Edge-Effect Externalities: Theoretical and Empirical Implications of Spatial Heterogeneity

By

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Abstract

This dissertation examines the impacts of distance-dependent spatial externalities on patterns of economic activity in a free-market setting. This class of externalities, which include such examples as smog dispersal, pesticide drift, and habitat degradation from roads, are referred to as "edge-effect externalities". Under edge-effect externalities, economic optimality will require not only the correct *allocation* of land to different uses, but also the correct *arrangement* of land uses. However, an unregulated free market will potentially fail to achieve an efficient arrangement of land uses.

Chapter 2 develops a spatially continuous one-dimensional model of edge-effect externalities. The model demonstrates that, while the externality creates an incentive for a recipient to distance himself from the generator, this distance is too small from a social standpoint. The model also demonstrates the potential for positive externalities between those impacted by the edge-effect externality.

Chapter 3 formally demonstrates the potential for edge-effect externalities to create non-convexities in the production possibilities frontier. Further, it demonstrates that conflicting border per unit area is a summary measure of landscape efficiency under edge-effect externalities, but this ratio will vary with the number, shape, and geographic concentration of

parcels in the externality-receiving use.

Chapter 4 develops a two dimensional agent-based cellular automaton model of free-market land use in an economy impacted by edge-effect externalities. It demonstrates that in an unregulated free-market without bargaining, both Pareto-efficient and inefficient equilibrium landscape patterns are possible. Initial configurations of firms, permanent geographic features, and transportation costs will impact final outcomes.

Chapter 5 tests the hypothesis that production patterns for California Certified Organic Farms reflect possible avoidance of negative spatial spillovers from surrounding conventional farms. Differences in parcel size, shape, and surroundings between C.C.O.F. and non-C.C.O.F. parcels are demonstrated. While inherently more vulnerable to losses from mandatory buffer zones, C.C.O.F. parcels are shown to potentially lose a much lower proportion of their land to buffers than non-C.C.O.F. parcels. However, very few C.C.O.F. farms border C.C.O.F. farms under separate management, indicating that growers have not managed to coordinate to capture potential positive externalities.

Professor James E. Wilen
Dissertation Committee Chair

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Chapter 1

Introduction

Many classic examples of externalities are inherently spatial: emissions from industrial smokestacks that decrease air quality for surrounding residents, release of effluent from a riverside factory that negatively impacts water quality for downstream users, and invasion of a farmer's field by a neighbor's cattle. Such examples are often used to illustrate the concept of an economic externality and to motivate the theoretical effectiveness of mitigation measures such as Pigovian taxes, liability rules, and bargaining between affected parties. Yet, models used to demonstrate externality impacts generally do not explicitly account for space [21, 3].

Not only are these classic examples inherently spatial, but they also exhibit *distance dependence*, with damaging impacts decreasing as the distance from the pollution source increases. This distance dependence implies that damages from the externality are spatially heterogeneous. Explicit recognition of this spatial heterogeneity raises new questions beyond those previously addressed by the externality literature. First, what location incentives are created by this class of externalities? Second, what impact does this spatial heterogeneity have on the potential productivity of the economic landscape? Third, will the incentives created by these externalities necessarily lead to economically efficient patterns of production? Finally, what does spatial heterogeneity imply for the design and potential effectiveness of policy interventions?

Ecological Edge Effects The characteristics of distance-dependent externalities such as those described above have much in common with the concept of an "edge-effect" developed in the ecology literature [15, 39, 28, 16, 40]. In keeping with this parallel, these externalities are titled "edge-effect externalities". The ecological term "edge effect" refers to ecosystem degradation that occurs at the borders between differing habitat patches [15, 39, 28, 16, 40]. A key feature of an edge effect is that degrading impacts, such as foreign plant species and predator migration, decline as 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, under ecological edge effects, habitat fragmentation leads to non-linear declines in intact interior habitat.

On an ecological level, the pattern and shape of economic land uses matter because the economic and ecological landscape are jointly determined. Economists have begun to recognize their role in predicting land use pattern and shape to provide critical modeling inputs for landscape ecologists. Geoghegan, Bockstael, Bell, and Irwin discuss these issues, noting that ecological models have traditionally imposed, rather than modeled, economic patterns of land use [12] . This approach, they argue, fails to capture the interrelationships between economic and ecological landscapes. If the spatial expansion of economic activity significantly fragments the ecological landscape, it will contribute in a non-linear way to habitat loss.

In fact, habitat degradation caused by landscape fragmentation can be viewed as a specific example of the broad class of edge-effect externalities. Further, 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. Specifically, fragmentation of the economic landscape can lead to non-linear declines in production possibilities.

Initial intuition might suggest that relatively lower values of land impacted by negative spillovers should encourage development of efficient patterns of land use. Empirical evidence suggests that the impact of both proximity to conflicting uses and landscape fragmentation are reflected in property values [5, 12, 13, 29, 22]. However, since externalities are present, the value of organizing land uses so as to create an efficient production landscape will not be reflected in land prices. This suggests that market forces do not necessarily lead to efficient patterns of production.

Modeling Goals This dissertation undertakes a systematic investigation of the impacts of edge-effect externalities on the economic landscape with the ultimate goal of understanding the impacts of edge-effect externalities on free-market land use patterns. In addition to providing theoretical insights regarding the landscape impacts of edge-effect externalities, a primary goal of this work is to develop a theoretical model that generates predictions conducive to testing with actual spatial data. Spatial heterogeneity results not only from edge-effect externalities but also from other economic factors such as transportation costs and variations in land quality. The model, therefore, must be able to account for these factors and produce spatially heterogeneous, disaggregated predictions. Second, economic landscapes are constantly evolving and are characterized by spatial and temporal dynamic complexity. The economic landscape may never reach a stable spatial equilibrium, and different development paths may lead to different equilibria. An effective model should therefore illustrate the dynamics of land use change, as well as possible spatial equilibria. Complex environments are often characterized by non-convexities and multiple equilibria, implying that a solution for the dynamic path and equilibrium outcome may be difficult to obtain via traditional optimization techniques. Therefore, the model should employ a solution method that succeeds under a high degree of heterogeneity and interdependency. Finally, the structure and scale of model predictions should ideally match the structure and scale of available spatial data.

Chapters 2 through 4 of the dissertation presents a series of theoretical models which both illustrate potential welfare losses due to edge-effect externalities and develop spatially explicit hypotheses for empirical testing. Chapter 2 presents a simple one-dimensional model that illustrates the individual incentives created by edge-effect externalities. This model is also used to illustrate the spatial aspects of potential market failure under edge-effect externalities, the potential effectiveness of traditional policy interventions that explicitly account for spatially heterogeneous damages, and the spatial mechanism of Coasean bargaining. The model is also used to illustrate positive externalities between externality recipients and to motivate the possibility that free-market patterns of production may not maximize aggregate production possibilities.

The potential for edge-effect externalities to induce non-convexities in the production possibilities frontier is formally illustrated in Chapter 3. Further, impacts of edge-effect externalities that are revealed only in a two-dimensional framework are illustrated. The chapter also introduces spatial statistics that reflect the relative efficiency of economic landscapes under edge-effect externalities.

Chapter 4 presents a two-dimensional cellular automaton model that demonstrates that free-market production patterns may be sub-optimal. Although economic landscapes may be locally efficient, they may also exhibit inefficient global fragmentation, and rearrangements of production may be welfare improving. In the model, land use decisions are made independently by owners of individual parcels, each taking the actions of neighbors and market parameters as given. A solution to the competitive equilibrium is reached through decentralized dynamic evolution of the economic landscape. Thus, potential difficulties inherent in solving for an economic equilibrium under substantial non-convexities are bypassed. Further, equilibrium outcomes are measurable both in terms of traditional measures of economic welfare and in terms of spatial statistics related to landscape pattern, laying the groundwork for testing of model hypotheses using real-world data. While it is beyond the scope of this dissertation to develop and calibrate a model to be tested explicitly using data on actual landscapes, the model demonstrates the feasibility of such an approach.

Edge Effects in California Agriculture Many examples of land-use conflicts in Central Valley agriculture can be characterized in terms of edge effect externalities. They reflect a range of institutional structures, liability rules, and mitigation measures. In addition to traditional policy interventions, negotiation between affected parties, mandatory buffer zones, and whole-landscape planning are important tools for managing potential conflicts.

Since the early 1990s, cotton production has been reintroduced to the Northern Central Valley, facilitated by new varieties that tolerate a shorter growing season. Conflicts between cotton farmers and rice farmers quickly developed after rice farmers reverted to the use of broad-spectrum pheonoxy herbicides. The switch occurred after weeds which plagued rice fields developed resistance to Londax, the previously used herbicide. Many crops are sensitive to pheonoxies, but cotton is hyper sensitive. Any contamination causes serious damage. By 1996, county regulations were instituted by the Glenn and Colusa County Agricultural Commissions to attempt to prevent damage. These restrictions initially included buffer zones for pheonoxy use and aerial spray restrictions. However, because of the high drift potential and extreme sensitivity of cotton, these restrictions were not completely effective. Zoning restrictions were considered but rejected. After lawsuits were filed by affected cotton growers, herbicide producers demanded complete restrictions on aerial pheonoxy applications in affected areas to protect themselves from litigation [10, 27, 9].

In Glenn County, a potential conflict between olive growers and cotton producers has been mitigated by the creation of a cotton growing zone. Cotton is a potential verticillium wilt carrier. This fungus can cause serious and permanent damage to olives, which constitute a major crop in Glenn county. A committee appointed by the County Board of Supervisors, which included representatives from the cotton growers, the olive growers, and representatives from the Board itself, drafted and adopted a county regulation which prohibits cotton production in much of the county. The result is in effect a “cotton zone” in the Southwest corner of the county. Buffer zones were considered but rejected. This was apparently an extremely emotional conflict, but seems to have been resolved successfully through the zoning arrangement [9].

In order to successfully produce hybrid seeds, growers must ensure that no similar species are grown in close enough proximity to cross-pollinate with the hybrid crops. Seeds produced by contracted growers must meet high standards of uniformity, otherwise the entire crop will be rejected. To prevent cross-pollination, coordination occurs at many levels. Seed companies attempt to assign contracts in a geographically coordinated fashion to minimize potential conflicts between growers, impose and monitor mandatory buffers between similar crops, and supply household gardeners with seeds in return for agreements not to grow certain varieties. Growers meet annually to negotiate agreements with their neighbors to coordinate planting decisions and ensure that buffer zone requirements imposed by seed companies are met.

Edge Effects in Organic Agriculture Many conventional farming practices have spatial spillovers that are incompatible with organic or sustainable production. Pesticide drift is the most obvious example. Other examples are more subtle. Monoculture and lack of habitat may result in decreased populations of beneficial predators and pollinators. An organic grower may suffer crop damage when harmful insects migrate from a neighbor's plot, and the organic grower cannot use pesticides to control the unwanted populations. The possibility of contamination by genetically modified organisms through cross-pollination has become an acute concern to organic producers. While liability for pesticide drift legally rests with the party applying the pesticides, under California Certified Organic Farming (C.C.O.F.) regulations, organic producers are nevertheless required to ensure a 25 foot buffer between organic land and land under potentially incompatible uses.

In interviews with both certified and non-certified organic growers, two points have stood out. First, geographic features play an important role for growers in terms of providing protection for their land. Many growers have commented on the benefits of a location such as the Capay Valley, where natural protection is provided by hills and Cache Creek, as opposed to an unprotected Central Valley location. Properties also often utilize hedgerows and tree windbreaks to provide both protection and habitat for beneficials insects, even when growers are not certified and are therefore not required to impose buffers.

Second, many organic growers report that good relations with their conventional neighbors have allowed them to mitigate conflicts. When buffer zones are required, some growers report imposing them on their own land, while others report that conventional neighbors maintained the buffers themselves. One grower stressed that in his opinion, the key to successful sustainable production was to be a part of a community of small farmers, regardless of their growing practices.

The case of the organic growers offers particular promise for empirical analysis. First, results related to the organic industry hold promise for lasting policy relevance. Due to fundamental differences in production practices between organic and conventional agriculture, conflicts will persist over time. Further, demand for organic products continues to expand in both domestic and international markets, so the viability of organic production is likely to be an issue of long-term importance. Since organic products are required to be free from genetically modified organisms, consumers concerned about G.M.O.'s may choose to purchase organic products, further expanding demand.

Second, buffer zone requirements have been in place since 1990, and will remain an important aspect of certification new proposed national organic standards [36]. These buffer zones requirements provide concrete, measurable evidence of the impacts of edge-effect externalities.[1] Further, the buffer zones are quite small in comparison to the size of organic parcels, implying that the most important spatial spillovers will occur from an organic grower's immediate neighbors. This results significantly simplifies empirical analysis of neighborhood effects.

Substantial fixed costs of relocation contribute to the possibility that free-market patterns of organic production may not be most efficient. Certified organic plots must go through

[1] The C.C.O.F. regulations require 25 foot buffers if there is "any concern about the possibility of contamination from adjacent areas" [7]. In 1997, 58% of C.C.O.F. growers were required to maintain at least one buffer zone, and of these growers, only 33% were able to sell crops grown in these buffer areas.

a three year transition phase before crops can be sold under a certified organic label. Thus, once production is established successfully in a given location, it is often not cost effective to relocate.

Last, but perhaps most important for successful empirical analysis, the data available to study California Certified Organic Farmers are excellent. Certification records are monitored each year to ensure that records are complete and coherent. Parcel map requirements are standardized, and street addresses and location descriptions are provided, so that the locations of parcels can successfully identified. Inspector's reports contain detailed descriptions of surrounding land uses and buffer zone requirements. While the population of certified growers in the region of analysis is small, the high quality of the available data offer inspire confidence in the validity of the results of this empirical analysis.[2]

Chapter 5 provides in-depth analysis of potential conflicts between California Certified Organic Farms and their conventional neighbors. Theoretical predictions outlined in Chapters 2 and 4 are evaluated through empirical analysis of locations and production patterns of C.C.O.F. farms in a two-county region of California's Central Valley. Data for this analysis come from a geographic information system constructed for the purposes of this study. The G.I.S. contains detailed information on crops grown and soil types for all agricultural parcels in each county. Further, parcel boundaries and buffer zone requirements are identified for C.C.O.F. parcels. This dataset facilitates a unique analysis of organic production landscapes. Comparisons of a series of landscape statistics for certified organic and non-

[2] An ideal data set for this two-county region would also have included location of non-certified organic farms. Unfortunately, data on locations of registered organic farms are not available for research purposes. Data on C.C.O.F. farms were obtained under a detailed set of confidentiality conditions.

certified organic parcels demonstrate significant differences between parcels consistent with avoidance of potential conflicts with conventional agriculture by certified organic farmers. These results demonstrate that avoidance of buffer zones is an important factor in determining locations and production patterns for C.C.O.F. farmers. The results also indicate that organic growers may be willing to pay a premium for crop land in protected locations. This price premium may constitute a barrier to entry into certified organic production, resulting in less organic production than would be socially optimal.

Chapter 2

Edge-Effect Externalities

2.1 Introduction

Spatial externalities are a common feature of economic landscapes and have a significant influence on the evolution of land use patterns. Standard externality theory tells us that without mitigation or bargaining, free-market land use allocations will not be Pareto optimal – too much land will be dedicated to harmful uses and too little land to beneficial uses. Under many significant spatial externalities, however, an additional dimension to market failure is possible – the free market will not achieve an efficient spatial configuration of land uses.

In many spatial externalities, negative externality impacts are most intense at the border with a generating land use, and damages decline in severity as distance from the offending land use increases. Examples include intrusion of noise, odors, and pollutants from industrial sites into residential areas, degradation of habitat reserves due to surrounding development, drift of agricultural pesticides into urban areas, and spillovers of criminal activity from dangerous neighborhoods. Under these "edge-effect externalities," optimality requires not only the appropriate *allocation* of land to differing uses, but the appropriate *arrangement* of land uses. Specifically, an arrangement of production sites that minimizes potentially conflicting borders will be most efficient. Many regulatory tools to address spatial externalities are available to policy makers. However, to date, the impact of these policies on land-use patterns has not been considered. This deficit motivates an important new research question: how effectively will potential mitigation measures, which include Pigovian taxes, liability rules, mandatory buffer zones, and zoning laws, encourage development of economically optimal patterns of land use? To answer this question, a comprehensive understanding of the incentives created by edge-effect externalities for an individual land user is needed.

This chapter presents a one-dimensional, spatially continuous and spatially dynamic theoretical model designed to illustrate these incentives. The problem is modeled in the context of land use conflicts between organic and conventional agricultural producers. First, socially optimal and purely competitive outcomes are examined under the assumption of efficient land-use arrangement, with like uses grouped together and maximal spatial separation between incompatible uses. The potential for spatially explicit Pigovian taxes, liability rules, and Coasean bargaining to achieve socially optimal land use allocation is demonstrated. The assumption of efficient arrangement of land uses is then relaxed to demonstrate the production impacts of land use fragmentation, to discuss the role of potential positive externalities between externality recipients, and to examine the potential for market equilibria in which compatible land uses remain geographically separated.

Three important results are emphasized. First, the externality creates an incentive for the recipient to distance himself from the generator, resulting in an individually optimal buffer zone. However, this incentive does not imply that the free-market outcome will coincide with the social optimum since the individually optimal buffer is smaller than is socially optimal. 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. These results imply that an unregulated free market may not lead to efficient patterns of land use. Further, they motivate an investigation of the impacts of policy interventions, such as taxation, liability rules, buffer zones, and zoning laws on land use patterns, as well as on the total allocation of land to various uses.

2.1.1 A Brief Literature Review

The potential for tradable permits to achieve a least-cost allocation of emissions in an economy with distance-dependent pollution dispersion has been examined by several authors [26, 20, 25]. These works recognize the importance of spatial spillovers when evaluating the potential for tradable permit schemes to achieve least-cost pollution abatement by explicitly accounting for spatially heterogeneous damages. However, they take both the optimal level of pollution output and the optimal location of polluting firms and of potential recipients as given. The first assumption is standard for cost-minimization schemes. The second represents a failure to consider optimization in the land-use arrangement dimension, since the possibility that externality recipients may relocate in response to local changes in emissions levels is not considered.

This chapter is preceded by several important spatially discrete models with assumptions consistent with edge-effect externalities that begin to address optimal firm location [4, 17, 1]. Baumol and Oates note that spatial externalities can potentially lead to non-convexities in aggregate production possibilities and that non-convexities can be mitigated by spatial separation of conflicting production processes. Helfand and Rubin characterize this separation solution as a “corner solution” and discuss the circumstances in which separation may be socially optimal. Albers examines optimal management decisions within a discrete spatial model consistent with the existence of edge effect externalities. Consistent with expectations, when spatial externalities are accounted for, it is optimal to group habitat cells and other complementary land uses. Some insight is lost in these models due to the spatially discrete modeling. Economically optimal distancing strategies, the possible emergence of voluntary buffer zones, and changes in optimal distances and buffers due to changes in economic conditions are not easily analyzed in a discrete setting.

Kanemoto reviews the early urban economics literature examining continuous spatial externalities with diminishing marginal impacts [18]. Models that focus on conflicts between an industrial and residential sector provide insight on the optimal location of a border between an externality generating activity and externality recipients. Models are based on a two-dimensional monocentric city in a featureless plain, but outcomes can be completely described in terms of a one-dimensional radius. Two important general results are highlighted. First, the rent gradient may be increasing with distance from the industrial / residential border if negative externality impacts outweigh the benefits of proximity. Second, if the externality is severe enough, a buffer zone between the industrial and residential zones may be socially optimal. This literature, in general, focuses only on socially optimal outcomes given an efficient arrangement of land uses.

Several authors [34, 11, 35] have analyzed the potential for spatial Pigovian taxes to achieve a socially optimal allocation of economic activity under spatial externalities with declining marginal damages. Tomasi and Weise, in the context of a spatially continuous one-dimensional model, demonstrate that under certain externality generation conditions, spatial Pigovian taxes can induce both the appropriate intensity of externality-generating production and the socially optimal location of a boundary between conflicting uses. These spatial pigovian taxes prove extraordinarily complex, as they depend on information on shadow values of land at differing points in space. They therefore cannot be viewed as a practical policy mechanism. Further, spatially heterogeneous taxes are not common in practice. The most common policy responses include zoning rules, mandatory buffer zones, and legal liability for damages. These mitigation mechanisms may well offer a more practical and cost-efficient way of encouraging optimal arrangement of land uses. However, a formal analysis of these policies is absent from the literature.

This chapter develops a simple three-producer model of edge-effect externalities appropriate for evaluating the market responses of affected parties to liability rules, mandatory buffers, and zoning regulations. The focus is on a more comprehensive understanding of free-market outcomes and the possible dimensions of market failure than has been provided in the previous literature, with particular emphasis on illustrating the spatial dimension of standard results and policy interventions. In particular, a spatial interpretation is provided for standard results related to the failure of the free market to equate marginal social benefits and costs, the difference in firm outputs and total externality damage between the social optimum and free-market outcome, and the operation of Pigovian taxes, liability rules, and Coasean bargaining.

This exposition serves several purposes. First, it provides a needed framework for understanding the incentives created by distance-dependent spatial externalities. Second, since spatial separation of potentially conflicting uses is assumed, production possibilities in the land use dimension are maximized, given the externality. This model therefore outlines a minimum degree of market failure under edge-effect externalities and provides a benchmark for measuring additional market failure that may occur due to landscape fragmentation. Further, by describing individual incentives along any given border, it provides a needed building block for two-dimensional spatial models. Two-dimensional models are arguably most appropriate to test the landscape pattern impacts of both traditional policy interventions, such as taxes and liability rules, and alternative measures common in practice, such as mandatory buffer zones and zoning laws.

2.2 A Simple Model

2.2.1 Land-use Arrangement

Total land available for production is represented by a line of length L. Three land uses are possible: production of organic agriculture (O), conventional agriculture (C), and an alternative use (A), which could represent grazing land, natural vegetation, or some similar use. Organic production is negatively impacted by an externality generated by the conventional producer. 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 nor negatively impact marginal externality damage.[1] In this model, the most efficient arrangement of land uses is imposed, with the alternative use located between the organic and conventional sites. An interpretation is that zoning rules are in place to separate incompatible uses. However, the length of the line segment occupied by each user is determined endogenously. Since decisions are spatially interdependent, it also implies that the location of shared borders and distance between land users are endogenous to the model. This facilitates a comparison of the socially optimal and free-market equilibrium distance between incompatible uses.

Locations of land uses are illustrated in Figure 2.1. The total amount of land occupied by each grower is defined by the difference between the upper and lower extensive margin

[1] These relationships between organic production, conventional production, and alternative land uses represent simplifying assumptions. The argument can be made that conventional producers experience negative spillovers from organic neighbors, and in some cases, alternative uses such as natural vegetation may enhance the productivity of surrounding organic farms.

of production for that user. Thus, the total amount of land farmed by each user is:

$$\text{Organic Land} = l_o - l_o^l \tag{2.1}$$

$$\text{Alternative Use Land} = l_a^h - l_a^l \tag{2.2}$$

$$\text{Conventional Land} = l_c^h - lc \tag{2.3}$$

where $l_o = l_a^l$ represents the location of a shared border between the organic farmer and alternative use, and $l_a^h = l_c$ represents the shared border between the alternative and conventional use. The amount of land in the alternative use therefore defines the distance between the organic and conventional borders.

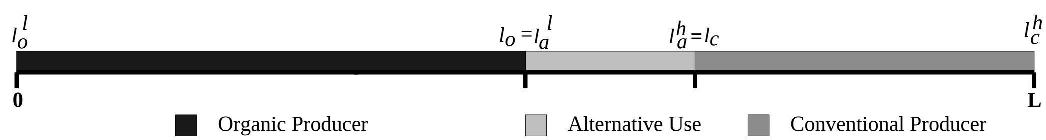


Figure 2.1: Land Use Locations: Interior Solutions

2.2.2 Production

For simplicity, land (l) is assumed to be the single input to the production process. This single input represents a composite of soil and labor inputs. Soil quality is assumed to be homogeneous over all available land. Production takes place on all land rented.

The Conventional Producer The conventional firm experiences diminishing returns to land as a factor of production and imposes a negative externality on the organic firm[2]. Since the amount of land she occupies increases as l_c decreases, her marginal product will decline as l_c gets smaller.[3]

Total production is found by integrating over all units of the land she occupies:

$$Y_C(l_c; L, \beta) = \int_{l_c}^{L} c(l; \beta)\, dl \tag{2.4}$$

where l represents an incremental land unit, $c(l; \beta)$ is the marginal product function, β is a vector of exogenous parameters, and $c(l; \beta)$ is *increasing* with l. Since land quality is assumed to be homogeneous, as long as she can occupy her optimal amount of land, C is indifferent about what production site she occupies. Further, an additional unit of production along either border would be equally valuable to her.

The Organic Producer The organic producer experiences a loss of production at the margin due to the presence of the conventional farmer that diminishes with the distance from C's production edge, the generation point of the externality damage. In this simple model, the severity of the externality depends only on O's distance from C, and not on the amount

[2] A justification for the assumption of diminishing returns could be that the farmer must monitor each part of the field daily, and given limited hours to allocate, the quality of her monitoring will decrease as the amount of land she has to monitor increases. An additional justification could be that the conventional farmer incurs distance-dependent transportation costs to market, while the organic farmer sells his produce on site.

[3] Representing this function graphically in a spatial context presents some difficulties, since for the conventional producer, an additional unit of land at any point in space should have the same marginal product since production possibilities are spatially homogeneous. As a compromise, the graphs are drawn so that marginal products at each border are equal.

of land occupied by C. The marginal damage at each point in space is represented as the value of a function $e_o(l)$.

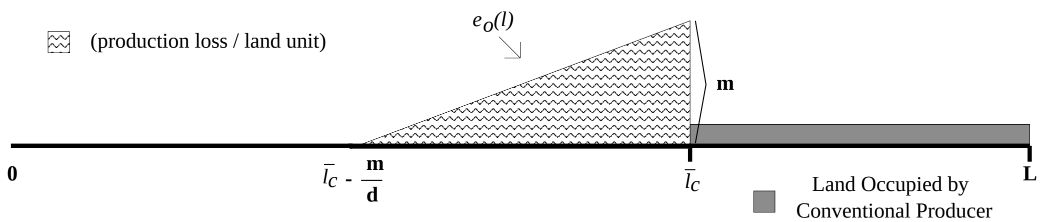


Figure 2.2: The Marginal Externality Damage Function

As a specific example, let the potential marginal production loss to O decline linearly and be equal to m at C's edge, or $e_o(l_c) = m$, where m represents the *maximal damage* possible from the externality. The production loss declines linearly as distance from the conventional border increases with slope d, the *dispersal* rate of damage. In this model, m and d are assumed to hold values so that there will be an interior point where O may produce free from the externality. This point will be reached at the l intercept of the externality damage function, $e_o(l_c)$. The damage function is illustrated in Figure 2.2.

O is assumed to operate according to a constant returns to land technology in the region where the externality impact is not present. Specifically, marginal productivity on any given unit of land is equal to α. While this is not consistent with the specification for C, it allows for a clear demonstration of key results – in particular, the fact that the spatial externality will impose distance-dependent diminishing marginal productivity on O's production possibilities if none were present before. This production result leads to the possible emergence of a buffer between the organic and conventional producer. The implications derived from this model generalize to one where O also operates under diminishing returns.

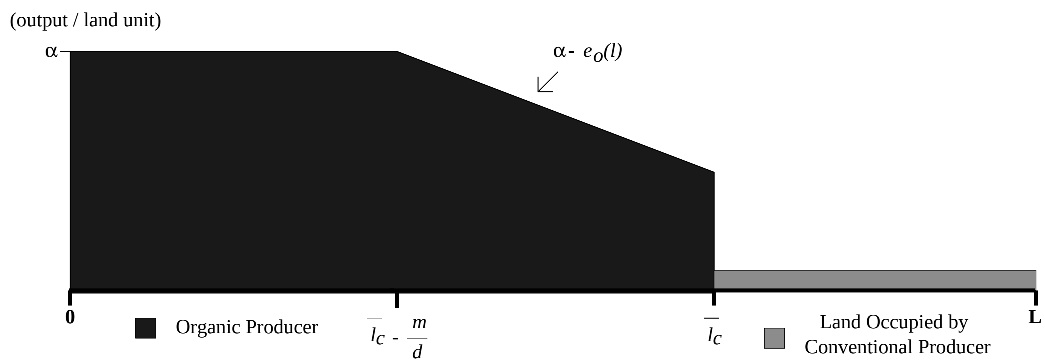


Figure 2.3: O's Potential Marginal Product

When O is close enough to C so that he is impacted by the externality, his marginal productivity will be equal to α less the marginal production loss due to the externality. This function is illustrated in Figure 2.3. O's total production can be found by integrating the functions over the two regions:

$$Y_O(l_o; 0, \bar{l}_c, m, d) = \int_0^{\bar{l}_c - \frac{m}{d}} \alpha \, dl + \int_{\bar{l}_c - \frac{m}{d}}^{l_o} \alpha - e_o(l) \, dl = \int_0^{\bar{l}_c - \frac{m}{d}} \alpha \, dl + \int_{\bar{l}_c - \frac{m}{d}}^{l_o} \alpha - (m - d(\bar{l}_c - l)) \tag{2.5}$$

The value $\bar{l}_c - \frac{m}{d}$ is the l intercept, where the externality impact is zero. If O could choose the lower bound of the first integrand, he would choose to back up production further, 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 choose a location that minimizes externality damage, all other things being equal. This result would still hold if O experienced diminishing returns to land for all production since marginal productivity would be relatively lower in the region of externality damage.

Spatial Properties of O's Production Technology The marginal productivity of land for O will depend on the location of the additional unit. If the lower margin of production is extended, implying a relaxation in the land constraint, O gains a unit of production in the externality-free range with marginal value α. If, however, O extends production one unit closer to C's border, the marginal gain is $\alpha - e_o(l_o)$. This marginal product will always be positive as long as the maximal damage is less than O's marginal productivity of land, α.

O's production function is now quasi-concave throughout: the externality has imposed diminishing returns to land as a factor of production in the direction of the generator's border. Formally, $\frac{\partial^2 Y_O}{\partial l^2} = -d$ in the region of externality damage. This production impact leads directly to the emergence of an optimal distance from the conventional border for the organic grower.

