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THE URBAN IMPACT OF THE ENDANGERED SPECIES ACT: A GENERAL EQUILIBRIUM ANALYSIS

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The urban impacts of the Endangered Species Act: A general equilibrium analysis ☆

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Abstract

We consider the general equilibrium implications of environmental regulations which result in a reduction of otherwise profitable residential development. Critical habitat designation under the Endangered Species Act is an important example. If the regulations affect a significant amount of land, they may have important effects on the rest of the regional economy—increasing rents and densities on lands not subject to the regulation, causing the conversion of lands from alternative uses, increasing the net developed area in the region, and decreasing consumer welfare. We develop a flexible general equilibrium simulation of the economic effects of critical habitat designation, explicitly considering the distributional effects upon owners of different types of land and upon housing consumers. The results of our simulation show that the most significant economic effects of critical habitat occur outside of the designated area. The prices and rents of non-critical habitat lands increase significantly. Incomes are redistributed across landlords, and the well being of housing consumers is further affected through these linkages.

Keywords: Land use regulation; Growth boundary

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1. Introduction

Under the Endangered Species Act, the US Fish and Wildlife Service (USFWS) is charged with designating "Critical Habitat," lands which may require special management to protect an endangered plant or animal species. This protection often restricts development of private land causing the price of land and the pattern of land usage throughout the region to adjust to reflect the scarcity of developable land. Critical habitat designations have the potential to create large economic impacts and affect significant numbers of people. First, critical habitat designations can be large.[1] Secondly, critical habitat lands often occur near urban areas.[2]

Lands may be excluded from the critical habitat designation if the economic costs of designation outweigh the benefits, unless the failure to designate such area will result in the extinction of the species [16 USC §1533(b)(2)]. Whereas the benefits of critical habitat designation and species preservation accrue to citizens in the nation as a whole (or perhaps all world citizens) the costs of critical habitat are borne by the local economy. Given the nature of land markets in an urban economy, the costs of providing similar critical habitat benefits can vary markedly depending on the location and scope of designated lands.

This paper uses a spatially explicit model of the economic interrelationships of housing consumers and producers to analyze the economic impacts of designating as critical habitat raw land that would otherwise have been used to produce housing in the region. We consider a closed region whose economic base is given, where relocation within the region is costless, but mobility to other regions is prohibitively expensive.[3] Changes arise because some significant amount of land cannot be used as intensively to produce housing after critical habitat designation.

In a stylized model of the regional economy, we evaluate the impacts of these regulations on the spatial allocation of capital, on the density of housing development, and on housing and land prices throughout the region. We also analyze the net effect of the land designation on the well-being of households and the distribution of rents among the region's landowners. Our results show the importance of using a general equilibrium framework for evaluating the impacts of land use regulations like critical habitat designation; a partial equilibrium analysis tends to underestimate the impacts and ignores large wealth transfers from consumers to owners of non-regulated lands.

Section 2 below surveys the surprisingly incomplete literature on this issue and summarizes prior work by economists studying environmental regulation of land uses. A model of the regional economy is sketched out in Section 3, and Section 4 traces out the qualitative impacts of critical habitat designation using this model. In Section 5 we use the model to estimate the economic impacts of critical habitat designation using stylized but reasonable parameters reflecting a regional economy.

[1] For example, the USFWS designated 4,140,440 acres in California as critical habitat for the red-legged frog in 2001, 1,184,513 acres in California and Oregon as critical habitat for vernal pool species in 2003, and 8,600,000 acres in Arizona, Colorado, Utah, and New Mexico as critical habitat for the Mexican spotted owl in 2004.

[2] In a recent analysis of critical habitat in California, Zabel and Paterson [25] sampled almost 400 FIPS-designated places (cities), with sizes ranging between 209 and 303,000 acres, finding an average of 1.62 percent of land area designated as critical habitat. However, among those 118 sampled FIPS places in which some land had been set aside for critical habitat, the median (mean) set aside was 6.9 percent (15.3 percent) of land area.

[3] In the alternative, "open region" formulation, where mobility between regions is costless, the well being of the region's residents is determined exogenously. Thus, the competitive equilibrium must yield the same level of utility for residents regardless of critical habitat designation in the region. This implies that the entire cost of critical habitat designation is reflected in the change in market value of the regulated lands.

