Landscape Outcomes in a Model of Edge-Effect Externalities: A Computational Economics Approach*

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Abstract

This paper examines the impact of distance-dependent spatial externalities, referred to as "edge-effect externalities", on free-market equilibrium land use patterns. Under edge-effect externalities, maximization of production possibilities will depend on minimization of landscape fragmentation, implying that both the correct allocation and the correct arrangement of land uses will be necessary conditions for an economically efficient outcome. Using an agent-based cellular automaton model, this paper 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. Further, edge-effect externalities can produce economic landscapes which are more dispersed and fragmented than the pure Von Thunen outcome.

Keywords: *Economic Geography, Spatial Externalities, Land-use Patterns, Edge-Effects*

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1 Introduction

1.1 Edge-effect Externalities

This paper examines the potential impacts of a particular class of spatial externalities, titled "edge-effect externalities", on free-market equilibrium patterns of land use. Edge-effect externalities are simply spatial externalities whose marginal impacts decline as distance from the generating use increases. Many common spatial externalities meet this definition. Examples include dispersion of noise, odors, and pollutants generated by industry into residential areas, spillovers of criminal activity from dangerous neighborhoods, degradation of habitat reserves due to surrounding development, and drift of agricultural pesticides into urban areas.

Under this class of externalities, production possibilities will depend on the spatial arrangement of land uses. Parallel with relationship between ecological edge effects, landscape fragmentation, and intact interior habitat, fragmentation of land use will decrease production possibilities. Therefore, economic efficiency under edge-effect externalities requires not only the correct *allocation* of land between uses, but also the correct *arrangement* of land uses. Focusing on the later point, this paper examines the efficiency of free-market land use patterns in an economy impacted by edge-effect externalities.

1.2 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. [2]. Literature to date has recognized that spatial arrangement of land uses may be important under spatial externalities. Baumol and Oates [2] 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 [4] characterize this separation solution as a "corner solution" and discuss the circumstances in which separation may be socially optimal. Albers [1] demonstrates that spatial agglomeration is efficient when positive spatial spillovers exist. Parker [7] demonstrates that under distance dependent spatial externalities, production possibilities decrease monotonically with landscape fragmentation.

However, 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 [2], Kanemoto [5], Tietenberg [9], and Freeman [3] have focused primarily on socially optimal outcomes. Tomasi and Weise [10] and Parker [7] analyze competitive outcomes in the context of a one-dimensional model, but assume efficient spatial agglomeration of generating and recipient uses.

This paper 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 2 of this paper will outline the model's assumptions regarding production technology and will illustrate the negative production impacts of edge-effect externalities. Section 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 will demonstrate and analyze equilibrium outcomes under transport costs, edge-effect externalities, and combinations of both influences. Finally, section 5 will offer conclusions and suggest directions for future work.

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.

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.

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 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 $b - \frac{m}{d}$:

Figure 1 represents a cross section of externality damage along any border shared with a recipient. 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 2:

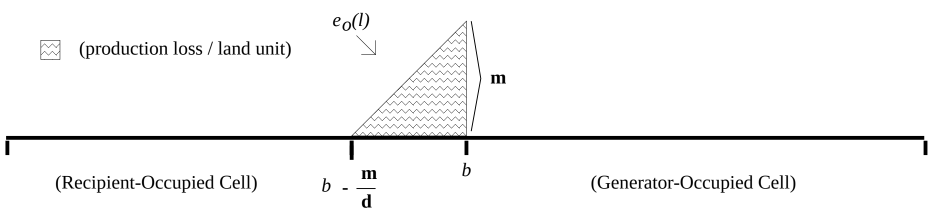

Figure 1: The Marginal Externality Damage Function

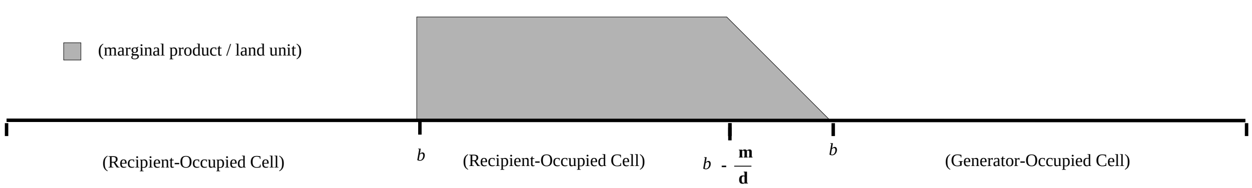

Figure 2: Cross-section of R's Production Possibilities

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. These results are demonstrated in Appendix A.

3 Markets

3.1 Returns to type G

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

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

3.2 Returns to type R

Recipients face a downward sloping, iso-elastic demand curve for their product and are price-takers. 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 (r, c) are given by:

$$\Pi_r = p_r[\rho - (\sum_i G_i * w)] - tc_r * \sqrt{(r - m_x)^2 + (c - m_y)^2} \tag{2}$$

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.

The strength of demand for recipient output is allowed to vary parametrically. 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 3.[2]

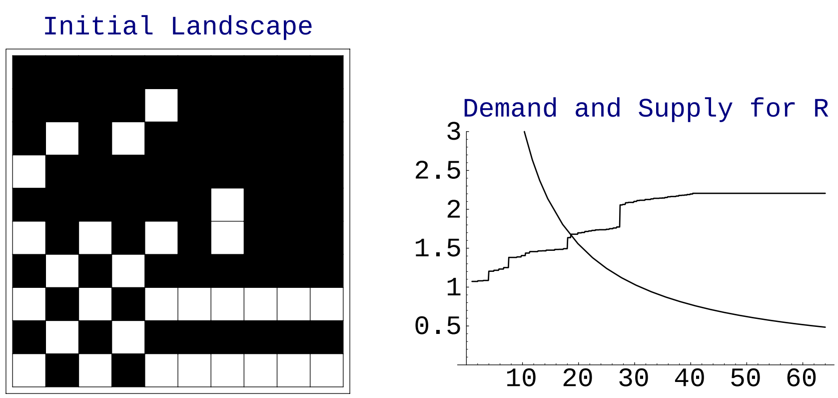

Figure 3: Sample Landscape and Supply Curve

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

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

[2]All the examples in this paper are based on the recipient demand curve $p_r = \frac{31}{Q_r}$. Border cells, assumed to represent fixed geographic features, are ignored in constructing the equilibrium. Note that in figure 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.

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 alternative, 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.[3]

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.[4]

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[3]Land uses perceived as permanent by the market, such as parks, stadiums, and schools could also fall under this classification.

[4]The Mathematica code which generated the results reported in this paper, along with additional graphics illustrating the evolution of each landscape, are available at http://www.agecon.ucdavis.edu/HOMEPAGES/D.Parker/D.Parker.

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.

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. In figures 4 and 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.