If C decreases her scale by one unit (or, alternatively, moves her border one additional distance unit away from O), and the location of O's border remains fixed, O will gain a unit of production in the constant returns range and lose a unit in the range of externality damage. The net gain is equal to the externality impact at that margin: $\frac{\partial Y_O}{\partial l_c} = e_o(l_o)$. This result is illustrated in Figure 2.4 and derived formally in Appendix A. The result may contradict an initial intuition that the gain would be equal to the marginal product at the organic border, $\alpha - e_o(l_o)$. The explanation for the result is that the generation point of the externality has shifted, thus, the point on the organic grower's land where no externality damage has occurred has also shifted. The result is a larger range of externality-free production for the organic grower, and a smaller range of production in the region impacted by the externality. This result is important for understanding the spatial interpretation for a socially optimal arrangement of production, discussed below. The condition for the social optimum will balance the value of shifting the generation point of externality damage against the loss of a unit of conventional production.

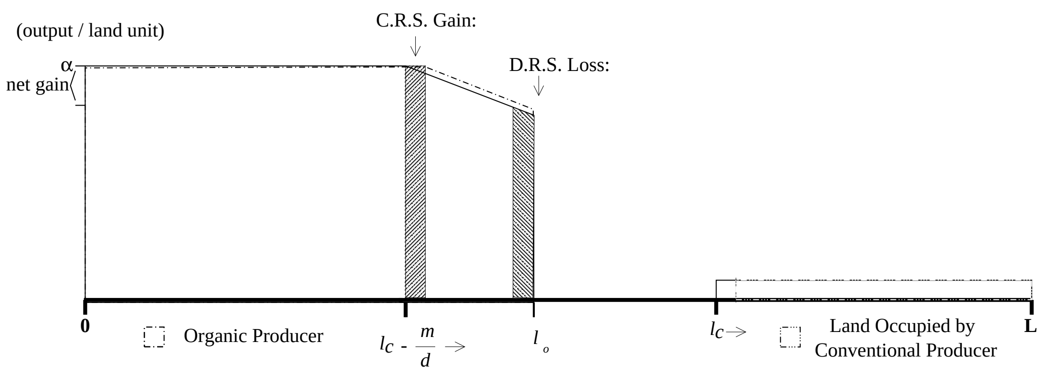


Figure 2.4: Production Gain by a Reduction in C's Scale (O's border fixed)

The Alternative Use The alternative use operates under constant returns to land with a fixed marginal product of h.[4] Since A is unaffected by externalities, A's productivity is independent of location. Given a choice of l_a^l and l_a^h, A's total production is simply:

[4]The free-market outcome can be viewed as a case where O and C choose to establish production in a region and must earn profits at least high enough to buy out the existing use.

$$Y_A(l_a^h, l_a^l; h) = \int_{l_a^l}^{l_a^h} h \, dl = h(l_a^h - l_a^l) \tag{2.6}$$

Closing the Model Socially optimal and free-market outcomes are modeled in a general equilibrium framework. General equilibrium models are commonly used to analyze externality problems since they clearly illustrate impacts on relative prices. The use of a general equilibrium model here allows traditional methodology to be used to illustrate deviations between the free market and socially optimal outcomes, putting this special externality case in the context of the general externality model. Therefore, a representative consumer is needed to close the model. This consumer gains utility from all three goods and is unaffected by the externality. The outcome illustrated here is based on utility function assumptions that lead to interior solutions for all three goods. The assumptions are:

$$U_O > 0, \quad U_O(0) = \infty$$

$$U_A > 0, \quad U_A(0) = \infty$$

$$U_C > 0, \quad U_C(0) = \infty$$

and that the Hessian of U with respect to the three goods is a negative definite matrix.

2.3 The Social Optimum

Analysis of the socially optimal outcome serves two purposes. First, it demonstrates that this class of externalities is simply a special case of the more general externality problem, and it facilitates a spatial interpretation of the traditional conditions for social optimality.

Second, it provides a benchmark against which to measure an unregulated free-market outcome and evaluate the potential effectiveness of potential policy interventions.

2.3.1 The Social Planner's Problem

The social planner maximizes the utility of the representative consumer subject to production and land availability constraints. The planner solves the following problem:

$$\max_{O,A,C,l_o^l,l_o,l_a^l,l_a^h,l_c,l_c^h} U(O,A,C) \quad s.t. \tag{2.7}$$

$O \leq Y_O(l_o; l_o^l, \bar{l}_c, m, d)$	(ρ_o)	Organic output
$A \leq Y_A(l_a^h, l_a^l; h)$	(ρ_a)	Alternative output
$C \leq Y_C(l_c; l_c^h, \beta)$	(ρ_c)	Conventional output
$l_o^l \geq 0$	(μ_o)	Lower organic margin
$l_o^l \leq l_o$	(ν_o)	Non-negative land use
$l_o \leq l_a^l$	(λ_{oa})	Organic location
$l_a^l \leq l_a^h$	(ν_a)	Non-negative land use
$l_a^h \leq l_c$	(λ_{ac})	Conventional location
$l_c \leq l_c^h$	(ν_c)	Non-negative land use
$l_c^h \leq L$	(μ_c)	Upper conventional margin

where O, A and C represent total consumption of each class of output and the remaining constraints serve to define firm locations and to ensure no overlap in land uses. The multipliers ρ_o, ρ_a, and ρ_c represent the value of an additional unit of consumption of each good.

The multipliers μ_o and μ_c represent the value of land in organic and conventional production at the left and right ends of the line, respectively. They will also reflect the value of extending the land constraint in either direction. The multipliers λ_{oa} and λ_{ac} represent the value of moving the organic / alternative production boundary and the alternative / conventional boundary, respectively.

Because it is assumed that the externality is never so severe as to prevent positive organic production, all land will be used for production. This implies that the constraints related to the μ and λ multipliers will bind and that the constraints related to the ν variables will be slack.[5] The reduced first-order conditions are:

$$\begin{aligned} \rho_o \frac{\partial Y_O}{\partial l_o} &= \lambda_{oa} \\ \rho_a \frac{\partial Y_A}{\partial l_a^l} &= -\lambda_{oa} \\ \rho_a \frac{\partial Y_A}{\partial l_a^h} &= \lambda_{ac} \\ \rho_o \frac{\partial Y_O}{\partial l_c} + \rho_c \frac{\partial Y_C}{\partial l_c} &= -\lambda_{ac} \end{aligned} \qquad \begin{aligned} \rho_o \frac{\partial Y_O}{\partial l_o^l} &= \mu_o \\ \rho_c \frac{\partial Y_C}{\partial l_c^h} &= \mu_c \end{aligned} \qquad \begin{aligned} \frac{\partial U}{\partial O} &= \rho_o \\ \frac{\partial U}{\partial A} &= \rho_a \\ \frac{\partial U}{\partial C} &= \rho_c \end{aligned}$$

2.3.2 Condition for Social Optimum

Combining first-order conditions:

$$\underbrace{\frac{\partial U}{\partial O}\frac{\partial Y_O}{\partial l_o}}_{MSB\ O} = \underbrace{-\frac{\partial U}{\partial C}\frac{\partial Y_C}{\partial l_c}}_{MSB\ C} - \underbrace{\frac{\partial U}{\partial O}\frac{\partial Y_O}{\partial l_c}}_{MSC\ C} \tag{2.8}$$

This is the familiar condition equating the marginal social values of production of the organic and conventional goods. Both the marginal social benefit and the marginal social cost

[5] By using the endpoints as lower and upper bounds when calculating production, it is implicitly assumed these constraints are slack.

(negative production impact) of C's production are accounted for. Some further analysis clarifies how space explicitly enters into this condition. Rearranging equation 2.8:

$$\frac{\partial U}{\partial O}\left(\frac{\partial Y_O}{\partial l_o} + \frac{\partial Y_O}{\partial l_c}\right) = -\frac{\partial U}{\partial C}\,\frac{\partial Y_C}{\partial l_c} \tag{2.9}$$

The expression in parentheses, $\frac{\partial Y_O}{\partial l_o} + \frac{\partial Y_O}{\partial l_c}$, represents the total productivity gain to O of decreasing C's production by one unit at the border closest to O and subsequently moving O's border one unit closer to C. The net gain is α units of production for O. A graphical interpretation, illustrated in Figure 2.5, provides clarification. Recall that a one-unit reduction in scale by C implies an additional unit of production possible in constant returns to scale region, where the net marginal productivity is equal to α. If O's scale stays fixed, it implies a decrease of one-unit in the production range negatively impacted by the externality (illustrated in Figure 2.4). However, $\frac{\partial Y_O}{\partial l_o}$ represents a one unit increase in O's scale, which exactly compensates for the production loss in the second range. The net impact is to provide an additional unit of externality-free production for O. In short, the expression in parenthesis represents the tradeoff at the margin between C's production and O's production. The result is formally demonstrated in Appendix A.

The condition for the social optimum then has a very simple representation in this case – production of the two goods will be balanced when

$$\frac{\partial U}{\partial O}\alpha = -\frac{\partial U}{\partial C}\,\frac{\partial Y_C}{\partial l_c} \tag{2.10}$$

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 addi-

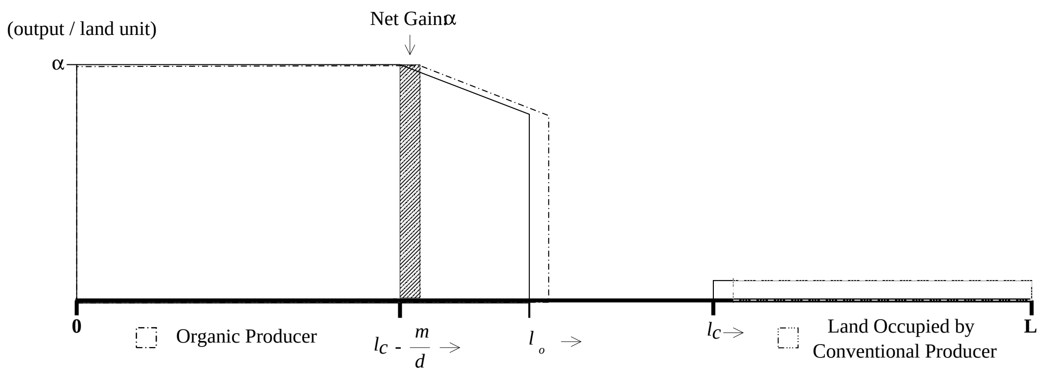


Figure 2.5: Production Gain by a Reduction in C's Scale (O's border moves)

tional unit of production by C.

Further, since $\frac{\partial Y_O}{\partial l_o^l} = \alpha$ and since the value of an additional unit of production of the conventional good at either extensive margin is equal, equation 2.10 can also be expressed as:

$$\mu_o = \frac{\partial U}{\partial O}(\alpha) = \frac{\partial U}{\partial C}\frac{\partial Y_C}{\partial l_c^h} = \mu_c \tag{2.11}$$

The socially optimal solution implies that values of an additional unit of available land at either end of the line are equated. This result may contradict initial intuition that a balance of marginal values at shared borders is a sufficient condition for optimality. In fact, it is necessary but not sufficient. Further, while marginal values of output at internal shared borders are equal ($\lambda_{oa} = -\lambda_{ac}$), shadow values are not equated at all borders. These differences in shadow values correspond to the spatial heterogeneity of externality damages. Specifically, land at the organic / alternative border is less valuable than land at the organic extensive margin, reflecting its lower productivity:

$$\lambda_{oa} = \rho_o(\alpha - e_o(l_o)) < \mu_o = \rho_o\, \alpha \tag{2.12}$$

2.4 The Free-market Outcome

In the free-market outcome, each producer takes market prices and the behavior of the other producers as given. Specifically, each land owner takes the others' locations as given. Since productivity for the alternative and conventional firms does not depend on others' locations, the locations of others' borders do not enter these choice problems. However, since O's productivity is specifically dependent on the location of C's nearest border, this border explicitly enters as a parameter in his choice problem.

2.4.1 The Conventional and Alternative Firms

The conventional producer will produce until the marginal value of production is equal to the rental rate of land, solving the general first-order equation $p_c c(l_c; L, \beta) = p_l$. C's optimal solution is independent of O's location or extent of production.

Because the alternative use operates under constant returns to land, the manager of the alternative land use will produce at any set of break-even prices, or more specifically, as long as $p_a h = p_l$.

2.4.2 The Organic Producer

In this model, the organic producer understands the nature of the externality damage and therefore implicitly chooses the level of damage he experiences by choosing how close to the conventional producer he farms. Freeman discusses a parallel example of acid deposition on land, using the terminology "depletable externality," and demonstrates that a depletable externality is simply a special case of the more general externality problem [11]. This chapter comes to the same conclusion. However, it substantially expands the definition of an externality used by Freeman to include the case where the recipient understands potential damages and implicitly chooses the level of externality damage experienced. Baumol and Oates [4] outline two essential conditions which define an environmental externality. First, the decision variables of one economic actor must have real (non-monetary) impacts on the utility or production relationships of another economic actor. Second, the first economic actor must not personally pay costs equal to the impacts to the second actor (in the case of a negative externality).

Freeman argues that the case of acid rain does not meet Baumol and Oates' definition of an externality, commenting "the essence of the externality problem is that individuals cannot choose the level of the externality affecting them [11]". It is argued here that, consistent with the conditions outlined by Baumol and Oates, the essence of the externality problem is that individuals' choices do not impact the *level* of externality-generating activity in the economy. In the problem outlined below, the organic producer understands and therefore chooses the level of damage he experiences. However, since the organic producer takes the location of the conventional producer's border as given, he also takes externality output as given – from his perspective, his choice of location does not impact the level of potential externality damage in the economy. Most important, the conventional producer does not account for the costs of externality damage to O when making her production choice. This lack of accounting for external costs and benefits of individual decisions is the essential feature of an externality which can lead to market failure. As demonstrated below, since this externality meets Baumol and Oates' fundamental definition, a deviation between the free-market (non-bargaining) outcome and the social optimum occurs, and the characterization of this market failure matches that of a traditional externality problem.[6]

The organic farmer maximizes profits from production, taking the location of the conventional producer's border and therefore the externality damage at each point in space as given. He will choose the location of his border, and therefore implicitly both the total amount of production and his distance from the conventional border, by renting and farming land to the point where the marginal value of production is equal to the marginal cost of an additional unit of land *given* the location of C's border. For a given $\bar{l_c}$, this optimal solution to the general first-order equation $p_o o(l_o; \bar{l_c}, m, d) = p_l$ will define O's distance from C. This result is demonstrated algebraically in the case of the linear externality. O's optimal

[6] The point that the ability to choose the level of damage experienced does not that externalities are appropriately controlled generalizes. For example, consumers have the opportunity to control their exposure to environmental externalities through their own purchase decisions in many cases. The case of the booming market for bottled water is one example. The purchase of home air filters is another. In these cases, the consumer's ability to personally control exposure is in no way linked to the amount of damage the consumer could potentially experience, and so, the level of market failure due to the externalities is not impacted by consumer avoidance behavior.

solution to the first-order condition is:

$$l_o^* = \underbrace{\frac{p_o(\alpha - m) - p_l}{p_o d}}_{B \leq 0} + \bar{l_c} = B + \bar{l_c} \tag{2.13}$$

The quantity B represents O's optimal distance from the conventional producer's border. This individually optimal buffer zone buffer is decreasing in d, the dispersal rate. Intuitively, a higher dispersal rate implies that the distance at which the externality impact is zero becomes smaller, and the marginal damage at any point in space other than the border is also smaller. It is increasing in m, the maximal damage. Higher damage at the generation point means that a greater distance is required to completely avoid the externality and that marginal externality damage is greater at every point. Therefore, the economic loss to the organic producer at any given distance from C's border will be greater for a given set of input and output prices. The optimal buffer is also decreasing in the price of the organic good and increasing in the rental rate of land.

Finally, O's optimal border location depends on the location of C's border. If C's border moves one unit farther away, O will move his border closer by one unit. Intuitively, C takes one step back and O responds with one step forward. This result is linked to the fact that the externality declines linearly and to the explicit assumption that the externality is not dependent on C's scale.

2.4.3 The Consumer

The single consumer owns all the land and all three firms. As is traditional in general equilibrium models with a single representative agent, her consumption and production decisions are modeled as being independent from one another. She receives income from the sale of land, which she owns, and from the profits from production. Her first-order conditions equate the marginal utility of each good to its market price, given her budget constraint.

2.4.4 The Free-Market Outcome

The Free-Market Condition Combining the first-order equations for production and consumption, the following familiar condition is obtained:

$$\underbrace{\frac{\partial U}{\partial O}\frac{\partial Y_O}{\partial l_o^*}}_{MSB\ O} = -\underbrace{\frac{\partial U}{\partial C}\frac{\partial Y_C}{\partial l_c^*}}_{MSB\ C} \tag{2.14}$$

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 conventional good. This condition clearly differs from the socially optimal outcome in the traditional way – marginal benefits of each method of production are equated, without accounting for marginal external costs. Once again, examination of the market rental rates, or market shadow values, of land at different points in space reveals the spatial dimensions of market failure. In both the socially optimal and free-market outcomes, values at the organic-alternative border and at the alternative-conventional border are equated. However, the market rental rate of land at these borders is higher in the free-market outcome than under the social optimum. In fact, the rent gradient for organic land is higher everywhere under the free-market outcome.

Additional insight regarding land rental rates comes from comparing shadow values of land at the extensive margin of production. In the socially optimal outcome, the shadow value of an additional unit of externality-free production land was equated to the shadow value of an additional unit land to produce the conventional good (Equation 2.10). In the free-market outcome, this private shadow value, $\frac{\partial Y_O}{\partial l_o^l} = \frac{\partial U}{\partial O}\alpha$, is higher. Specifically, from Equation 2.14 and noting that $\frac{\partial Y_O}{\partial l_o^*} = \alpha - e_o(l_o^*)$:

$$\text{O's Private Shadow Value} = \frac{\partial U}{\partial O}\alpha = \underbrace{-\frac{\partial U}{\partial C}\frac{\partial Y_C}{\partial l_c^*}}_{\text{opportunity cost}} + \underbrace{\frac{\partial U}{\partial O}\, e_o(l_o^*)}_{\text{value of avoided damage}} \tag{2.15}$$

Comparing Equation 2.15 to Equation 2.10 describing the social optimum, it is clear that the rental rate of a unit of externality-free land for O is higher by the value of externality damage avoided at the margin. The value of avoiding externality damage has been incorporated in the market rental rate of externality-free production land. This result is the spatial manifestation of the cost disadvantage faced by the organic producer due to the externality. It is a standard result in externality problems that relative output prices for the generator of the externality will be lower than is socially optimal due to uninternalized costs, and this price advantage over other firms will result in a higher relative level of production for the externality generation product than is socially optimal [3]. In this particular case, higher rental rates of organic land due to external costs potentially create a barrier to entry for organic firms, resulting in relatively less organic production and relatively more conventional production than is optimal.

Free-Market vs. Socially Optimal Land Allocation As expected, in the free-market outcome, less land is devoted to organic production and more to conventional production than is socially optimal. This standard result is easily demonstrated by comparing the conditions for a social optimum (Equation 2.8) and the free-market condition (Equation 2.14) and invoking monotonicity properties of the utility and production functions.

The standard result that the total externality damage occurring under the social optimum is less than under the free-market outcome also holds. The spatial aspect of these results is revealed through examination of the optimal scale for the alternative land use. It is easily demonstrated that the scale of production for the alternative use is larger under the social optimum than under the free-market situation. This larger scale of production for the alternative use has an important spatial implication. If the alternative use is viewed as a buffer separating the two potentially conflicting land uses, that buffer zone will be larger under the social optimum than under the free-market outcome. This implies that the total externality damage experienced by the organic producer will be smaller, since O's border will be farther from the externality generation point. More significantly, this result implies that in a free-market setting, potentially conflicting uses will be too close together, since the individually optimal buffer for the externality recipient is smaller than the socially optimal buffer. The result rationalizes the existence of buffer zones imposed by regulatory authorities. While an incentive exists for individuals to distance themselves from damaging activities, this incentive will not lead them to leave enough distance between themselves and the harmful land uses.

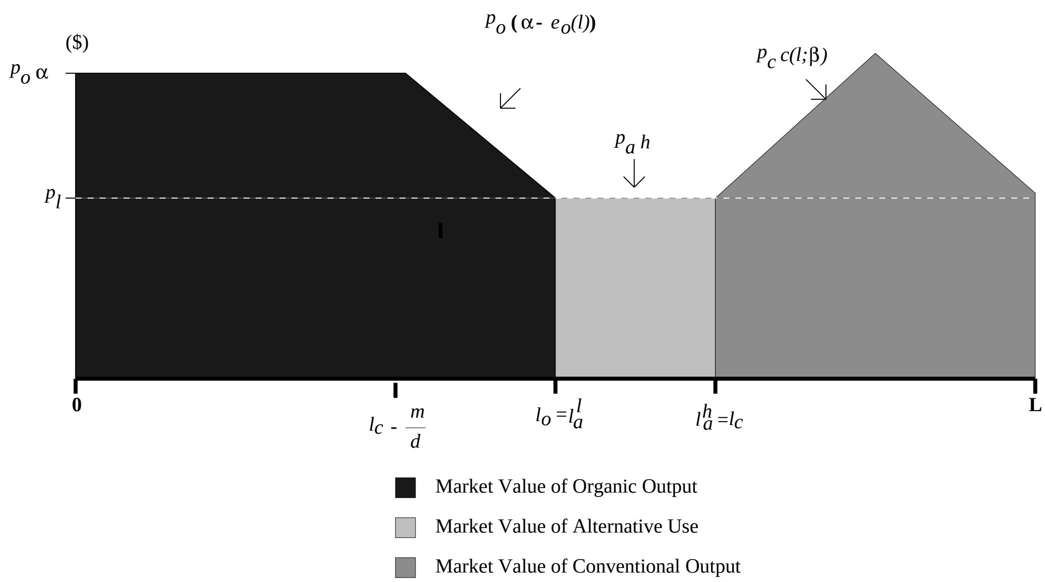


Figure 2.6: The Free Market Condition

The free-market outcome is illustrated in Figure 2.6. A numerical example of the solution to the competitive equilibrium is given in Appendix B.

2.5 Policy Interventions

2.5.1 Optimal Taxation

The social optimum can theoretically be decentralized in a market equilibrium under Pigovian taxes, as long as the marginal tax is distance-dependent. If C faces a tax dependent on the distance between her border and O's border, her profit maximization problem becomes:

$$\max_{l_c} \Pi_c = p_c Y_C(l_c; l_c^h, \beta) - p_l(l - l_c) - t(l_c - l_o) \tag{2.16}$$

The first-order condition for an interior solution is:

$$p_c c(l_c; L, \beta) - t = p_l \tag{2.17}$$

Combining with the first-order conditions from production and consumption, the new free-market condition becomes:

$$\frac{\partial U}{\partial O}(\alpha - e_o) = -\frac{\partial U}{\partial C}\frac{\partial Y_C}{\partial l_c} - t \tag{2.18}$$

If the tax is set such that $t = \frac{\partial U}{\partial O} e_o(l_o)$, the condition for a social optimum is obtained. It should be noted that this approach, while theoretically plausible, would be highly impractical due to information problems. Implementation of the tax would require a scientific understanding of the externality damage function, knowledge of the locations of potentially affected parties, and knowledge of the social values of their production.

2.5.2 Liability Rules

If C is liable for the market value of the damage caused to O by the externality, her profit maximization problem becomes:

$$\max_{l_c} \Pi_c = p_c Y_C(l_c; l_c^h, \beta) - p_l(L - l_c) - p_o \int_{l_c - \frac{m}{d}}^{\bar{l_o}} e_o(l)\, dl \qquad (2.19)$$

Her first-order condition is:

$$-p_c c(l_c; L, \beta) + p_o e_o(\bar{l_o}, l_c) = p_l \qquad (2.20)$$

Since the location of the organic producer's border now enters explicitly into C's choice problem, her solution will now be in terms of an optimal distance from O from O for C. The liability rule has induced an individually optimal buffer distance for C. She will produce only within a range such that her production revenue less the marginal externality compensation is equal to the price of land.

Assuming that the organic producer receives compensation for damages as a lump sum payment, his first-order condition will be unchanged because the payment falls out of the problem. Combining the first-order equations:

$$-p_c c(l_c; L, \beta) + p_o e_o(l_o, l_c) = p_o(\alpha - e_o(l_o))$$

Substituting marginal utilities for prices, and subtracting the value of the externality damage from both sides, the condition for the social optimum (Equation 2.10) is obtained.

The realism of the assumption that the organic producer sees the payment as lump sum deserves some consideration, especially because of the potential proximity and small number of players involved. In fact, the existence of a liability rule probably creates some strategic incentives for the affected party. Anecdotal evidence from cases other than the organic / conventional one suggests such strategic behavior does take place, indicating that the liability rule could create a market distortion that favors the organic grower, assuming complete property rights were in place.

2.5.3 Coase Theorem Results

If O can costlessly negotiate with both A and C, and the conventional producer has the right to pollute, the optimal allocation of land use can theoretically be achieved via Coasean bargaining. First, recall that C's free-market scale will be larger than socially optimal if she has the right to inflict the externality on O. Given that C faces diminishing marginal productivity, this implies a lower marginal product of land at C's extensive margin than under the social optimum. Given that the consumer experiences diminishing marginal utility from consumption of each good, it also implies a lower value for $\frac{\partial U}{\partial C}$ and a higher value for $\frac{\partial U}{\partial O}$.

Recall the condition for a social optimum (Equation 2.10):

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

Under the free-market outcome this will hold as an inequality, since the right side will be less than before. Further, the market price will equal the marginal utilities for each good in the free market outcome. Substituting from Equations B.10 and B.12:

$$p_o\alpha > -p_c\,\frac{\partial Y_C}{\partial l_c} \tag{2.21}$$

If O can convince C to occupy one less unit of land, and, at the same time, buy out A so as to increase his extensive margin, he will gain the value of one unit of production in the constant returns to scale range. The intuition is the same as in the above discussion of the condition for the social optimum – by getting C to take one step back, he shifts the intercept point where the externality impact is zero and gains a unit of production in the externality-free range. He will be willing to pay up to $p_o\alpha - p_l$, the net revenue in this range, to gain this additional production.

By using one less unit of land, C simply loses the net revenue from production on that last unit, or $p_c\frac{\partial Y_C}{\partial l_c} - p_l$. Subtracting p_l from both sides of 2.21, it is clear gains from trade are possible:

$$\underbrace{p_o\alpha - p_l}_{WTP_o} > \underbrace{-p_c\frac{\partial Y_C}{\partial l_c} - p_l}_{WTA_c}$$

Gains from trade will be exhausted when $p_o\alpha - p_l = -p_c\frac{\partial Y_C}{\partial l_c} - p_l$. This will define an optimal scale and border location for C. Substituting marginal utilities for prices and adding land prices, this condition becomes:

$$\frac{\partial U}{\partial O}(\alpha) = -\frac{\partial U}{\partial C}\frac{\partial Y_C}{\partial l_c} \tag{2.22}$$

exactly the condition for a social optimum from Equation (2.10). Thus, bargaining between the parties over land usage can theoretically achieve the social optimum. In effect, O will pay C to shift back the location of her border, or equivalently, to leave a buffer between her production edge and C's border. However, note that even in this simple example, bargaining is somewhat complex due to the spatial separation between the organic and conventional farmer. Externalities with far-reaching impacts are in fact quite common, so it is reasonable to expect that an impacted party may have to negotiate with a distant neighbor. Further, in the real world, a land user may be impacted by spillovers from neighbors on many sides. The actual bargaining problem faced by landowners, then, may quickly become so complex that bargaining may not be a viable option.