It is important to understand that critical habitat designation is but one example of land-use regulations; the analysis used in this paper is generalizable to other land-use regulations that restrict the supply of land within the region. For example, if critical habitat were designated in areas completely surrounding the region, the regulation would be analogous to an urban growth boundary.[4] Section 6 of this paper extends the model to examine the impacts to the regional economy from a regulation of this type.

2. Prior research

There are a few examples of work specifically aimed at evaluating the economic impacts of critical habitat designation. For instance, the Draft Economic Analysis of Critical Habitat Designation for Vernal Pool Species [6] measures the impacts of critical habitat as the resources consumed in the consultation process (hiring lawyers, scientists, and other experts, and complying with reporting regulations), and the lost revenue to land owners due to project modifications. Implicit in these calculations is the assumption that the price of housing in the designated region is constant before and after the designation. Sunding et al. [21] develop a broader framework that acknowledges additional costs of designation, including potential price changes that have welfare implications for both producers and consumers in the market, as well as lost welfare due to delay caused by the regulation. Their conclusion is that the impacts of designation may rest heavily on the underlying market conditions, and on the interaction of local regulations with the critical habitat enforcement. However, this partial equilibrium analysis does not account for potential impacts upon nearby areas as a result of the restrictions on the designated lands. The authors do not explicitly model other potential behavioral responses to critical habitat designation, such as changes in demand for neighboring lands not designated as critical habitat, or production decisions by housing suppliers in the region.

Critical habitat designation is but one form of land use regulation. An extensive economic literature does examine the impacts of market interventions which are analogous to parts of critical habitat designation. For instance, Watkins [23] develops a framework for analyzing the impacts of development charges, and he shows how fees will be shared between landowners and home buyers. Singell and Lillydahl [19] undertake an empirical examination of impact fees on newly constructed houses. They discover that existing home prices may rise in the presence of impact fees for new homes.[5] Skidmore and Peddle [20] estimate the effects of development impact fees imposed in some municipalities in a single Illinois county. They find that residential development rates were substantially reduced in fee areas compared to similar municipalities that did not enact the development fees. A recent paper by Quigley and Rosenthal [18] presents a survey of empirical evidence on the link between land use regulation and housing prices, finding examples of large effects of land use regulation on housing prices.

Another recent paper by Kiel [9] reviews the economic literature on the effects of environmental regulations and the housing market. After a comprehensive review of regulations under the Clean Air Act, the Safe Drinking Water Act, the Environmental Policy Act, and the Coastal

[4] However, an urban growth boundary differs in one important way from the analysis of critical habitat presented in this paper. Voluntary adoption of the urban growth boundary presupposes some set of regional public goods which benefit local residents; in the critical habitat case, the regulations are imposed by a higher level of government to benefit all national or world citizens. Local residents receive but a small fraction of the presumed biodiversity benefit of the activity.

[5] They hypothesize that this is because home buyers predict that property taxes on existing homes will decrease to offset the increased tax revenue generated by the impact fees.

Zone Management Act, among others, she concludes, "Surprisingly little is known about the impacts of environmental regulations on the price and quantity of housing in the United States" (p. 204). Kiel considers the Endangered Species Act explicitly, indicating that if the act "removes a significant amount of land from possible development, then the price of remaining developable land should increase, thus increasing the cost of supplying housing..."

There is some theoretical work on this topic. For example, Brueckner [5] has developed a model of growth controls in an open city. He shows that while consumers may remain indifferent about growth controls (as a consequence of the open city assumption), landowners may gain or lose when the growth controls affect land prices in the region. This model shows that growth controls will increase the value of developable land, while decreasing the value of land rendered undevelopable by the restrictions. More recently, Lee and Fujita [10] developed a theoretical model of efficient greenbelt location within an urban area. Their analysis emphasizes the local public amenities provided by the greenbelt, rather than the economic effects of the restrictions on land supply. Brueckner [4] is a closely-related examination of growth control boundaries. His work concentrates on land rather than housing, so his model generates larger losses to final consumers than the model presented here.[6] His analysis of policy solutions to combat urban sprawl highlights the difficulties of using these regulations to correct market failures from urban sprawl. He notes that overzealous enaction of growth boundaries may create larger costs than benefits and recommends the use of development fees and congestion taxes to internalize the externalities of sprawl. Our model extends his work to housing but does not consider externalities from urban development. Even in the absence of externalities, our work suggests that the costs from exogenously imposed growth boundaries can be quite high indeed.

