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The Implications of Heterogeneous Preferences for Environmental Zoning

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The Implications of Heterogeneous Preferences for Environmental Zoning

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Abstract: This paper examines the effects of environmental zoning policies on lakefront land development, sorting, and economic welfare in a model where agents are heterogeneous in preferences and income. Agents consume lakefront amenities that are endogenous to development and the sorting process yields lakes which differ by amenities and frontage prices. Our findings include the following: i) lakes become more homogeneous with a collapsing price premium as incomes grow, ii) zoning can preserve the sorting process and be welfare improving, and iii) land prices may not capture all welfare effects from zoning.

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1. Introduction

The process of land development can affect human welfare in a variety of ways. First, there are direct effects because the density of landscape development—or lack thereof—directly affects utility. Second, land development indirectly affects human welfare via its effect on the provision of ecological goods and services such as wildlife habitat. In response, a variety of land use policies have been proposed to control land development, including policies such as minimum lot size zoning, tradable development rights, and riparian buffer zones. An implication of growth controls is that they provide a signal to heterogeneous agents about the future state of the landscape. What is often overlooked is that agents can use this signal to sort themselves across a landscape in such a way as to generate heterogeneous ecological outcomes. Therefore, growth controls can influence human welfare directly through landscape pattern and indirectly through the ecological outcomes that arise due to the sorting process.

In this paper we examine the effects of environmental zoning policies on lakefront land development, sorting, and economic welfare in a model where agents are heterogeneous in preferences and income. While our focus is on lakefront zoning, the results are generally applicable to other types of zoning. The paper begins with an analytic framework in which heterogeneous individuals consume lakefront amenities that are endogenous to lakefront development. We show that both with and without zoning, in equilibrium agents sort themselves across lakes that differ in amenity levels and frontage prices. Agents who value environmental amenities most highly end up on relatively undeveloped, high-priced lakes. However, in the absence of zoning, there are too many heavily developed, low-priced lakes, and the relatively undeveloped, high-priced lakes are not as undeveloped as they should be, because of the externality effects associated with development.

We then explore the sorting equilibrium in a world where development is dynamic and irreversible. Initially, only a subset of the population –the "lake-loving rich" –resides on the lake system in the sorting equilibrium. We consider the case of increasing incomes over time, which make the lake system more attractive and feasible to the mass of agents with average incomes and average tastes. We demonstrate that in the absence of land use controls, the population residing on the lake system becomes more homogeneous –the high-amenity and low amenity lakes converge—with a reduced price premium on the high amenity lake and a potentially lower level of amenities. The increasingly homogeneous lakefront population can drive the lake system to a common state of environmental degradation.

We use simulations to examine potential sorting outcomes associated with heterogeneous zoning. Our results show that zoning policies can preserve sorting across the lake system. This has implications for the ecological steady-state of the lake system; not only does zoning directly result in less development on some lakes, but it influences the *type* of individual purchasing lakeshore property –that is, the individual's preference for the ecological goods and services provided by the lakeshore. In other words, by preserving agent sorting, environmental zoning induces differential social-ecological feedbacks across the lake system. Lakes dominated by agents with high amenity preferences are unlikely to evolve ecologically to the same state as lakes dominated by agents with lower amenity preferences.

In terms of welfare implications, our results show that zoning can be welfare-enhancing, although the distribution of welfare gains varies across landlords and residents who occupy lakefront property. While landlords can capture land rent from environmental zoning policies, our results demonstrate that residents can simultaneously lose welfare, with the characteristics of the population determining the distribution of welfare gains and losses. One implication of this finding is that land prices may not capture all welfare effects of environmental zoning.

This paper complements the body of literature regarding agent sorting across communities that differ in taxes and public services (e.g. Tiebout 1955; Hamilton 1976; Epple et al. 1993; Wheaton 1993; Epple and Sieg 1999). Most of the sorting literature assumes that community-specific amenities are exogenous (Epple and Sieg 1999; Sieg et al. 2004) and find that the sorting process results in high-amenity communities having high housing prices. Moreover, the previous literature is primarily concerned with a static sorting equilibrium and not in equilibrium adjustments to income growth or other disturbances to the system. In our paper, we analyze the adjustment of the sorting equilibrium to income growth where amenities are endogenous because they depend on the level of lakefront development and thus the locational choices of agents.

In the following section we present evidence of lakefront sorting based on survey findings from Vilas County, Wisconsin. In section 3 we develop an analytical framework to analyze the sorting of heterogeneous individuals across a lake system with income growth. The possibility that zoning operates as a signal for sorting is also introduced in section 3. In section 4 we develop a simulation model to explore potential general equilibrium adjustments to zoning policies and income growth, with a focus on the welfare impacts of environmental zoning. In section 5 we discuss the results and offer some concluding remarks.

2. Survey evidence of sorting and environmental zoning

Evidence of agent sorting across a lake system comes from a recent survey of lakeshore property owners in Vilas County, Wisconsin. Vilas County is located in the northeast corner of the state. Northeastern Wisconsin is a prime regional vacation destination, in part because it is heavily forested, and in part because it has the highest concentration of freshwater lakes in the world. Nearly 60% of the housing stock in Vilas County is seasonal; this proportion is about 70% for lakeshore properties.

The past 50 years have seen significant lakeshore development and a concomitant fragmentation of lakeshore riparian zones. The State of Wisconsin adopted lakeshore development ordinances in 1965, with the major restriction affecting development density being a minimum frontage requirement (MFR) of 100 feet. Over the years, 7 of Vilas County's 14 towns have adopted the stricter MFR of 200 feet, beginning with the town of Presque Isle in 1959.

Concerned about the impact on lake ecosystems of the rapid rate of lakeshore development, in 1997 the Wisconsin Department of Natural Resources developed a grant program to encourage the state's counties to develop "lake classifications", whereby lakes are classified according to the sensitivity of their ecosystems to development, and ordinances restricting lakeshore development are written accordingly. The VCLC was passed into law in 1999. It classifies lakes according to their ecological sensitivity (three levels, low medium and high) and level of development as of 1999 (three levels, low medium and high). The result is that every lake in the county falls in a cell of a 3x3 matrix of development and ecological sensitivity, with MFRs customized to each cell. The MFR is strictest for relatively undeveloped, ecologically sensitive lakes.

The survey of Vilas County lakeshore property owners was conducted in June 2005, 3300 randomly-selected lakeshore property owners were contacted with the request that they complete an Internet survey concerning their lakeshore property. The survey included a large variety of questions concerning lake recreation activities, knowledge of lake ecology, expectations about future development, and willingness to pay to prevent addition development. A follow-up mail survey was sent in January 2006 to every member of the original sample who did not respond to the Internet survey. The overall response rate was 52%.