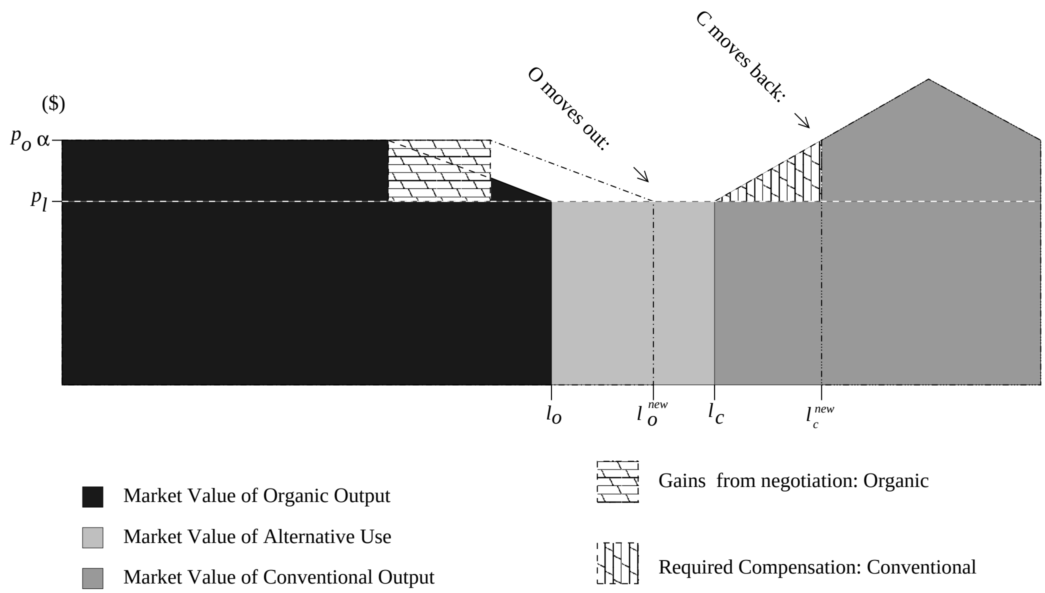


Figure 2.7: Coasean Bargaining

Gains from trade and the Coasean solution are illustrated in Figure 2.7.[7]

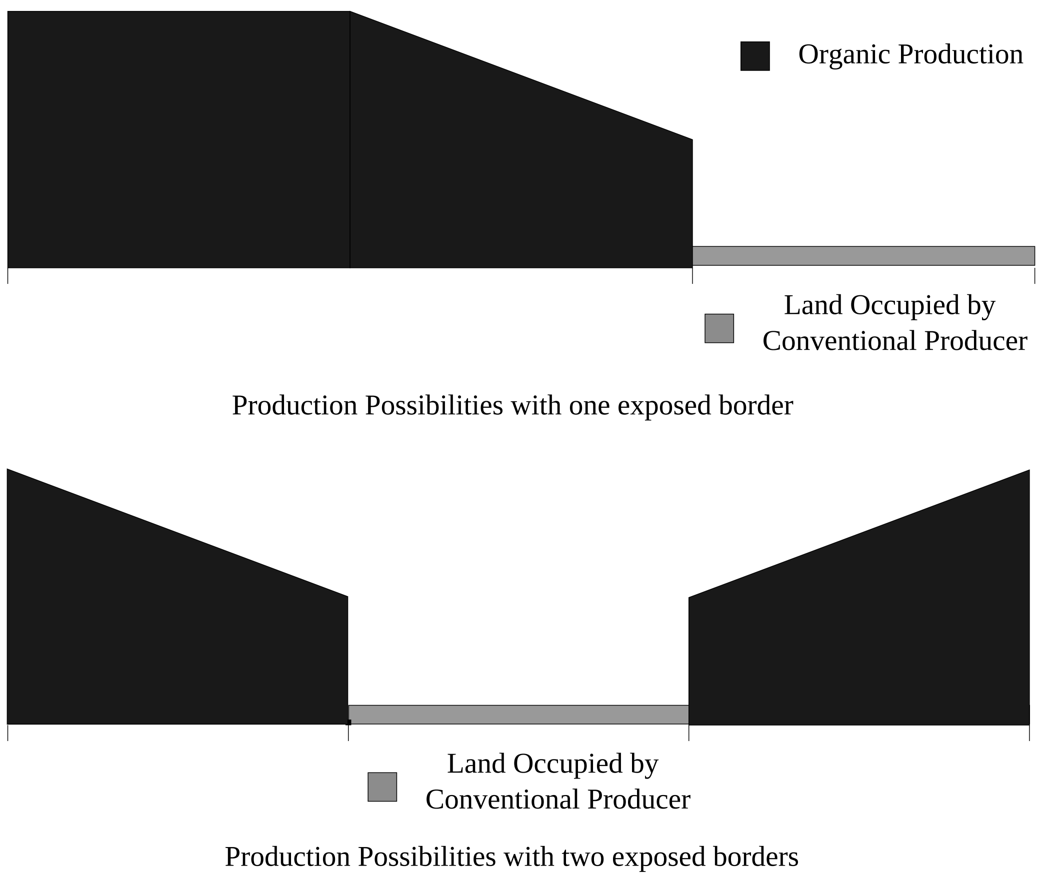


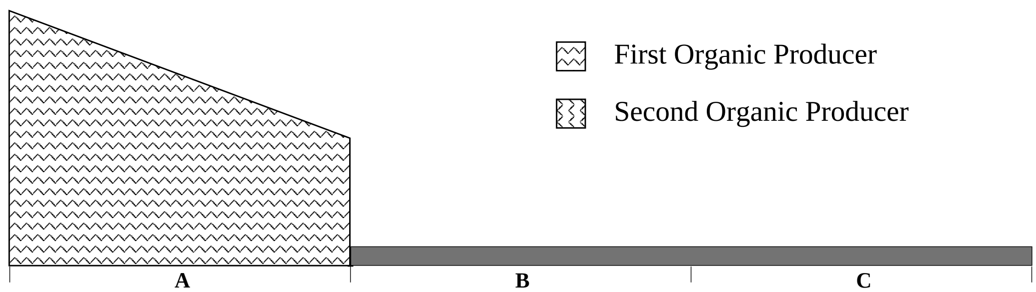
Figure 2.8: Production Loss from Vulnerable Edges

2.6 Landscape Fragmentation

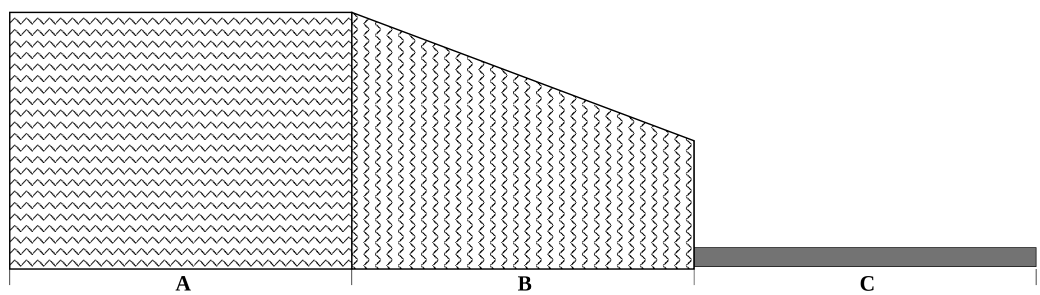
Since the average externality damage to O declines as the amount of land occupied by O increases, it is advantageous for O to occupy one contiguous parcel. By doing this, he minimizes the amount of border exposed to externality damages, or, in other words, he minimizes vulnerable edges. Figure 2.8 illustrates the production loss from farming non-contiguous parcels.

Imagine a case where there are two organic producers and one conventional producer active in the economy. It is 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 producers 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 2.9 illustrates this phenomenon. Imagine that two organic producers choose locations in a conventional landscape. 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.

[7] In this picture, the buffer, or amount of land occupied by A, remains constant. This is because the quantity impacts on market prices were ignored. As quantities change, relative prices will change due to the assumption of diminishing marginal utility.



The first organic producer would prefer the second to locate next to him:



But the payoffs for the second are the same at either location:

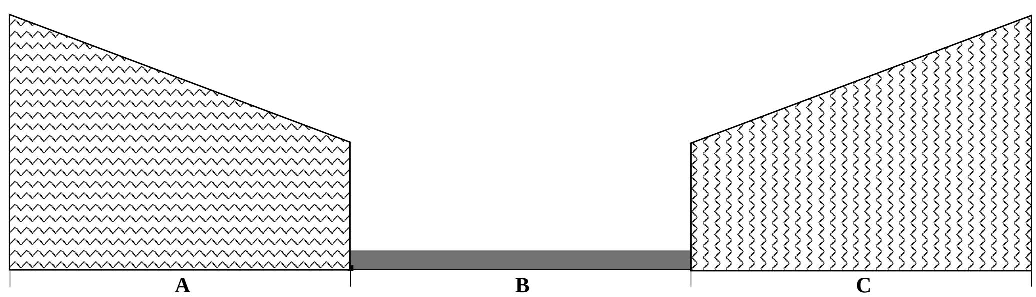


Figure 2.9: Multiple Recipients

The short lesson here is that Coasean 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.

2.7 Conclusions and Future Work

2.7.1 Conclusions

Standard Results in a Spatial Context This chapter has demonstrated the explicit spatial manifestation of results common to all standard externality models. The failure of the free market to equate marginal net social benefits of the impacted and generating use is reflected through deviations between private and social shadow values of land. Specifically, in the socially optimal outcome, the shadow value of an additional unit of land for the externality recipient and generating uses is equated, with the value of moving the generator's border farther from the recipient and therefore providing an additional unit of externality-free production land balanced against the marginal loss of a unit of the generator's production. However, in the free-market outcome, the equality of marginal private values implies that the value of avoiding externality damage on land free of the externality is fully incorporated in the land rent paid by the externality recipient, resulting in too little organic and too much conventional production. The standard result that the socially optimal level of output for the generating use is less than under the free market has implications for equilibrium distances between land uses. In a spatial context, the relatively smaller level of output for the generating use implies less land in the generating use and more land in the recipient and alternative uses. This implies a larger buffer zone between the externality generator and recipient than occurs in the free market. Because the recipient's border is then farther from the generator's border, it also implies that less externality damage occurs.

Finally, traditional policy interventions operate effectively as long as they explicitly account for space. A fixed marginal tax dependent on the externality generator's distance from the recipient's border, if correctly set, operates effectively as a corrective Pigovian tax. A liability rule succeeds by creating an incentive for the generator to distance himself from the recipient. Under Coasean bargaining, the recipient compensates the generator for moving production farther from the recipient's production border, or alternatively, for leaving a buffer between the two uses. Due to the complexities of spatial heterogeneity, strategic incentives, and multiple neighbor interactions, however, the practicality of these traditional policies is questionable.

Policy Implications Each one-dimensional implication outlined in this chapter leads to a corresponding policy question. The chapter has demonstrated that the market disadvantage experienced by externality recipients is manifested in terms of higher land rental rates for externality-impacted land uses. This leads to the question of whether a land taxation structure in which tax rates for externality-impacted land are relatively lower than for the generating use could successfully mitigate externalities.[8] It has been demonstrated that the externality creates a distancing incentive for the recipient that could be viewed as an individually optimal buffer zone. This incentive should theoretically encourage impacted land users to group together, encouraging the development of an economic landscape that maximizes production possibilities through geographic concentration of impacted land users. However, the chapter has also demonstrated that possible barriers to the development of efficient patterns are present. First, this individually optimal buffer zone provides less separation between conflicting uses than is socially optimal, implying that the free market may leave conflicting uses too close together. This result rationalizes one of the most commonly used mechanisms in land-use regulation, the imposition of buffer zones for externality-generating uses. However, the question of whether these mandatory buffer zones will encourage the development of economically optimal production patterns remains. Second, the chapter has demonstrated that production possibility impacts due to edge-effect externalities lead to the potential for positive externalities between externality recipients due to spatial economies of scale in production.[9] This result implies that the benefits of agglomeration will not be fully reflected in land prices, potentially resulting in inefficient and fragmented patterns of land use. The result rationalizes the existence of zoning laws and also suggests that institutional arrangements between neighboring land users may serve to address not only the potential

[8] Policies that provide for lower taxes for land committed to an agricultural use, such as California's Williamson Act, are examples of such a tax structure.

[9] These potential positive externalities are probably most relevant in cases where the optimal firm size is small, such as the case of small farms growing specialty crops, residential housing units, or small retail firms. Otherwise, the creation of one large firm would be a possible response to these increasing returns to spatial scale.

for negative spillovers between neighbors, but also to assure that potential positive externalities are realized.[10]

2.7.2 Expanding the Model

Scale-Dependent Externalities Many examples of edge-effect externalities exhibit scale dependence. In these cases, the externality damage at each point in space and the spatial extent of the externality increases as the amount of contiguous land occupied by the externality generator increases. An important example of a scale-dependent spatial externality in the news of late is the case of livestock feed lots, in particular, hog farms. A couple of important implications are suggested. First, the difference in buffer size between the free-market and socially optimal buffer will be smaller, since a decrease in scale by the generator has magnified impacts in terms of decreasing externality damage. Conversely, increases in scale can be very damaging. An interesting implication is that if externalities are scale dependent, it may be optimal to break up production by the externality-generating land user, in spite of the fact that smaller parcels for the generator may increase land-use fragmentation.

Two-dimensional Impacts A set of global questions related to the landscape impacts of edge-effect externalities remain. Under what initial geographic and economic conditions can efficient production patterns be expected to develop on their own? In cases where the market might not lead to efficient patterns, will policy interventions such as taxes, liability

[10] An example of the type of neighborhood compact that may cause both positive and negative externalities to be internalized is the type of integrated pest management agreement in which all neighbors agree to participate in a particular pest control regime.

rules, zoning laws, and mandatory buffer zones be equally effective at inducing both the correct scale and pattern of economic activity? Will the effectiveness of these measures in terms of their impact on relative prices and output depend on equilibrium patterns of land use? Due to the level of complexity of spatial interdependencies and neighbor interactions in a two-dimensional landscape over a simplified one-dimensional model, a two-dimensional modeling approach is appropriate for addressing these questions. Chapters 3 and 4 lay the groundwork for a two-dimensional model designed to address these policy questions.

Chapter 3

Edge-Effect Externalities and Non-Convexities

Because Chapter 2 focused on the implications of edge-effect externalities for the allocation of land to and for the distance between potentially conflicting land uses, an intriguing feature of edge-effect externalities – their potential to induce non-convexities – was largely set aside. The link between externalities and potential non-convexities in production possibilities has been recognized for some time [6, 4, 17]. This link has largely been discussed in abstract theoretical terms. Edge-effect externalities offer a concrete, accessible, and policy relevant example of these potential non-convexities. This chapter outlines the potential production impacts of non-convexities under edge-effect externalities. Chapter 4 illustrates possible impacts that non-convexities may have on land-use patterns in a free-market setting.

3.1 Non-convexities and Land Use Allocation

The potential for externalities to create a non-convex production possibilities frontier as allocation of land varies between two land uses is outlined by Baumol and Oates [4]. A simple, one-dimensional model demonstrates this possibility in the case of edge-effect externalities.

The hypothetical landscape is illustrated in Figure 3.1. Available land is represented by a square, with no negative production impacts occurring at the edges of the square. The parcel occupied by the recipient is square and originates at the Southeast corner of the landscape. For mathematical simplicity, the externality damage is represented by a fixed loss at the recipient's border. Recipient production is zero within a one unit distance of the generator. This representation is consistent with a mandatory buffer left by the recipient use. The production impacts of a marginally declining production loss would be similar. Finally, the constant marginal productivity of each unit of productive land is normalized to one. Without the externality, this production possibilities frontier would be a straight line due to the assumption of constant returns to scale.

The landscape boundary has length L. The length of the shared boundary occupied by the generator is represented by g. The side of the recipient's plot has length r, and e represents the extent of the externality loss. This leaves the externality recipient with a core production area represented by the darkest shading.

Formally, production for the recipient is:

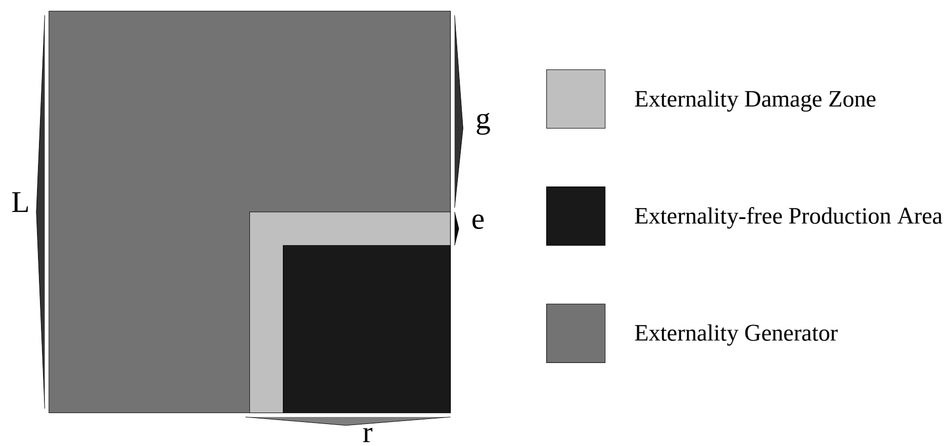


Figure 3.1: Two Dimensional Landscape

$$Y_r = (r - e)^2 \tag{3.1}$$

Note, the recipient's average product is increasing and approaches 1 as $e \to 0$ or as $r \to \infty$:

$$AY_r = \frac{(r - e)^2}{r^2} \tag{3.2}$$

Production for the generator is:

$$Y_g = L^2 - (L - g)^2 \tag{3.3}$$

The land constraint equation is $L = g + r$. By solving equations 3.1 and 3.3 for r and g, respectively, and substituting these values into the land constraint, an equation for the production possibilities frontier can be derived. This frontier represents the tradeoff between output by the externality generating and receiving uses. The equation is:

$$Y_g = L^2 - Y_r - 2e\sqrt{Y_r} - e^2 \tag{3.4}$$

Note that the frontier is now downward sloping and strictly convex:

$$\frac{dY_g}{dY_r} = -(1 - \frac{1}{\sqrt{Y_r}}) < 0 \tag{3.5}$$

$$\frac{d^2Y_g}{dY_r{}^2} = \frac{1}{2Y_r{}^{\frac{3}{2}}} > 0 \tag{3.6}$$

A graph for $L = 12$ and $e = 1$ follows. Conceptually, the graph represents output combinations as the area of the square occupied by r varies from 0 to 144 units.

This demonstration of the potential non-convexity of the production set parallels that found in Baumol and Oates [4], although their demonstration is based on a production externality with constant marginal impacts. What are the practical implications of this theoretical possibility? First, the implications will depend on the empirical likelihood of a non-convexity. Edge effect externalities fall into the class likely to result in non-convexities as reviewed by Burrows [6], since they are characterized by decreasing marginal damages and multiplicative dependence. If non-convexities are empirically important, they may lead to corner solutions, where a landscape is locally dominated by one production process.

Baumol and Oates note that non-convexities can be mitigated by spatial separation of conflicting production processes. In their example, the production advantage driving this

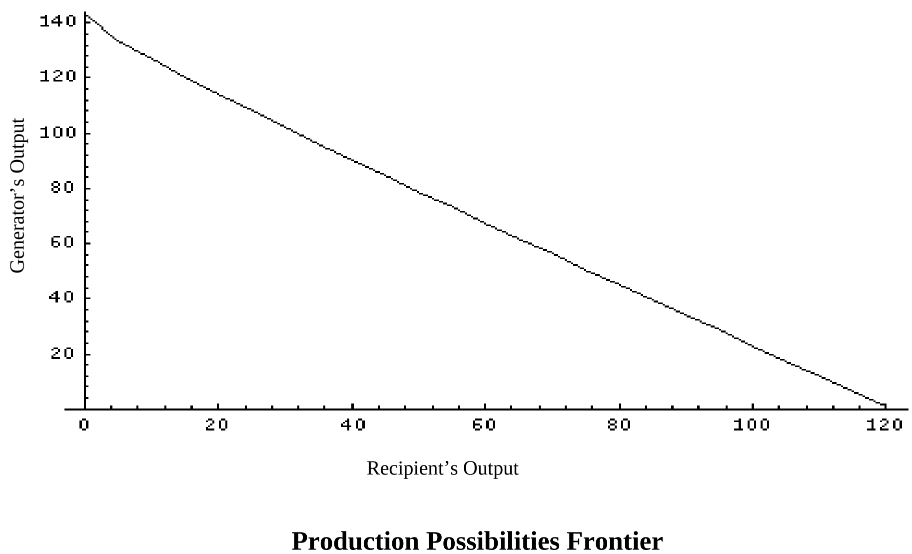


Figure 3.2: Non-convex Production Possibilities Frontier

result is imposed as an assumption and not derived from production and externality relationships. In the case of edge-effect externalities, this separation has a natural interpretation – the land use potentially damaged by the externality is far enough away so that externality impacts are negligible. These results on non-convexities related to the allocation of land between uses can be completely described in the framework of a one-dimensional model, such as that presented in chapter 2. While these results have been recognized in the literature for some time, attention has faded due perhaps to a lack of empirical, policy-relevant examples of the phenomenon.

3.2 Non-convexities and Land-use Arrangement

The above demonstration of the potential for a non-convex production possibilities frontier focuses on varying land allocation between two possible uses. In the case of edge-effect externalities, an additional source of non-convexities is possible. Holding the allocation of land between each use fixed, fragmentation of the economic landscape can result in non-linear declines in production possibilities. This result parallels the impacts of ecological edge effects, where habitat fragmentation can result in non-linear declines in intact interior habitat. These non-convexities have several possible implications. First, a "corner solution" may imply a spatial equilibrium in which a disadvantaged land use is driven out of a particular region. This result may depend on the arrangement of land uses. If several similar land uses are efficiently arranged, they may maintain a viable economic presence in a local landscape. However, if they are geographically dispersed, the activity may not be economically viable and may become locally extinct. This corner solution may be not socially optimal. This naturally suggests the next implication. Not only can non-convexities be mitigated through spatial separation of conflicting land uses, non-convexities can be minimized if land uses are efficiently arranged. These results may have important implications for land-use planning and the design of zoning laws.

A set of simple, stylized examples illustrates the production possibility impacts of land-use fragmentation under edge-effect externalities. These examples are based on the landscape illustrated in Figure 3.1, and use differences in the number of and shape of parcels to illustrate the impacts of land-use fragmentation. The impacts of fragmentation on production possibilities, measured through average productivity, are reported in Table 3.1.

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

Table 3.1: Economic Impacts of Landscape Fragmentation

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 [24]. 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, designed to reflect inequality in area distribution, independent of the number of separate parcels. It is conceptually similar to "eveness" indices found in ecology.[1].

In figure 3.3, 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" 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 that minimizes conflicting 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.

These production losses due to landscape fragmentation are a key, previously unrecognized possible dimension to market failure under edge-effect externalities. The full extent of potential losses are apparent only in a two-dimensional framework. Non-convexities result-

[1] Additional detail on these statistics is provided in Chapter 5

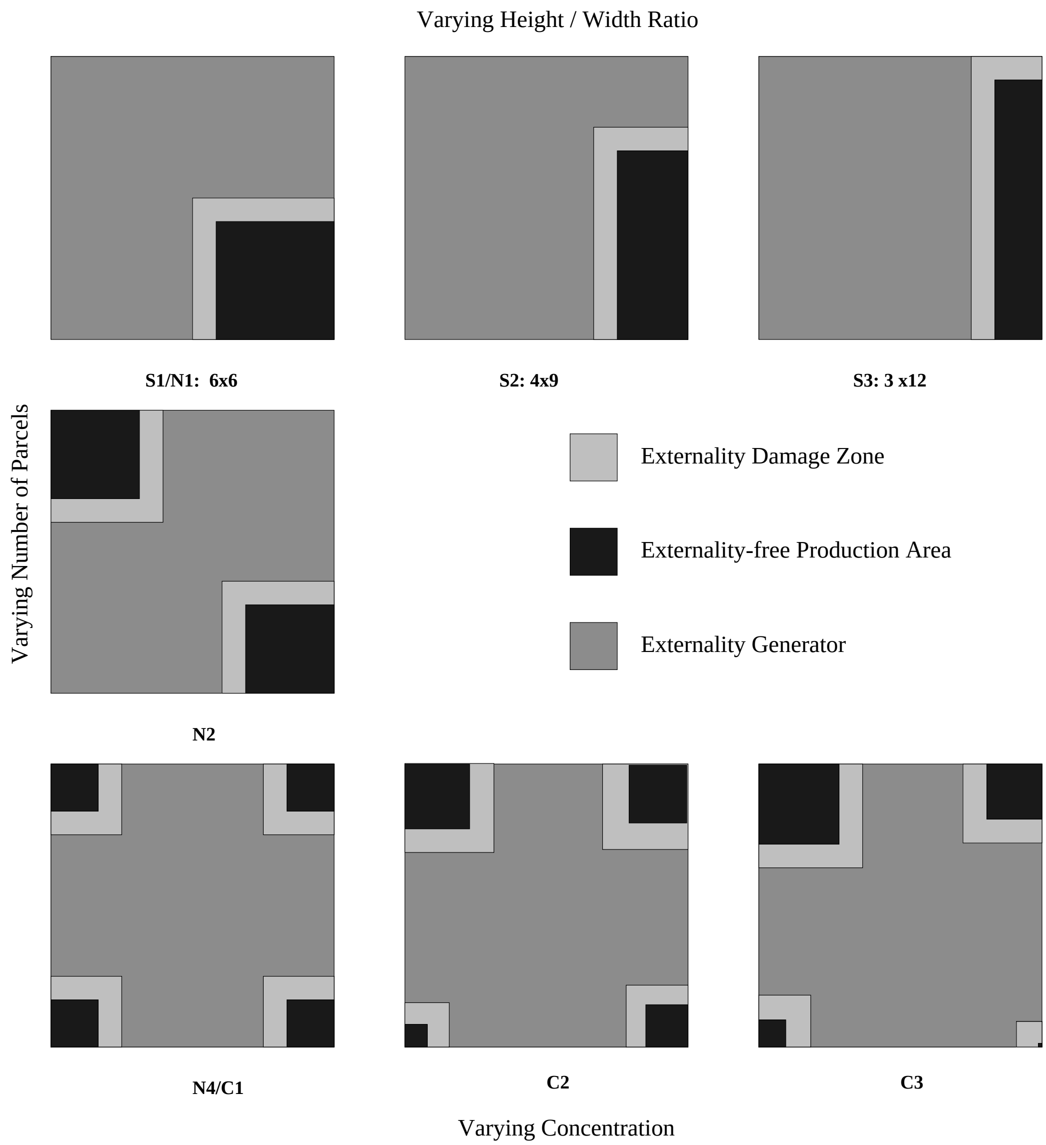


Figure 3.3: Varying Parcel Configurations

ing from externalities have been previously recognized as important due to their potential to lead to corner solutions. In many economic problems, non-convexities have been shown to play an additional important role. They may lead to multiple equilibria in theoretical free-market outcomes, with some equilibria dominating others from a welfare perspective. In the case of edge-effect externalities, the implication is that multiple outcomes in terms of patterns of economic activity may be possible, with some patterns of activity Pareto dominating others. Thus, the free market may not only fail to achieve the correct allocation of land between uses, it may also fail to achieve efficient patterns of production. This possibility is the focus of Chapter 4.

Chapter 4

A Computational Economics Approach to Landscape Outcomes under Edge-Effect Externalities

4.1 Landscape Outcomes

In general, analysis of market failure under externalities has focused on aggregate production outcomes. It has long been recognized that under externalities, too much production from the externality generating use will occur, and an insufficient quantity of the recipient's product will be supplied. [21, 3]. As discussed in Chapters 2 and 3, the relationship between the spatial arrangement of land uses and non-convexities in production possibilities has been recognized for some time. Yet, literature to date on distance dependent spatial externalities has not yet addressed the question of arrangement of land uses in free-market outcomes. Most authors, including Baumol and Oates [4], Kanemoto [18], Tietenberg [34], and Freeman [11] have focused primarily on socially optimal outcomes. Tomasi and Weise [35] and Parker [30] analyze competitive outcomes in the context of a one-dimensional model, but assume efficient spatial agglomeration of generating and recipient uses.

This chapter analyzes free market land use patterns under distance-dependent spatial externalities, using a cellular automaton model where cell occupants chose land use type to maximize profits from production. Profits are potentially influenced by demand and production parameters, types of adjacent neighbors for externality recipients, and distance dependent transportation costs to markets. Several key results are demonstrated:

- Either transportation costs or edge-effect externalities may be sufficient to define a spatial equilibrium of land uses.
- Initial distributions of recipients and generators do not influence the equilibrium configuration of firms under transport costs only.
- Initial conditions will influence the equilibrium spatial configuration under spatial externalities. These initial conditions can include the initial spatial distribution of firms and the existence of protective geographic features.
- Under externalities, competitive equilibrium outcomes may not be Pareto optimal due to initial conditions which lead to inefficient patterns of production. Specifically, equilibrium landscapes may be too fragmented in the sense that more than one cluster of

recipient firms exist. However, individual clusters will tend to evolve to relatively efficient, edge-minimizing shapes.

- Spatial externalities may induce the traditional Von-Thunen landscape to become more fragmented and dispersed than without externalities. Thus, spatial externalities represent an alternative explanation for geographic dispersion of economic activity to that of monopolistic competition. Sufficiently high transportation costs will outweigh incentives created by externalities, and agglomeration will occur. However, the shape of the recipient cluster will be more compact than without externalities, reflecting the profit tradeoff between protected edges and lower transaction costs.

Section 4.2 of this chapter will outline the model's assumptions regarding production technology and will illustrate the negative production impacts of edge-effect externalities. Section 4.3 will outline the economics of landscape evolution, including the supply behavior of each type of producer and the rules governing transitions between types of production. Section 4.4 will demonstrate and analyze equilibrium outcomes under transport costs, edge-effect externalities, and combinations of both influences. Finally, Section 4.5 will offer conclusions and suggest directions for future work.

4.2 Production

Production takes place costlessly on each 1 unit square plot of land. Land is the single input to production. Two land uses are possible in this simple economic landscape, an externality generating use, and an externality recipient use.

4.2.1 Generators

Type "generator" (G) can produce with an average product of γ, normalized to 1 for simplicity. It is assumed that the generator's optimal scale of land use is exactly reached within the bounds of the 1 unit plot of land. Therefore, no agglomeration economies are present for generators, and the amount of production is independent of the types of the generator's neighbors. This story is consistent with an externality-generating land use that operates at a relatively small optimal scale, such as a unit of residential housing, a small farm under a single manager, or a small retail business.

4.2.2 Recipients

The second type, R, can potentially produce with an average product of ρ on each square unit of land. This value is also set to 1. However, type R is potentially impacted by a negative production externality generated by G's production. The externality damage is spatially dependent, with marginal damage decreasing as distance from the generator's border increases. For this particular application, the marginal damage is assumed to decrease linearly and to reach zero within the neighboring cell. This implies that the externality will impact only the plot of land adjacent to the generator.

An illustration in Figure 4.1 clarifies the externality damage function. At the border of G's production site, R experiences a loss of production of magnitude m. This marginal loss declines as distance from the border b increases according to a dispersal parameter d and reaches zero at point $b - \frac{m}{d}$. Total externality damage δ is found by integrating over the range of damage and the length of the border. For this application, parameter values are imposed which result in total loss of production of $1/8$ unit along each border. A cross-section of R's marginal production possibilities along a border with a recipient (no externality damage) and along a border with a generator (impacted by the externality) are illustrated in Figure 4.2.

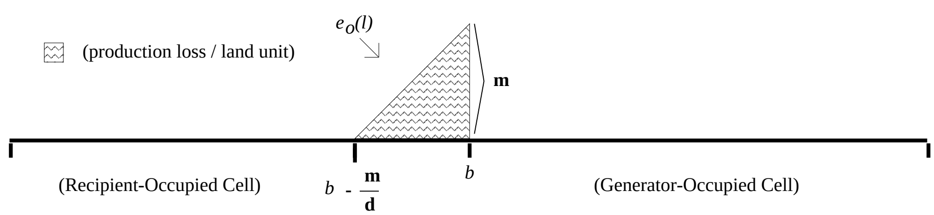


Figure 4.1: The Marginal Externality Damage Function

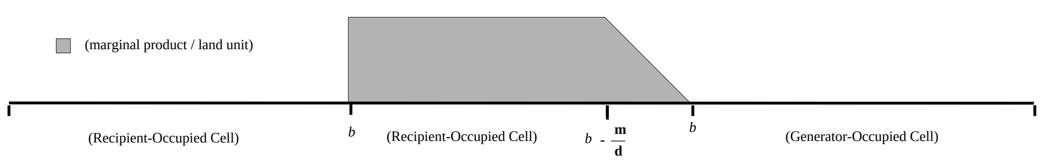


Figure 4.2: Cross-section of R's Production Possibilities

It is clear that total possible production for type R will depend on the number of borders shared with a generator, and that a location sharing no borders with a generator will be most productive. This production impact has implications for the efficiency of any production landscape impacted by edge-effect externalities. In general, a landscape which minimizes borders between recipients and generators, or alternatively, in which recipients are maximally agglomerated, will maximize production possibilities. For any fixed area of recipient production, production possibilities will decrease as the number of production sites increases, the shape of production sites becomes less compact, and the distribution of production between sites becomes less skewed.

4.3 Markets

A very simple structure consistent with the metaphor of conventional and organic agricultural producers is imposed on the model. Markets for the generating good are well developed, and demand and supply are sufficiently high so that each can be considered exogenous. The recipient use, consistent with a local, niche market, faces downward sloping demand and locally determined aggregate supply. These assumptions regarding recipient demand and production provide sufficient convexity to produce an economic equilibrium where both products are produced within the region.