3. The basic economic model

The regional economic model consists of a population of identical utility-maximizing consumers who rent housing services, commute to the Central Business District (CBD), and consume a numeraire good. Housing services for the economy are produced by competitive firms combining land and capital throughout the region. Spatial variation in commuting costs leads to variation in population densities and the prices of land and housing services.

Models of this kind were first introduced by Alonso [1], and extended and popularized by Mills [11], Muth [12], and Beckmann [2]. Papers by Wheaton [24] and Pines and Sadka [15] are among the better known examples of attempts to deconstruct these models using comparative statics. Brueckner [3] provides a comprehensive review of this literature. We follow Brueckner's presentation, adopting the same notation whenever possible. The model is static in the sense that it focuses on the equilibrium of the local economy. Using this model, we examine the impacts of land supply restrictions which arise from critical habitat designation.

Assume land rents are a function of distance to the CBD, x, and the consumer utility level. Utility, u, is derived from housing, q, and other goods, c. The land rent function is given by $r(x,u)$, and utility maximizing housing demand is given by $q(x,u)$. The profit maximizing capital intensity (capital-land ratio) of housing production, $S(x,u)$, is similarly a function of location and consumer utility. Housing output per unit of land is a function of capital intensity, $h(S(x,u))$.

[6] If consumers derive utility from land, they suffer when land prices increase. If they derive utility from housing, they can substitute capital for land when land prices rise, mitigating the losses from higher land prices.

Population density at any location is simply the total quantity of housing produced per unit of land divided by the quantity of housing demanded per person,

$$D(x,u) = \frac{h(S(x,u))}{q(x,u)}. \tag{1}$$

The economic equilibrium must satisfy two conditions. First, land must be successfully bid away from its alternative use. Let r_a represent the opportunity cost of land, and $\bar{x}$ be the distance to the border of the economically productive region. Then the rent for land devoted to housing at the border must equal the rent in its highest alternative use,

$$r(\bar{x},u) = r_a. \tag{2}$$

Since $\partial r/\partial x < 0$, Eq. (2) specifies that all land devoted to housing is successfully bid away from the alternate use.

Secondly, the supply of housing must equal the demand for housing within the region as a whole. The number of people living at any distance x is given by $2\pi x D(x,u)\,\mathrm{d}x$. Integrating over the entire developed region yields the total population, N.

$$\int_0^{\bar{x}} 2\pi x D(x,u)\,\mathrm{d}x = N. \tag{3}$$

The economic equilibrium is obtained when all residents achieve a common utility level regardless of their choice of location, when profit maximizing housing producers earn normal profits throughout the region, when all land used to produce housing is successfully bid away from its alternate use, and when the region's population lives within the built-up region. The values which solve this system describe the spatial pattern of housing prices, land rents, capital intensity of housing, and housing density. Housing prices decline with distance from the center. Land prices decline more steeply than housing prices. Population density decreases with distance from the center.

4. Critical habitat designation

Suppose a regulator chooses to designate a non-negligible amount of land as critical habitat in this regional economy. The critical habitat designation is characterized by its size and location within the region, both of which play important roles in determining the ultimate welfare impacts upon residents and land owners in the economy. We assume critical habitat designations can be approximated by three parameters: x^*, the distance from the center of the region to the area devoted to critical habitat; k, the number of radians that the designation occupies; and $\hat{x}$, the "depth" of the designation. We assume the critical habitat is k radians of an annulus of width $\hat{x}$ at distance x^* from the center of the region. The total designated area is thus $k\hat{x}(x^* + \hat{x}/2)$ as indicated in Fig. 1.