The survey results indicate that people are indeed sorting across Vilas county lakes, and suggest that agents are responding to lakeshore zoning restrictions, either directly, by calculating (in a loose sense) that a lake's future state of development depends on current development restrictions (as specified in the VCLC), or indirectly, as reflected by the finding that lakes that are relatively undeveloped because of their long period of protection under strict town ordinances are settled by a different type of lakeshore property owner than those lakes in towns that through the years remained under weaker state ordinances until the adoption of the VCLC in 1999.

Figures 1 makes this point. The figure is drawn from the following question on the survey:

> "If you could make no more than three changes to your lake from the following list, to make your lake more like what you consider the "ideal" lake, which would you choose?"

The list included 18 possible changes, ranging from “make my lake bigger” to “make my lake quieter –fewer motor boats and jet skiis”. Figure 1 reports the proportion of respondents in each of four categories who included among their three changes, “Reduce the amount of development on my lake”. The categories distinguish respondents who bought their properties in 1999 or later (recall that the VCLC was adopted in 1999) from those who bought their properties before 1999, and distinguishes between those respondents on lakes with an MFR of 150 feet and those on lakes with an MFR of 300 feet. Keeping in mind that under the lake classification the MFR decreases with development density (so that the MFR is less strict on more heavily developed lakes), the figure reveals strong heterogeneity with respect to preferences over lakeshore development: respondents on relatively undeveloped lakes are actually *more* likely to identify reduced development as one of the changes they would most like to make on their lake. The figure also suggests that the VCLC is directly affecting this sorting: the disparity in responses between respondents on lakes with MFRs of 150 feet vs. 300 feet is greater *after* the VCLC was imposed. That is, although the sorting across lake development levels is generally evident in the data, it is strongest for recent purchasers. Similar sorting results are apparent throughout the survey. For instance, individuals on highly developed, relatively unrestricted lakes are more likely to participate in waterskiing and jet skiing.

3. Analytic model of lakefront sorting

In this paper we assume that people’s choice of lakefront property depends on the amount of frontage they can purchase and the amount of amenities present on the lake. Development along a lake impacts the amenity flow to each parcel and we assume that the amenity flow is decreasing in the density of lakeshore development. Therefore, each landowner on the lake contributes to the lake specific public good—amenities—but is not compensated for their specific contribution to the public good.

3.1 Static model

Suppose there are J lakes on the lake system, each with fixed boundaries. Further, suppose a lake provides a level of amenity A, and the price of shoreline frontage on the lake is P. Amenities and prices are endogenous to development. For simplicity, we assume that each individual on a lake consumes frontage level f, and a composite private good b. Households differ in income, y, and in a taste parameter, α, which defines the household's valuation of the lake-specific amenity. The continuum of households is described by the joint distribution of y and α, according to the density f(y, α). Each household is assumed to solve the following problem:

$$\max_{f,b} \quad U(\alpha, A, f, b) \quad s.t. \quad Pf = y - b \tag{1}$$

Alternatively, the preferences of a household can be described by the indirect utility function derived by solving (1):

$$V(\alpha, A, P, y) = U(\alpha, A, f(\alpha, A, P, y), y - Pf(\alpha, A, P, y)) \tag{2}$$

Since households prefer higher levels of amenities and lower prices, there is an indirect indifference curve in the (A, P) plane with the following positive slope:

$$M(\alpha, A, P, y) = \left.\frac{dP}{dA}\right|_{V=\hat{V}} = -\frac{\partial V(\alpha, A, P, y)/\partial A}{\partial V(\alpha, A, P, y)/\partial P} > 0 \tag{3}$$

M() is assumed to be monotonically increasing in α and y, which implies that indifference curves in the (A, P) plane satisfy the single crossing property in α (Epple and Sieg 1999), where agent indifference curves in (A, P) space only cross once. Single crossing implies $\frac{d^2P}{dAdy} > 0$ and $\frac{d^2P}{dAd\alpha} > 0$, and agents with high levels of α are willing-to-pay more for a given increment in A (Cooper 1984).

Let (A_i, P_i) and (A_j, P_j) be the level of amenities and frontage price on lakes i and j, and suppose that some individuals prefer (A_i, P_i) and others prefer (A_j, P_j). Then the set of individuals indifferent between the two lakes is given by (α, y) such that

$$V(\alpha, A_j, P_j, y) = V(\alpha, A_i, P_i, y) \tag{4}$$

Epple and Platt (1998) show if M() is monotonic in y and α, then (4) implicitly defines a monotonic function α(y) satisfying indifference between (A_i, P_i) and (A_j, P_j). We assume an equilibrium exists[3] and present necessary conditions that hold in equilibrium for lakes that differ in amenities and, hence, differ in frontage prices and the characteristics (y and α) of inhabitants.

Proposition 1/ *This proposition is adapted from Epple and Sieg (1999). Consider an equilibrium allocation in which no two lakes have the same frontage prices. For such an allocation to be a spatial equilibrium, there must be an ordering of lake pairs, {(A_1, P_1), (A_2, P_2),….,(A_J, P_J)}, such that the following holds:*

1) *Boundary Indifference: individuals on the boundary of two adjacent lakes are indifferent between the two and are characterized by the set:*

$$I_j = \{(\alpha, y) \mid V(\alpha, A_j, P_j y) = V(\alpha, A_{j+1}, P_{j+1}, y)\}, \forall j = 0,1,\ldots,J \tag{5}$$

where (A_0, P_0) and (A_{J+1}, P_{J+1}) indicate off-lake systems.

[3] Epple and Platt (1998) found that equilibrium exists in computational examples in a model with both income and preference heterogeneity. Epple et al. (1993) provide a rigorous proof of existence in a model with just income heterogeneity.

2) *Sorting: Let $\alpha_j(y)$ be the implicit function defined by (4). Then, for each y, the residents of lake j consist of those with preferences α, given by*

$$\alpha_{j-1}(y) < \alpha < \alpha_j(y) \qquad (6)$$

3) *Increasing bundles: Consider two lakes i and j such that $P_i>P_j$. Then $A_i>A_j$ if and only if $\alpha_i(y) > \alpha_j(y)$.*

Proof/ See appendix.

Proposition 2 presents conditions for the sorting equilibrium when residents have a continuous distribution of income and amenity preferences. If all individuals have an identical income, then the sorting occurs by preferences alone, where individuals with high α reside on high-amenity, high-price lakes. If individuals differ by income and preferences, several lakes may have residents of a given preference, so that lakes are not perfectly sorted by preferences alone. Instead, the sorting equilibrium is represented by layered "slices" of the joint distribution of y and α where each slice encompasses the population on a given lake.