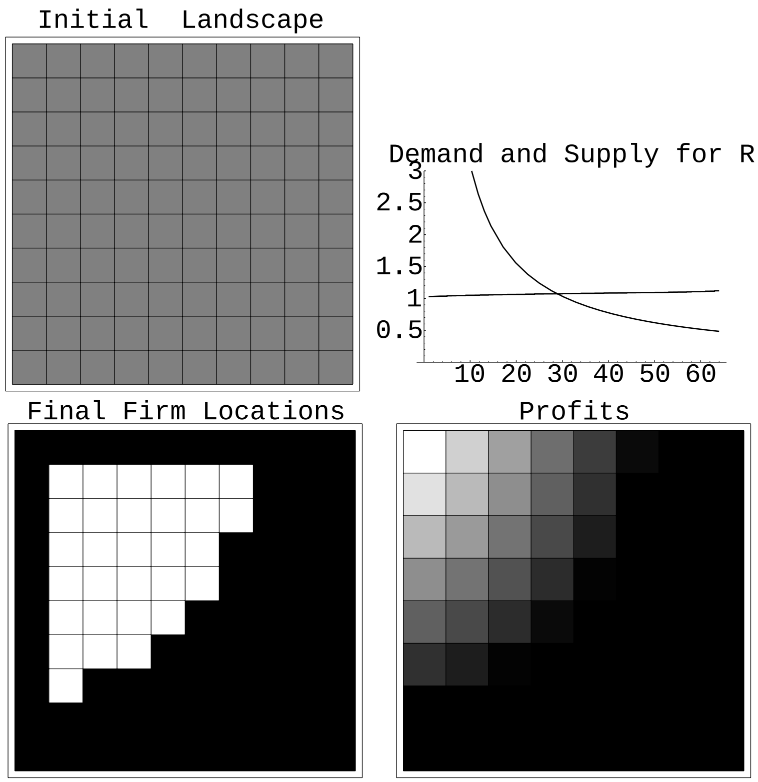
In each of these examples, the initial landscape edges contain all generating firms and no protective features. In fact, any initial landscape would lead to the same patterns of production seen here under transport costs only, since the spatial equilibrium under transport costs depends only on the location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

4.2 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.

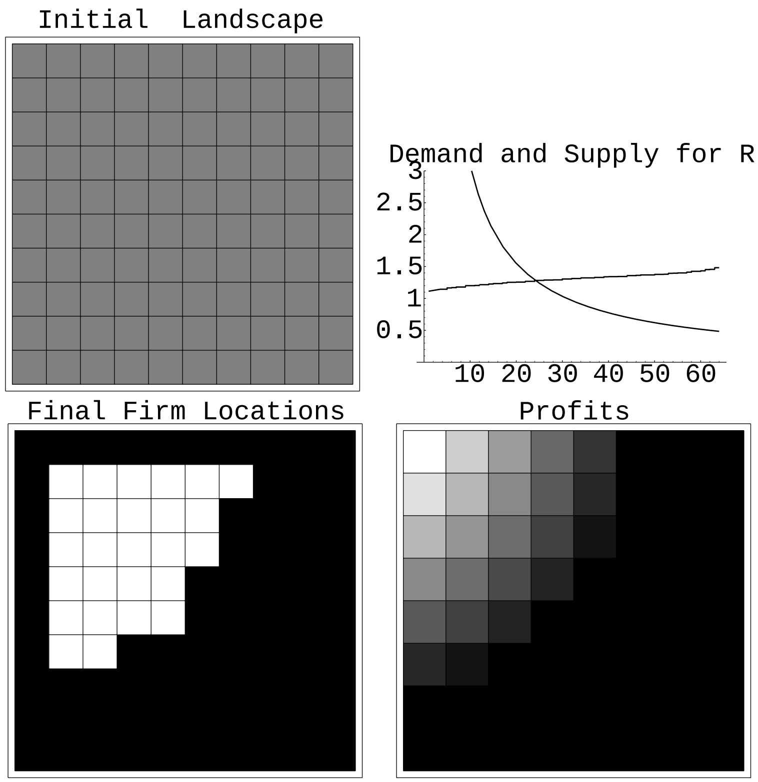
4.2.1 Initial Distributions

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 6, a relatively fragmented initial landscape leads to an efficient



Final 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: A Northwest market with low transport costs and no externalities



Final 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 5: A Northwest market with higher transport costs and no externalities

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.[5] 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).[6] 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.

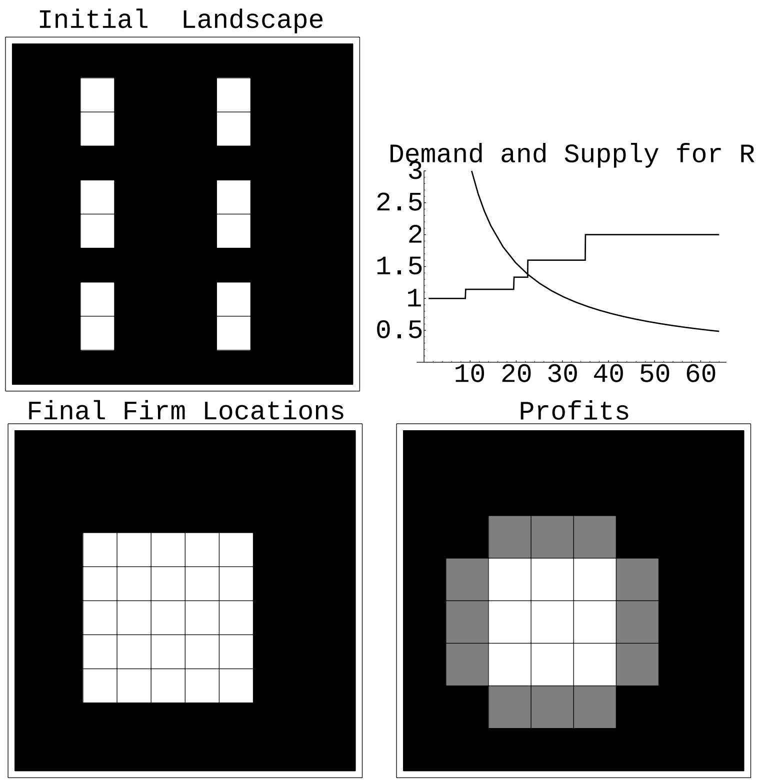
The second case clearly demonstrates the potential for emergence of a landscape that is not Pareto optimal under edge-effect externalities. Any move which would case agglomeration of the two clusters would be Pareto improving. Recipients at the borders where the two clusters connected would gain protected 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 8 demonstrates this Pareto-improving rearrangement. Notice, however, that it would not be profitable for any single recipient to switch to another clusters under the initial outcome (figure 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.[7]

The third example (figure 9) demonstrates the emergence of a highly inefficient landscape.

[5] 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.