If $x^* > \bar{x}$, then the critical habitat is located outside of the urbanized region. The economy within the built up region is not affected, and the impact of critical habitat designation is simply the lost land rents of the regulated lands. If r_d represents the rents for lands designated as critical habitat, then the lost land rents due to critical habitat designation are given in Eq. (4). If the designation does not reduce the rent of the regulated land ($r_d = r_a$), then the designation is costless.

$$\text{Land Rent Losses} = k\hat{x}\left(x^* + \frac{\hat{x}}{2}\right)(r_a - r_d). \tag{4}$$

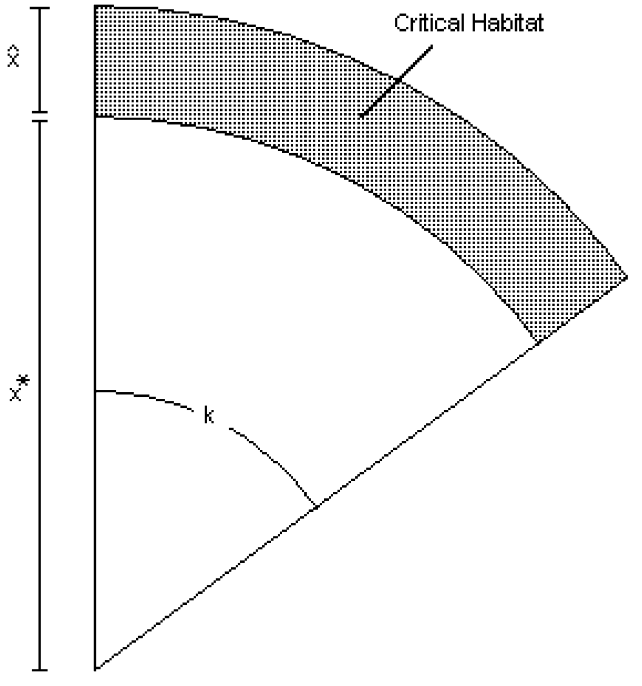


Fig. 1. Geography of critical habitat designation.

We now turn to the case in which there are impacts upon consumers and producers outside of the regulated lands. This occurs when critical habitat is designated for lands that would otherwise be used in the production of housing services (i.e., when $x^* < \bar{x}$). In this case, the regional equilibrium must adjust to accommodate the households who would otherwise reside on the lands designated as critical habitat. For simplicity, we assume that lands designated as critical habitat cannot be used to produce housing at all. We also assume that the depth of the designation is such that it is not optimal for residents to "leap-frog" and develop beyond the critical habitat. This assumption is merely for analytic tractability.[7] However, we do allow builders to expand the city by converting land to housing at the boundary.[8] This pattern of regulation can be reflected in the economic model by modifying Eq. (3). Equation (3) becomes

$$\int_0^{x^*} 2\pi x D(x,u)\,\mathrm{d}x + \int_{x^*}^{\bar{x}} (2\pi - k)x D(x,u)\,\mathrm{d}x = N. \tag{5}$$

Equation (5) states that the population must fit within the built up region, which only includes $2\pi - k$ radians past a distance of x^* due to critical habitat designation. It reinforces the notion

[7] Although we also assume that lands designated as critical habitat are prohibited from producing housing, the results are qualitatively identical if critical habitat merely decreases the allowable density of housing. The model can easily incorporate "costly delay" in the development process. This possibility is formally the same as an excise tax on housing, but does not qualitatively change the results.

[8] Of course, if $k = 2\pi$ the critical habitat designation is analogous to the designation of an urban growth boundary. See Section 6 for the impacts of a growth boundary.

that critical habitat designation will have only minor impacts if it is located outside of the built up region (since when $x^* = \bar{x}$, (5) reverts to (3), as it does if $k = 0$).

The comparative statics solution for the system is not presented here, but the intuition is straightforward. Designating more land as critical habitat reduces the supply of land available for housing. For the system to remain in equilibrium, the displaced residents must find housing elsewhere. The increased demand for housing elsewhere causes unregulated lands to be developed more intensely, including the development of lands at the periphery that would not have been developed but for critical habitat designation.