The "slice" representing the sorting equilibrium is shown in Figure 2, where for simplicity we aggregate across lakes to show the slice of the population on the entire lake system. The slice could be horizontal or vertical to the amenity axis, or the slice could be somewhere in between—as in Figure 2. The upper boundary is represented by the set of agents indifferent between the highest-amenity, highest-priced lake on the system, and the bundle of amenities and prices on an alternate off-lake system:

$I_J = \{(\bar{\alpha}, \bar{y}) \mid V(\bar{\alpha}, A_J, P_J, \bar{y}) = V(\bar{\alpha}, A_{J+1}, P_{J+1}, \bar{y})\}$, where $A_{J+1}>A_J$ and $P_{J+1}>P_J$. The exogenous alternate system (hereafter referred to as the high off-lake alternative) could represent a separate lake system that is more pristine and expensive to visit, or it could represent some other location with a high level of amenities and high prices (e.g. a beach-front hut on a tropical island). Likewise, the lower boundary is represented by the set of agents who are indifferent between the lowest-amenity, lowest-priced lake on the system, and being off the system entirely: $I_1 = \left\{(\underline{\alpha}, \underline{y}) \mid V(\underline{\alpha}, A_1, P_1, \underline{y}) = V(\underline{\alpha}, A_0, P_0, \underline{y})\right\}$ where $A_0 < A_1$ and $P_0 < P_1$. The bundle (A_0, P_0) refers to the amenity and price pair on the system hereafter referred to as the low off-lake alternative.

An important difference between this model and that of Epple and Sieg (1999) is that this model concerns only the subset of the population residing on the lake system. This makes the model somewhat akin to an open-city model where agents can reside in alternate cities (e.g. Brueckner 1990). However, utility varies across individuals in our model rather than always equilibrating to some exogenous constant level as in traditional open-city models.

A primary feature of the sorting equilibrium in proposition 1 is that lakes are differentiated by amenities and prices, such that higher amenity lakes have higher prices. The slice of the population on the lake system (figure 2) consists of J layered slices corresponding to the J lakes on the system. The highest amenity lake on the system is comprised of a population with higher amenity preferences and/or higher incomes than the population on any of the lower amenity lakes.

3.2 The effect of income growth on lakefront sorting

In the absence of growth controls, development proceeds over time in response to changes in *private* benefits and costs. Given that not all benefits and costs are incorporated in the development decision, and development is quasi-irreversible, the development state at any point in time reflects an accumulation of inefficient decisions.

Zoning is a fairly blunt means of incorporating *social* benefits and costs in the development process, but its effect is sharpened by the opportunity for heterogeneous agents to sort themselves into the zones (lakes) they prefer. In effect, non-uniform zoning implicitly recognizes the heterogeneity of preferences in the population, but relies on the market to determine who ends up in which zone.

To set the stage for understanding the effects of environmental zoning, we first examine analytically the effect of income growth on development and sorting equilibria in the absence of zoning. We use income growth as the driver for development because this is likely one of the primary forces underlying lakeshore development. Suppose there is an income shock which shifts the distribution of income upwards but doesn't shift the distribution of tastes: formally, $f(\alpha, y)$ shifts to $f'(\alpha, y)$. The number of people on the lake system before the shock is defined by $\int_{\underline{\alpha}}^{\bar{\alpha}}\int_{\underline{y}}^{\bar{y}} f(\alpha, y)dyd\alpha$, and the population with these same preferences and incomes after the shock is assumed to be larger than before the shock: $\int_{\underline{\alpha}}^{\bar{\alpha}}\int_{\underline{y}}^{\bar{y}} f'(\alpha, y)dyd\alpha > \int_{\underline{\alpha}}^{\bar{\alpha}}\int_{\underline{y}}^{\bar{y}} f(\alpha, y)dyd\alpha$. Proposition 2 describes the new sorting equilibrium after the shock.

Proposition 2*: A positive income shock, such that* $\int_{\underline{\alpha}}^{\bar{\alpha}}\int_{\underline{y}}^{\bar{y}} f'(\alpha, y)dyd\alpha > \int_{\underline{\alpha}}^{\bar{\alpha}}\int_{\underline{y}}^{\bar{y}} f(\alpha, y)dyd\alpha$*, will result in a new sorting equilibrium with the following characteristics:*

1. A more homogeneous population, with the boundary lakes defined by:

$$I_1 = \left\{(\underline{\alpha}', \underline{y}') \,|\, V(\underline{\alpha}', A_1', P_1', \underline{y}') = V(\underline{\alpha}', A_0, P_0, \underline{y}')\right\} \text{ where } (\underline{\alpha}', \underline{y}') > (\underline{\alpha}, \underline{y})$$

$$I_J = \left\{(\bar{\alpha}', \bar{y}') \,|\, V(\bar{\alpha}', A_J', P_J', \bar{y}') = V(\bar{\alpha}', \bar{A}, P_J, \bar{y}')\right\} \text{ where } (\bar{\alpha}', \bar{y}') < (\bar{\alpha}, \bar{y})$$

2. *The price premium between the highest amenity lake and the lowest amenity lake will be less than before the shock:* $P_J' - P_1' < P_J - P_1$.
3. *Amenity levels on each lake are no higher than before:* $A_j' \leq A_j$ *for all j.*

Proof/ see appendix.

Proposition 2 states that the new sorting equilibrium results in a lake system which has a more homogeneous population and a lower price premium between lakes. The intuition for the increased homogeneity of the population is the following. The increase in income serves to increase the demand for lake frontage. With reference to Figure 1, the frequency distribution of the population shifts up in the y-dimension, so that the population mass covering the original slice of the lake system in $\alpha - y$ space is greater. This bids up the price of frontage. At the same time, because development is irreversible, the level of amenities on each lake cannot increase, and more typically decrease. Keeping in mind that lakes are defined by their amenities and prices, it follows that lakes in the system are necessarily less attractive after incomes rise. Consequently, individuals originally at the upper boundary of the lake system, $(\overline{\alpha}, \overline{y})$, prefer to move up to the high off-lake alternative, and individuals at the lower boundary, $(\underline{\alpha}, \underline{y})$, prefer to move down to the low off-lake alternative. The result is that even as the income shock increases the number of individuals on the lake system, the "slice" of the population on the lake system is thinner –that is, the population on the lake system is more homogeneous.

The intuition for the decrease in the price premium associated with a high amenity lake follows immediately from the increasing homogeneity of the lake population. The price premium for high-amenity lakes depends on *both* heterogeneity of development on the lakes, *and* heterogeneity in the population residing on the lake system. As the population becomes more homogeneous, competitive pressures assure that prices become more homogeneous as well; quite simply, there is less pressure to bid up the price of high-amenity lakes when the difference between the most and least amenity-loving agents on the lake system is relatively small. While a collapsing price premium seems to intuitively imply a faster rate of development on higher amenity lakes relative to lower amenity lakes, our derivation of the collapsing price premium arises from the increasing homogeneity of the lake population. It is possible for a collapsing price premium to occur concurrent with unchanging lakefront amenity levels, or with lakefront amenity levels which decline as incomes grow. The ultimate effect of income growth on amenity levels depends on the general equilibrium adjustment process used to sort residents across lakes. Simulation methods are used below to explore such adjustment.