4.3.1 Returns to type G

Type G faces perfectly elastic demand for her product, which can be sold at a constant price of p_g, normalized to 1 for simplicity. Therefore, the profitability of operating as type G in any given cell is simply:

$$\Pi_g = p_g * \gamma = 1 \tag{4.1}$$

4.3.2 Returns to type R

Recipients face a downward sloping, iso-elastic demand curve for their product. The structure of demand is known, and recipients calculate expected price by assuming that one additional firm (their own firm) enters the market. Profitability for producing as type R in any given cell is impacted by the surrounding geography of the cell, since production losses occur when adjacent cells are occupied by types G. Profits are also potentially impacted by transportation costs to market, which are calculated according to the cell's Euclidean distance to the market location and a constant marginal transport cost, tc_r.

Total profits from recipient production in cell located at (i, j) are given by:

$$\Pi_r = p_r \left[\rho - \left(\sum_i G_i * w \right) \right] - tc_r * \sqrt{(i - m_x)^2 + (j - m_y)^2} \tag{4.2}$$

where each G_i represents a neighboring cell in the generating use, and the location of the market is (m_x, m_y). With $\rho = \gamma = 1$, it is clear that unless a recipient is in a location with no neighboring generators, a price premium over p_g will be required to induce a cell occupant to chose type R. This price premium will include compensation for losses due to externality damage and for transportation costs.

For any number of protected borders and transportation cost, there will be a price p_r

which will just induce a cell occupant to covert from generator to recipient status[1]. This price defines the supply price for a recipient with a given geographic location. The price is the solution for p_r to the identity $\Pi_r(p_r; \rho, w, tc_r) = \Pi_g(p_g; \gamma)$.

The total quantity supplied at each price is found by summing production for all recipients willing to supply at that price. It is important to note that this is a *myopic* supply curve. Each producer is in effect making his or her supply decision assuming that all others in the landscape will not change their types. Most important, each producer does not account for the fact that his neighbors may change type in the same round.

All the examples presented in this chapter are based on the recipient demand curve $p_r = \frac{31}{Q_r}$. The equilibrium market price and quantity of recipients is determined by the intersection of supply and demand. This equilibrium for an arbitrary initial landscape configuration with a market in the Northwest corner of the board and transportation costs of 0.01 is illustrated in Figure 4.3.[2]

4.3.3 Rules of the Game

A "move" for any given cell consists of a comparison between profits as type G and profits as type R, given the market price p_r calculated above and a choice of whichever type offers highest profits. The model operates over the inner rows of the board only, with the rows of cells along the outer edges representing permanent geographic features. An al-

[1] In the model, if profits from both uses are equal, the cell occupant chooses recipient status.

[2] Border cells, assumed to represent fixed geographic features, are ignored in constructing the equilibrium. Note that in Figure 4.3, the total equilibrium quantity of recipient production is less than the total number of recipient-occupied cells due to production losses from externality damage.

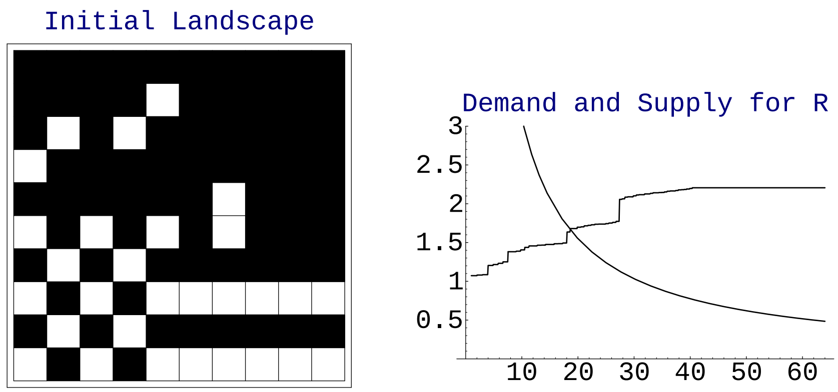


Figure 4.3: Sample Landscape and Supply Curve

ternative, often used in cellular automaton models, would be to wrap the edges of the game board to create an edgeless landscape. The choice to impose hard edges is most appropriate for this application. The primary reason is that under edge-effect externalities, location next to permanent geographic features which provide externality protection for recipients is a common phenomenon. Organic growers, for example, often tend to cluster next to geographic features which provide protection from pesticide drift, such as streams and hillsides. Permanent sound-proof walls are also often constructed as buffers between freeways and residential areas. Since permanent geographic edges are important in the real world, it is important to include them in the model.

The myopic supply behavior described above leads to the possibility of economically implausible oscillation of land uses. For example, a naive recipient may have two generator neighbors and thus decide to switch to generator status. However, if each of those generator neighbors has several recipient neighbors, they will each switch to recipient status. In order to avoid this type of oscillation, in each round, every other cell is allowed to choice type according to a checkerboard pattern. For example, in the first round, cells [(2,3), (2,5), (2,7) ... (3,2), (3,4), (3,6) ...] move, and in the second round cells [(2,2), (2,4), (2,6) ... (3,3), (3,5), (3,7) ...] move. Alternatives would have been to let cells move sequentially according to some random process, or to implement a “Poisson alarm clock” which ensured that each cells moved at a certain rate on average. The disadvantage of these strategies is the amount of noise introduced into the outcomes. Since outcomes are highly path dependent, final outcomes would be highly dependent on random sequencing of moves, and the impacts of initial conditions on final outcomes would have been very difficult to distinguish. Given the current sequencing rules, outcomes are influenced by the sequencing process, but the influence of the sequencing process is consistent for each outcome.[3]

4.4 Spatial Equilibria

If neither transportation costs or spatial externalities are present, no unique spatial equilibrium exists. Given an iso-elastic demand curve $p_r = \frac{31}{Q_r}$, a landscape with 64 cells available for production, and a price of \$ 1 per unit for type G, the total demand for R’s product will be 31 units. Any spatial configuration which assigns 31 units to R’s production and the remaining 33 units to G’s production would result in a stable equilibrium.

[3] The Mathematica code which generated the results reported in this chapter is available from the author on request.

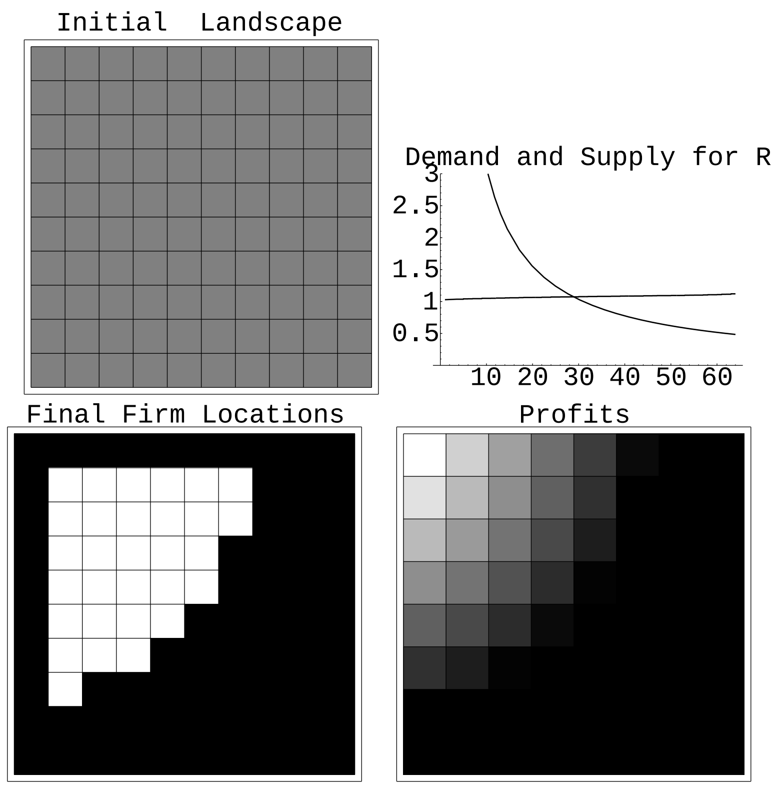
4.4.1 The Von Thunen Model

As in the traditional Von Thunen model of the rent gradient of land surrounding a city, transport costs alone are sufficient to induce a unique equilibrium. Two examples of the Von Thunen outcome are presented. In this examples, no externality damage occurs. In Figures 4.4 and 4.5, recipient producers are arrayed in concentric circles surrounding the the market located in the Northwest corner of the landscape, with the most profitable locations closet to market. Generators, not impacted by transport costs, occupy the residual hinterlands. As transport costs increase, the number of recipient producers and total surplus in the economy decreases.

In each of these examples, the initial landscape edges contain all generating firms and no protective features. In fact, any initial landscape would lead to the same patterns of production seen here under transport costs only, since the spatial equilibrium under transport costs depends only on the location of the market and the degree of transportation costs.

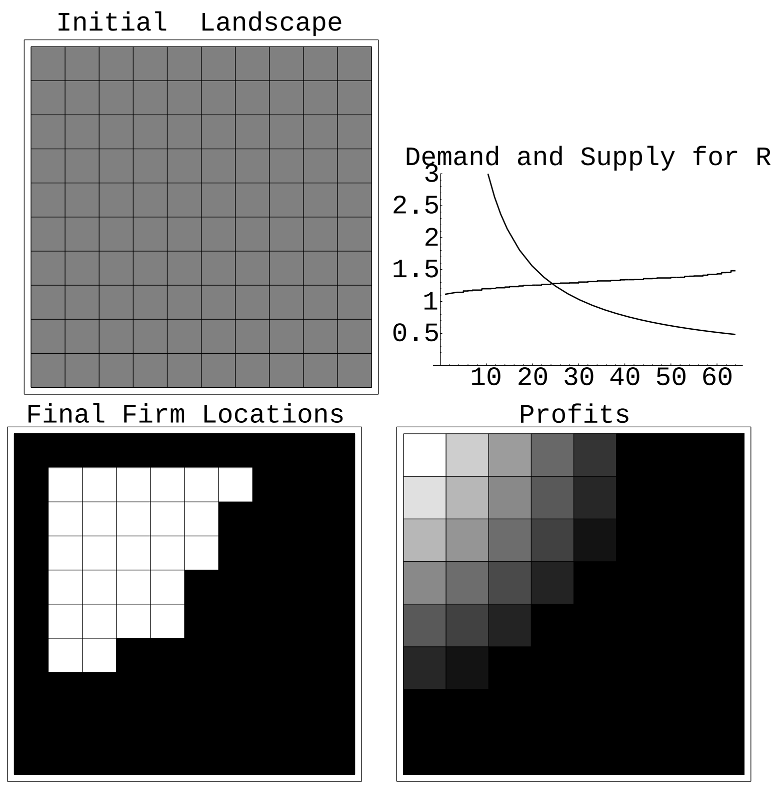
4.4.2 Externality-induced Equilibria

In the absence of transport costs, edge-effect externalities are often sufficient to define a unique spatial equilibrium. This equilibrium will be influenced by initial conditions and may or may not be efficient. Both the initial distribution of recipients and generators and initial geography, expressed by the fixed cells of the landscape's border, will influence the equilibrium outcome.



Equilibrium Results	
Transportation costs:	0.01
Total Recipient Production:	30.
Total Generator Production:	34.
Total Producer Surplus for R:	30.5439
Total Consumer Surplus:	499.175
Total Surplus:	563.719

Figure 4.4: A Northwest market with low transport costs and no externalities



Equilibrium Results	
Transportation costs:	0.04
Total Recipient Production:	26.
Total Generator Production:	38.
Total Producer Surplus for R:	27.9526
Total Consumer Surplus:	494.302
Total Surplus:	560.255

Figure 4.5: A Northwest market with higher transport costs and no externalities

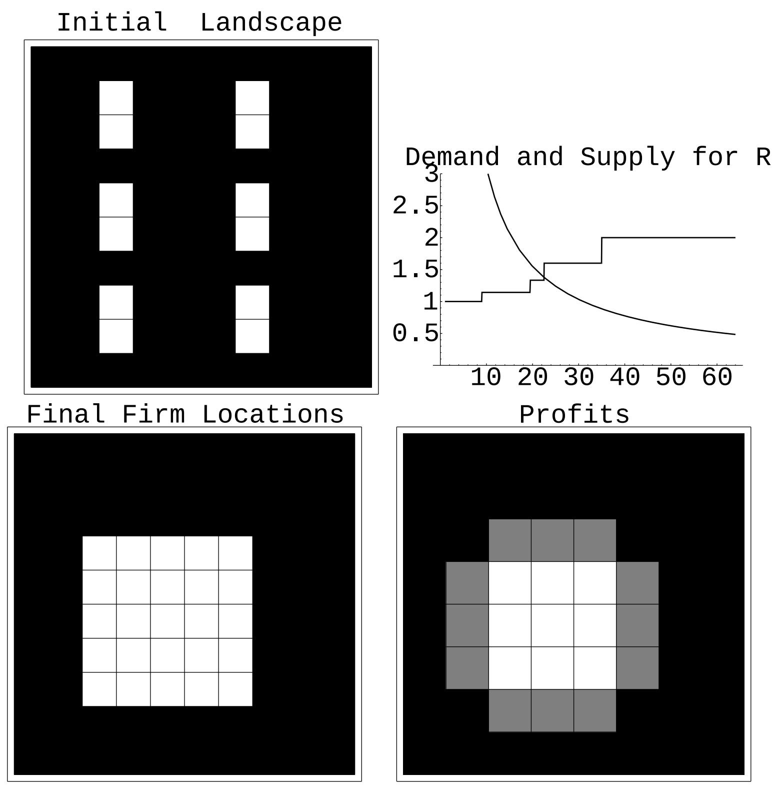
Initial Distributions

In the absence of any permanent protective borders, the initial configuration of generators and recipients can determine the final equilibrium landscape. Equilibrium landscapes will vary in efficiency. In Figure 4.6, a relatively fragmented initial landscape leads to an efficient outcome, with a single, compact cluster of recipients. This result seems surprising, but can be explained by the small number of recipient producers in the initial landscape. This case is consistent with a market where demand has suddenly shifted up substantially. The initial number of recipients, 12, is much lower than the number the market can now support, 25. With little initial production, prices are initially high, encouraging many generators to convert to recipient status, and resulting in connections between small clusters of recipients.[4] Those producers who are less profitable, given the new connections in the landscape, then leave the recipient market, and the landscape evolves to an efficient pattern.

The second example demonstrates initial distributions of firms which lead to the emergence of an inefficient landscape. In this case, the initial number of recipients (32) is more than can be supported by current demand (30).[5] However, the large initial number of recipients may have contributed to a relatively inflexible landscape, resulting in the two clusters of firms since prices are not high enough to induce firms to pioneer recipient production in new locations.

[4] In this model, no mechanism is in place to cut off the supply of recipients when the demand curve intersects a flat segment of the supply curve. Therefore, supply can overshoot, causing a fall in price and undershoot of supply in the next round.

[5] This number of recipients is larger than in the first outcome due to the inefficient arrangement of production. More recipient firms are required to meet market demand, leaving less land available for production of G's product. This illustrated the essence of market failure with respect to the arrangement of production under edge-effect externalities.



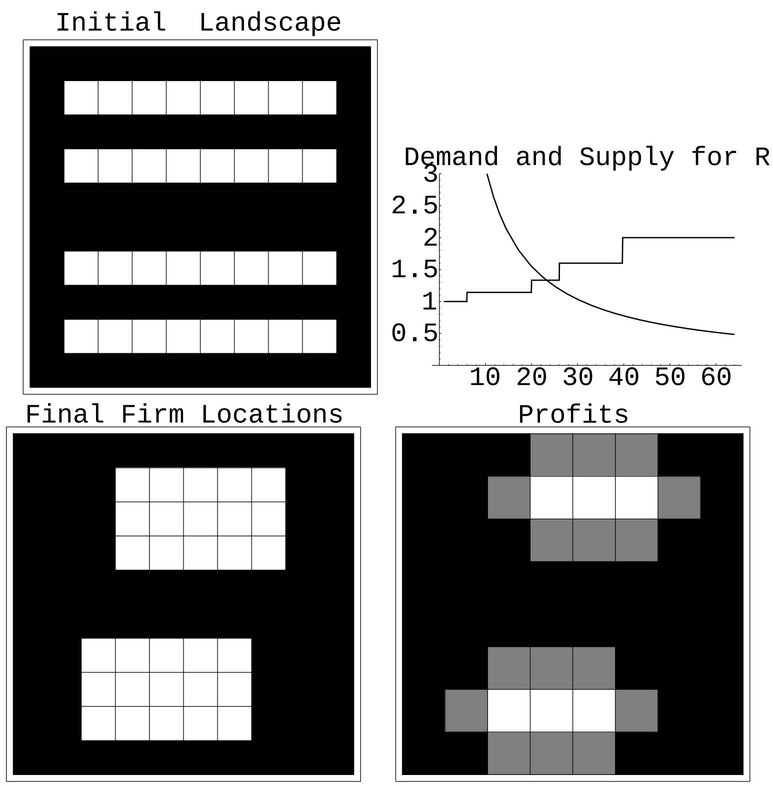
Equilibrium Results	
Transportation costs:	0.
Total Recipient Production:	22.5
Total Generator Production:	39.
Total Producer Surplus for R:	30.
Total Consumer Surplus:	458.338
Total Surplus:	527.338

Figure 4.6: A fragmented landscape under externalities leads to an efficient outcome

The second case clearly demonstrates the potential for emergence of a landscape that is not Pareto optimal under edge-effect externalities. Any move which would cause agglomeration of the two clusters would be Pareto improving. Recipients at the borders where the two clusters connect would gain protected edges and therefore increase their production. Since there are no transport costs and profits depend only on neighbors and not location, recipients who maintain the same number of protected edges would be no worse off. Figure 4.8 demonstrates this Pareto-improving rearrangement. Notice, however, that it would not be profitable for any single recipient to switch to another production site under the initial outcome (Figure 4.7), since market prices are too low to compensate for the loss of protective edges. The important implication is that coalition formation may be necessary to motivate transitions which achieve an efficient landscape.[6]

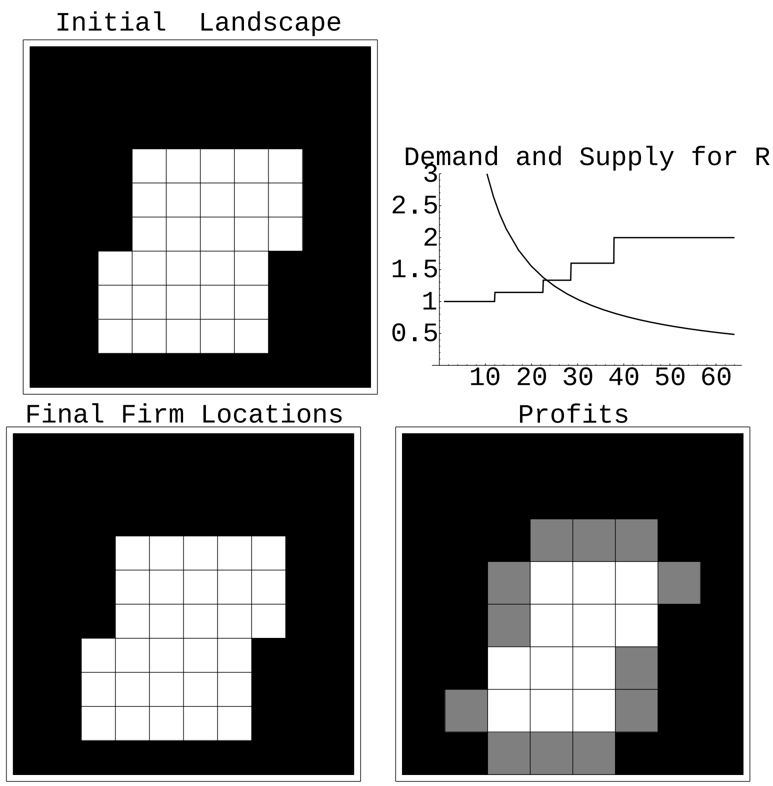
The third example (Figure 4.9) demonstrates the emergence of a highly inefficient landscape. Once again, the initial number of recipient producers (28) is more than the market can support in its final inefficient production landscape of 24 producers producing 19.75 units. The final outcome contains several clusters of recipients, with clear potential for Pareto improvement. Note also that if recipients were more agglomerated, more recipient production would be supported since the supply curve would be flatter. Recall from the previous example that this market could support up to 25 firms with total production of 22.5 if they were efficiently located.

[6] Thanks go to Scott Page for suggesting this example.



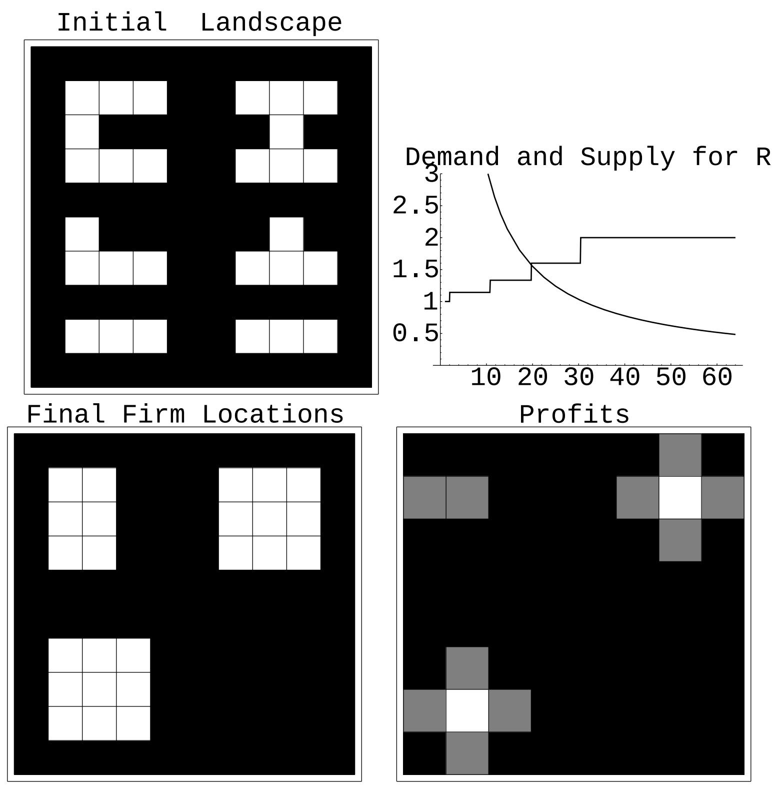
Equilibrium Results	
Transportation costs:	0.
Total Recipient Production:	26.
Total Generator Production:	34.
Total Producer Surplus for R:	34.6667
Total Consumer Surplus:	458.338
Total Surplus:	527.004

Figure 4.7: An inefficient outcome under externalities: the shrinking market



Equilibrium Results	
Transportation costs:	0.
Total Recipient Production:	28.5
Total Generator Production:	34.
Total Producer Surplus for R:	36.
Total Consumer Surplus:	458.338
Total Surplus:	528.338

Figure 4.8: A Pareto-Improving Rearrangement



Equilibrium Results	
Transportation costs:	0.
Total Recipient Production:	19.75
Total Generator Production:	40.
Total Producer Surplus for R:	26.3333
Total Consumer Surplus:	458.338
Total Surplus:	524.671

Figure 4.9: An inefficient outcome under externalities: fragmentation

Geography

Figures 4.10, 4.11, 4.12, and 4.13 demonstrate equilibria determined by the locations of protective geographic features. In Figure 4.10, a unique set of protective edges result in an equilibrium outcome that is efficient. A single agglomerated group of recipients exists, and the shape of the recipient cluster is the most compact possible for this landscape. In comparison, in Figure 4.11, the single protected location leads to agglomeration of recipients, but the shape of the recipient cluster is relatively inefficient, since the height/width ratio deviates from 1. The second outcome has a lower total surplus, in spite of the fact that more protected edges exist in this landscape than in the first. In the third case (Figure 4.12), two potential protected locations encourage development of two disconnected clusters of recipients. Since the shape of these clusters is relatively efficient, the third landscape results in a higher total surplus than the second.[7] The fact that distribution of activity between the two clusters is relatively skewed also contributes to the relative efficiency of this landscape.

However, in the third outcome, a move which agglomerates recipients is Pareto improving. For example, if the cluster in the Southeast quadrant of the board were moved to the Northwest, total surplus would rise. (See Figure 4.13). In this case, four protective geographic borders would be lost, but a total of six protected borders would be gained – three in each recipient cluster. This example demonstrates the importance of positive externalities between recipients. If the Southeast cluster represented a single firm, recipients in the Northwest would have to compensate the Southeast firm to relocate in order for a more ef-

[7] The length of protected edges in the third landscape is the same as the second.

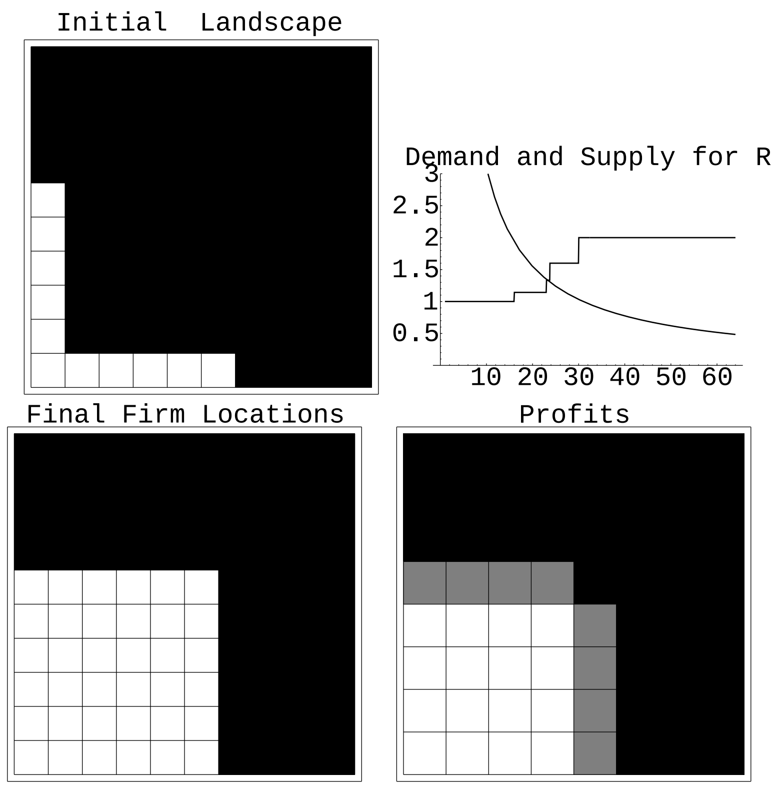
ficient production landscape to be realized.

4.4.3 Transport Cost / Externality Interactions

As demonstrated above in Figures 4.4 and 4.5, under transport costs only, recipient firms will be clustered around the market place. The addition of edge-effect externalities will change the character of the transport cost outcome. Specifically, landscapes with externalities also present may be more dispersed than landscapes without externalities. Further, shapes of recipient clusters will be more compact than the traditional Von Thunen outcome. Finally, equilibrium outcomes may not be Pareto efficient, and an initially welfare-decreasing rearrangement of production may be required to restore the economy to a Pareto-improving path.

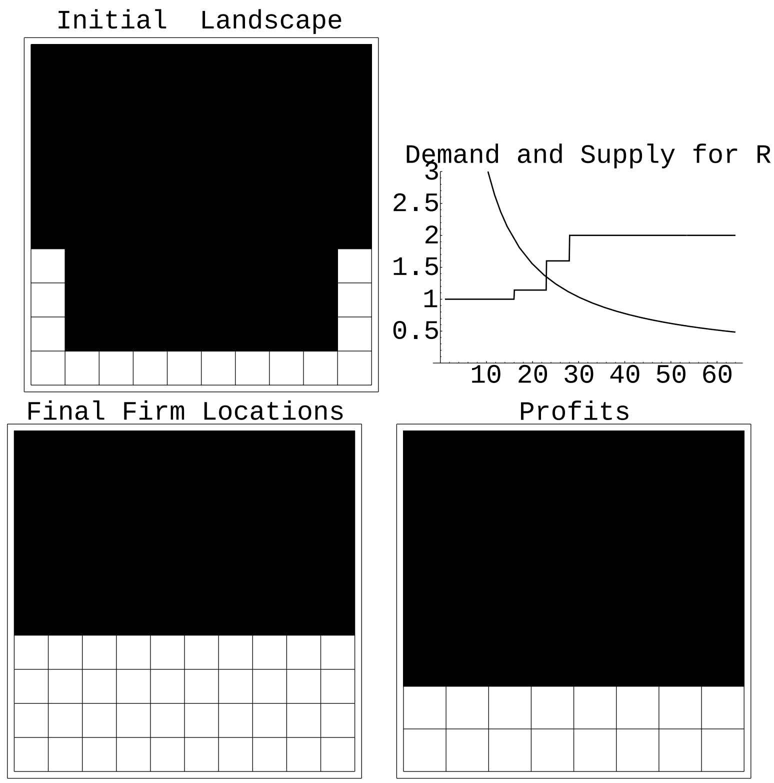
In all the following examples, a market is located in the Northwest corner of the landscape. The first case illustrated (Figure 4.14) introduces weak transportation costs of 0.01 to the landscape analyzed in Figure 4.12. The outcome with these transportation costs and no externalities is illustrated in Figure 4.4. In this case, the introduction of transport costs induces agglomeration of firms into an efficient cluster. However, the shape of the recipient cluster is more compact than under pure transport costs, reflecting the tradeoff between externality protection and transportation costs. Figure 4.15 illustrates the same landscape with higher transport costs of 0.05. Once again, the resulting cluster is more compact than the one illustrated in Figure 4.5.[8]

[8] Transportation costs are slightly higher in this example, but the comparison is still valid.