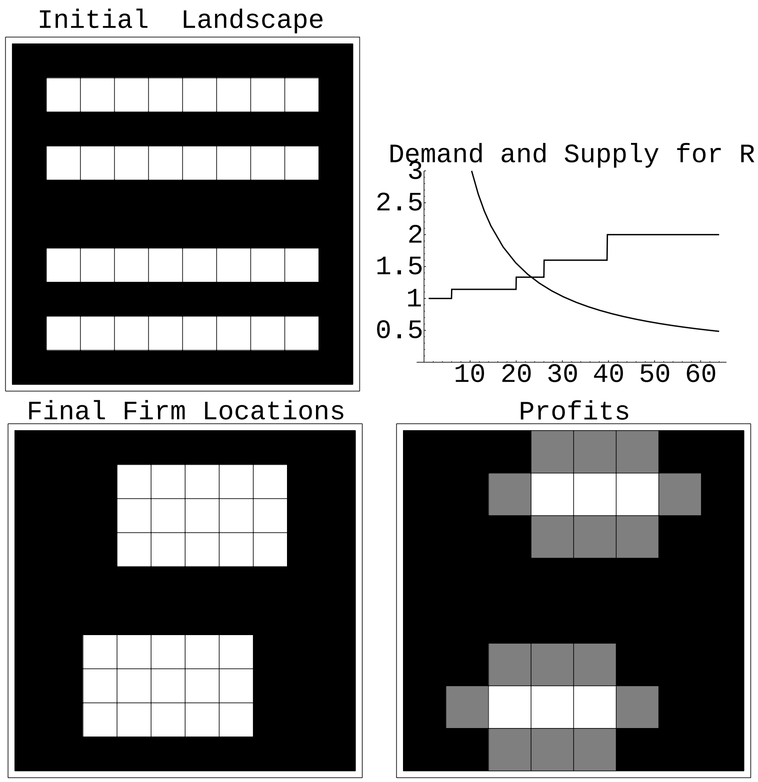
[6] This number of recipients is larger than in the first outcome due to the inefficient arrangement of production. More recipient firms are required to meet market demand, leaving less land available for production of G's product. This illustrated the essence of market failure with respect to the arrangement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

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



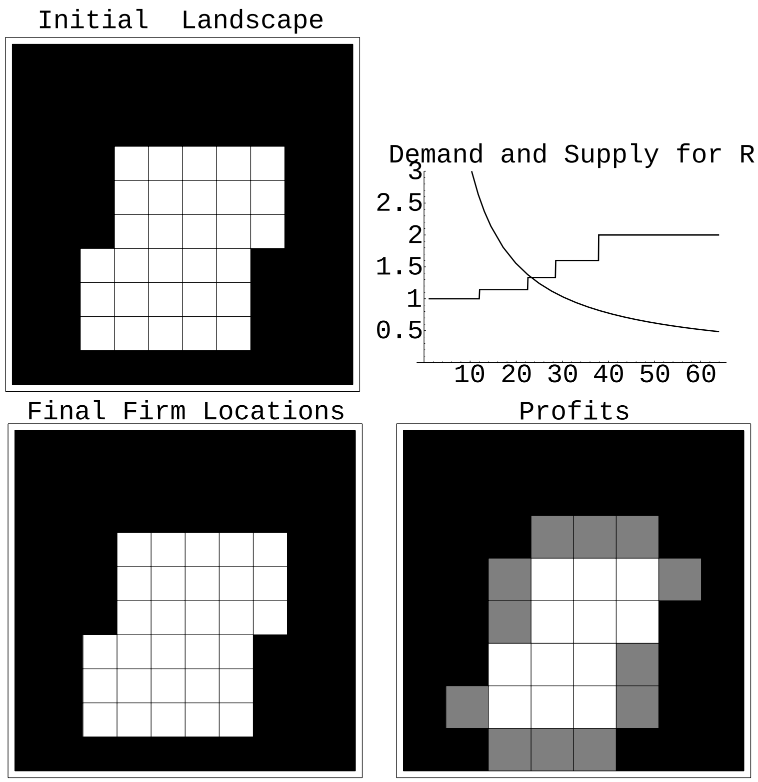
Final Results	
Transportation costs:	0.
Total Recipient Production:	22.5
Total Generator Production:	39.
Total Producer Surplus for R:	30.
Total Consumer Surplus:	458.338
Total Surplus:	527.338

Figure 6: A fragmented landscape under externalities leads to an efficient outcome



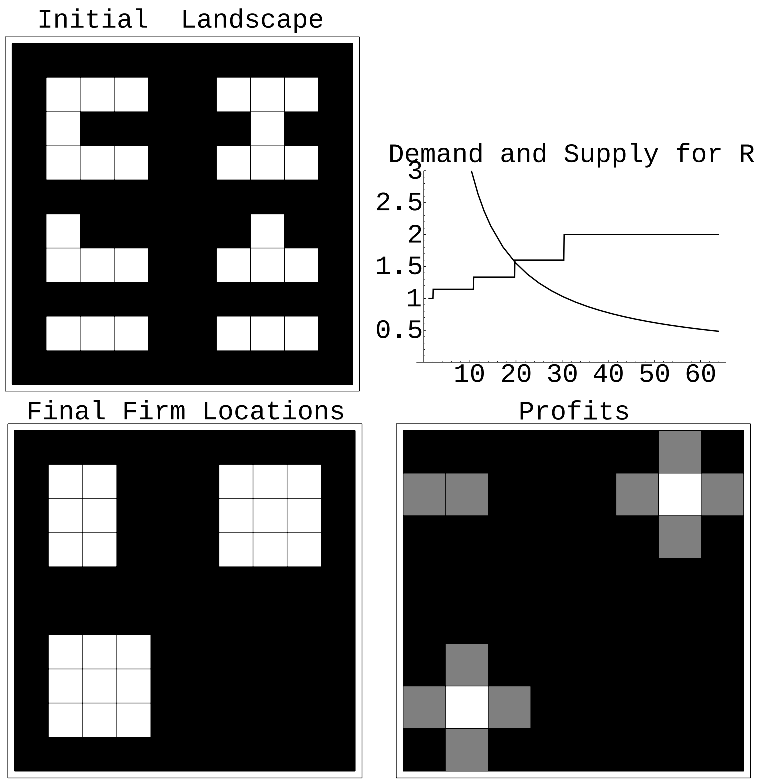
Final Results	
Transportation costs:	0.
Total Recipient Production:	26.
Total Generator Production:	34.
Total Producer Surplus for R:	34.6667
Total Consumer Surplus:	458.338
Total Surplus:	527.004

Figure 7: An inefficient outcome under externalities: the shrinking market



Final 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 8: A Pareto-Improving Rearrangement



Final 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 9: An inefficient outcome under externalities: fragmentation

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.