3.3 Environmental zoning and the sorting equilibrium with rising incomes

Environmental zoning on lake shorelines typically involves restrictions on the amount of frontage individuals may own –so-called minimum frontage restrictions (MFRs). Such restrictions are aimed at increasing the flow of environmental goods and services on lakes by reducing the number of properties allowed to develop along the shoreline. These goods and services –the amenity of our formal model –are not pure private goods. The decision to subdivide a parcel reduces the flow of these goods and services to all agents on the lake, yet this cost is not borne by the decision maker. Lakeshore zoning is one way to correct this inefficiency. Papenfus and Provencher (2005) show that MFRs can either increase or decrease aggregate welfare. Importantly, they assumed a homogenous population, and so the optimal MFR is uniform. Yet the typical zoning ordinance is not uniform –the Vilas county Lake Classification is no exception –and in general preferences are not heterogeneous. This leads to the question, What are the consequences of heterogeneous zoning in a world of heterogeneous agents?

Consider, for instance, the following example. Suppose there is a system of two lakes (J=2) where $P_1<P_2$ and $A_1<A_2$. Further, suppose incomes rise resulting in new prices (P') and amenity levels (A'), where $P_j'>P_j$ and $A_j'<A_j$ for j=1,2. In adjusting to the new equilibrium, some people who chose Lake 2 prior to the income shock will be better off moving to the high off-lake alternative. In addition, some people who chose Lake 1 prior to the income shock will move to Lake 2, and some people on the low off-lake alternative may move onto Lake 1. This process will result in a collapsing price premium and a more homogeneous population between the two lakes. Now suppose Lake 2, and only Lake 2, was zoned such that no additional development could occur, in which case $A_2'=A_2$. Under such a zoning policy, we'd expect the following consequences: some people may remain on Lake 2 rather than move to the high off-lake alternative; some people may stay on Lake 1 rather than move to Lake 2; some people may stay on the low off-lake alternative rather than move to Lake 1; and Lake 1 amenity levels may be lower if more people locate on Lake 1. The ultimate effects of zoning on welfare would consist of the following: a loss of utility to some residents for not being able to locate on the lake of their choosing, a potential gain in utility for some residents of Lake 2 for the higher amenity levels, and a gain in land rent resulting from higher frontage prices on the two lakes. To explore this example more thoroughly, we move to simulation methods to investigate the impacts of zoning.

4. Simulation model of lakefront sorting with environmental zoning

4.1 Simulation model design and sorting equilibrium

In this section we develop a simulation model of lakefront zoning with a parameterized utility function to demonstrate the possibility of the following outcomes: a) zoning can be welfare increasing; b) zoning preserves heterogeneity, not only directly by limiting development on some lakes, but also indirectly by providing an institutional constraint conducive to the sorting process; and c) in the absence of zoning, income growth can lead to a faster rate of development on lakes that initially have lower development densities—and higher amenities—than lakes that initially have higher development densities.

The simulation model is based on a system of two lakes—a low amenity lake (Lake 1) and a high amenity lake (Lake 2) —as well as exogenous "low" and "high" off-lake alternatives, where the low alternative (indexed by the subscript "0") has a low frontage price and amenity level, and the high alternative (indexed by the subscript "3") has a high frontage price and amenity level. The simulation derives the equilibrium location choice among these four alternatives for each member of a population of 20,000 residents, with each resident defined by a pair $\{\alpha, y\}$. The population was drawn from a bivariate normal distribution of α and y with zero correlation. Zero correlation implies that high-income individuals are no more likely to have high amenity preferences than low-income individuals.

We adopt the utility specification used by Epple and Sieg (1999) and assume the indirect utility function for individual *k* on lake *j* is given by

$$V(\alpha, A_j, P_j, y_k) = \left\{ \alpha A_j^{\rho} + \left[\exp\left(\frac{y_k^{1-\nu} - 1}{1-\nu} \right) \exp\left(-\frac{BP_j^{\eta+1} - 1}{\eta + 1} \right) \right]^{\rho} \right\}^{1/\rho} \qquad (7)$$

where η<0, α>0, ρ<0, ν>0, and B>0. For the two lakes of our system, the amenity level is endogenous, and depends on residential density:

$$A_j = \gamma \left[\frac{F_j}{N_j} \right]^{\mu}, \tag{8}$$

where F_j is the shoreline frontage on lake j, j=1,2, N_j is the total number of residents who settle on the lake, and $\gamma, \mu > 0$.

Resident k's demand for frontage on lake j can be derived by appealing to Roy's identity and expressed as

$$F_j(P_j, y_k) = BP_j^{\eta} y_k^{\nu} \tag{9}$$

From (9) it is apparent that η and ν are the frontage demand elasticities for price and income, respectively. The parameter ρ indicates the strength of the amenity preference, and combined with ν, shifts the population slice representing the lakefront residents (e.g. figure 2) from parallel to vertical to the amenity preference axis. The appealing aspect of this specification is that the slope of an indirect indifference curve in the (A, P) plane is positive (Epple and Sieg 1999), thus satisfying the single-crossing properties necessary for the sorting equilibrium described above. Each simulation fixes the utility parameters ($\alpha, \rho, \nu, \eta, B$), amenity function parameters (γ, μ), and off-lake frontage prices and amenity levels $\left(P_0, A_0, P_3, A_3\right)$. Conditional on these parameters, an equilibrium is obtained in iterative fashion by initially specifying prices, P_j, j=1,2, and amenity levels A_j, j=1,2, for the two system lakes, and determining the location choices made by the simulated population conditional on these prices and amenity levels. The choices made by individuals generate estimates of amenity levels $\hat{A}_j$, j=1,2, and aggregate frontage demand, $\hat{F}_j$, for each lake of the system j=1,2. The condition for an equilibrium is that these estimates of amenities and aggregate frontage demand on the lake system are "close enough" to the values initially used to generate choices in the population. Formally, a nonlinear gradient algorithm searches over the feasible set of $\{P_1, A_1, P_2, A_2\}$ for values satisfying the condition,

$$\sum_{j=1}^{2} \left| \frac{\hat{A}_j - A_j}{A_j} \right| + \left| \frac{\hat{f}_j - \overline{f}_j}{\overline{f}_j} \right| < \varepsilon , \quad (10)$$

where ε is an arbitrarily small positive value.