Figure 2 is a schematic of the city with and without critical habitat. Without critical habitat, the equilibrium is a circular built-up region of radius $\bar{x}_0$, represented by the broken line. The equilibrium with critical habitat causes the conversion of lands from the alternate use to housing production, expanding the built-up region to the solid line at $\bar{x}_1$. Along the ray from the center of the region to point A, the price of all lands has increased (as shown in Fig. 3 (a)). Lands that had

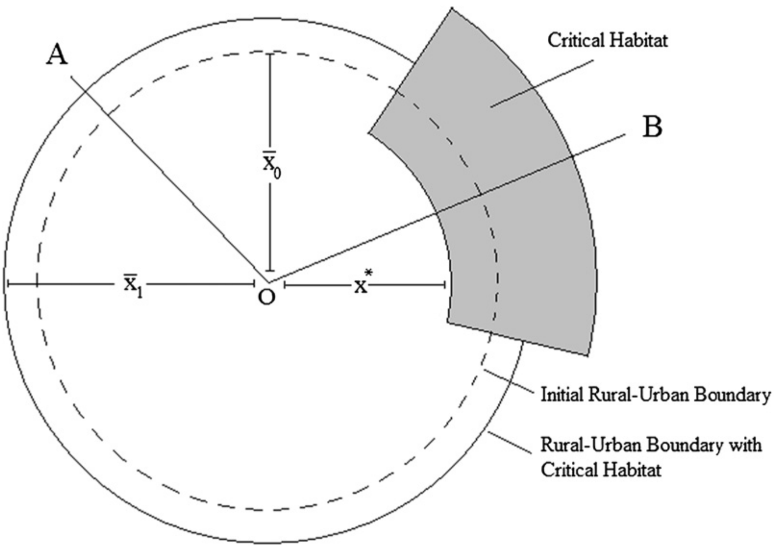
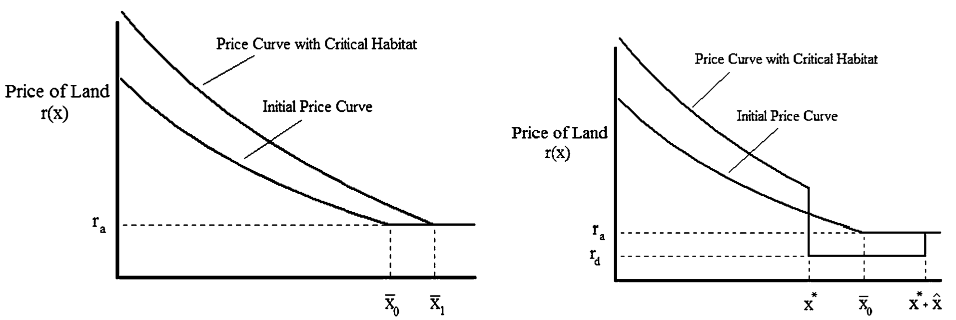


Fig. 2. Equilibrium with critical habitat designation.



(a) Origin to point A

(b) Origin to point B

Fig. 3. Equilibrium land price gradients.

been developed previously are worth more due to the increased scarcity, causing the conversion of lands which would otherwise remain undeveloped to housing production. Fig. 3 (b), a cross section of land prices from the center of the region through critical habitat to point B, again shows that lands not designated as critical habitat are more valuable, while the critical habitat lands are less valuable. Specifically, for $x^* < x < \bar{x}_0$, lands that would have been developed to produce housing now simply earn r_d, and lands located $\bar{x}_0 < x < x^* + \hat{x}$ have price r_d instead of r_a.

4.1. *Effects upon landowners*

Owners of unregulated lands will benefit from increased land prices, while landowners of critical habitat stand to lose from the designation. To compare the gains of the winners with the losses of the losers, consider the aggregate land rent in the region, R:

$$R = \int_0^{x^*} 2\pi x \cdot r(x, x^*, k)\,\mathrm{d}x + \int_{x^*}^{\bar{x}(x^*,k)} (2\pi - k)x \cdot r(x, x^*, k)\,\mathrm{d}x. \tag{6}$$