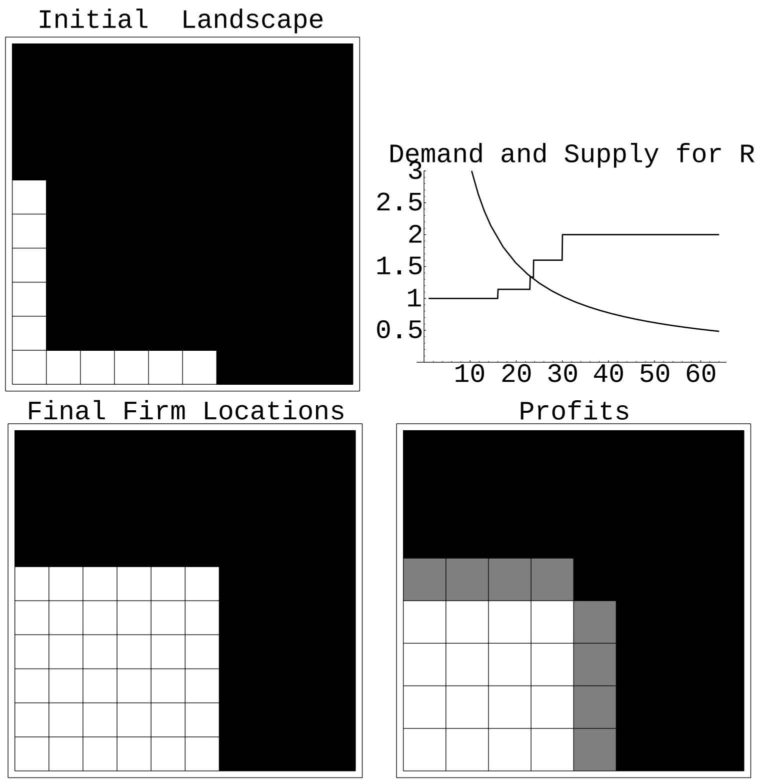
4.2.2 Geography

Figures 10, 11, 12, and 13 demonstrate equilibria determined by the locations of protective geographic features. In figure 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 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 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.[8] The fact that distribution of activity between the two clusters is relatively skewed also contributes to the relative efficiency of this landscape.[9]

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 13). In this case, four protective geographic borders would be lost, but a total of 6 protected border 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 or perhaps the firm in order for a more efficient production landscape to be realized.

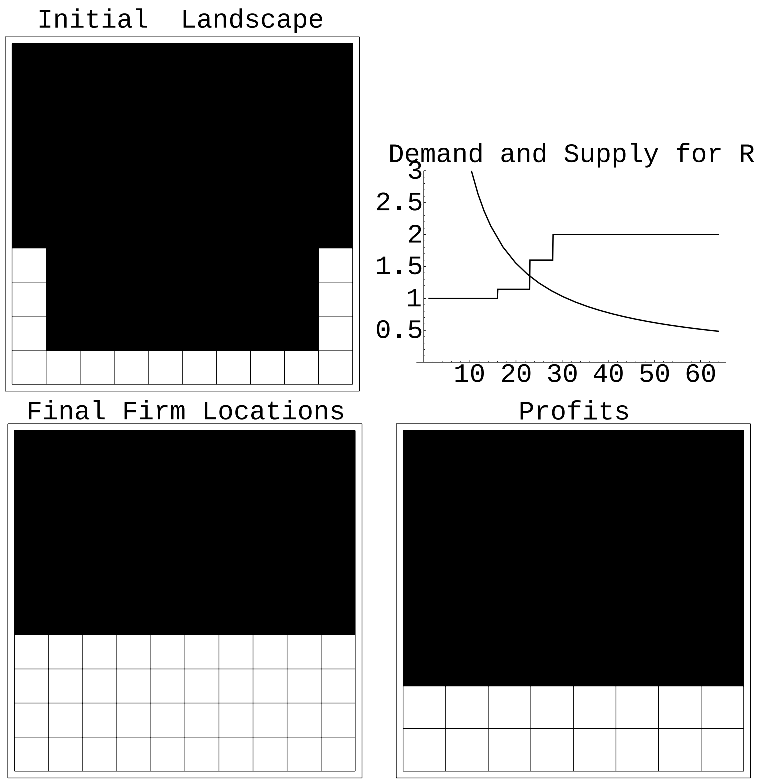
[8]The length of protected edges in the third landscape is the same as the second.

[9]See Appendix A for a formal exposition of this point.



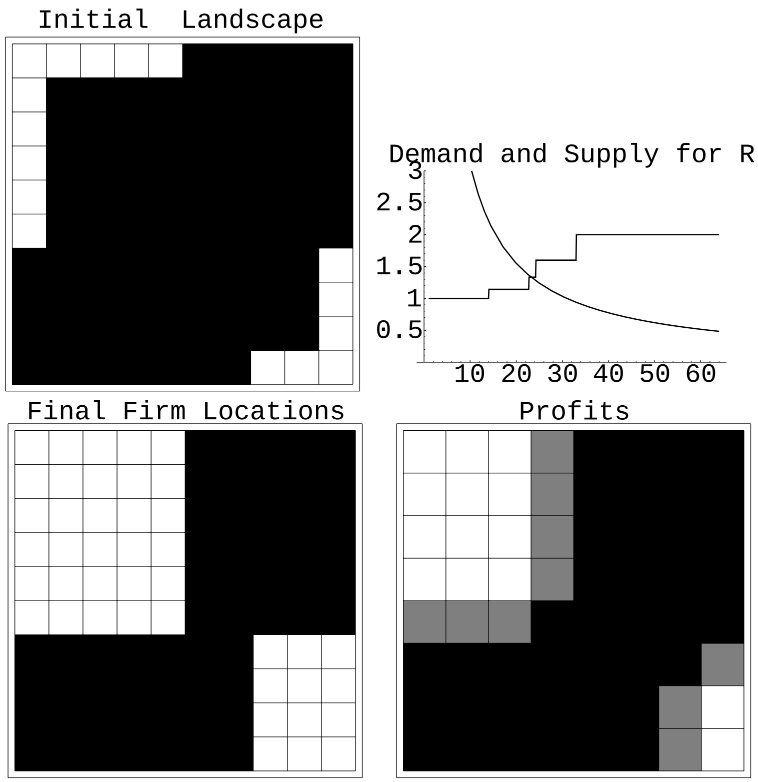
Final Results	
Transportation costs:	0.
Total Recipient Production:	23.75
Total Generator Production:	39.
Total Producer Surplus for R:	31.6667
Total Consumer Surplus:	458.338
Total Surplus:	529.004