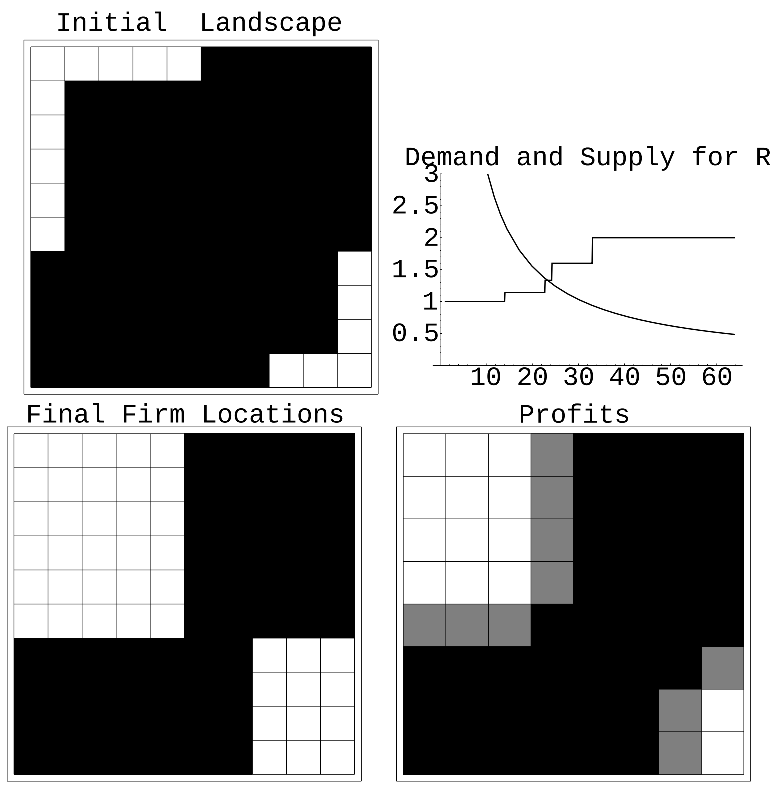
Equilibrium Results	
Transportation costs:	0.
Total Recipient Production:	23.75
Total Generator Production:	39.
Total Producer Surplus for R:	31.6667
Total Consumer Surplus:	458.338
Total Surplus:	529.004

Figure 4.10: An efficient geography under externalities



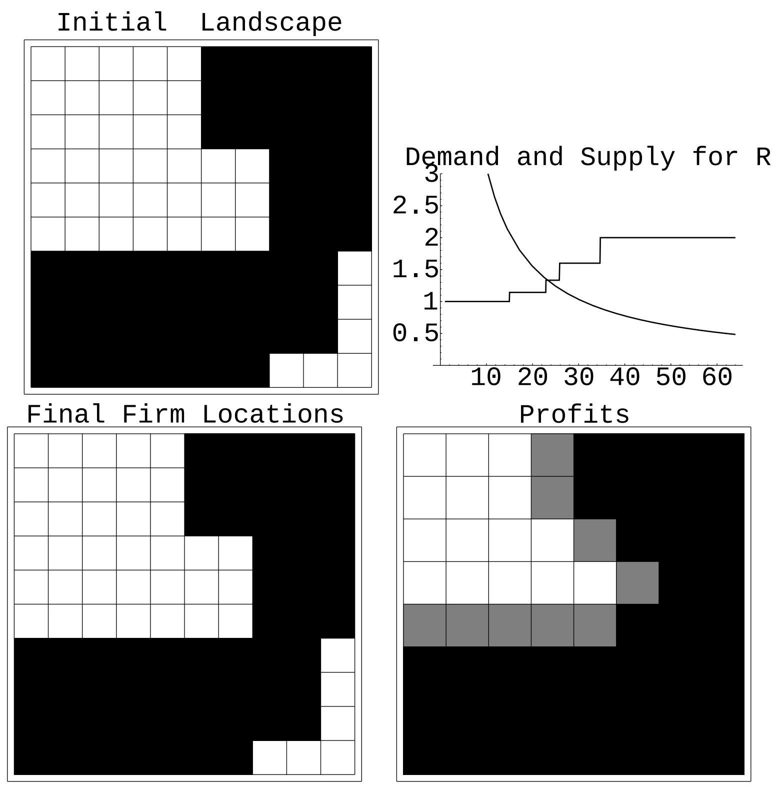
Equilibrium Results	
Transportation costs:	0.
Total Recipient Production:	23.
Total Generator Production:	40.
Total Producer Surplus for R:	26.2857
Total Consumer Surplus:	447.483
Total Surplus:	513.768

Figure 4.11: An inefficient geography under externalities: Agglomeration but no compactness



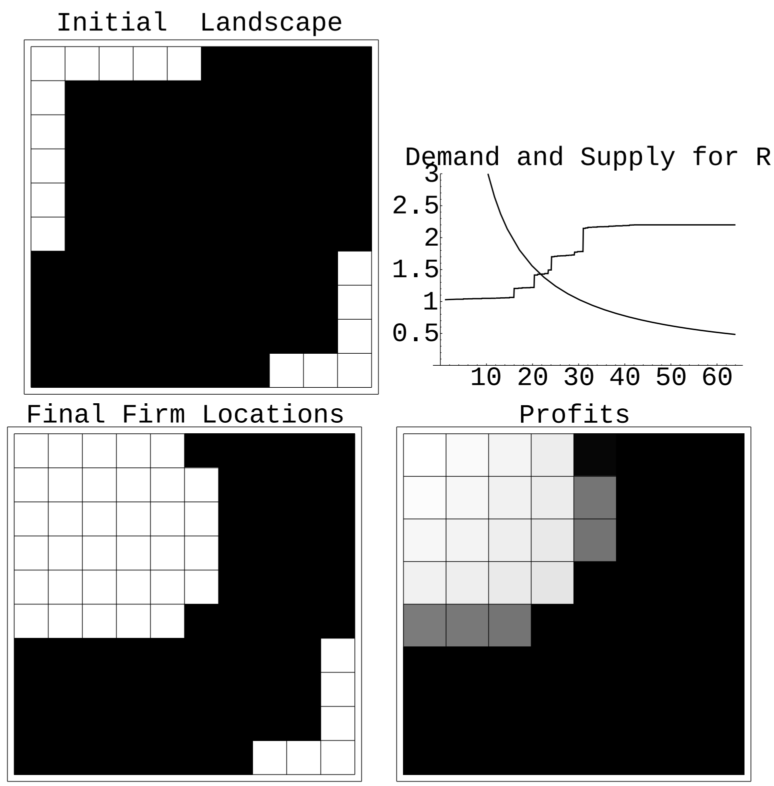
Equilibrium Results	
Transportation costs:	0.
Total Recipient Production:	24.25
Total Generator Production:	38.
Total Producer Surplus for R:	32.3333
Total Consumer Surplus:	458.338
Total Surplus:	528.671

Figure 4.12: Geography induces inefficient fragmentation under externalities



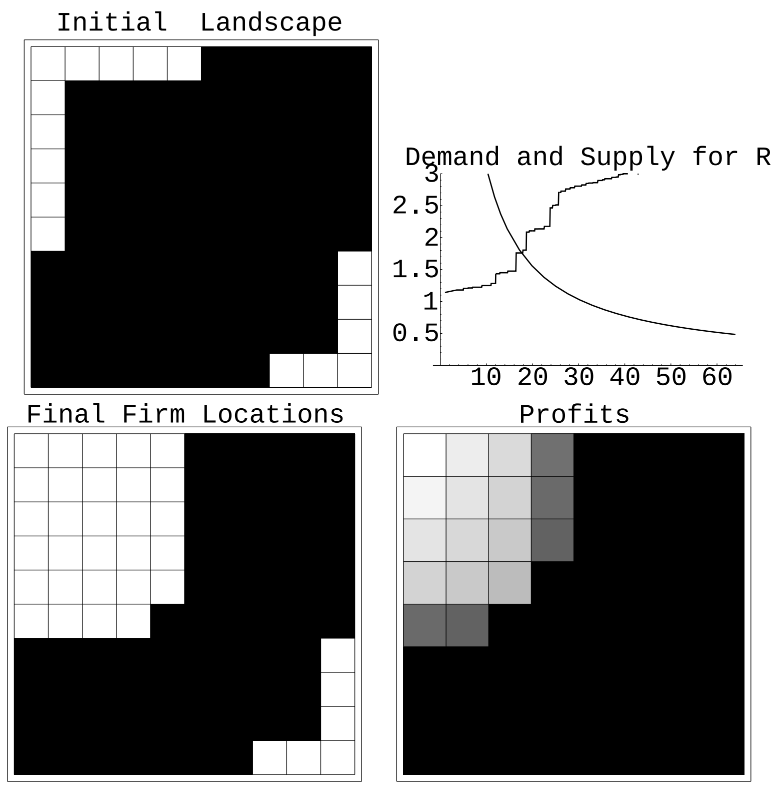
Equilibrium Results	
Transportation costs:	0.
Total Recipient Production:	25.875
Total Generator Production:	38
Total Producer Surplus for R:	32.5
Total Consumer Surplus:	458.338
Total Surplus:	528.838

Figure 4.13: Rearrangement is Pareto-improving: net gain in protected edges



Equilibrium Results	
Transportation costs:	0.01
Total Recipient Production:	21.875
Total Generator Production:	40.
Total Producer Surplus for R:	30.0798
Total Consumer Surplus:	492.596
Total Surplus:	562.676

Figure 4.14: An efficient outcome under externalities: low transport costs



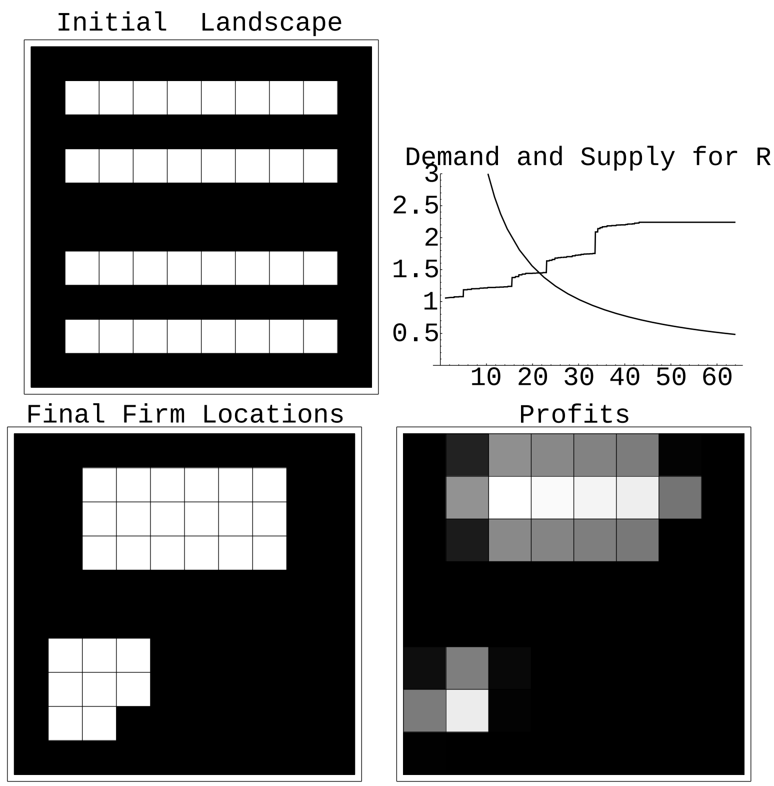
Equilibrium Results	
Transportation costs:	0.05
Total Recipient Production:	17.875
Total Generator Production:	45.
Total Producer Surplus for R:	27.0266
Total Consumer Surplus:	484.912
Total Surplus:	556.938

Figure 4.15: An efficient outcomes under externalities: higher transport costs

Figures 4.16 and 4.17 illustrate the impact of the initial configuration of firms on the Von Thunen outcomes, using the landscape illustrated in Figure 4.7 and increasing transport costs of 0.01 and 0.04. (The pure Von Thunen outcomes for these transport costs are illustrated in Figures 4.4 and 4.5.) In this case, weak transport costs are not sufficient to induce agglomeration of recipients. The equilibrium pattern is clearly not Pareto optimal. The top cluster could shift to the West, resulting in lower transportation costs for all recipients in the cluster. The Southern cluster could also shift North, resulting in lower transport costs for all and additional protected edges for a group of recipients. However, when transport costs are sufficiently high (Figure 4.17), recipients agglomerate into an efficient pattern, one which minimizes transport costs and is relatively compact.

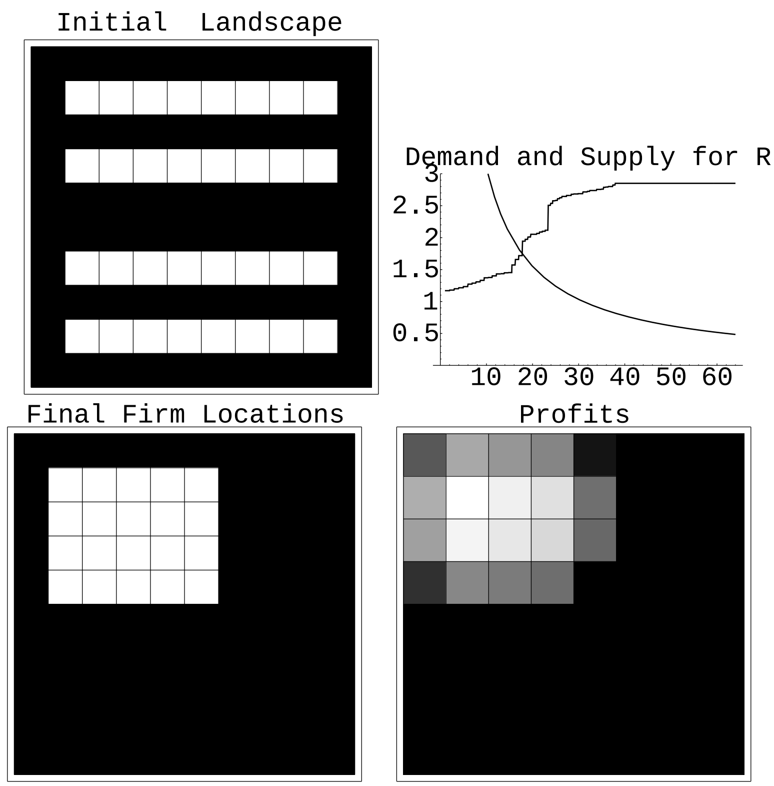
The final example illustrates a landscape influenced by both protective geographic features and the initial distribution of recipients. In Figure 4.18, in spite of a market located in the Northwest corner of the landscape, recipients cluster quite far from the market. The final landscape is not efficient. Figure 4.19 illustrates a welfare improving rearrangement of firms.

As transport costs increase, (Figure 4.20) the single cluster of recipients moves towards the market, but the shape of the cluster remains relatively inefficient. The equilibrium outcome in this case has an interesting feature. An initial rearrangement of firms, by moving the two firms at the Southern edge of the landscape to the Northeast corner of the recipient cluster, does not improve total welfare. The decrease in transportation costs is insufficient to offset the net loss of a protected border. However, if the market is allowed to evolve from



Equilibrium Results	
Transportation costs:	0.01
Total Recipient Production:	22.25
Total Generator Production:	38.
Total Producer Surplus for R:	30.5329
Total Consumer Surplus:	492.194
Total Surplus:	560.727

Figure 4.16: A dispersed landscape under weak transport costs and externalities



Equilibrium Results	
Transportation costs:	0.04
Total Recipient Production:	17.75
Total Generator Production:	44.
Total Producer Surplus for R:	26.5952
Total Consumer Surplus:	486.79
Total Surplus:	557.385

Figure 4.17: Higher transport costs induce efficiency

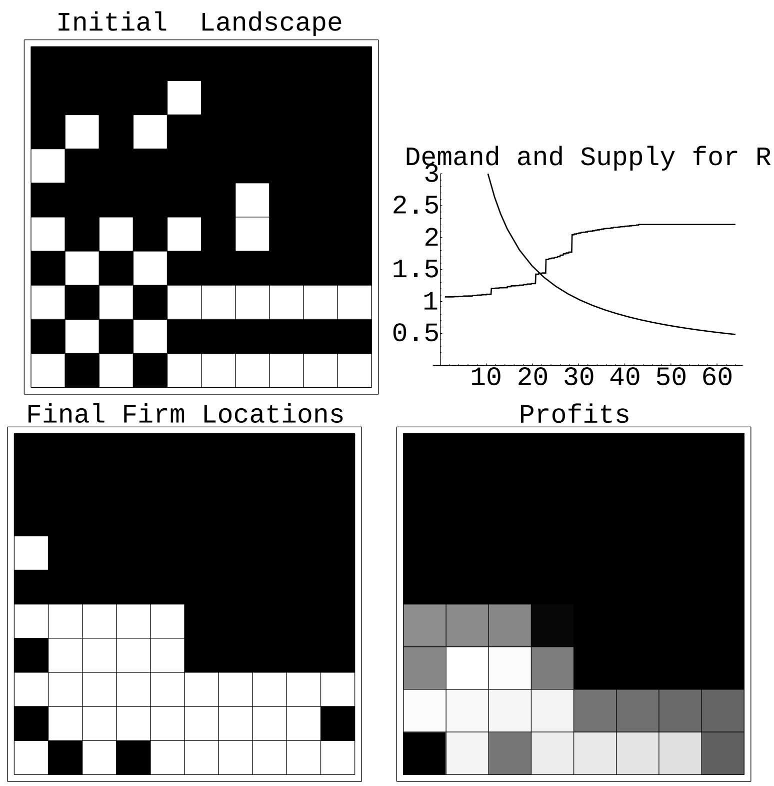
this new, rearranged landscape, the final outcome has higher total welfare than the initial equilibrium. This result is illustrated in Figure 4.21. Still, in the final outcome, all firms are not better off than in the initial outcome. The firm located in cell (7,4), for example has lost a protective edge and is therefore worse off. This example illustrates that side payments or some other form of compensation may be required to achieve an efficient arrangement of firms, due to the potential for positive externalities between recipient firms in this economy.

A general point of these examples is that landscapes impacted by edge-effect externalities tend to be more dispersed than landscapes without these externalities. Thus, edge-effect externalities represent a possible explanation for the emergence of fragmented and dispersed urban landscapes and for the dispersion of economic activity between geographic centers. This explanation for dispersal represents an alternative to that produced by monopolistic competition, which has received much attention in the economic geography literature of late.

4.5 Conclusions and Extensions

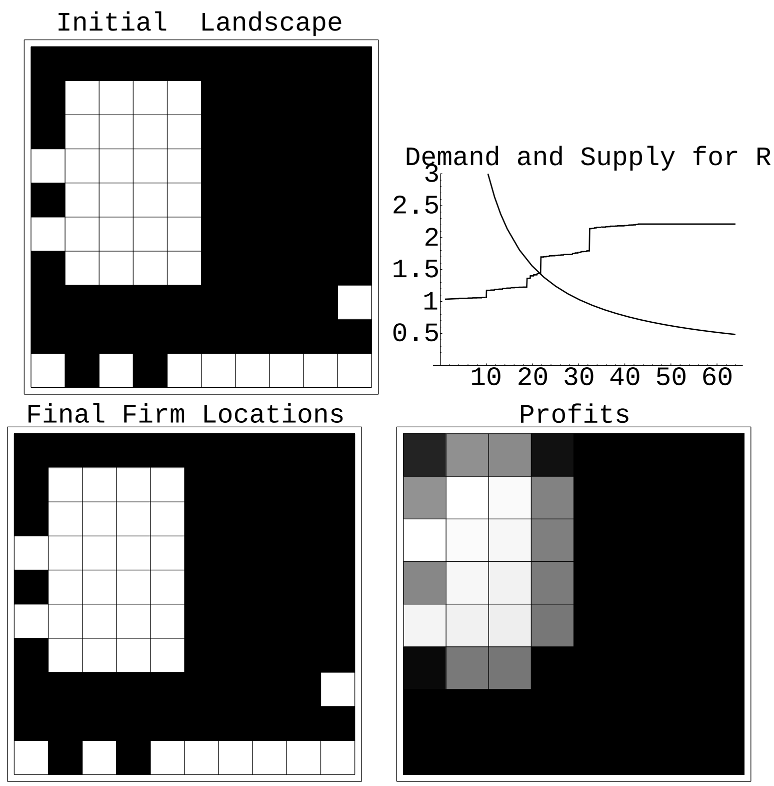
4.5.1 Conclusions

Previous work examining the efficiency impacts of distance dependent spatial externalities has omitted an important dimension: the spatial arrangement of equilibrium land uses. This chapter demonstrates that many equilibrium land use patterns are possible under these "edge-effect externalities". Some of these outcomes will be relatively efficient, but others



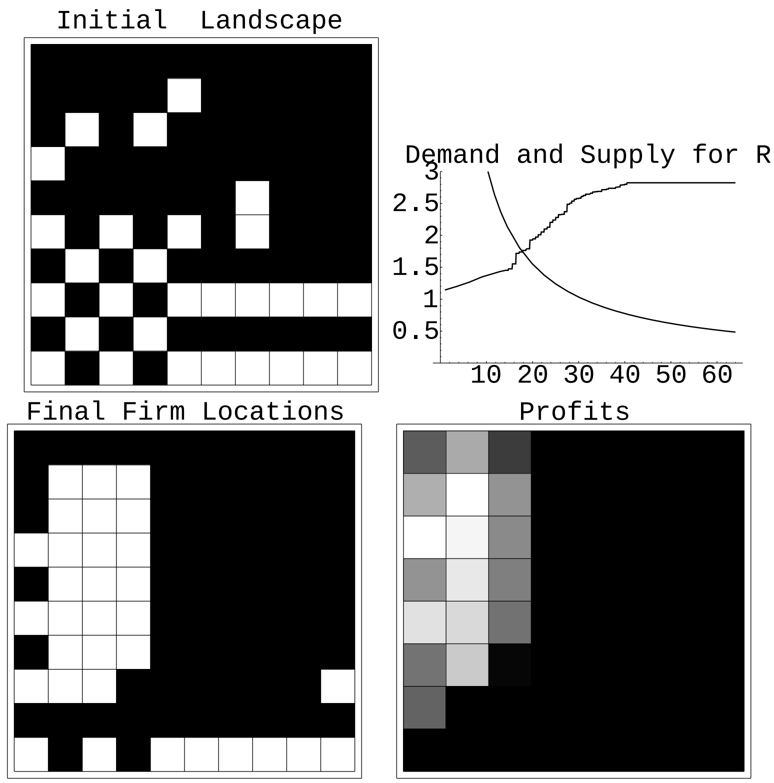
Equilibrium Results	
Transportation costs:	0.01
Total Recipient Production:	22.125
Total Generator Production:	40.
Total Producer Surplus for R:	29.8865
Total Consumer Surplus:	492.162
Total Surplus:	562.048

Figure 4.18: An inefficient outcome under externalities due to the initial distribution



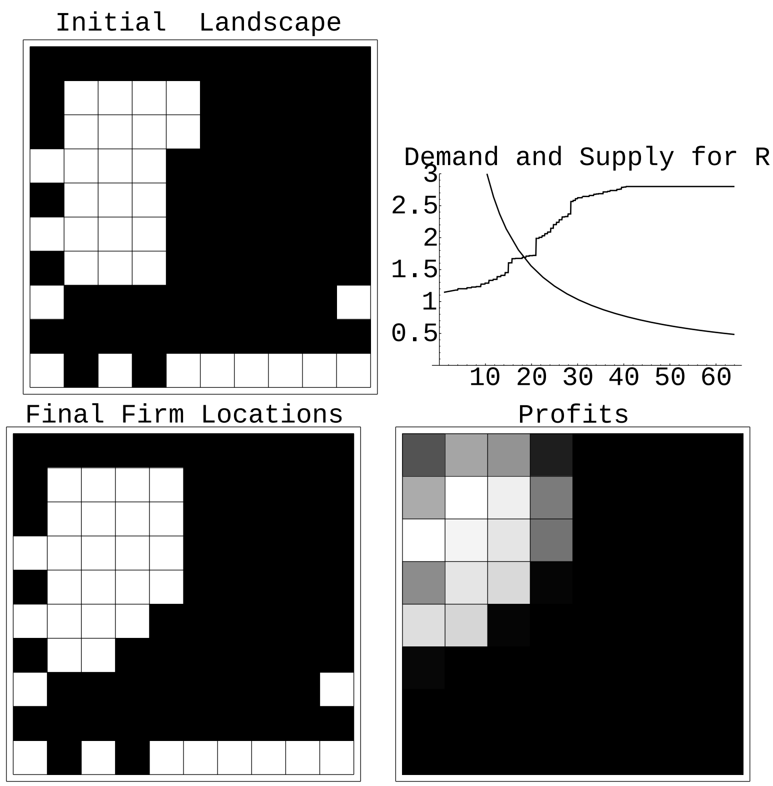
Equilibrium Results	
Transportation costs:	0.01
Total Recipient Production:	21.75
Total Generator Production:	40.
Total Producer Surplus for R:	30.0263
Total Consumer Surplus:	492.479
Total Surplus:	562.505

Figure 4.19: A Pareto-improving rearrangement



Equilibrium Results	
Transportation costs:	0.04
Total Recipient Production:	17.875
Total Generator Production:	44.
Total Producer Surplus for R:	27.0472
Total Consumer Surplus:	486.571
Total Surplus:	557.618

Figure 4.20: Transportation costs induce agglomeration under externalities, but not efficiency



Equilibrium Results	
Transportation costs:	0.04
Total Recipient Production:	18.75
Total Generator Production:	43.
Total Producer Surplus for R:	27.6372
Total Consumer Surplus:	487.442
Total Surplus:	558.08

Figure 4.21: A rearrangement leads to evolution of an efficient landscape

may be highly inefficient. Due to inefficient patterns of production, production by many recipient firms will be required to meet market demand, leaving an insufficiently small amount of land for production of other outputs. In many cases, a rearrangement of land uses which is Pareto-improving is possible. In others, an initially welfare diminishing rearrangement may place the economy on a path which leads to an outcome with higher total welfare. However, there may be winners and losers in this economy, indicating the potential need for side payments or other interventions.

Further, edge-effect externalities can induce equilibrium landscapes which are more dispersed than landscapes without externalities when transportation costs are present. This result sheds light on the emergence of fragmented and sprawling patterns of residential development at the edges of cities. It also demonstrates that spatial externalities can provide incentives similar to those of monopolistic competition for dispersing economic activity.

4.5.2 Agenda for future work

Analytical rigor This chapter demonstrates an important series of possible outcomes under edge-effect externalities, but it does not characterize the conditions under which these possible outcomes will occur. A greater exploration of the impacts of initial conditions, including the number and pattern of recipient firms, the pattern and amount of protective geographic features, and the location of markets and degree of transport costs on final outcomes is called for. Some questions to target:

- Is there a relationship between the efficiency of the initial landscape and the efficiency of the equilibrium landscape?
- Which landscape patterns represent stable economic equilibria? How do production and market parameters impact the stability of landscape patterns?
- Under what conditions can an optimal equilibrium outcome be induced by an initially suboptimal rearrangement of land uses?

Extending the model Three features of the economy outlined in this model encourage land use transitions and the development of a relatively efficient landscape. First, supply is allowed to overshoot demand when market equilibria occur along flat segments of the demand curve. This high price incentive encourages pioneering firms to occupy new locations, encouraging the development of links between recipient clusters. The result, however, is that more recipients often enter the market than can be supported. When price falls in the next round due to oversupply, the recipients in the more efficient locations remain. Second, there are no fixed costs of changing land use type. In the real world, fixed costs of land use transitions are generally present. The introduction of fixed costs would slow down rates of land use transitions, and may substantially impact the efficiency of final outcomes. Finally, the externality damage is assumed to disperse completely in a one cell range, implying that an externality generator only impacts her immediate neighbors. In reality, distance-dependent spatial externalities can either disperse very quickly or travel long distances. If externality damage impacts non-contiguous neighbors, there may be fewer opportunities to form efficient recipient clusters.

Several features of the model, however, imply that landscape transitions may be less flexible than is realistic. First, recipients take others' locations as given, failing to anticipate that their neighbors may also change type, as discussed earlier. An assumption with more realism would be to let each producer choose the type that maximizes profits, given his neighbor's best response to that choice. Under this assumption, producers would be assumed to look as far as their neighbors' neighbors in making their decision. Producers would still be boundedly rational, since they would have knowledge of only their local neighborhood.

Chapter 2 demonstrated that Coasean bargaining can theoretically lead to a Pareto optimal outcome in the case where one recipient and one generator are present in the economy. [32]. The current model does not allow for bargains either between recipients and generators or between recipients. A model that includes the possibility of bargaining may therefore increase the efficiency of final landscape outcomes.

Policy Interventions The current model can be used to examine the impact of common policy mitigations on landscape outcomes. Pigovian taxes are the policy response that has received the most attention in the literature [34, 11, 35]. However, no analysis has been done examining the influence of taxes on equilibrium landscape outcomes. If they do not actually encourage efficient production patterns, then Pigovian taxes will not lead to Pareto optimal outcomes in a competitive economy, contrary to the results of the current literature.

Pigovian taxes under spatial externalities prove extraordinarily complex, as they depend on information on shadow values at differing points in space. Further, spatially heterogeneous taxes are not common in practice. The most common policy responses to edge-effect externalities are zoning rules, mandatory buffer zones, and legal liability for damages. The impacts of these three mechanisms on landscape patterns could be examined in an expanded model.

The Competitive Economy as a Search Mechanism Due to the impact of the spatial arrangement of land uses on production possibilities, the social planner's problem under edge-effect externalities becomes highly non-linear. In a landscape with no geography and no transport costs, an efficient landscape can be found by minimizing borders between recipients and generators per unit area, as demonstrated in Chapter 3. However, the introduction of protective geographic features and transport costs banishes easy analytical solutions. The current free-market model can be viewed as search algorithm which attempts to identify the most efficient pattern of production. Clearly, it is only partially successful, as demonstrated by the many examples in this chapter. If Coasean bargaining or policy mitigations prove to lead to efficient landscapes, a competitive model could also serve as a search algorithm to identify efficient landscapes[9]. This modeling tool could be particularly useful for landscape planners attempting to identify economically optimal habitat configuration under ecological edge effects.

[9] Credit goes to Jeffrey Williams for this insight.

Making the Empirical Link An expanded model can be used to generate a series of refutable hypotheses related to the impacts of production and market parameters, bargaining, Pigovian taxes, buffer zones, liability rules, and zoning laws on equilibrium landscape patterns, with the relative efficiency of final landscape outcomes measured through descriptive landscape statistics. An additional set of hypotheses which relate initial conditions to final outcomes can also be generated. Using Geographic Information Systems technology, the same descriptive landscape statistics can be generated for real-world landscapes, providing empirical tests for the model's hypotheses. This comprehensive approach is taken by White and Engelen [38], who demonstrate using a cellular automaton model and a series of digitized urban landscapes that urban landscape patterns can be represented by fractal models.

Chapter 5

Edge-Effect Externalities and California Certified Organic Farmers

5.1 Introduction

Demand for organic foods has been increasing steadily in recent years, and production of organic crops in California has steadily increased in response. Currently in California, many growers choose to have their production processes certified by an external certification agency. For growers marketing their products to retail outlets, to food processors, and for export markets, certification is critical in order to obtain price premia. The certification process aims to verify that growing practices are in compliance with state organic standards. While certification is currently not required, upon the likely adoption of the National Organic Standards Act, farm products labeled or represented as organic will require external certification [36]. The majority of organic acreage in California is certified organic, and California Certified Organic Farmers is a major organic certifier. In 1994, 80% of the acreage representing 90% of total organic sales were certified. Of the certified acreage, 80% is certified by C.C.O.F. [19].