Consider the impacts upon R as we alter the parameters which determine the extent and location of critical habitat in the region. Using Leibniz' Rule:

$$\begin{aligned}\frac{\partial R}{\partial k} = {} & \int_0^{x^*} 2\pi x \cdot \frac{\partial r(x)}{\partial k}\,\mathrm{d}x - \int_{x^*}^{\bar{x}(x^*,k)} x \cdot r(x, x^*, k)\,\mathrm{d}x \\ & + \int_{x^*}^{\bar{x}(x^*,k)} (2\pi - k)x \cdot \frac{\partial r(x)}{\partial k}\,\mathrm{d}x + (2\pi - k)\bar{x} r(\bar{x}) \frac{\partial \bar{x}}{\partial k},\end{aligned} \tag{7}$$

$$\begin{aligned}\frac{\partial R}{\partial x^*} = {} & \int_0^{x^*} 2\pi x \cdot \frac{\partial r(x)}{\partial x^*}\,\mathrm{d}x + 2\pi x^* r(x^*) + \int_{x^*}^{\bar{x}(x^*,k)} (2\pi - k)x \cdot \frac{\partial r(x)}{\partial x^*}\,\mathrm{d}x \\ & + (2\pi - k)\bar{x} r(\bar{x}) \frac{\partial \bar{x}}{\partial x^*} - (2\pi - k)x^* r(x^*) \frac{\partial \bar{x}}{\partial x^*}.\end{aligned} \tag{8}$$

Without assuming functional forms for the utility of residents and the production technologies available to producers, Eqs. (7) and (8) are of ambiguous sign. Nevertheless, it is useful to decompose the change in rents into the increases and decreases to landowners in different locations. Figure 4 displays the geographical locations of these landowner groups. The landowners can be divided into four separate groups ($\bar{x}_0$ [$\bar{x}_1$] refers to the distance to the boundary of the built up region without [with] critical habitat designation, and $r_0(x)$ [$r_1(x)$] refers to the land price function without [with] critical habitat designation):

(1) The owners of land which would otherwise be developed and is not designated as critical habitat, shown as region A in Fig. 4. These landowners gain from the increased price of their land as it gets developed more intensely. The total gains for these landowners are equal to $\int_0^{x^*} 2\pi x(r_1(x) - r_0(x))\,\mathrm{d}x + \int_{x^*}^{\bar{x}_0} (2\pi - k)x(r_1(x) - r_0(x))\,\mathrm{d}x$.

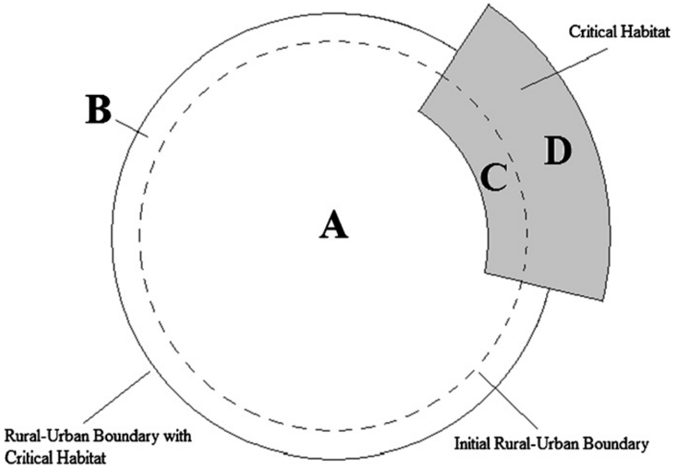


Fig. 4. Geography of critical habitat impacts.

(2) The owners of land which would otherwise be undeveloped at the edge of the region is now developed as a consequence of critical habitat designation. These lands are shown as region B in Fig. 4. These owners gain increased land rents equal to $\int_{\bar{x}_0}^{\bar{x}_1}(2\pi - k)x(r_1(x) - r_a)\,\mathrm{d}x$.
(3) The owners of land which would otherwise be developed but is now designated as critical habitat, shown as region C in Fig. 4. These landowners lose from not being able to develop their lands. The aggregate loss in rent is $\int_{x^*}^{\bar{x}_1} kx(r_d - r_0(x))\,\mathrm{d}x$.
(4) The owners of land that would otherwise remain undeveloped but is now designated as critical habitat, shown as region D in Fig. 4. These landowners lose rents if their lands are designated as critical habitat, and the rent to lands so designated is lower than the alternate use of that undeveloped land (when $r_d < r_a$). We assume that $r_d = r_a$, and thus these landowners are not affected by the designation.