Figure 10: An efficient geography under externalities



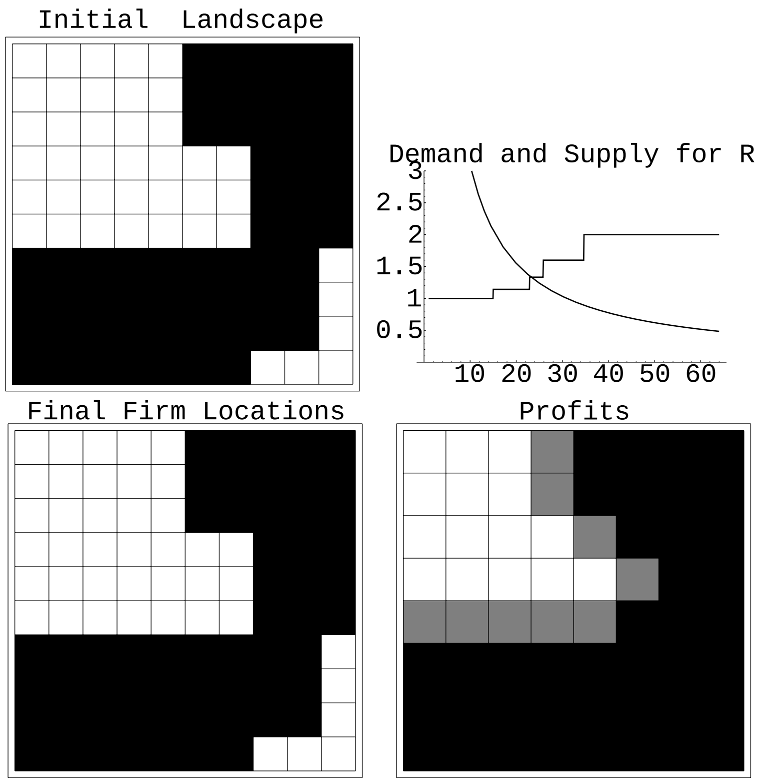
Final Results	
Transportation costs:	0.
Total Recipient Production:	23.
Total Generator Production:	40.
Total Producer Surplus for R:	26.2857
Total Consumer Surplus:	447.483
Total Surplus:	513.768

Figure 11: An inefficient geography under externalities: Agglomeration but no compactness



Final 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 12: Geography induces inefficient fragmentation under externalities



Final 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 13: Rearrangement is Pareto-improving: net gain in protected edges

4.3 Transport Cost / Externality Interactions

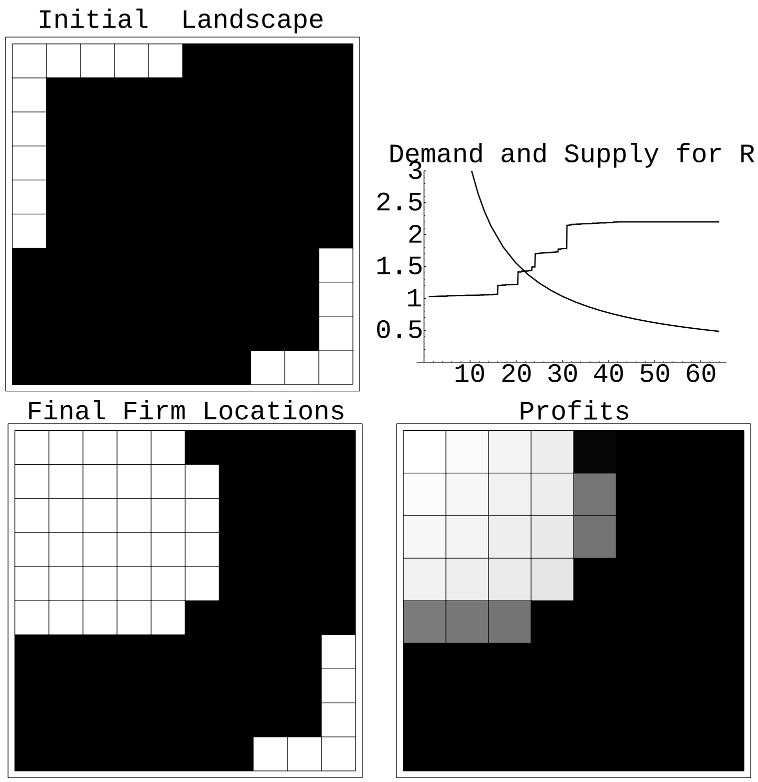
As demonstrated above in figures 4 and 5, under transport costs only, recipient firms will be clustered around the market place. The addition of edge-effect externalities will change the character of the transport cost outcome. Specifically, landscapes with externalities also present may be dispersed 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 14) introduces weak transportation costs of 0.01 to the landscape analyzed in figure12. The outcome with these transportation costs and no externalities is illustrated in figure 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 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 5.[10]

Figures 16 and 17 illustrate the impact of the initial configuration of firms on the Von Thunen outcomes, using the landscape illustrated in figure 7 and increasing transport costs of 0.01 and 0.04. Once again, the pure Von Thunen outcomes for these transport costs are illustrated in figures 4 and 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 17), recipients agglomerate into an efficient pattern, one which minimizes transport costs and is relatively compact.

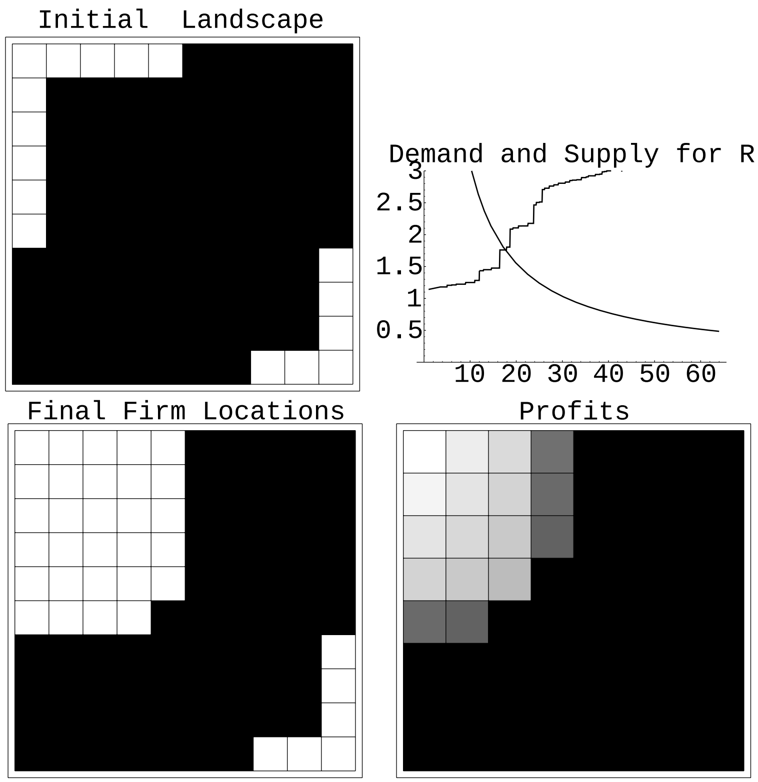
The final example illustrates a landscape influenced by both protective geographic features and the initial distribution of recipients. In figure 18, in spite of a market located in the Northwest corner of the landscape, recipients cluster quite far from the market. The

