition would suggest that market prices will provide appropriate agglomeration incentives for recipients. However, when located next to one another, the two organic producer impose mutual positive externalities by providing externality protection. Further, these positive externalities are asymmetric – the producer farthest from the generator will receive higher benefits, and the producer closest lower benefits. The potential asymmetric positive externalities will not be reflected in land prices. Figure 7 illustrates this phenomenon. Imagine that two organic producers choose location in a conventional landscape.

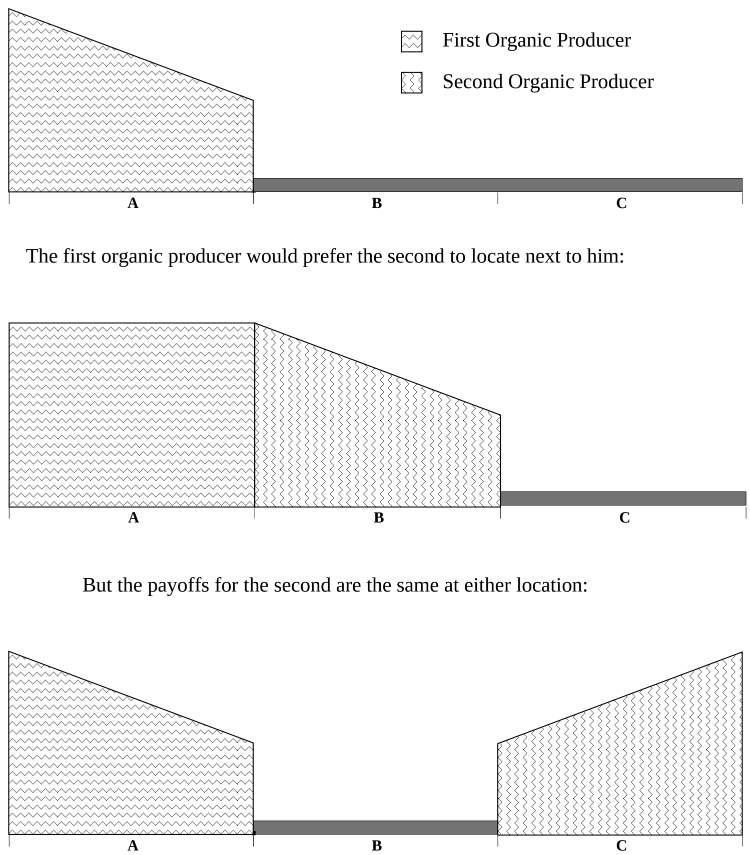

Figure 7: Multiple Recipients

Each would prefer a location sharing no borders with a conflicting use. The first producer locates at A. His payoffs are highest if the second producer locates at B since he gains two protected borders. However, *her* payoffs will be the same at either B or C: in each location, she gains one protected border.

The short lesson here is that Coasian bargaining between externality recipients, not simply between generators and recipients, may be necessary to achieve optimal solutions. In fact, it may be a critical factor if the economy is to reach the optimal *arrangement*, as well as *allocation* of land uses.

Concluding Remarks

Extensions The simple one-dimensional model outlined above can be used to examine the impact of liability rules and mandatory buffer zones and to illustrate the potential for successful Coasian bargaining. Further, interesting results emerge when the magnitude of the externality damage depends on generator's scale of production.[7]

The Empirical Challenge The great challenge in all of spatial economics is to link one-dimensional predictions to two-dimensional data. In this case, specific predictions can be linked to landscape statistics such as those discussed above, and, using G.I.S. , these statistics can be calculated for actual economic landscapes. Hypotheses regarding optimal distancing can also be tested using G.I.S. calculated weighted distance indices. This approach will be taken to analyze location decision of organic farmers in California's Central Valley. Specific hypotheses regarding parcel shape, the proximity of parcels to protective geographic features, and the spatial relationship of organic and conventional growers will be tested with two specific questions in mind. First, are the locations and patterns of production of organic producers consistent with cost-minimization in relation to externality damage? Second, are organic growers relatively agglomerated, as would be predicted by incentives created by edge effect externalities?

[7]Work in progress on these topics is outlined in "Economic Impacts of Edge Effect Externalities on Land Use Decisions", available by request to parker@primal.ucdavis.edu, or at http://www.agecon.ucdavis.edu/HOMEPAGES/D.Parker/D.Parker.

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