Certification requires that an organic grower's production site be free from potential contamination by prohibited materials. One of the most probable sources of contamination come from spatial spillovers from surrounding land uses, including drift of prohibited chemicals or possible cross-pollination with genetically modified crops.[1] Therefore, in cases where an inspector determines that contamination is possible from a neighboring use, the organic producer is required to leave a twenty-five foot buffer zone between the edge of his certified production site and the neighboring land use. Thus, C.C.O.F. growers average cost of production is increased when borders are shared with an incompatible land use, since the grower losses potentially productive land to buffer zones.

Organic growers may also incur production losses when located next to conventional production sites due to incompatible production practices.[2] Growers may have difficulties maintaining populations of beneficial insects at borders with conventional farms [14] and managing pest migrations from surrounding conventional farms. Thus, they are potentially impacted by edge-effect externalities which would increase their costs of production even absent a buffer zone requirement.

[1] Growers are required to conduct periodic soil tests, and pesticide sales are carefully monitored and regulated in California, so the probability that an individual grower would use prohibited materiels on his or her own land is low.

[2] Conventional producers may also incur such losses when located next to organic farms.

This chapter tests the hypothesis that these potential negative spatial spillovers from conventional farms impact the locations and patterns of production of certified organic farming operations. A series of landscape statistics which reflect geographic avoidance of costs from maintaining buffer zones are presented. Using cross-sectional data on all agricultural parcels in a two-county region of California's Sacramento Valley, these statistics for both certified organic parcels and comperable non-organic parcels are generated. Comparisions demonstrate statistically significant differences consistent with avoidance of potential buffers zones by certified organic growers.

As demonstrated in Chapter 3, productivity of an organic landscape impacted by edge-effect externalities will decrease non-linearly with landscape fragmentation. Further, conflicting border per unit area is a broad empirical measure of the impact of edge effects. This broad measure varies according to several geographic dimensions, some related to geometry of individual parcels and others related to landscape relationships between parcels. At a landscape level, they include parcel contiguity and the distribution of land area between parcels. At an individual parcel level, these dimensions include parcel size and shape.

The relatively abstract measure of conflicting border per unit area translates into concrete terms in the case of certified organic growers, since the costs of spatial spillovers can be measured through land area in required buffer zones. For certified organic growers, costs due to buffer zones will increase as the proportion of their production land in mandatory buffer zones increases. Therefore, land in buffer zones as a percentage of total land area is a broad empirical measure of the landscape efficiency of organic production sites with respect to avoidance of edge-effect externalities.

This broad empirical measure is sufficient to test the hypothesis that organic parcels differ from non-organic parcels in a manner consistent with avoidance of edge-effect externalities. However, a breakdown of these differences along the possible dimensions of fragmentation in the case of organic farms may reveal policy-relevant information. Is organic production concentrated in relatively few large contiguous parcels, even if many non-contiguous parcels exist? Are organic parcels likely to be located next to other organic parcels? Do organic farmers avoid buffer zone losses by farming larger parcels than non-organic farms, implying that the optimal scale for an organic farm may be larger than for a non-organic farm? Are organic parcels inherently less “edgy” than non-organic parcels?

Measures related to total border per unit area provide an incomplete description of the potential costs related to buffer zones incurred by the organic grower. A parcel with a high border per unit area ratio may not lose any production land to buffer zones if surrounding land uses do not pose a threat to the integrity of organic production. Therefore, a parcel bordering natural areas, another organic farm, or roadways which provide sufficient buffers from neighboring uses may be particularly attractive to organic growers. This possibility raises additional policy-relevant questions related to organic parcels. Is an organic parcel more likely to border a potentially compatible land use? If so, how much do surrounding land uses contribute to lower potential costs from buffer zones on organic parcels?

The Geography of Market Failure Inherent in this analysis of organic landscapes is the question of whether parcel geography reflects both individual and cooperative cost-minimization with respect to buffer zones. On an individual basis, an organic grower has the ability to minimize buffer costs through geographically concentrating farm production, farming parcels with a low ratio of border per unit area, locating next to other non-organic but compatible land uses, and obtaining the cooperation of neighboring conventional farms in avoiding drift. However, the potential for returns to cooperation between organic growers exists as well. When organic growers farm parcels next to those farmed by other organic growers, each grower gains the benefits of a border where no buffer zone is required. Thus, there are potential positive externalities between growers that can only be captured though spatial clustering of organic farms.

The question addressed by this chapter is not simply whether spatial spillovers from conventional to organic farms exist. Due to the imposition and enforcement of mandatory buffer zones, these costs are concrete and documented. Rather, the chapter attempts to answer two interlinked questions related to geographic aspects of market failure. The first question is whether costs related to buffer zones are sufficiently high to motivate spatial mitigation by individual organic growers. This question relates to individual organic growers' response to negative spatial externalities and provides evidence as to whether spatial spillovers from conventional to organic growers are an economically significant policy issue. The second question is whether the potential positive externalities between organic growers, induced by the existence of negative spillovers from conventional to organic growers, have led to the development of an efficient landscape of separate organic farms. The answer to this question may suggest whether external policy interventions related to whole-landscape planning for zones of both organic and conventional production are indicated.

5.2 Spatial Information in Economic Analysis

The use of explicit spatial information in agricultural economics research is a new but quickly developing methodology. This spatial information is often derived using Geographic Information Systems technology (G.I.S.), a computerized system which can both represent and analyze spatial data. For the most part, the goal of recent empirical studies which utilize information on spatial relationships has been to use economic and physical information to predict land use. Often, land use transitions have been the focus. The general approach of these papers has been to generate variables reflecting spatial relationships using geographic information systems software. These variables then serve, along with other relevant information, as explanatory variables in a limited dependent variable model. The goal is to model how each factor contributes to the probability of finding land in a particular use. The degree of disaggregation of land uses and use of spatial information varies with the studies.

Parks [33] estimates regional land use shares for developed, forested, and agricultural lands in Georgia. Spatial information in this model is limited to regional location. Chomitz and Gray [8] estimate an empirical model of land use in Belize based on the Von Thunen hypothesis that land will be devoted to its highest valued use, which will be determined in part by transportation costs. They construct a weighted transport distance variable designed to reflect transportation costs, and find that transport distance significantly impacts the probability of finding land in an agricultural use. Neither of these papers explicitly considers the impact of surrounding land uses on land use probabilities.

Palmquist, Roka, and Vukina [29] explicitly test for the influence of a distance-dependent spatial externality on property values. Using a hedonic model, they estimate the price gradient of residential properties as a function of distance from hog operations, a source of substantial negative externalities. They find statistically significant increases in property values as distance to the hog operations increases. They use the term “localized externality”.

Bockstael et al. [5, 12, 13] have constructed a detailed G.I.S. model of the Patuxent watershed in Maryland which predicts land use probabilities in a two-step process. First, land use values are predicted using a hedonic model which includes variables reflecting spatial relationships. Second, these values are used in a model predicting use conversions which includes information on conversion costs and zoning constraints. Their spatial variables include the proportion of land in a given neighborhood devoted to forest, agriculture, and cropland, the length of conflicting edges between residential and commercial, industrial, or mining uses, and the amount of the surrounding area in open space. Through these spatial variables, their model explicitly tests for the influence of positive and negative spatial externalities on property values. Consistent with expectations, land values increase with the proportion of surrounding open space and pasture, and decrease with the proportion in cropland and the length of conflicting edges. Legget and Bockstael, utilizing the same G.I.S. model, link localized variations in water quality to their negative impacts on residential property values [22].

Bockstael and her colleagues have begun to consider the impacts of landscape pattern on property values and have analyzed the impact of some landscape ecology statistics such as fractal dimension on property values [12, 13]. However, they have not developed explicit theoretical predictions as to the impact of landscape pattern on property values.

This chapter contributes to the developing literature on empirical economic spatial analysis in two important aspects. First, this particular empirical application offers promise for isolating and measuring impacts of negative externalities. In urban and residential settings, any one property is most likely influenced by a high number of surrounding land uses. In the agricultural setting examined in this chapter, given that parcel sizes are large relative to the dispersal radius of potential negative externalities, few surrounding uses potentially impact a particular parcel. Further, estimation of property value impacts requires the use of hedonic techniques. In order for hedonic estimates to correctly reflect the impact of surrounding land uses, all other relevant influences must be controlled for. In this study, externality impacts can be measured directly through examination of buffer zone requirements.

The second significant contribution of this chapter is to provide an explicit theoretical motivation for hypotheses related to the economic impacts of landscape pattern. While the potential for spatial externalities to produce non-convexities has been recognized for some time [4], this chapter is the first to explicitly demonstrate these impacts and to illustrate the possible geometric dimensions of non-linear production loss. Further, this chapter is the first work to measure theoretical impacts related to edge-effects using real-world data. While a comprehensive statistical model designed to predict the probability of finding an agricultural parcel in organic production is not developed here, this work motivates the inclusion of a variety of landscape statistics which reflect potential edge-effect externalities in such a model and therefore lays the groundwork for model development.[3]

5.3 Data and Sampling Methods

Landscape statistics have been computed from a geographic information system constructed for this study. This G.I.S. includes maps of all agricultural parcels for a two-county region in California's Sacramento Valley. Maps of County 1 are from the 1994 cropping season, and maps of County 2 are from 1997. These base layer parcel maps were obtained from California's Department of Water Resources.

Locations and parcel boundaries of organic farms certified by California Certified Organic Farmers were added to the base parcel maps. Certification records containing information on parcel locations, surrounding land uses, and buffer zone requirements were obtained via a research agreement with C.C.O.F.. According to the terms of this agreement, locations and parcel boundaries of individual farms, as well as crop varieties, numbers of C.C.O.F. parcels, and acreage totals by county must remain confidential. Therefore, no maps of the organic landscape or explicit figures on parcel size or crops grown are included in this study.

[3] A preliminary empirical specification for such a model is presented in Appendix C

In instances where organic parcel boundaries did not appear on the base parcel maps, digitized copies of county assessors' maps were used to create parcel boundaries. STATSGO soil maps and related attribute data produced by the Natural Resource Conservation Service were used to determine soil capability class codes. Soil class definitions are available from the Natural Resource Conservation Service [37]. Map coverages from TIGER and California's TEALE data center were also used to pinpoint locations of organic farms via street addresses and section-township-range codes.

The Department of Water Resources base parcel layers report detailed information on crop types, breaking down possible crops into a total of eight primary codes and seventy six secondary codes. County 1 contains 2396 agricultural parcels representing 48 secondary codes and County 2 contains 4308 agricultural parcels representing 61 secondary codes.

A cross-sectional sample of comparison parcels was selected by first identifying soil classes for the organic parcels. A list of unique combinations of soils classes and D.W.R. secondary land use codes for crops grown was then constructed, excluding farmsteads and natural vegetation occurring on certified organic land. Non-C.C.O.F. parcels sharing the same combination of soil class and secondary crop classification were then selected as a comparison group.[4] Once again, the specific values of the secondary crop classifications are not revealed in order to maintain confidentiality.

Buffer zone requirements for organic growers were instituted in 1990 after the passage of the California Organic Foods act. Since that time, some growers have left organic certi-

[4] In some cases, soil class and crop combinations occurring for C.C.O.F. parcels were not represented in the cross-sectional sample. C.C.O.F. parcels for these classes were included in tests of aggregate differences in means, but were excluded from analysis which controlled for soil and crop types.

fication due to conflicts with neighboring land uses, and others have relocated to more protected locations. These changes have occurred over a period of years, as growers and certifiers have become aware of potential conflicts and have attempted to remedy them. Further, many growers may initially have required buffers on many of their borders, but over time, they have forged agreements with neighbors so that buffer zones are not required. The process of landscape change with response to buffers, then, moves slowly, and the organic landscapes examined in this study, from 1994 and 1997, most likely represent landscapes which are still in transition towards equilibrium. It is therefore likely that the incidence of buffers in these landscapes is higher and concentration of organic production lower than would be seen in a landscape where complete adjustment to buffer requirements had occurred.[5]

5.4 Results and Analysis

The broad empirical question addressed by this analysis is whether edge-effect externalities have a significant influence on the location and patterns of production of certified organic farms. As discussed above, an appropriate empirical measure of this result is whether certified organic parcels have a lower ratio of land in mandatory buffer zones than would comparable non-certified organic parcels. This ratio will vary both with parcel geometry and with the proportion of land surrounding the parcel in an incompatible land use. A series of statistics reflecting parcel geometry and neighboring land uses are presented below.

[5] Base data for a time series of organic parcels exist, and examination of landscape changes over time is a goal of future work.

The potential production impacts of variation in each geographic dimension are illustrated by linking variations in parcel geography to percentage of area lost to buffer zones.

5.4.1 Parcel Geometry

The following examples illustrated the impacts of differences in area concentration, parcel contiguity, parcel size, and parcel shape under the assumption that buffers are required on all exposed borders. This illustration outlines possible losses to buffer zones independent of neighboring land uses. For several of these statistics, borders between contiguous parcels are dissolved and statistics are calculated for the resulting larger parcels. These statistics illustrate the impacts of geographic clustering of organic farms and reflect possible benefits from spatial agglomeration of compatible land uses. For these examples, both parcels farmed by the same grower and parcels farmed by separate growers are agglomerated. This aggregation unfortunately obscures some possible insights regarding individual vs. cooperative spatial mitigation. If one large grower's farm consists of many small parcels, statistics may indicate that production is quite geographically concentrated, even though no coordination between growers has occurred. However, the aggregation is necessary due to limits on data availability for non-organic farms. While each organic parcel can be linked to the management of a particular grower, the non-organic parcels cannot be grouped by farm manager.

Reporting of statistics at the level of contiguous C.C.O.F. parcels does address a potential problem regarding the lack of farm-level data, however. If C.C.O.F. farms were simply more diversified than non-C.C.O.F. farms in terms of crops grown in a given year, many of the statistics reported here would indicate differences between the parcels. For instance, C.C.O.F. parcels would be both smaller and would be more likely to border another C.C.O.F. parcel. However, differences between contiguous clusters of C.C.O.F. parcels and individual non-C.C.O.F. parcels could not be due simply to a higher level of crop diversity on C.C.O.F. farms. This comparison goes beyond a comparison of C.C.O.F. farms to non-C.C.O.F. farms since it compares C.C.O.F. *farms* to non-C.C.O.F. *parcels*.

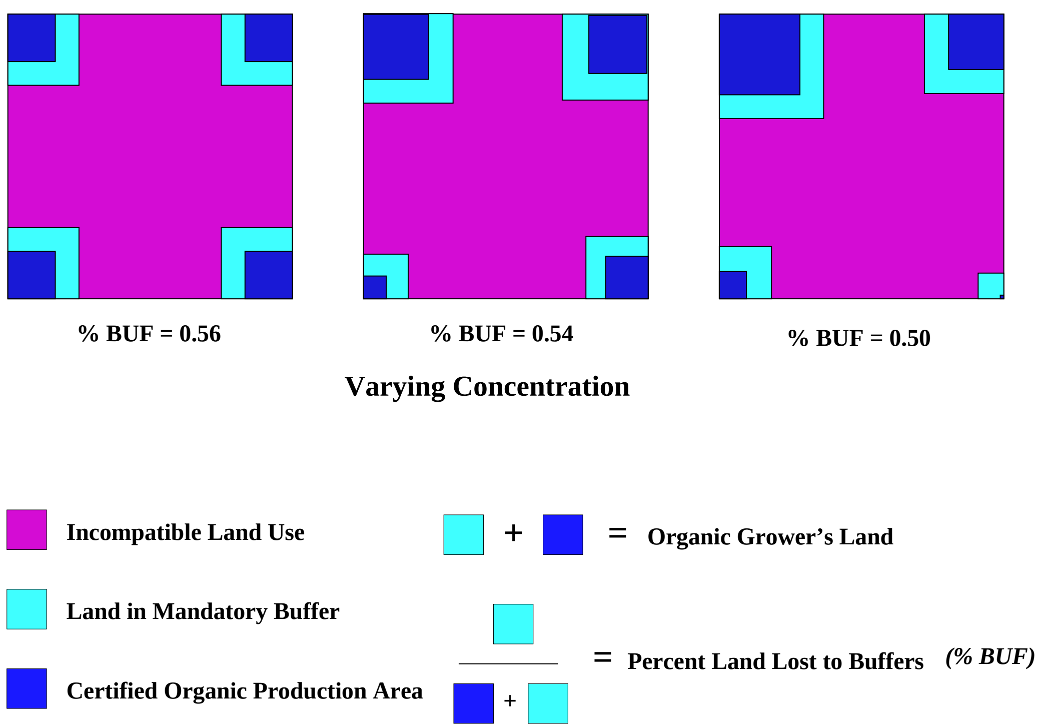


Figure 5.1: Concentration of Production Area

Concentration Independent of the number and arrangement of parcels in the landscape, the concentration of area among parcels will impact landscape productivity. Even if many non-contiguous parcels exist, the production landscape may be fairly efficient if the majority of production is concentrated in relatively few parcels. This result is illustrated in Figure 5.1. The panel on the left illustrates the least efficient landscape, holding the number of parcels and geographic arrangement of parcels fixed. Moving to the right, as production becomes more concentrated, edge per unit area and therefore losses from buffer zones decrease.

In a landscape context, "evenness" indices measure relative landscape concentration, independent of the number of parcels [24]. Some intuition for these measures can be gained through a comparison to the familiar Herfindahl index, used by economists to measure distribution of market share and therefore indirectly to measure market power. The value of the Herfindahl index on its own will vary with the number of firms in the marketplace even if the structure of the distribution of shares between firms remains the same. The parallel to the Herfindahl index in landscape ecology is a "diversity index", which measures the distribution of area between land-use classes, not controlling for the number of differing land-use classes.

The Herfindahl index can be normalized to control for the number of firms in the market by taking a ratio with the value of the Herfindahl for that number of firms, if each had an equal market share:

$$\text{N. Herf} = \frac{\sum_{i=1}^{n}(1/n)^2}{\sum_{i=1}^{n}(\frac{a_i}{A})^2} \tag{5.1}$$

$$\tag{5.2}$$

The two evenness indices presented here, Shannon's evenness index and Simpson's evenness index, similarly control for the number of land-use classes in a landscape. They are designed to reflect possible dominance of a landscape by particular land-use classes, controlling for the total number of land-use classes. Rather than calculate these statistics using land-use classes, the statistics are calculated treating each separate parcel as a class. Therefore, they reflect the concentration of production among C.C.O.F. and non-C.C.O.F. parcels, respectively, with lower index values reflecting a higher degree of concentration. The two indices are:

$$\text{Shannon's E. I.} = \frac{-\sum_{i=1}^{n}(\frac{a_i}{A}) * \ln(\frac{a_i}{A})}{\ln n}$$

$$\text{Simpson's E. I.} = \frac{1-\sum_{i=1}^{n}(\frac{a_i}{A})^2 *}{1-\frac{1}{n}}$$

Group	*County 1*	*County 2*
Contiguous C.C.O.F.	0.808	0.812
Contiguous Comparison	0.855	0.631

Table 5.1: Shannon's Evenness Index

Group	*County 1*	*County 2*
Contiguous C.C.O.F.	0.929	0.933
Contiguous Comparison	0.983	0.935

Table 5.2: Simpson's Evenness Index

Results for the evenness indices are presented in Tables 5.1 and 5.2. These measures are summary statistics for an entire landscape and cannot be calculated on a parcel by parcel basis. Therefore, statistical comparisons between C.C.O.F. and non-C.C.O.F. indices are not easily computable.[6] Further, these statistics are reported on a county by county basis, since aggregation of the two counties would imply that the neighboring landscapes remained the same from 1994 to 1997. For both counties, many firms both entered and exited certification during this time period.

For County 1, C.C.O.F. parcels exhibit more concentration than non-C.C.O.F. parcels. For County 2, results differ for each index number. While spatial concentration of production may be efficient in terms of edge effects, it may not make economic sense given size differences between organic and non-organic parcels. For organic farms, a highly concentrated landscape would also imply a high variance in parcel size. Since the average organic farm is smaller than the average non-organic farm, a high variance in parcel size would necessarily imply the existence of some very small farms geographically isolated from other organic farms. These small farms are not likely to be economically efficient, especially given

[6] One possible way of drawing a statistical comparison would be to compute indices for smaller, overlapping regions, then compare these indices statistically. Further, it is possible that a relationship exists between these statistics and results of a spatially autoregressive statistical model. This is a topic for future investigation.

the fixed costs of organic certification. Thus, it is not surprising that small differences are seem in geographic concentration of production.

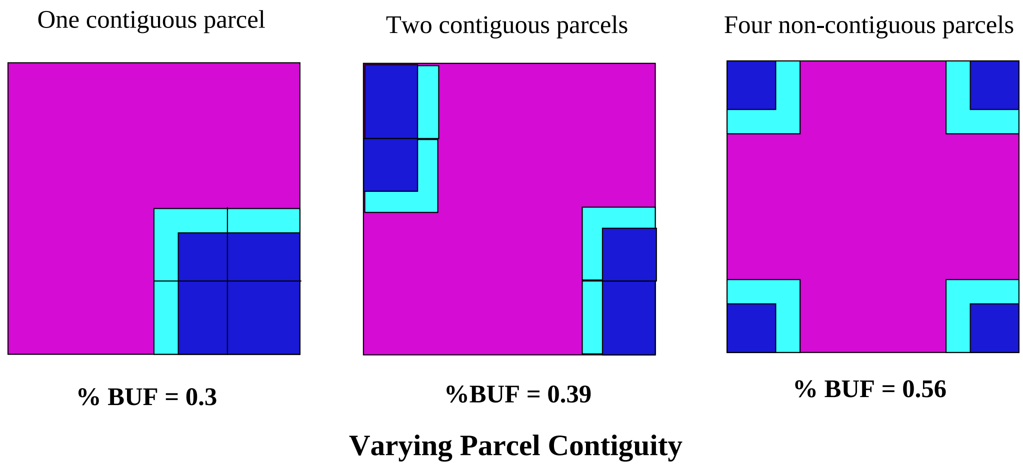


Figure 5.2: Parcel Contiguity

Parcel Contiguity A simple measure of geographic dispersion of land uses is the number of parcels located next to another parcel in a similar use relative to the total number of contiguous parcels. In Figure 5.2, different arrangements of four equal-area parcels are illustrated. The most efficient arrangement of the parcels, in terms of land lost to buffer zones, is to have all four parcels grouped together. As the number of separate clusters of parcels increases, a higher proportion of land is lost to buffer zones. The least efficient arrangement of production is to have all parcels geographically dispersed.

Figure 5.2 provides an illustration of the potential for positive externalities between growers. If the optimal scale for an organic grower is small, each of the four plots may be under separate management. It would be most efficient for the parcels to be located next to one another. However, due to potential for positive externalities between growers, this arrangement of land uses may not occur in the free market [31]. Further, these potential externalities are asymmetric. For example, the grower in the Southeast corner of this production landscape would much prefer the parcel configuration in the first panel to that in the third. Yet, the grower located at the Northwest parcel in the cluster of growers in the first panel would be indifferent between that outcome and the least efficient outcome in the third panel. This Northwest grower is imposing positive externalities on the Southeast grower by providing a protected border. More important, since damages from the edge effects are spatially heterogeneous, benefits from spatial agglomeration are asymmetric. The grower occupying the Southeast parcel receives highest benefits, followed by the growers occupying the Northeast and Southwest parcels.

Group	*County 1*	*County 2*
C.C.O.F. Parcels	0.59	0.20
Comparison Group	0.50	0.06

Table 5.3: Ratio of Contiguous Parcels to Total Parcels

Results related to parcel contiguity are presented in Table 5.3. For both counties, the landscape of non-C.C.O.F. farms exhibits more contiguity than the landscape of non-C.C.O.F. farms. There are two possible explanations for these results. The first is that the number of farms in the comparison group is substantially higher than for the C.C.O.F. parcels. Therefore these farms dominate the landscape, are much more likely to share borders, and therefore are much more likely to form contiguous clusters. The second explanation relates to the surroundings of each farm. The narrow valleys of these two counties are areas very attractive to organic farmers, and there is a high proportion of natural vegetation and natural waterways. Perhaps these protective landscapes connect C.C.O.F. parcels. If these protective landscapes are included in the analysis, C.C.O.F. parcels may exhibit more contiguity. Two extensions to the current analysis of parcel contiguity are suggested. The first is to develop a contiguity statistic that controls for the relative proportion of the landscape occupied by each use. The second is to examine landscape contiguity including protective land uses.

Statistical Tests All of the remaining statistics discussed can be calculated on both a whole-landscape and a parcel by parcel basis. Therefore, formal statistical comparisons can be done between C.C.O.F. and non-C.C.O.F. parcels. Two simple approaches are taken. For the first, unweighted parcel means are compared using t-tests and assuming unequal variances between C.C.O.F. and non-C.C.O.F. parcels. For the second approach, means for each statistic, conditioned on the parcel's crop type and soil class combination and the parcel's certified organic status, are computed using simple linear regressions. The general regression equation specification is:

$$Y = D\beta + \text{CCOF}\,\alpha + \epsilon \tag{5.3}$$

where

Y	$=$	Value of spatial statistic
D	$=$	D1-D39: Soil class / crop type combination dummies
β	$=$	Vector of estimated conditional means for each conventional soil / crop type
CCOF	$=$	Dummy variable for certified organic status
α	$=$	Average deviation from conventional conditional mean for C.C.O.F. parcels
ϵ	$=$	Error term

Each of the 39 crop type / soil class dummies reflects a unique Department of Water Resources agricultural secondary code and STATSGO soil class. An example would be "processing tomatoes on Class 2 soil". Due to the confidentiality agreement under which the C.C.O.F. data were obtained, the crop types for these dummies cannot be individually reported. These dummies are included solely to control for soil and crop type.

For each of these regressions, the coefficient on the soil class and crop type dummy represents the conditional mean for a non-C.C.O.F. parcel for that soil / crop type, and the coefficient on the C.C.O.F. dummy represents the average deviation from this conditional mean for all soil / crop types for that statistic. If the parameter α is significantly different from zero, the hypothesis of differences between C.C.O.F. and non-C.C.O.F. parcels is supported.

These preliminary regressions, estimated through ordinary least squares, do not correct for very probable spatial relationships in the error structure, and therefore the standard errors are most likely biased. However, some spatial correlation will be controlled for by controlling for soil type and crop. Further, substantial positive spatial autocorrelation is most likely present, and this positive autocorrelation would reduce the variance between parcels and therefore result in higher significance levels for coefficient estimates. The regression approach is used only for parcel by parcel comparisons, since groups of C.C.O.F. parcels will not have a unique soil type / crop code.

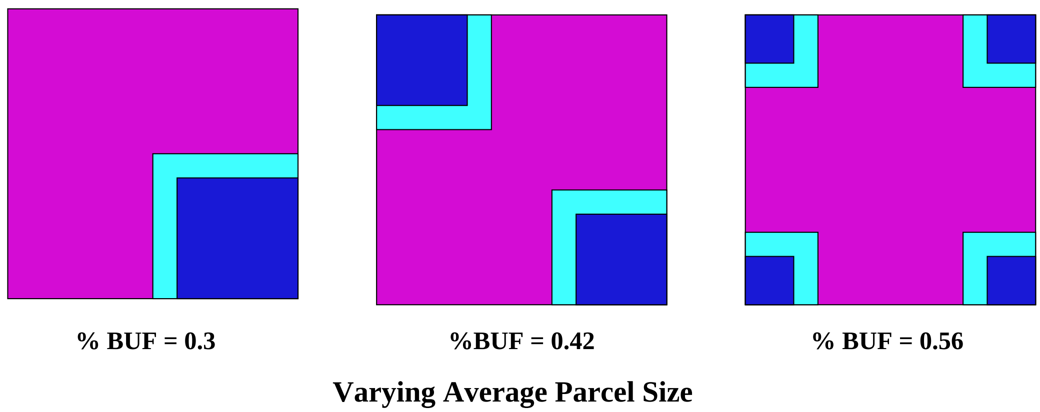


Figure 5.3: Average Parcel Size

Parcel Size Productivity of a landscape with losses due to edge effects will vary with the number of parcels per unit area, or, equivalently, with average parcel size. Figure 5.3 illustrates this phenomenon. Holding area fixed, as the number of parcels in the landscape increases, the proportion of borders to total area and therefore the proportion of land lost to buffer zones increases.

Table 5.4 reports average parcel sizes for both counties, and Table 5.14 reports regression results. In Table 5.4, the t-statistics and P-values for C.C.O.F. parcels and contiguous parcels refer to tests of differences between the means for these groups and the mean for

Group	*Mean*	*S.D.*	*t-stat*	*P-value*
C.C.O.F. Parcels	60836	85514	26.0997	0.0001
Contiguous C.C.O.F. Parcels	239289	382197	1.9733	0.0535
Comparison Group	344432	580046		

Table 5.4: Differences in Average Parcel Size

the comparison parcels. For instance, the t-statistic for the test that the average C.C.O.F. parcel is smaller than the average comparison parcel is 26.0997, indicating that differences are significant at the 99.99% level. To maintain confidentiality, sample sizes and degrees of freedom are not reported for t-tests. The total sample size used for all regressions is 4249. Statistics for both individual parcels and for agglomerated groups of C.C.O.F. farms are reported. Both simple t-tests and regressions indicate that average parcel size for C.C.O.F. parcels is significantly smaller than for non-C.C.O.F. parcels. Regression estimates indicate that the average C.C.O.F. parcel is smaller than the average non-C.C.O.F. parcel by approximately 20.02 hectares. This implies that in this dimension, C.C.O.F. parcels are significantly more vulnerable to proportional losses of productive land from buffer zones. While clusters of contiguous C.C.O.F. farms occupy much more area, these clusters of parcels are still significantly smaller than non-C.C.O.F. individual parcels, meaning that in many cases, entire C.C.O.F. farms are smaller than individual non-C.C.O.F. parcels.

On a parcel by parcel level, these results would also be consistent with a higher optimal level of geographic diversity for organic farms. Geographic diversity may reduce risk for the organic grower by creating an ecologically resilient landscape. It is also possible that diversity is beneficial to growers from a marketing perspective. Many of these growers market their products at farmers markets or through subscription agriculture, and in each of these cases, being able to offer a wide range of products may provide a marketing advantage. However, a higher level of diversity per acre is not a sufficient explanation for differences in size between contiguous C.C.O.F. parcels and non-C.C.O.F. parcels. A possible explanation is that optimal scale for an organic farm is smaller than for a conventional farm.