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



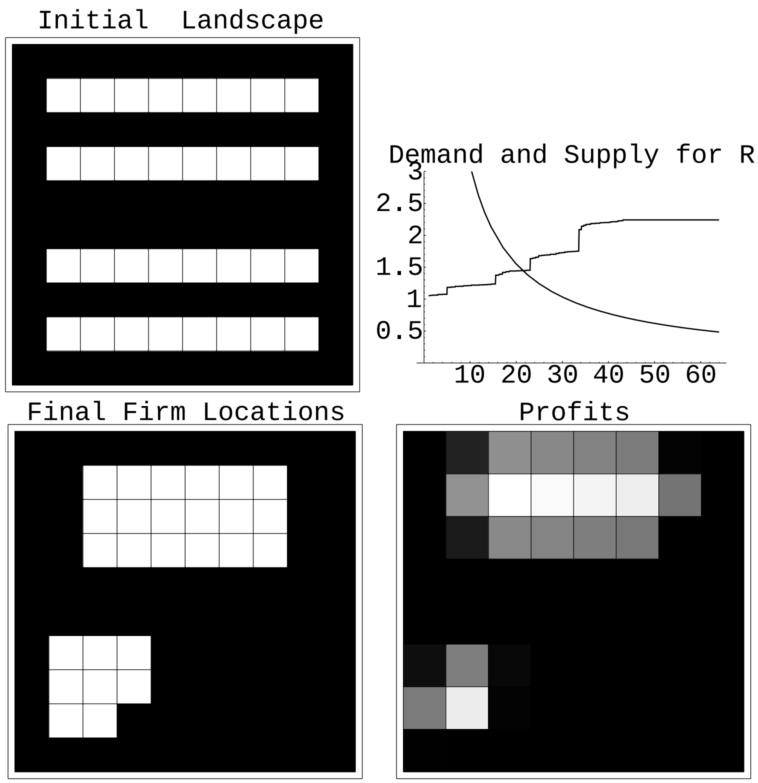
Final Results	
Transportation costs:	0.01
Total Recipient Production:	21.875
Total Generator Production:	40.
Total Producer Surplus for R:	30.0798
Total Consumer Surplus:	492.596
Total Surplus:	562.676

Figure 14: An efficient outcome under externalities: low transport costs



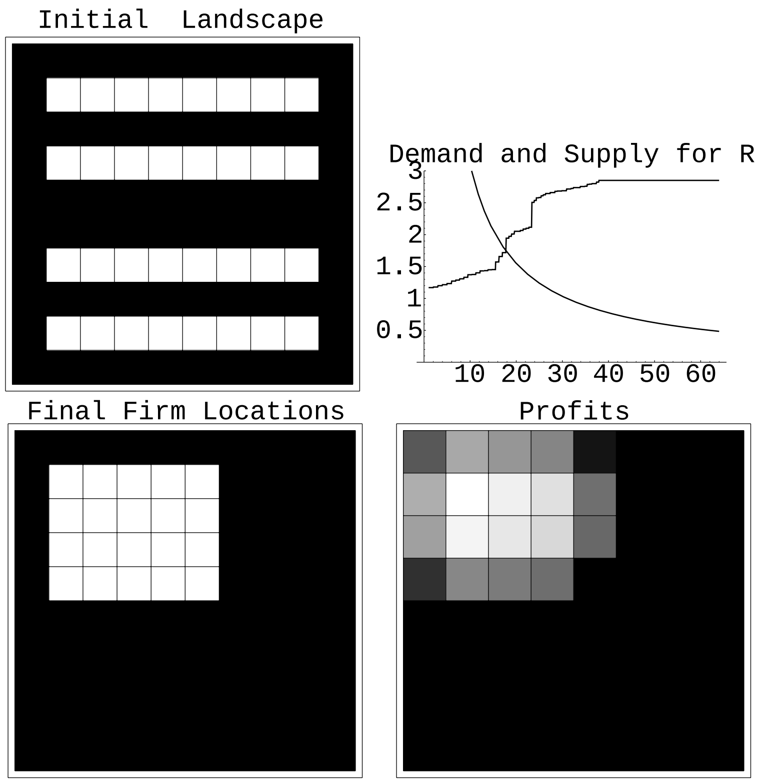
Final Results	
Transportation costs:	0.05
Total Recipient Production:	17.875
Total Generator Production:	45.
Total Producer Surplus for R:	27.0266
Total Consumer Surplus:	484.912
Total Surplus:	556.938

Figure 15: An efficient outcomes under externalities: higher transport costs



Final 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 16: A dispersed landscape under weak transport costs and externalities



Final 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 17: Higher transport costs induce efficiency

final landscape is not efficient. Figure 19 illustrates a welfare improving rearrangement of firms.

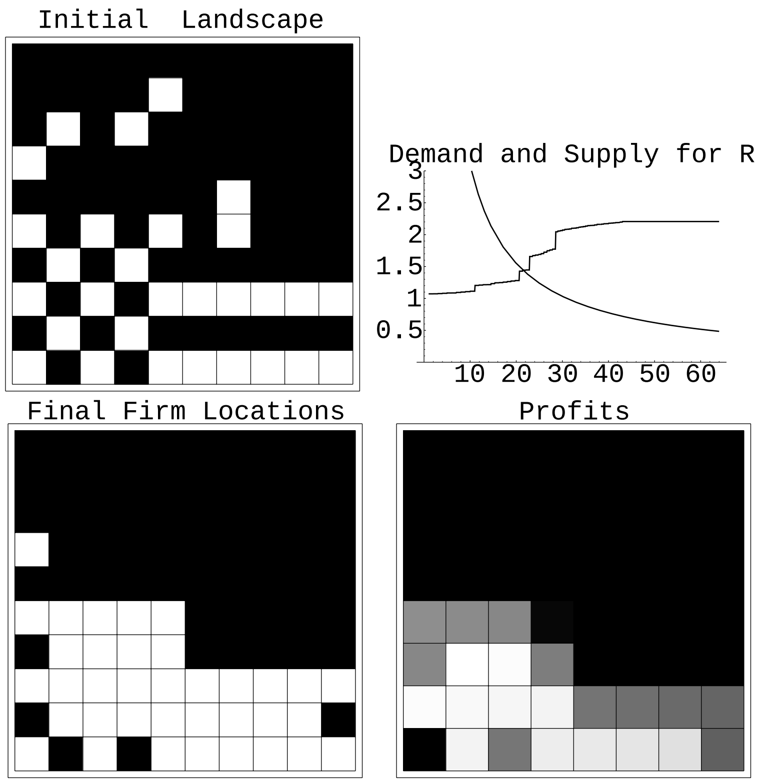
As transport costs increase, (figure 20), the single cluster of recipients moves towards the market, but the shape of the cluster remains relatively inefficient. The equilibrium outcome in this case has an interesting feature. An initial rearrangement of firms, by moving the two firms at the Southern 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 this new, rearranged landscape, the final outcome has higher total welfare than the initial equilibrium. This result is illustrated in figure 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.