In our analysis we derive results for the two sets of parameters presented in Table 1. These sets generate equilibria with distinctly different "slices" in the $\alpha - y$ plane. As shown in Figure 3, the first set generates a baseline equilibrium with a relatively high amount of α-heterogeneity within lakes, and the second generates a baseline equilibrium with a relatively high amount of income heterogeneity within lakes. This is largely due to differences in the income elasticity of demand for frontage, ν, which is much higher in the second set of parameters than in the first. The first column of Table 2 provides baseline equilibrium results for the two parameter sets. In both equilibria Lake 2 is less densely developed[4] than Lake 1 and approximately 26% of the total population resides on the two lakes, with most of the remaining population (98%) residing on the low off-lake alternative. The price premium for Lake 2 is 0.80 for parameter set 1 and 0.28 for parameter set 2.

[4] While the total number of people on Lake 2 exceed the total number on Lake 1, the density of development on Lake 2 is lower than Lake 1 because Lake 2 has significantly more frontage than Lake 1.

4.2 Simulation experiments

We conduct three different types of simulation experiments to examine how the system departs from the baseline equilibrium under different scenarios involving income growth and environmental zoning. In the simulations, zoning is represented by a constraint on the number of individuals allowed on one or both lakes of the system. In the first experiment, we investigate the welfare impact of "marginal" zoning –that is, a marginal reduction in the population on the high amenity lake (Lake 2). Since lakefront development reduces lake amenities (see equ. 8), an individual's decision to develop can affect the utility of all other lakefront residents—an effect external to the market. Therefore, marginal zoning should increase aggregate welfare. In the second experiment, we investigate the impact of income growth on the sorting equilibrium to verify the analytical results in section 3 and to examine the possible adjustment of lakefront amenities to income growth, an effect which was ambiguous in section 3. In the third experiment, we investigate the impact of income growth in the presence of environmental zoning, by fixing the number of residents on Lake 2 at the level obtained at the baseline sorting equilibrium and then letting income grow.

4.2.1 Experiment 1: Marginal zoning without income growth

In this experiment we keep income constant and impose two marginal zoning policies that reduce the number of residents on Lake 2 from the baseline equilibrium by about 0.7% (zoning-1) and 1.4% (zoning-2). Results are presented in Tables 2 and 3 for both sets of parameters, under the columns labeled "zoning-1" and "zoning-2". For both sets of parameters, prices on both lakes increased, and the price premium on Lake 2 increased, as the zoning restriction became tighter. The price on Lake 1 increased because it is a substitute for Lake 2, and so the zoning restrictions on Lake 2 served to increase demand for frontage on Lake 1.

Focusing now on parameter set 1, Table 2 indicates that increasingly strict zoning on Lake 2 results in a net movement down the lake system; a small number of individuals initially at the high off-lake alternative move down to Lake 2, some individuals from Lake 2 move down to Lake 1, and some individuals on Lake 1 move down to the low off-lake alternative. Such adjustments to the new equilibrium are spurred by the amenity effects from zoning Lake 2, and the simple fact that some people who would have chosen Lake 2 without zoning are prevented from settling on the lake under the zoning restrictions. Table 3 provides the distribution of resident gainers and losers under zoning. Under both zoning restrictions there are many more losers than gainers. *All* of the original residents of Lake 1 must lose; those who stay on the lake face higher prices and lower level of amenity, and those who move down to the low off-lake alternative are choosing an alternative that was inferior under the baseline equilibrium. *All* of the residents who move down to Lake 1 from Lake 2 must lose, because Lake 1 is now less attractive than it was under the baseline equilibrium, and these residents chose not to settle on Lake 1 under the baseline equilibrium. *Some* of the residents who choose to remain on Lake 2 lose, because the price increase for frontage overwhelms the utility gain from the increase in the amenity level. *All* of the residents who move down from the high off-lake alternative must gain, because they are abandoning an alternative for which there is no change in utility from the baseline equilibrium.[5]

[5] We enumerate the winners and losers only for this case, to give the reader a sense of the conceptual logic behind distributional impacts of the various simulation scenarios.

Despite the fact that there are many more resident losers than winners, the welfare effect of the zoning restrictions are positive, as expected, because the price increase presents landlords with a windfall. The first zoning restriction results in a loss of $133 in welfare to residents, but landlords gain $243, for a net welfare gain of $110. The second zoning restriction generates similar results for a welfare gain of $183.[6]

As evident from Table 2, zoning restrictions under parameter set 2 generate a more complicated resident shuffling than under parameter set 1. In this experiment, no residents moved from the high off-lake alternative to Lake 2, while some original Lake 2 residents moved to the high off-lake alternative, and others moved down to Lake 1. In addition, some residents moved from Lake 1 to the low off-lake alternative. As reported in Table 3, the distribution of resident gainers and losers includes no gainers under either zoning policy, as the entire original lake population loses welfare under both zoning policies. As with the first parameter set, though, the net effect of the zoning restrictions is an increase in welfare, because of the rent increases that accrue to landlords.

4.2.2 Experiment 2: Sorting equilibrium with income growth

In this experiment we investigate the sorting equilibrium adjustment under rising incomes. The first income shock raises everyone's income by $1000 while the second income shock raises everyone's income by $2000. This experiment is a direct test of the analytical results in section 3. Results are in Table 2 under the columns labeled "Growth Equilibrium 1" and Growth Equilibrium 2". Results for the two sets of parameters are qualitatively the same, and so here we discuss the results in the context of the first parameter set. The population on lakes 1 and 2 becomes more homogenous –that is, the

[6] Of course, landlords and residents are often one and the same, and so it is entirely possible that *all* residents end up better off. Nonetheless, distinguishing landlords from residents as we do here serves the purpose of providing insights to the nature of gains and losses.

slices in $\alpha - y$ space defining location choices become narrower as income grows; a result predicted analytically. A second result which was predicted analytically is the decline in the price premium between the two lakes; an outcome which falls from application of the single-crossing property to the increasingly homogeneous lake population. A third result which was analytically ambiguous is the effect of income growth on the amenity levels for the two lakes. For the two sets of parameters used in the simulation model, Lake 2 gains residents and loses amenities as income grows, while the number of residents and the amenity level on Lake 1 remains unchanged. So, the simulation results demonstrate the intuitive but analytically ambiguous possibility that higher amenity lakes will develop relatively quicker than low amenity lakes when incomes are growing.

4.2.3 Experiment 3: Zoning with income growth

In this experiment we use the same income growth as above, but the zoning policy restricts development on Lake 2 to its pre-growth level, so that the zoning restriction is essentially a development moratorium. Results for both parameter sets are in Table 2 under the columns labeled "Zoning with Growth 1" and "Zoning with Growth 2". The first parameter set generates the result that development on Lake 1 increases slightly as income increases, though there is a considerable amount of movement across locations; in particular, residents move down a level (e.g. from Lake 2 to Lake 1), but not up (e.g. from Lake 1 to Lake 2).[7] Curiously, the population of gainers under the first income increase is substantially greater than under income growth 2 (Table 3), as 70% of

[7] This "downward flow" in location choice due to zoning was also found for parameter set 1 in the first experiment, but is not found for parameter set 2. The explanation for this is complicated by the fact that the amenity function differs across the two parameter sets, in addition to the income elasticity of frontage demand.

the pre-zoning population of Lake 2 gains welfare under zoning with the first income increase, while only 5% gain welfare under zoning with the second increase. Nonetheless it remains true that in the aggregate the development moratorium is costly to residents, and becomes more costly as income grows (net consumer loss is $1 after the first income shock and $68 under the second shock), though, due to rent increases, the net social welfare effect of the moratorium is positive, and increasing with income (the aggregate welfare change is +$11 after the first income shock, and +$68 after the second shock).