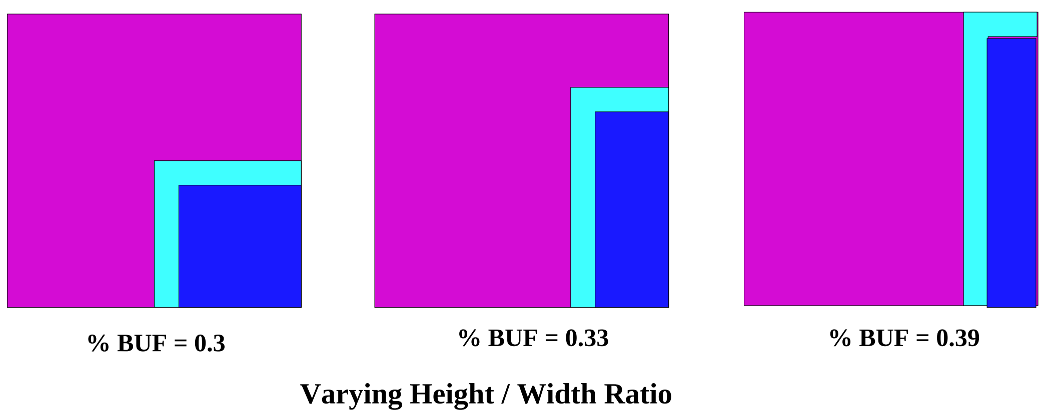


Figure 5.4: Parcel Shape

Parcel Shape Parcel shape will impact potential losses due to edge effects. A shape which is most compact (a shape with equal length sides for angled shapes and a circle for continuous shapes) will minimize edge per unit area. In Figure 5.4, a square parcel shape minimizes losses from buffer zones. As the parcel becomes longer and more narrow, holding area fixed, the proportion of land lost to buffer zones increases.

Tables 5.5 and 5.15 present results on average parcel compactness for the three parcel

Group	*A-W M.S.I.*	*Mean*	*S.D.*	*t-stat*	*P-value*
C.C.O.F. Parcels	1.270	1.287	0.226	4.3427	0.0001
Contiguous C.C.O.F. Parcels	1.329	1.302	0.172	2.3362	0.0229
Comparison Group	1.458	1.359	0.365		

Table 5.5: Differences in Parcel Shape

categories. The statistics reported compare the perimeter to area ratio for each parcel to the value of the ratio for a circular shape of the same area [24]. The area-weighted mean shape index, a whole-landscape measure, is calculated as:

$$\text{A-W M.S.I} = \sum_{i=1}^{n} \left\{ \frac{p_i}{2\sqrt{\pi a_i}} \right\} \left\{ \frac{a_i}{A} \right\} \tag{5.4}$$

At the individual parcel level, the statistic on parcel shape $\frac{p_i}{2\sqrt{\pi a_i}}$ is compared between parcels. Both simple mean comparisons and regression results indicate that parcel shapes for C.C.O.F. parcels are more compact, indicating that C.C.O.F. parcels are inherently less vulnerable in this dimension to losses from buffer zones. Interestingly, contiguous clusters of C.C.O.F. parcels are less compact than individual parcels. This result may be a reflection of slow transitions to organic production in many “mixed” (organic and conventional) operations, which tend to occur on a parcel by parcel basis, implying irregularly shaped organic parcels in the short run.

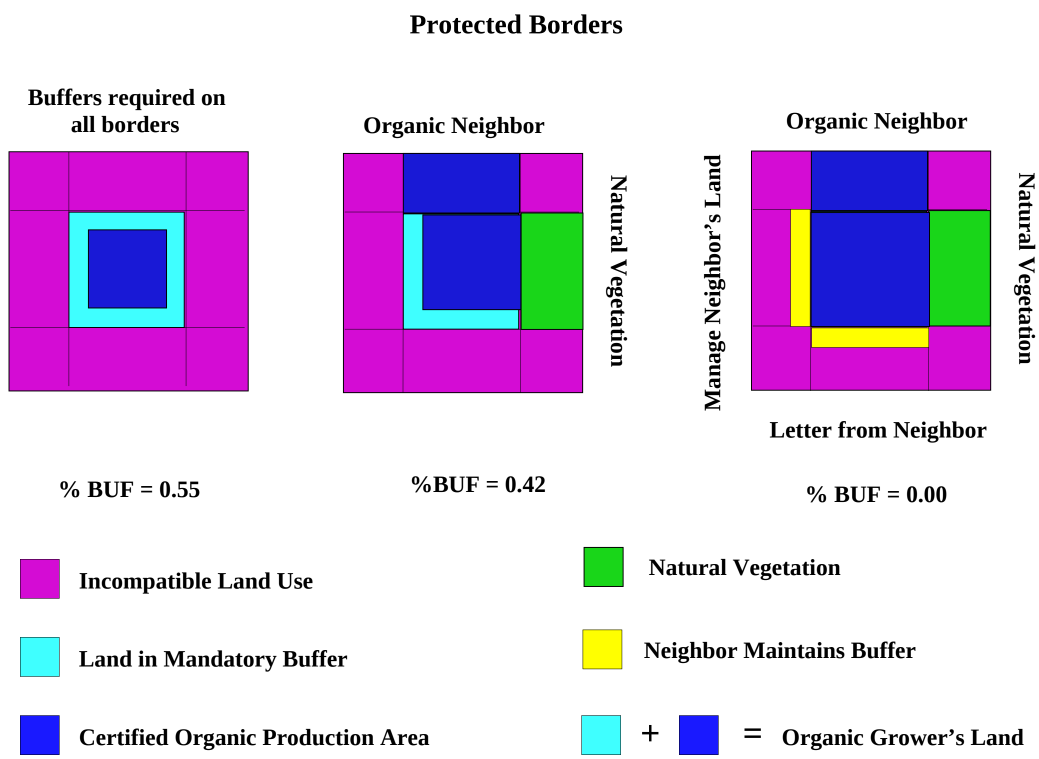


Figure 5.5: Neighboring Land Uses

5.4.2 Neighboring Land Uses

In addition to parcel geometry, the total amount of land in mandatory buffers will depend on the proportion of borders on which buffers are actually required. There are several ways in which C.C.O.F. growers can avoid leaving buffer zones along a given border. If a buffer zone is not required on a given border, for purposes of this chapter, that border is referred to as “protected”. Figure 5.5 illustrates potential sources of protected borders, using a single parcel and considering only neighboring land uses directly sharing a border with the organic parcel. In the first panel, all neighboring uses are conflicting uses, and buffers are required on all borders. In the second panel, two borders are shared with another C.C.O.F. farm and natural vegetation, and no buffers are required on these borders. In the last panel, in addition to sharing two borders with non-conflicting uses, the grower has negotiated agreements with neighboring conventional farms so that buffers are maintained on the neighbor’s land. In the first case, the neighboring conventional grower has provided a written statement that he will not use any prohibited substances within twenty-five feet of the border of the C.C.O.F. parcel. In the second case, the organic grower has agreed to manage a twenty-five foot buffer on the conventional neighbor’s land as organic. These last two cases, actual occurrences for many C.C.O.F. farms, are consistent with the theoretical operation of a liability rule and Coasean bargaining under edge-effect externalities, as demonstrated in Chapter 2. In the following examples, statistics reflecting each of these three cases are illustrated.

The first case is a worst-case scenario regarding buffers. The second reflects estimated buffers and, given data availability, is the only practical means of comparing land lost to buffers between C.C.O.F. and non-C.C.O.F. parcels. Information on actual buffer zone requirements for C.C.O.F. farms is contained in the C.C.O.F. inspectors' reports and has been added to the G.I.S. constructed for this project. Since non-organic parcels haven't been inspected, it is unknown exactly what buffer zones would be required on these parcels. Therefore, the type of surrounding land use is used as a proxy for the probable imposition of a mandatory buffer zone. This facilitates comparisons between C.C.O.F. and non-C.C.O.F. parcels which reflect their potential vulnerability to buffer zones. Proximity to roads and waterways will soon be added to this estimate to increase its accuracy. In the third case, the actual incidence of buffer zones in C.C.O.F. parcels is examined. This analysis both illustrates the extent to which C.C.O.F. farms are able to avoid potential buffer zones and facilitates an assessment of the accuracy of estimating buffer zone requirements using surrounding land uses as a proxy.

Buffers on All Borders In order to summarize the inherent vulnerability of parcels of each type and to provide a frame of reference for statistics on estimated and actual buffer zones, buffer incidences are calculated assuming that buffers are required on all borders. Descriptive statistics and simple tests of mean differences are reported in Table 5.6, and regression results are reported in 5.16.[7] The total proportion reported in Table 5.6 is a whole-landscape measure and represents the actual proportion of the entire production landscape

[7] This and other remaining regressions are run using proportions as dependent variables. While these variables are continuous, avoiding biased standard errors which occur with limited dependent variable models, the variables are bounded between zero and one. Ordinary least squares regressions in these cases do not bound estimates of dependent variables to be within this range. A possible response to this problem would have been to transform the dependent variable using a logistic transformation. However, in the current format, regression coefficients are easily interpreted, so that transformation was not done.

potentially in buffers. The “mean” is a per-parcel average. C.C.O.F. parcels are inherently more vulnerable to losses from buffer zones. The average C.C.O.F. parcel would lose 12.05% of its land to buffer zones, while the average non-ccof parcel would lose only 5.23%. Regression results controlling for crop and soil type estimate that the average C.C.O.F. parcel would lose 6.87% more land to buffers. This higher level of inherent vulnerability is most likely due to the fact that the C.C.O.F. parcels are much smaller than non-C.C.O.F. parcels. Since buffer zones are never required between C.C.O.F. parcels, the percentage of land potentially lost to buffer zones on the outside borders of contiguous clusters of C.C.O.F. parcels is reported. Clusters of contiguous parcels are inherently less vulnerable than individual parcels and are not statistically more vulnerable than non-C.C.O.F. parcels, indicating that some benefits have been captured through concentration of production.

Group	*Total prop.*	*Mean*	*S.D.*	*t-stat*	*P-value*
C.C.O.F. Parcels	0.1205	0.2178	0.1178	12.4602	0.0001
Contiguous C.C.O.F. Parcels	0.0587	0.1246	0.0846	0.8907	0.3770
Comparison Group	0.0523	0.1142	0.1006		

Table 5.6: Proportion of Land in Buffer Zones, Buffers on All Borders

Buffers with Conflicting Land uses To create an empirical proxy for the imposition of a buffer zone requirement, a list of “compatible” land uses was compiled, drawing from C.C.O.F. inspectors’ reports. The definition included parcels in natural vegetation, natural riparian areas, natural waterways, pasture lands, fallow crop land, and other C.C.O.F. farms.

Three sets of statistics are presented in Tables 5.7, 5.17, 5.8, 5.18, 5.9, and 5.19. The first report the percentage of borders on which buffers would be required. An alternative interpretation of this statistic for the whole landscape proportion is that it represents the probability that a border is shared with at least one incompatible land use. The parcel level proportion represents the average percentage of a parcel's border on which buffers are maintained. These statistics will be independent of the inherent vulnerability of the parcels to losses from buffers, since they don't depend on the ratio of border per area. The second statistics report the percentage of total land that would be lost to mandatory buffers. These statistics reflect each parcel's inherent vulnerability to losses of productive land. The third set of statistics report the proportion of potential buffer land actually in mandatory buffers. These statistics, like the first set, are largely independent of buffer vulnerability. Since buffers are never required on internal borders with other C.C.O.F. parcels, the statistics for contiguous C.C.O.F. parcels reflect the protective influences of non-C.C.O.F. compatible land uses, such as natural vegetation and waterways.

All statistics demonstrate that locating next to compatible land uses is an important source of protected borders for C.C.O.F. farms. C.C.O.F. farms are much less likely to share a border with a conflicting land use. C.C.O.F. parcels share an average of around 29% of their borders with an incompatible use while non-C.C.O.F. parcels border non-compatible uses on an average of around 96% of their borders. Regression results indicate that the average C.C.O.F. parcel is 68% less likely to share a border with an incompatible use. C.C.O.F. parcels also lose a lower percentage of their land to buffer zones per parcel than would non-

C.C.O.F. parcels. The average C.C.O.F. parcel would lose an estimated 5.67% of its land to buffer zones, while the average non-C.C.O.F. parcel would lose 8.42%. Regression estimates indicate that C.C.O.F. parcels lose around 4.9% less land to buffers. In terms of the amount of land potentially in buffers zones (land within the buffer zone distance of a border), C.C.O.F. farms are estimated to maintain buffers on around 33% of this land, while non-C.C.O.F. parcels are estimated to maintain buffers on around 77%. These results are even more striking in light of the inherent higher level of vulnerability of C.C.O.F. parcels to losses from buffer zones described in Tables 5.6 and 5.16.

Group	*Total prop.*	*Mean*	*S.D.*	*t-stat*	*P-value*
C.C.O.F. Parcels	0.3299	0.2875	0.2700	36.1138	0.0001
Contiguous C.C.O.F.	0.5343	0.5095	0.3443	9.6847	0.0001
Comparison Group	0.9723	0.9681	0.1355		

Table 5.7: Buffers Required from Incompatible Land Uses

Group	*Total prop.*	*Mean*	*S.D.*	*t-stat*	*P-value*
C.C.O.F. Parcels	0.0310	0.0567	0.0652	5.8406	0.0001
Contiguous C.C.O.F.	0.0386	0.0840	0.0752	0.0194	0.9846
Comparison Group	0.0404	0.0842	0.0850		

Table 5.8: Proportion of Land in Buffers, Incompatible Uses

Group	*Total prop.*	*Mean*	*S.D.*	*t-stat*	*P-value*
C.C.O.F. Parcels	0.3397	0.2979	0.2730	24.2078	0.0001
Contiguous C.C.O.F.	0.6557	0.6619	0.2924	2.6500	0.0106
Comparison Group	0.7737	0.7691	0.2873		

Table 5.9: Estimated Proportion of Potential Buffer Land in Buffers

5.4.3 Actual C.C.O.F. Buffer Requirements

Using information from C.C.O.F. inspectors' reports, statistics on actual buffer zones were computed. In this case, agreements between neighbors as well as protection from compatible neighboring uses are accounted for. Additionally, cases where roadways and minor waterways provided protection are included.[8] These results are presented in Tables 5.10 and 5.11. For both counties, these values are substantially lower than those for surrounding land use only. This indicates that roads, waterways, and cooperative agreements are important factors in avoiding mandatory buffers. Growers actually maintain buffers on only around 19% of their borders, much less than the estimate of 33% based on surrounding land uses. Further, the low values reported in these figures illustrate that C.C.O.F. growers manage to substantially avoid losses of productive land from buffer zones. Therefore, they strongly support the hypothesis that avoidance of buffer zones is an important factor in determining locations and patterns of production for certified growers.

Table 5.13 outlines actual sources of protection for C.C.O.F. parcels.[9] Both surround-

[8] The D.W.R. coverages include only major roadways and waterways. Information for actual C.C.O.F. parcels comes from inspector's reports.

[9] Values do not sum to 100 percent. Conditions are potentially overlapping and not exhaustive. For example, a parcel may border natural vegetation and be separated from this vegetation by a creek. In some cases,

Group	*Total prop.*	*Mean*	*S.D.*
C.C.O.F. Parcels	0.1844	0.1320	0.2191

Table 5.10: Actual Proportion of C.C.O.F. Borders with Buffers

Group	*Total prop.*	*Mean*	*S.D.*
C.C.O.F. Parcels	0.02310	0.02083	0.03965

Table 5.11: Actual Proportion of C.C.O.F. Land in Mandatory Buffers

Group	*Total prop.*	*Mean*	*S.D.*
C.C.O.F. Parcels	0.1895	0.1349	0.2222

Table 5.12: Actual Proportion of Potential Buffer Land in Buffers

ing land uses and agreements with neighbors provided protection from mandatory buffer zones. Shared borders with other organic parcels were the most common source of protection. It is important to note that in both counties, few instances of organic farms under different management located next to one another occurred. Of all borders shared with another organic parcel, only 2.9 % of these borders were shared with another organic grower. Thus, the high proportion of protected borders for County 1 related to bordering another organic parcel (44.4 %) occur due to the fact that many organic farms in this region contain a large number of contiguous plots of different crops. Borders with natural vegetation and waterways were also important sources of protection. Roads as buffers were important for both counties. Negotiated agreements, including letters from neighbors and management of a buffers on the neighbor's land, were also a source of protection, but these negotiated agreements overall represented a low proportion of protected buffers.

Source of Protection	*Proportion*
Organic Neighbor	0.4451
Bordered by Natural Vegetation	0.2210
Road provided buffer	0.1435
Bordered Natural Waterway	0.1032
Letter from neighbor	0.0548
Managed buffer for Neighbor	0.0225

Table 5.13: Reasons for Protected Borders for C.C.O.F. Parcels

a reason for waiving a buffer zone requirement was not given by the inspector.

5.4.4 Landscape Analysis: Extensions

The empirical results presented here, focused mainly at the individual parcel level, lay the groundwork for more comprehensive analysis. Several questions related to the landscape of organic producers remain. These questions focus on the development of organic neighborhoods. Factors other than the benefits of shared borders, such as sharing of information, expertise, and processing infrastructure, may lead to geographic concentration of organic production. This concentration could be measured through spatial statistics which compare the distribution of distances between C.C.O.F. plots to the distribution of distances between non-C.C.O.F. plots. This analysis also excludes the influence of transportation costs. Therefore, the set of implications developed in Chapter 4 regarding interactions between transportation costs and edge-effect externalities have not been examined. These interactions have implications for the values of spatial clustering indices. If edge-effect externalities were completely unimportant, C.C.O.F. parcels would be expected to be uniformly dispersed radially around marketing sites. If transport costs are an important factor for C.C.O.F. location, and edge-effect externalities are also important, the radial distribution of C.C.O.F. parcels would not be uniform, but would exhibit spatial clustering, holding distance from markets constant. If transport costs prove insignificant and spatial clustering is evident, this would imply that benefits from externality avoidance exceeded benefits from lower transport costs.

5.5 Discussion and Conclusions

The statistics presented provide evidence that finding a location protected from potentially conflicting uses is an important factor for certified organic farmers. Parcels farmed by certified growers, while inherently more vulnerable to proportional losses of productive land from buffer zones than comparable non-certified organic parcels, appear quite protected from losses due to buffer zones. On first glance this appears to be an optimistic finding. A positive interpretation is that buffer zone regulations are not having substantial impacts on the economic viability of organic production. A naive interpretation would be that externality impacts are mitigated through the efforts of organic growers, implying that welfare losses due to the spatial externalities are negligible.

However, this optimistic interpretation fails to consider this case in the context of theoretical results related to externalities in general and edge-effect externalities in particular. In theory, market price distortions occur under externalities, with the result of too much production from the externality-generation use occurring, and too little production occurring from the externality-receiving use [4]. In the case of edge-effect externalities, this price distortion takes a particular form. As demonstrated in Chapter 2, in a free-market outcome without complete bargaining, the value of operating free from the externality found in a protected location will be capitalized into the market rental rate of land. In this particular case, C.C.O.F. growers' bids for protected location will be increased by the value of the damage avoided. These relatively higher land rental rates for organic producers may push less efficient organic growers out of the certified organic market. The loss of these growers reflects the lower production by the organic industry theoretically expected under externalities. As also noted in Chapter 2, the avoidance behavior of potential externality damage demonstrated by C.C.O.F. farmers does not imply that market distortions due to externality damage are reduced. Externality avoidance does not equal externality mitigation [11, 32].

However, this avoidance behavior by C.C.O.F. growers may contribute to a relatively efficient landscape of organic farming. Chapter 4 demonstrated that under edge-effect externalities, while the free market may lead to globally inefficient patterns of production, locally, parcel geometry will be relatively efficient. More specifically, production may be dispersed among several geographically isolated production sites, but production patterns may evolve which minimize conflicting borders with incompatible uses at individual sites. This theoretical prediction appears to hold in the case of C.C.O.F. farmers. Farmers do not appear to have captured gains from cooperation, since very few C.C.O.F. farms share borders with other C.C.O.F. farms. Yet, individual farmers appear to be very successful at avoiding losses of productive land from buffer zones.

The failure of C.C.O.F. farms to capture potential benefits from spatial agglomeration indicates that policies which encourage the development of organic landscapes may be beneficial. Both certified organic producers and producers using conventional methods could potentially benefit from a spatial arrangement of production which minimizes potential conflicts. Precedents exist for such policies in California in cases where production process for two crops are incompatible. For example, in 1997 in Glenn county, production of cotton was limited to a particular zone of the county to protect existing olive trees from contamination by verticillium wilt [9]. Buffer zone regulations are also often imposed and enforced through county agricultural commissions. In discussions with organic farmers regarding possible policies to encourage the development of organic landscapes, growers have emphasized that successful policies, from their perspective, would be both flexible and voluntary. Possible policies might include preferential tax structures for land in organic uses or subsidies to growers during the three-year transition period to establish organic certification.[10]

To evaluate growers' potential response to such policies, a comprehensive empirical model designed to predict factors which increase the probability of successful organic production is needed. An ideal model would include local prices for both organic and conventional produce.[11] The model would also account for proximity to potential marketing outlets, such as metropolitan areas, local farmers' markets, and organic processing plants. Soil quality would also be included as an explanatory variable.

In addition, many of the statistics described in this chapter would serve as dependent variables designed to reflect the attractiveness of a particular parcel in terms of its potential to avoid costs from mandatory buffers. For each individual parcel, statistics on parcel size and shape would be included. In order to account for surrounding land uses and neighborhood impacts, the model would have a spatially autoregressive error structure [2].[12] Given a spatial lag greater than one, this structure has the advantage that the impact of local, but not contiguous, organic farms may be accounted for. While few C.C.O.F. farms in the data examined are located next to one another, significant spatial clustering of these farms is appar-

[10] Transition subsidies are used in Sweden to encourage entry into the organic farming industry [23].
[11] Reliable data on prices for organic products are lacking at this point in time.
[12] A preliminary empirical specification for such a model is presented in Appendix C.

ent. There are many reasons why such clustering might occur. Neighboring organic farmers may share specialized expertise, and therefore having organic neighbors may increase a grower's chances of succeeding at organic farming. With many local organic neighbors, conventional neighbors may be more familiar with the requirements for organic farming, and as a result, fewer conflicts may occur. Conventional growers with successful organic neighbors may decide to emulate their success and therefore might be more likely to transition to organic production. Estimation of a complete model, controlling for the factors described above, would reveal whether spatial correlations exist independent of the influence of protective locations. If these spatial correlations are found, it may imply that positive returns to spatial scale in organic agriculture are present for reasons beyond benefits from externality avoidance. This result would further strengthen the rational for policies which encourage development of regions of organic production.

Variable	*Est. Parameter*	*S.E.*	*T-stat*	*P-value*
D1	149144	148845.15157	1.002	0.3164
D2	63597	76313.452012	0.833	0.4047
D3	69042	146636.24236	0.471	0.6378
D4	121221	186953.40828	0.648	0.5168
D5	182042	39815.299504	4.572	0.0001
D6	164674	25831.598653	6.375	0.0001
D7	147600	176253.69887	0.837	0.4024
D8	89057	79776.739097	1.116	0.2643
D9	53165	186953.40828	0.284	0.7761
D10	63872	84809.909511	0.753	0.4514
D11	176038	132170.15205	1.332	0.1830
D12	185395	47856.351606	3.874	0.0001
D13	269360	53963.519721	4.992	0.0001
D14	253531	52610.070778	4.819	0.0001
D15	522853	35488.288020	14.733	0.0001
D16	438248	23549.964542	18.609	0.0001
D17	360450	95174.838916	3.787	0.0002
D18	359514	20212.132022	17.787	0.0001
D19	181924	32198.402156	5.650	0.0001
D20	448217	31387.420024	14.280	0.0001
D21	141326	51100.973832	2.766	0.0057
D22	1517565	58787.559400	25.814	0.0001
D23	105648	118655.45602	0.890	0.3733
D24	111490	137188.89034	0.813	0.4165
D25	461916	24836.270550	18.598	0.0001
D26	158290	71361.501685	2.218	0.0266
D27	106986	187537.82485	0.570	0.5684
D28	201958	177171.10866	1.140	0.2544
D29	155571	306446.43403	0.508	0.6117
D30	97762	216240.99343	0.452	0.6512
D31	269141	47543.270729	5.661	0.0001
D32	436165	59105.974699	7.379	0.0001
D33	273931	186953.40828	1.465	0.1429
D34	344477	83575.378561	4.122	0.0001
D35	189456	374345.55666	0.506	0.6128
D36	539492	88103.851500	6.123	0.0001
D37	96019	264495.49799	0.363	0.7166
D38	98775	115344.98071	0.856	0.3919
D39	76472	159553.47819	0.479	0.6318
D40	54381	167150.75712	0.325	0.7449
D41	80917	132247.74899	0.612	0.5407
D42	76326	264495.49799	0.289	0.7729
D43	70790	528577.10512	0.134	0.8935
D44	34167	373760.45541	0.091	0.9272
D45	50666	528577.10512	0.096	0.9236
D46	596630	132144.27628	4.515	0.0001
CCOF	-200232	41843.411048	-4.785	0.0001

Model Fit:	*N*	*R-square*	*F Value*
	4249	0.3649	51.373

Table 5.14: Regression Results: Average Parcel Size

Dependent Variable is Parcel Size in Square Meters

Variable	*Est. Parameter*	*S.E.*	*T-stat*	*P-value*
D1	1.303612	0.10129834	12.869	0.0001
D2	1.289601	0.05193603	24.831	0.0001
D3	1.298400	0.09979504	13.011	0.0001
D4	1.236957	0.12723336	9.722	0.0001
D5	1.386359	0.02709677	51.163	0.0001
D6	1.370700	0.01758000	77.969	0.0001
D7	1.331110	0.11995155	11.097	0.0001
D8	1.349868	0.05429301	24.863	0.0001
D9	1.209216	0.12723336	9.504	0.0001
D10	1.290669	0.05771839	22.361	0.0001
D11	1.417591	0.08994997	15.760	0.0001
D12	1.319684	0.03256921	40.519	0.0001
D13	1.303235	0.03672551	35.486	0.0001
D14	1.304027	0.03580441	36.421	0.0001
D15	1.384763	0.02415198	57.335	0.0001
D16	1.343035	0.01602721	83.797	0.0001
D17	1.333315	0.06477237	20.585	0.0001
D18	1.365128	0.01375561	99.242	0.0001
D19	1.386832	0.02191301	63.288	0.0001
D20	1.346791	0.02136108	63.049	0.0001
D21	1.316791	0.03477737	37.863	0.0001
D22	1.544303	0.04000857	38.599	0.0001
D23	1.420109	0.08075238	17.586	0.0001
D24	1.328814	0.09336553	14.232	0.0001
D25	1.348193	0.01690262	79.762	0.0001
D26	1.387535	0.04856592	28.570	0.0001
D27	1.385336	0.12763109	10.854	0.0001
D28	1.440554	0.12057590	11.947	0.0001
D29	1.407057	0.20855576	6.747	0.0001
D30	1.317722	0.14716538	8.954	0.0001
D31	1.336633	0.03235614	41.310	0.0001
D32	1.391484	0.04022527	34.592	0.0001
D33	1.238154	0.12723336	9.731	0.0001
D34	1.475369	0.05687822	25.939	0.0001
D35	1.400980	0.25476531	5.499	0.0001
D36	1.321930	0.05996012	22.047	0.0001
D37	1.301340	0.18000555	7.229	0.0001
D38	1.380913	0.07849940	17.591	0.0001
D39	1.398974	0.10858601	12.884	0.0001
D40	1.351258	0.11375643	11.879	0.0001
D41	1.289797	0.09000278	14.331	0.0001
D42	1.300952	0.18000555	7.227	0.0001
D43	1.275253	0.35972943	3.545	0.0004
D44	1.458458	0.25436712	5.734	0.0001
D45	1.129383	0.35972943	3.140	0.0017
D46	1.518809	0.08993236	16.888	0.0001
CCOF	-0.076921	0.02847703	-2.701	0.0069

Model Fit:	*N*	*R-square*	*F Value*
	4249	0.9350	1286.196

Table 5.15: Regression Results: Parcel Shape

Dependent Variable Measures Deviation of Parcel Shape from a Circle

Variable	*Est. Parameter*	*S.E.*	*T-stat*	*P-value*
D1	0.243714	0.02647772	9.204	0.0001
D2	0.202230	0.01357522	14.897	0.0001
D3	0.182396	0.02608478	6.992	0.0001
D4	0.244416	0.03325671	7.349	0.0001
D5	0.156617	0.00708265	22.113	0.0001
D6	0.159982	0.00459512	34.816	0.0001
D7	0.167402	0.03135336	5.339	0.0001
D8	0.174214	0.01419130	12.276	0.0001
D9	0.208824	0.03325671	6.279	0.0001
D10	0.222136	0.01508664	14.724	0.0001
D11	0.149982	0.02351144	6.379	0.0001
D12	0.129420	0.00851306	15.203	0.0001
D13	0.077115	0.00959945	8.033	0.0001
D14	0.106232	0.00935868	11.351	0.0001
D15	0.090940	0.00631293	14.405	0.0001
D16	0.084402	0.00418925	20.147	0.0001
D17	0.104455	0.01693043	6.170	0.0001
D18	0.097679	0.00359549	27.167	0.0001
D19	0.155530	0.00572770	27.154	0.0001
D20	0.080352	0.00558344	14.391	0.0001
D21	0.168596	0.00909023	18.547	0.0001
D22	0.061726	0.01045758	5.903	0.0001
D23	0.179122	0.02110734	8.486	0.0001
D24	0.202934	0.02440421	8.316	0.0001
D25	0.074428	0.00441807	16.846	0.0001
D26	0.159892	0.01269433	12.596	0.0001
D27	0.204744	0.03336067	6.137	0.0001
D28	0.172353	0.03151656	5.469	0.0001
D29	0.204196	0.05451305	3.746	0.0002
D30	0.257644	0.03846661	6.698	0.0001
D31	0.129716	0.00845736	15.338	0.0001
D32	0.102104	0.01051422	9.711	0.0001
D33	0.091146	0.03325671	2.741	0.0062
D34	0.097482	0.01486703	6.557	0.0001
D35	0.117993	0.06659146	1.772	0.0765
D36	0.066737	0.01567259	4.258	0.0001
D37	0.172306	0.04705049	3.662	0.0003
D38	0.182648	0.02051845	8.902	0.0001
D39	0.227989	0.02838260	8.033	0.0001
D40	0.170089	0.02973406	5.720	0.0001
D41	0.175602	0.02352525	7.464	0.0001
D42	0.191563	0.04705049	4.071	0.0001
D43	0.126105	0.09402736	1.341	0.1799
D44	0.264769	0.06648738	3.982	0.0001
D45	0.130954	0.09402736	1.393	0.1638
D46	0.167954	0.02350684	7.145	0.0001
CCOF	0.068700	0.00744343	9.230	0.0001