5 Conclusions and Extensions

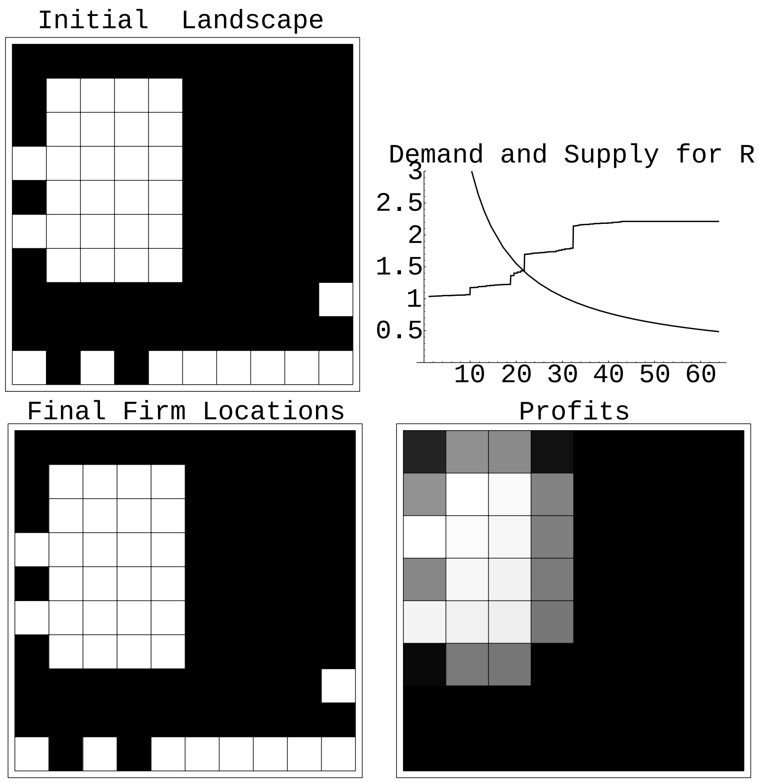
5.1 Conclusions

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



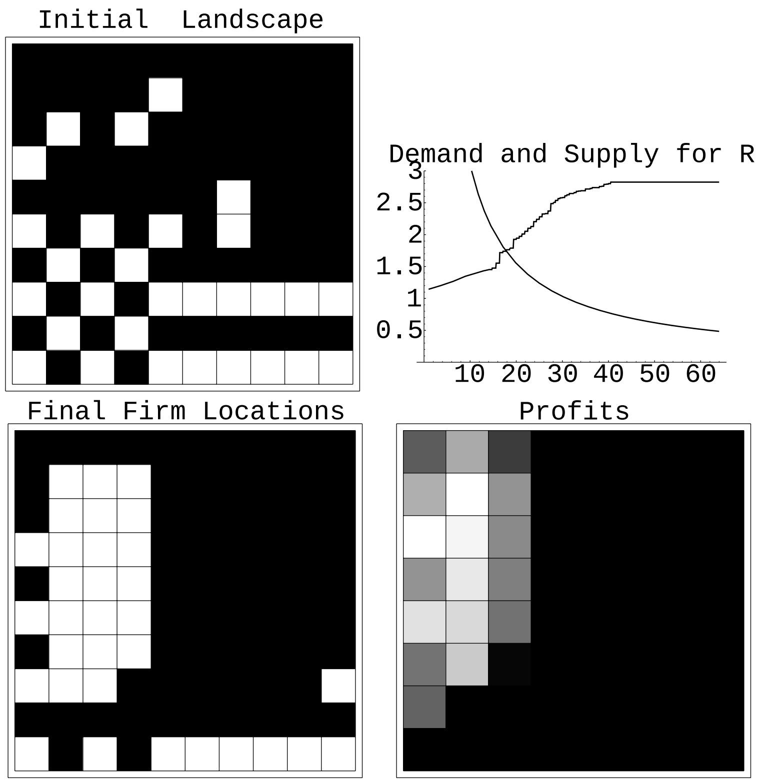
Final Results	
Transportation costs:	0.01
Total Recipient Production:	22.125
Total Generator Production:	40.
Total Producer Surplus for R:	29.8865
Total Consumer Surplus:	492.162
Total Surplus:	562.048

Figure 18: An inefficient outcome under externalities due to the initial distribution



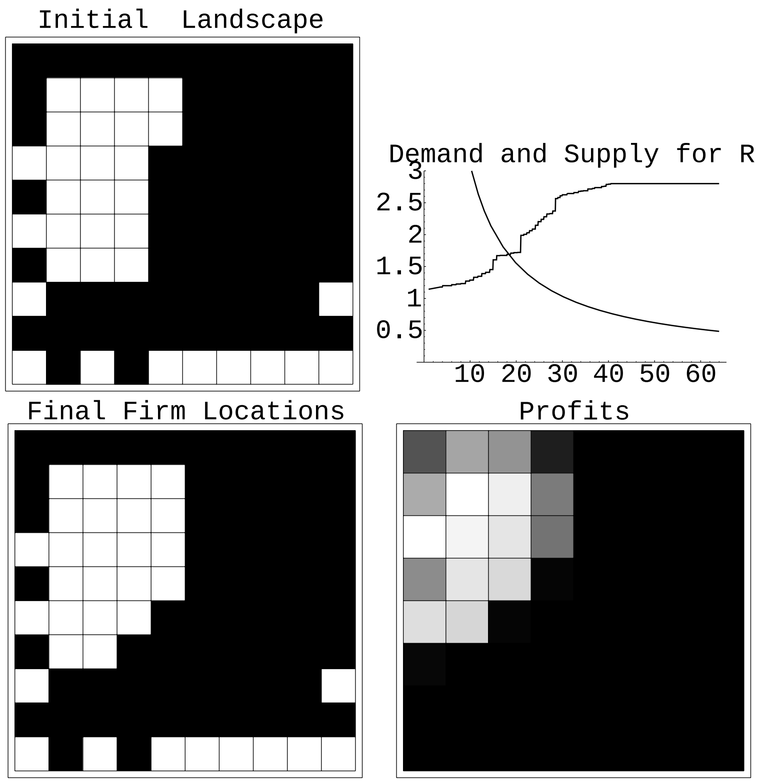
Final Results	
Transportation costs:	0.01
Total Recipient Production:	21.75
Total Generator Production:	40.
Total Producer Surplus for R:	30.0263
Total Consumer Surplus:	492.479
Total Surplus:	562.505

Figure 19: A Pareto-improving rearrangement



Final 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 20: Transportation costs induce agglomeration under externalities, but not efficiency



Final 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 21: A rearrangement leads to evolution of an efficient landscape

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.

5.2 Agenda for future work

5.2.1 Analytical rigor

This paper 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 are stable, and which are fragile? 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?