Under the second parameter set there is virtually no new development as incomes rise, though once again there is a considerable amount of movement across locations, and this time these changes in location are not unidirectional. As found in the first experiment, no residents moved from the high-off-lake to Lake 2, while some original residents of Lake 2 move to the high off-lake alternative and others moved to Lake 1. In addition, some residents moved from Lake 1 to the low off-lake alternative. The development moratorium leaves *all* residents worse off as income grows, though once again this loss is sufficiently compensated by an increase in land rents that aggregate social welfare increases as income grows.

5. Conclusion

In this paper we demonstrate that heterogeneous agents can sort themselves across lakes where amenities differ and are endogenous to development. However, lakefront amenities are provided by individual frontage decisions and have public good characteristics that will be underprovided in the market equilibrium. Therefore, environmental zoning, in which development is restricted in terms of development density, can be welfare improving by forcing individuals to consume more of the private good—frontage. Our simulation findings support the contention that zoning can be welfare improving, although the majority of residents tend to lose welfare while landowners gain welfare through increasing land prices.

Rising incomes affect the sorting equilibrium by making lakes more homogeneous with a reduced price premium between high and low amenity lakes. This result arises because i) increasing incomes make the lake system more attractive to the mass of individuals with average amenity preferences and average incomes, ii) land prices rise due to excess demand, and iii) lakefront amenities cannot increase because of the quasi-irreversible nature of development. So, the combination of rising land prices without a corresponding amenity gain causes residents who were just indifferent between the lake system and either alternate system to prefer an alternate system. In the simulation model we verify the increasing homogeneity of the lake system, but we also find that there exists a situation where the high amenity lake develops faster than the low amenity lake as incomes rise. So, it is possible for the sorting mechanism to break down over time, which has implications for lakes where ecological functions are negatively impacted by shoreline development.[8] In particular, the biological diversity across lakes can potentially be diminished as previously pristine lakes develop and become more similar to lakes that were already heavily developed. Therefore, our findings indicate that one role for environmental zoning is to preserve the sorting process and maintain heterogeneity across lakes.

This paper's findings regarding the welfare effects of zoning has implications for hedonic analyses of land prices and environmental zoning (e.g. Spalatro and Provencher

[8] Ecological studies have shown that increased shoreline development results in lower levels of coarse woody debris (e.g. downed trees) which provide important habitat for fish production (Christensen et al. 1997).

2001; Netusil 2005). In particular, there may be welfare effects from environmental zoning that are not captured by land prices, primarily because many original lakefront residents—as opposed to landlords—can potentially have their utility diminished by environmental zoning.[9] In particular, zoning the high amenity lake not only affects the utility of residents on that lake, but it also affects the utility of residents on other lakes through resident movement as the sorting equilibrium adjusts. Our results indicate that it is a mistake to consider only land prices in the calculation of the welfare effects of environmental zoning. For non-marginal changes, an aggregate social welfare measure should include the compensating variation of residents whose utility is altered by zoning. Future iterations of this paper intend to explore the possibility of finding increasing land prices which correspond with lower total welfare.

[9] This result is consistent with Bartik's (1988) analysis of the welfare impacts of exogenous amenity changes with hedonic price models.

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Figure 1. Evidence of sorting from survey data (see text)

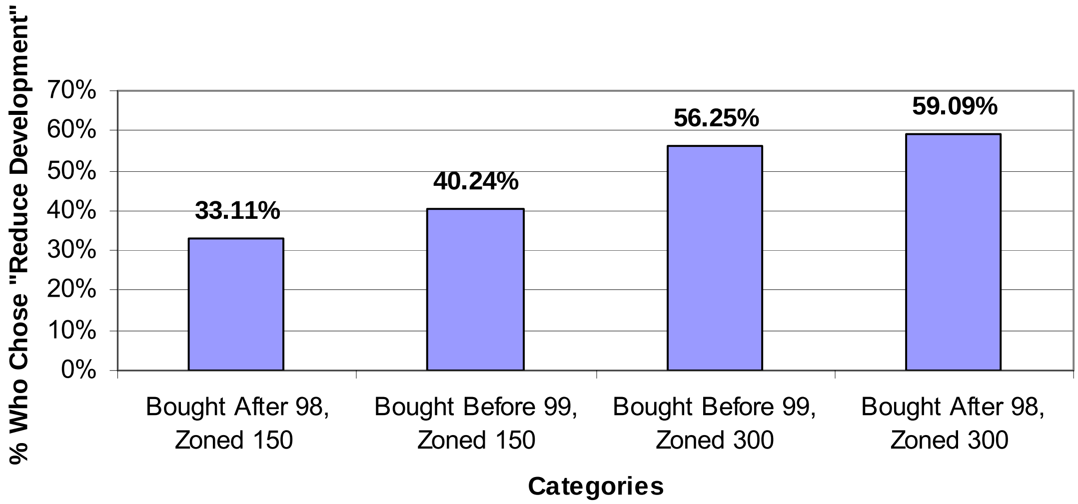


Figure 2. Sorting equilibrium (see text)