Model Fit:	*N*	*R-square*	*F Value*
	4249	0.6481	164.640

Table 5.16: Regression Results: Buffers on All Borders

Dependent Variable is Proportion of Land in Buffers

Variable	*Est. Parameter*	*S.E.*	*T-stat*	*P-value*
D1	1.029947	0.02968151	34.700	0.0001
D2	0.990911	0.01521782	65.115	0.0001
D3	0.975659	0.02924102	33.366	0.0001
D4	1.023012	0.03728075	27.441	0.0001
D5	0.997586	0.00793965	125.646	0.0001
D6	0.997725	0.00515113	193.691	0.0001
D7	1.004384	0.03514710	28.577	0.0001
D8	1.011052	0.01590844	63.554	0.0001
D9	1.050407	0.03728075	28.176	0.0001
D10	1.002617	0.01691211	59.284	0.0001
D11	1.000678	0.02635631	37.967	0.0001
D12	0.997452	0.00954313	104.520	0.0001
D13	1.005423	0.01076097	93.432	0.0001
D14	0.996039	0.01049108	94.942	0.0001
D15	1.004405	0.00707679	141.929	0.0001
D16	0.996958	0.00469615	212.293	0.0001
D17	0.961489	0.01897900	50.661	0.0001
D18	1.000869	0.00403054	248.321	0.0001
D19	0.690084	0.00642075	107.477	0.0001
D20	1.001531	0.00625903	160.014	0.0001
D21	0.710642	0.01019015	69.738	0.0001
D22	0.998230	0.01172294	85.152	0.0001
D23	0.979059	0.02366132	41.378	0.0001
D24	0.909662	0.02735711	33.251	0.0001
D25	0.999057	0.00495265	201.722	0.0001
D26	1.013851	0.01423034	71.246	0.0001
D27	0.923318	0.03739729	24.689	0.0001
D28	0.987424	0.03533004	27.949	0.0001
D29	0.789046	0.06110909	12.912	0.0001
D30	0.908384	0.04312105	21.066	0.0001
D31	0.991698	0.00948070	104.602	0.0001
D32	1.001398	0.01178644	84.962	0.0001
D33	1.024350	0.03728075	27.477	0.0001
D34	1.000000	0.01666593	60.003	0.0001
D35	1.087236	0.07464899	14.565	0.0001
D36	1.002599	0.01756896	57.066	0.0001
D37	1.023575	0.05274357	19.407	0.0001
D38	1.000000	0.02300117	43.476	0.0001
D39	0.967918	0.03181688	30.422	0.0001
D40	1.000000	0.03333186	30.001	0.0001
D41	0.986131	0.02637179	37.393	0.0001
D42	0.920892	0.05274357	17.460	0.0001
D43	1.000000	0.10540461	9.487	0.0001
D44	1.000000	0.07453231	13.417	0.0001
D45	1.000000	0.10540461	9.487	0.0001
D46	0.193330	0.02635115	7.337	0.0001
CCOF	-0.683570	0.00834408	-81.923	0.0001

Model Fit:	*N*	*R-square*	*F Value*
	4249	0.9881	7394.979

Table 5.17: Regression Results: Estimated Borders Buffered

Dependent Variable is Proportion of Borders where Buffers are Required

Variable	*Est. Parameter*	*S.E.*	*T-stat*	*P-value*
D1	0.139145	0.02278985	6.106	0.0001
D2	0.154024	0.01168444	13.182	0.0001
D3	0.146953	0.02245164	6.545	0.0001
D4	0.216280	0.02862465	7.556	0.0001
D5	0.105246	0.00609617	17.264	0.0001
D6	0.115377	0.00395511	29.172	0.0001
D7	0.108643	0.02698641	4.026	0.0001
D8	0.123005	0.01221471	10.070	0.0001
D9	0.199683	0.02862465	6.976	0.0001
D10	0.179810	0.01298534	13.847	0.0001
D11	0.113668	0.02023672	5.617	0.0001
D12	0.102380	0.00732734	13.972	0.0001
D13	0.070033	0.00826242	8.476	0.0001
D14	0.093699	0.00805519	11.632	0.0001
D15	0.076056	0.00543365	13.997	0.0001
D16	0.069687	0.00360576	19.327	0.0001
D17	0.072214	0.01457233	4.956	0.0001
D18	0.078318	0.00309470	25.307	0.0001
D19	0.085225	0.00492993	17.287	0.0001
D20	0.068186	0.00480576	14.188	0.0001
D21	0.060681	0.00782413	7.756	0.0001
D22	0.036914	0.00900103	4.101	0.0001
D23	0.139673	0.01816747	7.688	0.0001
D24	0.152629	0.02100515	7.266	0.0001
D25	0.064367	0.00380271	16.927	0.0001
D26	0.135464	0.01092624	12.398	0.0001
D27	0.121076	0.02871413	4.217	0.0001
D28	0.126973	0.02712687	4.681	0.0001
D29	0.094491	0.04692036	2.014	0.0441
D30	0.139617	0.03310891	4.217	0.0001
D31	0.103400	0.00727940	14.204	0.0001
D32	0.081922	0.00904978	9.052	0.0001
D33	0.060001	0.02862465	2.096	0.0361
D34	0.071509	0.01279632	5.588	0.0001
D35	0.157517	0.05731648	2.748	0.0060
D36	0.063180	0.01348968	4.684	0.0001
D37	0.127556	0.04049721	3.150	0.0016
D38	0.060379	0.01766060	3.419	0.0006
D39	0.122111	0.02442942	4.999	0.0001
D40	0.088956	0.02559264	3.476	0.0005
D41	0.071339	0.02024860	3.523	0.0004
D42	0.053192	0.04049721	1.313	0.1891
D43	0.055670	0.08093105	0.688	0.4916
D44	0.089758	0.05722689	1.568	0.1169
D45	0.035313	0.08093105	0.436	0.6626
D46	0.027938	0.02023276	1.381	0.1674
CCOF	-0.049050	0.00640669	-7.656	0.0001

Model Fit:	*N*	*R-square*	*F Value*
	4249	0.5381	104.138

Table 5.18: Regression Results: Estimated Proportion of Land in Buffers

Dependent Variable is Proportion of Land Lost to Mandatory Buffers

Variable	*Est. Parameter*	*S.E.*	*T-stat*	*P-value*
D1	0.702438	0.07362976	9.540	0.0001
D2	0.789337	0.03775025	20.909	0.0001
D3	0.853608	0.07253707	11.768	0.0001
D4	0.922727	0.09248090	9.977	0.0001
D5	0.676121	0.01969557	34.329	0.0001
D6	0.734656	0.01277821	57.493	0.0001
D7	0.634825	0.08718804	7.281	0.0001
D8	0.751493	0.03946344	19.043	0.0001
D9	0.932002	0.09248090	10.078	0.0001
D10	0.830693	0.04195322	19.800	0.0001
D11	0.752480	0.06538108	11.509	0.0001
D12	0.813429	0.02367327	34.361	0.0001
D13	0.887956	0.02669433	33.264	0.0001
D14	0.892993	0.02602481	34.313	0.0001
D15	0.800642	0.01755512	45.607	0.0001
D16	0.822253	0.01164954	70.582	0.0001
D17	0.679677	0.04708047	14.436	0.0001
D18	0.811159	0.00999841	81.129	0.0001
D19	0.547061	0.01592770	34.346	0.0001
D20	0.849628	0.01552653	54.721	0.0001
D21	0.372741	0.02527830	14.746	0.0001
D22	0.674891	0.02908065	23.208	0.0001
D23	0.806595	0.05869571	13.742	0.0001
D24	0.775830	0.06786371	11.432	0.0001
D25	0.861573	0.01228585	70.127	0.0001
D26	0.864318	0.03530065	24.484	0.0001
D27	0.712153	0.09277000	7.677	0.0001
D28	0.825463	0.08764186	9.419	0.0001
D29	0.640491	0.15159094	4.225	0.0001
D30	0.663541	0.10696870	6.203	0.0001
D31	0.815007	0.02351840	34.654	0.0001
D32	0.781910	0.02923816	26.743	0.0001
D33	0.582971	0.09248090	6.304	0.0001
D34	0.770749	0.04134253	18.643	0.0001
D35	0.980857	0.18517884	5.297	0.0001
D36	0.881151	0.04358264	20.218	0.0001
D37	0.714529	0.13083892	5.461	0.0001
D38	0.345326	0.05705811	6.052	0.0001
D39	0.563847	0.07892688	7.144	0.0001
D40	0.513923	0.08268506	6.215	0.0001
D41	0.375763	0.06541946	5.744	0.0001
D42	0.308835	0.13083892	2.360	0.0183
D43	0.441456	0.26147311	1.688	0.0914
D44	0.269236	0.18488941	1.456	0.1454
D45	0.269661	0.26147311	1.031	0.3025
D46	0.199318	0.06536828	3.049	0.0023
CCOF	-0.460736	0.02069883	-22.259	0.0001

Model Fit:	*N*	*R-square*	*F Value*
	4249	0.8962	771.671

Table 5.19: Regression Results: Estimated Proportion of Potential Buffers Land in Buffers

Dependent Variable is Land in Buffers / Land within Buffer Distance of Border

Chapter 6

Conclusions

The impacts of distance-dependent spatial externalities have been the focus of previous theoretical and empirical analysis. Two important features of this class of externalities have been unrecognized in previous work. The first is the spatially dynamic location incentives that they create. This thesis demonstrates that edge-effect externalities influence the optimal location of an affected land user. Specifically, the impacted land user will locate an optimal distance from the generator of the externality. The second previously unrecognized feature of edge-effect externalities is the influence of the arrangement of land uses on the potential productivity of the economic landscape. Under edge-effect externalities, the production possibilities frontier is potentially non-convex with respect to the arrangement of land uses. Holding the allocation of land uses fixed, the productivity of the economic landscape will increase as the fragmentation of land uses decreases. These positive returns to spatial scale imply potential positive externalities between impacted land users. When grouped together, they provide mutual benefits through shared borders where no externality damage occurs. These two previously unrecognized features of edge-effect externalities lead to the central question addressed in this dissertation: what impact will spatially dynamic incentives have on the efficiency of equilibrium landscape patterns?

Non-convexities due to edge-effect externalities can be illustrated with a one-dimensional model, but full implications are only apparent in two dimensions, mandating a two- new-line dimensional modeling approach. A strictly analytical two-dimensional model would be very difficult to solve due to a high degree of spatial interdependencies, since at a minimum, the choices of one land user depend also on the choices of that land user's four contiguous neighbors. Further, ideally, a two-dimensional theoretical model should be amenable to testing using real-world data. A model designed for calibration using two-dimensional G.I.S. data would ideally have the same spatial structure as the data in terms of number of parcels in the landscape. With increasing availability of high-resolution remotely sensed land use data, highly disaggregated data on land-use will become the rule rather than the exception. In combination, the large number of land uses, high degree of spatial interdependency, and potential for non-convexities make strictly analytical models highly impractical for disaggregated, two-dimensional land use models.

The alternative modeling approach taken in Chapter 4 bypasses these computational difficulties, since an economic equilibrium is reached through the uncoordinated interactions of individual agents. The model thus directly expresses the classic "invisible hand" metaphor used to describe evolution towards an economic equilibrium. In this dissertation, the two-dimensional model is used to generate a set of stylized predictions which are tested indirectly using empirical data. Even this simple, stylized model, however, illustrates a series of outcomes which would have been very difficult to generate using a purely analytical model with an set of imposed equilibrium conditions. Further, it facilitates analysis focusing on free-market, rather than socially optimal, outcomes. It demonstrates the key point that the incentives created by edge-effect externalities are not necessarily sufficient to result in efficient patterns of production. In many cases, welfare improving rearrangements of land uses are possible in free-market equilibrium landscapes. Therefore, it illustrates that inefficient patterns of land use are a previously unrecognized dimension to market failure under edge-effect externalities. This result strengthens the rationale for policies such as zoning rules and buffer zone regulations which may encourage development of efficient economic landscapes.

Further, the model illustrates the impact that edge-effect externalities will have on a traditional Von Thunen landscape. Where benefits from externality avoidance exceed benefits from lower transportation costs, edge-effect externalities encourage development of locally more compact and geographically more dispersed production landscapes. Therefore, these spatial externalities provide an explanation for dispersal of economic activity in space. This result may explain fragmented patterns of development often seen at the edges of cities.

Theoretical predictions are tested through a cross-sectional analysis of production patterns of certified organic and comparable non-certified organic agricultural parcels. While some analysis is done of whole-landscape impacts of edge-effect externalities, the primary focus of this empirical analysis is on externality avoidance at the level of an individual organic producer. The goals of this empirical analysis are two-fold. The first is to demonstrate that certified organic parcels differ from non-organic parcels in ways that are consistent with avoidance of negative spillovers from incompatible land uses. The second goal is to illustrate a series of spatial statistics, measurable at the individual parcel level, which are appropriate for inclusion in a more general statistical model of the probability of finding a parcel in a particular land use. These variables on parcel size, shape, and neighboring land use could enhance the explanatory power of any model of land uses where distance-dependent externalities are economically important.

Results strongly support hypotheses regarding differences between C.C.O.F. and non-C.C.O.F. parcels in terms of their losses of production land to mandatory buffer zones. C.C.O.F. parcels in general have a more compact shape than non-C.C.O.F. parcels, implying that C.C.O.F. parcels would potentially lose a lower proportion of land to buffer zones than a less compact non-C.C.O.F. parcel of the same area. However, C.C.O.F. parcels are much smaller than non-C.C.O.F. parcels, leaving them more vulnerable to losses in this dimension. In sum, the C.C.O.F. parcels are inherently more vulnerable to buffer zones losses than non-C.C.O.F. parcels.

Even given this inherent higher level of vulnerability to losses of land to mandatory buffers, estimates of buffer zone losses using surrounding land uses as a proxy for the requirement of buffer zones demonstrate that C.C.O.F. parcels lose a significantly lower proportion of land to mandatory buffer than would non-C.C.O.F. parcels. This is due to the fact that these parcels are much more likely to share a border with a compatible land use – both other organic farms and undeveloped land – than non-C.C.O.F. parcels. The short lesson from this analysis is that protection from edge-effect externalities is an important factor for success of certified organic farms.

This dissertation has demonstrated several key results regarding the impact of spatially heterogeneous externalities on patterns of economic activity. Yet, perhaps the broader goal of the dissertation has been to demonstrate the possibilities of new modeling approaches. This dissertation does not achieve the ultimate goal of developing a full-scale theoretical model and calibrating this model using real-world data. However, by developing basic mechanics of the theoretical model, and by developing theoretically motivated spatial statistics which can be calculated using G.I.S. technology, the dissertation provides the building blocks for development of a full-scale model.

It is important to note that the models developed in this dissertation rely on new and evolving technological tools – the sophisticated and flexible programming environment of Mathematica, and the tremendous spatial data analysis capabilities of Geographic Information Systems. New technologies loosen previous constraints on the scope and types of models that scientists can build. By providing new tools, these technologies challenge our collective imagination to expand the limits of our modeling paradigm. Hopefully, this dissertation has demonstrated some small ways in which our modeling paradigm can be expanded while still relying on the frameworks and insights developed by previous methodologies.

Appendix A

Production Spatial Dynamics

In terms of mathematical structure, the model presented in Chpater 2 is equivalent to a temporally dynamic model in which a decision maker chooses optimal switching points between activities. Because of this mathematical structure, describing changes in production technology due to changes in parameters is somewhat more complex than in a static problem and follows the same mathematical approach taken when examining a temporally dynamic problem.

For example, the derivative $\frac{\partial Y_O}{\partial l_c}$ is found using Leibnitz' rule:

$$\frac{\partial Y_O}{\partial l_c} = \alpha(\frac{\partial(\bar{l_c} - \frac{m}{d})}{\partial l_c}) - (\alpha - e_o(\bar{l_c} - \frac{m}{d}))(\frac{\partial(\bar{l_c} - \frac{m}{d})}{\partial l_c}) + \int_{\bar{l_c} - \frac{m}{d}}^{l_o} \frac{\partial \alpha - e_o}{\partial l_c}\, dl \tag{A.1}$$

This is equal to:

$$\underbrace{\alpha}_{\text{C.R.S. gain}} \underbrace{-\alpha + (m + (l_c - l_o))}_{\text{D.R.S. loss}} = \underbrace{e_o(l_o)}_{\text{net gain}} \tag{A.2}$$

The result is illustrated in Figure 2.4.

This result facilitates a formal demonstration of the assertion that $\frac{\partial Y_O}{\partial l_o} + \frac{\partial Y_O}{\partial l_c} = \alpha$:

By definition, $\frac{\partial Y_O}{\partial l_o} = \alpha - e_o(l_o)$. This represents the net marginal productivity gained by using another unit of land for production of the organic good, holding C's location fixed. From equation (A.2), $\frac{\partial Y_O}{\partial l_c} = e_o(l_o)$. This represents the productivity gain from moving C's border one unit away from O's border, holding O's location fixed. Thus, the net productivity effect of reducing C's scale by one unit and allowing one more unit of production for O is $\frac{\partial Y_O}{\partial l_o} + \frac{\partial Y_O}{\partial l_c} = (\alpha - e_o(l_o) + e_o(l_o)) = \alpha$. The result is illstrated in Figure 2.5.

Appendix B

A Competitive Equilibrium Example

Using a set of simple functional forms consistent with the assumptions of the model and a set of arbitrary parameter values, a numerical solution to the competitive equilibrium problem presented in Chapter 2 is outlined.

C's supply decision: As a specific example, assume that C's marginal productivity declines linearly, with marginal product

$$c(l_c;\beta_1,\beta_2,L)=\beta_1+\beta_2 l$$

C's resulting quadratic total production is given by:

$$C(l_c;\beta_1,\beta_2,L)=\beta_1(L-l_c)+\frac{\beta_2}{2}(L-l_c)^2 \tag{B.1}$$

C's general first-order condition for profit maximization is:

$$p_c c(l_c;L,\beta)=p_l \tag{B.2}$$

with specific solution l_c^*:

$$l_c^* = \frac{p_l - \beta_1 p_c}{\beta_2 p_c} = \frac{p_l}{\beta_2 p_c} - \frac{\beta_1}{\beta_2} \tag{B.3}$$

A's supply decision: A will supply at any price consistent with the first-order conditions for profit maximization:

$$p_a \frac{\partial Y_A(l_a^h, l_a^l; h)}{\partial l_a^l} + p_l = 0 \tag{B.4}$$

$$p_a \frac{\partial Y_A(l_a^h, l_a^l; h)}{\partial l_a^h} - p_l = 0 \tag{B.5}$$

$$\tag{B.6}$$

The solution implies:

$$p_a h = p_l \tag{B.7}$$

for any scale of production for A.

O's supply decision: Using the linear form of the externality defined in equation 2.5, O's total production, taking C's location as fixed, is:

$$O(l_o; \bar{l_c}, m, d) = (\alpha - m + d\bar{l_c})l_o - \frac{d}{2}{l_o}^2 + m\bar{l_c} - \frac{d}{2}\bar{l_c}^2 - \frac{m^2}{2d} \tag{B.8}$$

Her general first-order condition for profit maximiation is:

$$p_o o(l_o; \bar{l_c}, m, d) = p_l \tag{B.9}$$

with specific solution from equation 2.13:

$$l_o^* = \frac{p_o(\alpha - m) - p_l}{p_o d} + \bar{l_c}$$

Consumer demands General assumptions regarding the consumer's utility function are:

$$U_O > 0, \quad U_O(0) = \infty$$

$$U_A > 0, \quad U_A(0) = \infty$$

$$U_C > 0, \quad U_C(0) = \infty$$

and that the Hessian of U with respect to the three goods is a negative definite matrix.

Her general first-order conditions for utility maximization are:

$$\frac{\partial U}{\partial O} = p_o \tag{B.10}$$

$$\frac{\partial U}{\partial A} = p_a \tag{B.11}$$

$$\frac{\partial U}{\partial C} = p_c \tag{B.12}$$

$$p_o O^D + p_a A^D + p_c C^D = \underbrace{p_l(l_o^* + (l_a^{h*} - l_a^{l*}) + (L - l_c^*)) + \Pi_O^* + \Pi_C^*}_{\text{Income ``}I\text{''}} \tag{B.13}$$

As a specific example, let the consumer have Cobb-Douglass preferences over consumption of the organic and conventional goods:

$$U(O, A, C) = O^\gamma A^\delta C^{1-\gamma-\delta}$$

Her demands are:

$$O^D = (\gamma)\frac{I}{p_o} \tag{B.14}$$

$$A^D = (\delta)\frac{I}{p_a} \tag{B.15}$$

$$C^D = (1-\gamma-\delta)\frac{I}{p_c} \tag{B.16}$$

Using the explicit functional forms described above, equations B.20, B.21, B.22, B.3 2.13, B.7, B.14, B.15, B.16 and the constraints on land-use location from equation 2.7 can be used to determine a competitive equilibrium, along with the market clearing conditions:

$$C^D = C^*(l_c^*; \beta_1, \beta_2, L) \tag{B.17}$$

$$A^D = A^*(p_l, h) \tag{B.18}$$

$$O^D = O^*(l_o^*; l_c^*, \alpha, d, m) \tag{B.19}$$

As a specific example, the following arbitrary paramter values are imposed:

$$\begin{aligned}
c(l_c; \beta_1, \beta_2, L) &= \beta_1 + \beta_2 l = -2 + l \\
e_o(l) &= m - d(\bar{l_c} - l) = 2 - (\bar{l_c} - l) \\
\alpha &= 2 \\
h &= 1 \\
L &= 4 \\
\delta = \gamma = 1 - \delta - \gamma &= 1/3
\end{aligned}$$

The CE solution is calculated as follows:

1. Find C^* by substituting l_c^* into equation B.1:

$$C^*(l_c^*(p_l, p_c, \beta_1, \beta_2); \beta_1, \beta_2, L) = \beta_1(L - l_c^*) + \frac{\beta_2}{2}(L - l_c^*)^2 = 2 - \frac{{p_l}^2}{2{p_c}^2} \tag{B.20}$$

2. Substitute l_c^* for $\bar{l_c}$ in the equation for l_o^* (2.13):

$$l_o^*(l_c^*(p_l, p_c, \beta_1, \beta_2), p_l, p_o, \alpha, d, m) = \frac{p_o(\alpha - m) - p_l}{p_o d} + \; l_c^* = 2 + \frac{p_l}{p_c} - \frac{p_l}{p_o}$$

3. Find O^* by substituting in l_o^* and l_c^*. Recall that the kink in O's production function is determined by C's location, so l_c^* appears in the integrand as well as in l_o^*. (equation B.8):

$$\begin{aligned} O^*(l_o^*(p_c,\beta_1,\beta_2,p_l,p_o,\alpha,d,m)) &= (\alpha - m + dl_c^*)l_o^*(l_c^*) - \tfrac{d}{2}l_o^*(l_c^*)^2 \\ &\quad + ml_c^* - \tfrac{d}{2}{l_c^*}^2 - \tfrac{m^2}{2d} \\ &= 2 + \tfrac{2p_l}{p_c} - \tfrac{{p_l}^2}{2{p_o}^2} \end{aligned} \tag{B.21}$$

4. Find A^* by imposing the market clearing conditions on the land market:

$$A^*(p_c,\beta_1,\beta_2,p_l,p_o,\alpha,d,m) = \int_{l_o^*}^{l_c^*} hdl = \frac{p_l}{p_o} \tag{B.22}$$

5. Use the first order conditions for A (B.4,B.5) to eliminate the rental rate of land: $p_l = p_a h$, implying also that $p_l(l_a^{h*} - l_a^{l*}) = p_a h(l_a^{h*} - l_a^{l*}) = p_a A^*$.

6. Substitute C^* and O^* into the profit functions. Note, income reduces:

$$\begin{aligned} I &= p_l(l_o^* + (l_a^{h*} - l_a^{l*}) + (L - l_c^*)) + \Pi_O^* + \Pi_C^* \\ &= p_l(l_o^* + (L - l_c^*)) + p_oO^* - p_l l_o^* + p_cC^* - p_l(L - l_c^*) + p_l(l_a^{h*} - l_a^{l*}) \\ &= p_oO^* + p_aA^* + p_cC^* \end{aligned}$$

Note that I am assuming that input demands equal input supplies.

7. Using the simplified expression for income, rearrange B.17, B.18, and B.19 to obtain:

$$\begin{aligned} O^* &= \frac{\gamma}{1-\gamma}\,\frac{p_cC^* + p_aA^*}{p_o} \\ A^* &= \frac{\delta}{1-\delta}\,\frac{p_oO^* + p_cC^*}{p_a} \\ C^* &= \frac{(1-\gamma-\delta)}{\gamma+\delta}\,\frac{p_oO^* + p_aA^*}{p_c} \end{aligned}$$

This system provides two linearly independent equations which are functions of p_o, p_a, and p_c. Specifically,

$$
\begin{aligned}
O^* &= \frac{p_a A^* + C^* p_c}{2p_o} \\
A^* &= \frac{p_c C^* p_c + O^* p_o}{2p_a} \\
C^* &= \frac{p_a A^* + O^* p_o}{2p_c}
\end{aligned}
$$

Solving for O^* and C^* in terms of A^*:

$$
C^* = \frac{p_a}{p_c} A^* = \frac{1}{p_c p_o}
$$
$$
O^* = \frac{p_a}{p_o} A^* = \frac{1}{{p_o}^2}
$$

8. I normalize $p_a = 1$ for convenience. I can then solve the above equations for p_o and p_c in terms of parameters, plugging in the values for optimal output in terms of p_c and p_o from above, and use these solutions to find market clearing inputs and outputs. Continuing with the example, solving the first equation from above for p_o I obtain:

$$
-2 + \frac{1}{2{p_c}^2} + \frac{1}{p_c p_o} = 0 \Rightarrow p_o = \frac{-2p_c}{1 - 4{p_c}^2}
$$

Substituting this result in to the second equation, I obtain

$$
1 + \frac{3}{8{p_c}^2} + \frac{2}{p_c} - 2{p_c}^2 = 0 \Rightarrow p_c = 1.20711; p_o = 0.5
$$

Finally, $l_o = l_a^l = 0.828427$, and $l_a^h = l_c = 2.82843$. Again, from equations (B.4,B.5), the rental rate of land at the borders between uses is equal to $p_a h$, or in this example, 1.

Appendix C

An Empirical Land-use Model

Equation C.1 describes hypothesized empirical determinants of the probability of finding a particular parcel in certified organic production. Because output price and cost data are not included, this specification could be viewed as taking the proportion of land as organic in the particular region as given. This model contains several innovations as compared to similar models present in the literature. The first is the inclusion of the length of borders shared with neighboring parcels in organic and compatible land uses. The second is the inclusion of parcel size and a parcel shape index. These innovations represent potential influences of edge-effect externalities on the attractiveness of a particular parcel for organic farming.

The equation describing determinants of the land use of a parcel spatially located at i, j with four contiguous neighbors is:

$$Pr(Y_{i,j} = 1) = F\left(LY^N_{i,j}\rho + P\pi + G\gamma + D\tau + S\sigma + C\psi + \epsilon^N\lambda\right) \tag{C.1}$$

where F is some cumulative probability density function,

$$LY^N_{i,j}\rho = \begin{bmatrix} L^{i,(j-1)}_{i,j}Y_{i,(j-1)} & L^{i,(j+1)}_{i,j}Y_{i,(j+1)} & L^{(i-1),j}_{i,j}Y_{(i-1),j} & L^{(i+1),j}_{i,j}Y_{(i+1),j} \end{bmatrix} \begin{bmatrix} \rho^{i,(j-1)}_1 \\ \rho^{i,(j+1)}_1 \\ \rho^{(i-1),j}_1 \\ \rho^{(i+1),j}_1 \end{bmatrix}$$

$$\epsilon^N\lambda = \begin{bmatrix} \epsilon_{i,j} & \epsilon_{i,(j-1)} & \epsilon_{i,(j+1)} & \epsilon_{(i-1),j} & \epsilon_{(i+1),j} \end{bmatrix} \begin{bmatrix} 1 \\ \lambda^{i,(j-1)}_1 \\ \lambda^{i,(j+1)}_1 \\ \lambda^{(i-1),j}_1 \\ \lambda^{(i+1),j}_1 \end{bmatrix}$$

and

$$
\begin{aligned}
Y_{i,j} &= \text{1 if organic, 0 if non-organic} \\
L_{i,j}^{r,c} &= \text{Length of shared border between neighbors} \\
\rho_1^{r,c} &= \text{First-order spatial autocorrelation parameter} \\
P &= \text{Total length of shared border with non-organic protective land uses} \\
\pi &= \text{Parametric influence of protective land uses} \\
G &= \text{Vector of parcel area and shape index} \\
\gamma &= \text{Parametric influences of parcel area and shape} \\
D &= \text{Vector of impedence-weighted road distances to markets} \\
\tau &= \text{Parametric influence of transport costs} \\
S &= \text{Vector of soil class dummies} \\
\sigma &= \text{Parametric influence of soil classes} \\
C &= \text{Vector of crop type dummies} \\
\psi &= \text{Parametric influence of crop type} \\
\epsilon_{r,c} &= \text{Error term for the } r,c\ th \text{ parcel} \\
\lambda_1^{r,c} &= \text{Parametric first-order lagged error influence}
\end{aligned}
$$

This model is specified with only first-order spatial lags. The underlying assumption is that only immediate neighbors matter. The appropriate number of spatial lags could established through tests for spatial autocorrelation[1] It is reasonable to expect that all of the $\rho_1^{r,c}$ are equal, or equivalently that the influence of any organic neighbor on the probability

[1] Using the notation of Anselin [2], this model is equivalent to Anselin's generalized autoregressive model with weighting matrices W_1 and W_2 with values of one for all contiguous neighbors and zero otherwise.

of finding a parcel in an organic use is the same. Given this assumption, $LY_{i,j}^{N}\rho$ would reduce to a single variable reflecting the length of border shared with another organic farm. It is important to note, however, that the model would still be spatially autoregressive, since dependent variables serve as explanatory variables.

It is also reasonable to assume that the $\lambda_1^{r,c}$ are equal. These parameters would reflect spatial correlation between parcels not accounted for by the spatially lagged dependent and the independent variables. They may represent the influence of variables not accounted for in the specification, such as local strength of demand for organic produce, or geographic conditions such as land topography.

This specification allows for the possibility that the influence of an organic neighboring land use and of a non-organic compatible neighboring land use differ. If statistical tests rejected the hypothesis $\rho = \pi$, the hypothesis of neighborhood effects for organic growers beyond the benefits of protection from externalities would be supported. As discussed in Chapter 5, these impacts could include such factors as benefits from shared knowledge and technology.

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