5.2.2 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 surely 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 impactes 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.

Under edge-effect externalities, two types of externalities play an important role. Negative externalities between generators and recipients lead to too much production in the generating use and too little in the recipient use. Positive externalities between recipients also play an important role, as they lead to economies of agglomeration. Coasean bargaining can theoretically lead to a Pareto optimal outcome in the case where one recipient and one generator are present in the economy. ([8]). 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. Work on a model which includes both best-response behavior and the potential for bargaining between neighbors is in progress.

5.2.3 Policy Interventions

The current model can be used to examine the impact of common policy mitigations on landscape outcomes. Pigouvian taxes are the policy response that has received the most attention in the literature ([9, 3, 10]). However, no analysis has been done examining the influence of taxes on equilibrium landscape outcomes. If they do not actually encourage efficient production patters, then Pigouvian taxes will not lead to Pareto optimal outcomes in a competitive economy, contrary to the results of the current literature.

Pigouvian 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.

5.2.4 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 appendix A. 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 paper. 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. This modeling tool could be particularly useful for landscape planners attempting to identify economically optimal habitat configuration under ecological edge effects.

5.2.5 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, Pigouvian 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 similar to the one taken by White and Engelen ([11]), who demonstrate using a cellular automaton model and a series of digitized urban landscapes that urban landscape patterns can be represented by fractal models. This approach is currently being taken by the author to examine the impact of mandatory buffer zone regulations imposed on California Certified Organic Farmers on the evolution of agricultural landscapes in California's Central valley.

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A Production Possibilities Impacts

A set of simple, stylized examples illustrates the production possibility impacts of edge-effect externalities. Available land is represented by a square, with no negative production impacts occurring at its edges. Parcels occupied by recipients originate at corners, implying that each parcel shares two borders with a generator. For mathematical simplicity, the externality damage is represented by a fixed loss at the recipient's border – no positive production is possible within one unit of the generating border. The production impacts of a marginally declining production loss are similar. A_i is the area of a given parcel, and TA is the total land area, and n is the total number of parcels affected by the externality. The marginal productivity of each unit of productive land is equal to ρ, normalized to one.

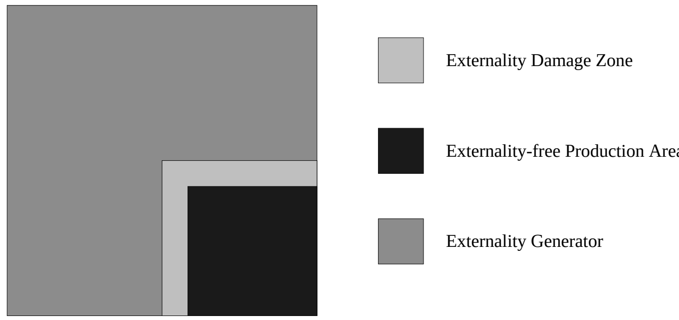

Figure 22: Two Dimensional Landscape

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 [6]. 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.

In figure 23, 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

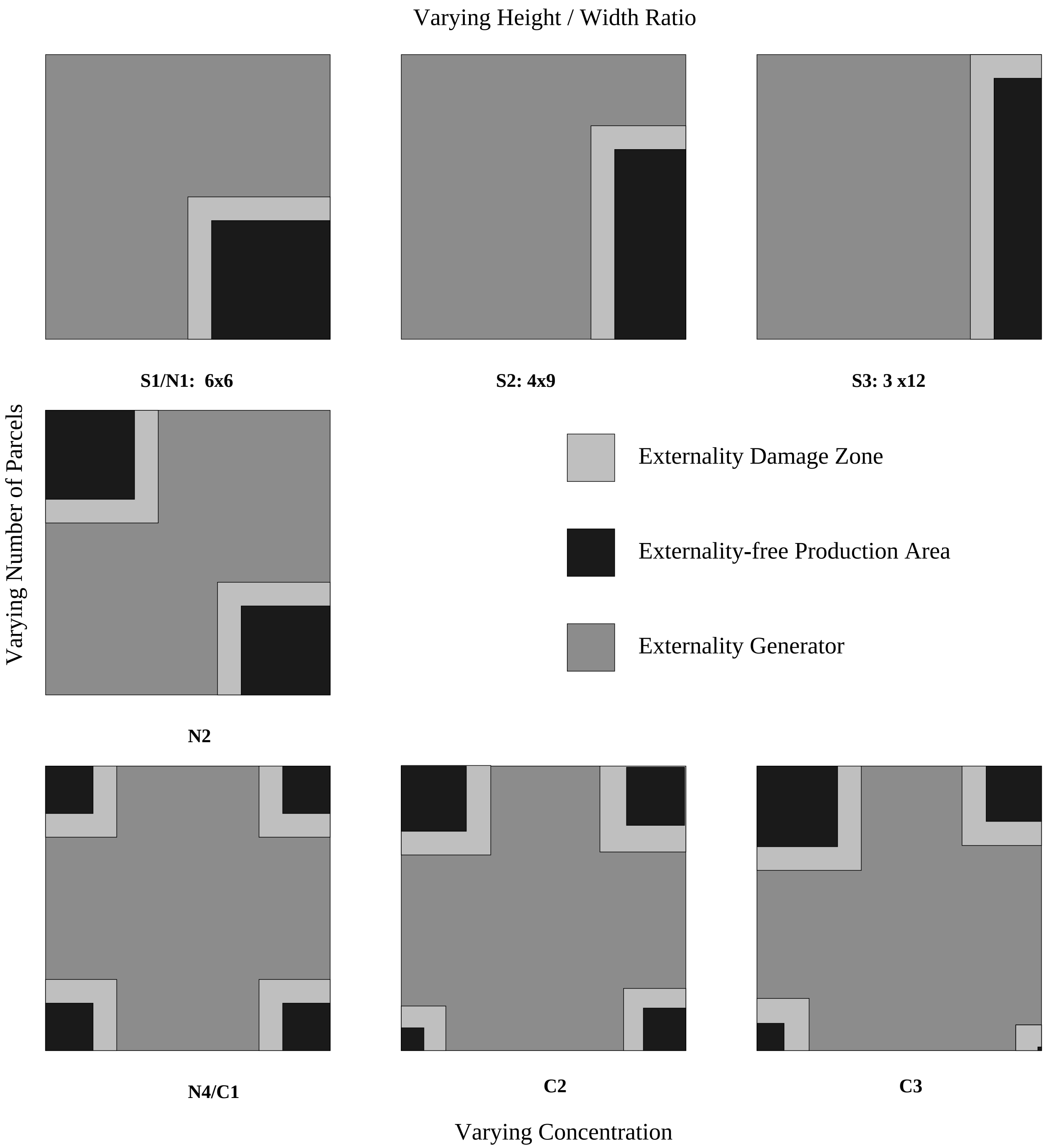

Figure 23: Varying Parcel Configurations

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.

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