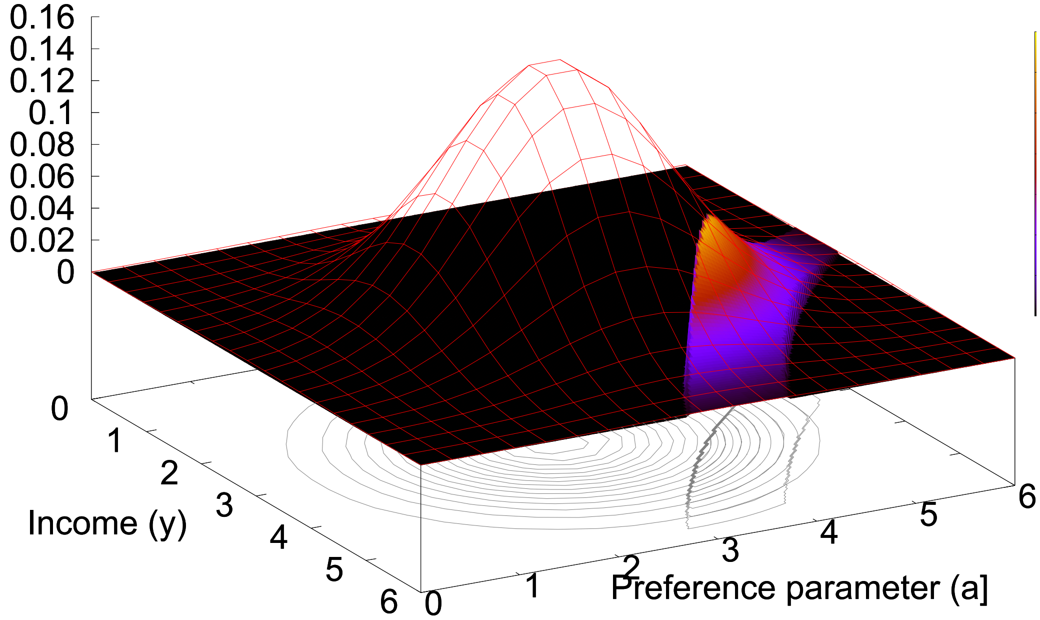
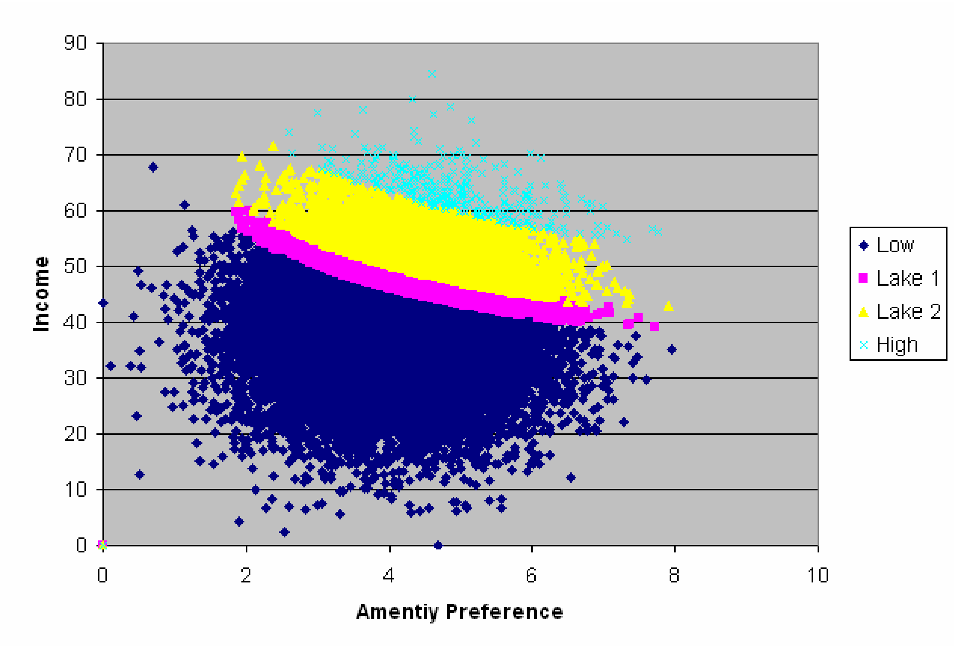


Figure 3. Initial equilibria

3.a Parameter set 1



3.b Parameter set 2

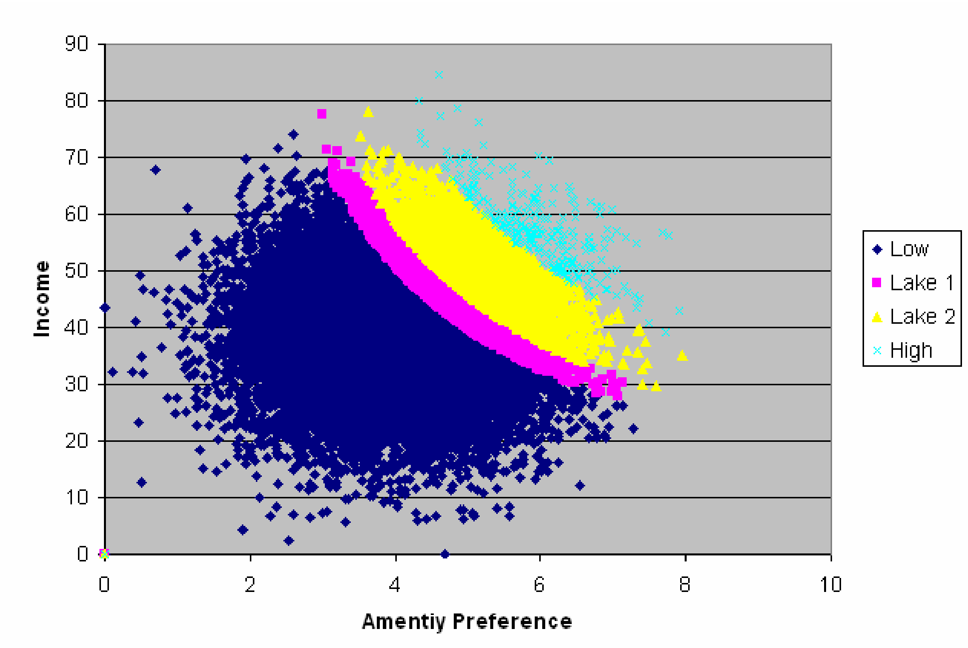


Table 1: Simulation Parameters

		Parameter set 1	Parameter set 2
Parameters	v	0.60	0.95
	η	-0.50	-0.50
	ρ	-0.75	-0.75
	B	0.43	0.43
	γ	1397.13	1.14
	μ	2.19	8.43
Amenities	Low Off-Lake	10	10
	High Off-Lake	500	2000
Price	Low Off-Lake	50	50
	High Off-Lake	155	64
Frontage	Lake 2	1136.85	5261.28
	Lake 1	848.55	4856.09

Table 2: Simulation Results

		Initial equilibrium	Zoning 1	Zoning 2	Growth equilibrium 1	Growth equilibrium 2	Zoning with growth 1	Zoning with growth 2
Parameter Set 1								
Amenities	Lake 2	175.00	177.64	180.33	174.66	172.30	175.00	175.00
	Lake 1	150.00	149.75	148.20	150.01	149.89	149.99	148.34
Price	Lake 2	147.45	147.61	147.75	148.54	149.12	148.55	149.25
	Lake 1	146.65	146.72	146.73	147.76	148.41	147.76	148.40
Price Premium	P2-P1	0.80	0.88	1.01	0.79	0.72	0.80	0.85
# of Residents	High Off-Lake	291	289	287	636	1078	635	1076
	Lake 2	2938	2917	2898	2942	2960	2938	2938
	Lake 1	2353	2353	2366	2353	2353	2358	2365
	Low Off-Lake	14418	14441	14449	14069	13609	14069	13621
Objective Function		0.0000	0.0097	0.0198	0.0085	0.0091	0.0155	0.0205
Welfare	Lake 2 Rent	$167,629	$167,808	$167,968	$168,870	$169,533	$168,883	$169,677
	Lake 1 Rent	$124,440	$124,503	$124,510	$125,378	$125,929	$125,379	$125,924
	Compensating Variation		-$133	-$226			-$1	-$70
	Total Change		$110	$183			$11	$68
Parameter Set 2								
Amenities	Lake 2	1000.00	1059.18	1122.30	982.00	970.72	1000.00	1000.00
	Lake 1	500.00	497.50	497.50	500.00	500.09	500.00	500.09
Price	Lake 2	63.78	63.80	63.83	63.79	63.79	63.80	63.80
	Lake 1	63.50	63.50	63.51	63.52	63.53	63.52	63.53
Price Premium	P2-P1	0.28	0.30	0.32	0.27	0.27	0.28	0.28
# of Residents	High Off-Lake	260	264	280	631	1039	633	1042
	Lake 2	2353	2337	2321	2358	2361	2353	2353
	Lake 1	2358	2358	2350	2358	2358	2358	2359
	Low Off-Lake	15029	15041	15049	14653	14242	14656	14246
Objective Function		0.0000	0.0124	0.0505	0.0104	0.0213	0.0122	0.0236
Welfare	Lake 2 Rent	$335,564	$335,686	$335,806	$335,612	$335,634	$335,648	$335,692
	Lake 1 Rent	$308,361	$308,376	$308,406	$308,440	$308,488	$308,446	$308,497
	Compensating Variation		-$46	-$99			-$11	-$15
	Total Change		$90	$188			$32	$52

Table 3 Resident Gainers and Losers

Baseline lake choice		Zoning 1	Zoning 2	Zoning with growth 1	Zoning with growth 2
Parameter Set 1					
High off-lake	Gainers	2	4	1	2
	Losers	0	0	0	0
Lake 2	Gainers	109	177	2045	141
	Losers	2829	2761	897	2819
Lake 1	Gainers	0	0	0	0
	Losers	2353	2353	2353	2353
Low off-lake	Gainers	0	0	0	0
	Losers	0	0	0	0
Parameter Set 2					
High off-lake	Gainers	0	0	0	0
	Losers	0	0	0	0
Lake 2	Gainers	0	0	0	0
	Losers	2353	2353	2358	2361
Lake 1	Gainers	0	0	0	0
	Losers	2358	2358	2358	2358
Low off-lake	Gainers	0	0	0	0
	Losers	0	0	0	0

Proofs

Proof of proposition 1: This proof is adapted from Epple and Platt (1998). Begin by ordering lakes by increasing amenities, $A_J>A_{J-1}>\ldots.>A_2>A_1$. Since V() is increasing in A and decreasing in p, equilibrium prices must satisfy $p_J>p_{J-1}>\ldots.>p_2>p_1$. To prove 1), note that boundary indifference follows directly from the continuity of V() and the continuum of agents. To show parts 2 and 3, fix y. Boundary indifference implies that a household $(\alpha_{j-1}(y), y)$ is indifferent between (A_{j-1}, p_{j-1}) and (A_j, p_j). The single-crossing property implies the following:

For $\alpha > \alpha_{j-1}(y)$ (e.g. α in fig. A1) => $(A_j, p_j) \succ (A_i, p_i)$ for all i<j,

For $\alpha < \alpha_j(y)$ (e.g. α in fig. A1) => $(A_j, p_j) \succ (A_i, p_i)$ for all i>j.

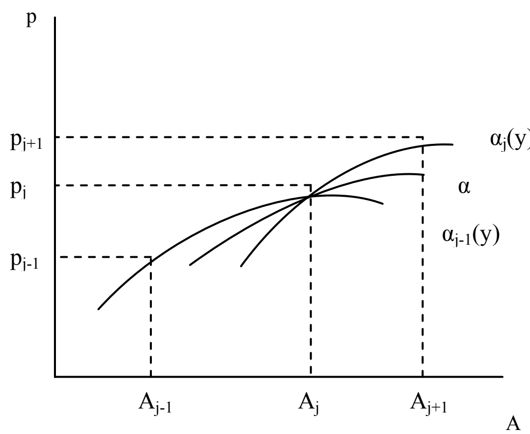


Fig. A1

Proof of proposition 2: Given that $\int_{\underline{\alpha}}^{\bar{\alpha}}\int_{\underline{y}}^{\bar{y}} f'(\alpha, y) dy d\alpha > \int_{\underline{\alpha}}^{\bar{\alpha}}\int_{\underline{y}}^{\bar{y}} f(\alpha, y) dy d\alpha$, one of three things must happen to restore equilibrium. Either prices have to rise, there has to be more building (and fewer amenities), or there has to be a combination of building and increasing prices.

a. If equilibrium is restored by more building, then amenities fall on every lake and people who were originally indifferent at the border lakes—those described by either $(\underline{\alpha}, \underline{y})$ or $(\bar{\alpha}, \bar{y})$ -- will be better off either on no lake or on the alternative system. Therefore, the lake system must become more homogeneous.
b. If equilibrium is restored by a price increase alone, then either $(\underline{\alpha}', \underline{y}') > (\underline{\alpha}, \underline{y})$, $(\bar{\alpha}', \bar{y}') < (\bar{\alpha}, \bar{y})$, or both. We show that either of the first two options alone leads to a contradiction.
    i. If $(\underline{\alpha}', \underline{y}') = (\underline{\alpha}, \underline{y})$ and $(\bar{\alpha}', \bar{y}') < (\bar{\alpha}, \bar{y})$ then A_1'=A_1 and p_1'=p_1 to maintain border indifference. However, this implies p_J'-p_1'>p_J-p_1, which violates the single-crossing property.
    ii. If $(\underline{\alpha}', \underline{y}') > (\underline{\alpha}, \underline{y})$ and $(\bar{\alpha}', \bar{y}') = (\bar{\alpha}, \bar{y})$ then A_J'=A_J and p_J'=p_J to maintain border indifference. But, if $(\underline{\alpha}', \underline{y}') > (\underline{\alpha}, \underline{y})$, then every $\alpha_j'(y) > \alpha_j(y)$ to fit everyone onto each lake without building. Therefore, $\alpha_J'(y) > \alpha_J(y)$ and p_J'>p_J by the single-crossing property. This is a contradiction.

2. Since $(\underline{\alpha}', \underline{y}') > (\underline{\alpha}, \underline{y})$ and $(\bar{\alpha}', \bar{y}') < (\bar{\alpha}, \bar{y})$, then p_J'-p_1'<p_J-p_1 by the single-crossing property.
3. Amenities cannot increase because lakefront development is defined as irreversible.