4.2. *Effects upon residents*

To summarize the economic effects of critical habitat upon consumers, we calculate the equivalent variation (EV) of the policy implementation. The equivalent variation is the amount by which the income of the representative consumer must be changed in the absence of the policy to yield the same utility level as if the policy had been implemented.

$$EV = \mathrm{d}y : \bar{u}(y,\ \textit{Critical Habitat}) = \bar{u}(y + \mathrm{d}y,\ \textit{No Critical Habitat}). \tag{9}$$

5. A quantitative application

The economic model can be solved using assumed functional forms for the production and consumer utility functions. The solution to the unconstrained model can be compared with the solution when critical habitat is designated for a portion of the area.

Assume that the utility function is Cobb–Douglas,

$$U(c, q) = c^{1-\alpha} \cdot q^{\alpha}, \quad 0 < \alpha < 1, \tag{10}$$

and the housing production function is also Cobb–Douglas,

$$h(S) = A \cdot S^{\gamma}, \quad 0 < \gamma < 1,\ A > 0. \tag{11}$$

Appendix A indicates how the model can be solved under these assumptions. Here we present the results from one application of the model. Our assumptions are noted below.

(1) Assume the utility function for consumers is Cobb–Douglas with $\alpha = 0.25$. Households devote one quarter of their incomes to housing expenditures, the income elasticity of demand for housing is one, and the elasticity of substitution is also one. These stylized facts are consistent with survey and empirical evidence about consumer behavior, at least with respect to permanent income. See, for example, Goodman [7], or Quigley [16].
(2) Assume the production function for housing is Cobb–Douglas with $\gamma = 0.70$, and $A = 1$. Thirty percent of the value of housing is accounted for by land and the remainder is capital improvements. This is roughly consistent with rules of thumb used in the assessment for property taxes (see, for example, Oates and Schwab [14]) and with econometric evidence on production functions. See, for example, Muth [13] or Quigley [17]. This is also consistent with recent evidence on the elasticity of substitution in housing production (see Thorsnes [22]).
(3) Assume transportation costs for commuting are \$400 per mile per year. This represents a combination of out-of-pocket commuting costs and the cost of residents' time. The mileage rate for business travel by private auto for tax purposes was \$0.36 per mile in 2005 (see IRS Publication 463, 2004), while the remaining \$0.44 per mile represents lost time due to due to commuting. At an average wage rate of \$30 an hour (see below) and a travel speed of 30–40 miles per hour, commuting time is assumed to be valued at about half of the wage rate.
(4) Assume the income of households is \$60,000 per year.
(5) Assume the rental value of land in the alternate use is \$250,000 per square mile, or just under \$400 per acre.
(6) Assume the rental rate of capital, the real interest rate, is 3 percent.
(7) Assume the region is expected to grow to a population of 400,000 households. Assuming 2.2 members per household means the region is about the size of the Tucson, AZ metropolitan area and has a comparable average household income.
(8) We also assume 33 percent of land area is used for residential housing, while the remaining two thirds is used for alternative urban uses, streets, commercial areas, etc. This is consistent with estimates reported in widely used textbooks (e.g. Hartshorn [8]).

Under these stylized assumptions, we solve the model for the utility level of the residents, the geographic size of the developed region, and the spatial patterns of land rents, housing prices, housing consumption, and capital intensity. The solution to the model indicates that the built-up area extends for 34.75 miles. The total built up area is about 3700 square miles; the aggregate annual rent on the developed land is about \$1.6 billion or about \$2000 per acre per year.

We now designate about four percent of the land area as critical habitat, with residential construction forbidden, but the alternative use still permitted. At a distance of 32 miles from the center, we impose these critical habitat regulations on $\pi/2$ radians in the region. Column 4 of Table 1 summarizes these effects. The geography of this designation is qualitatively identical to that in Fig. 1, and Figs. 3(a) and (b).

Approximately 150 square miles have been designated as critical habitat. This regulated land, which would otherwise have been developed for residential purposes, now earns \$250,000 per

Table 1
The economic impacts of varying radians of land as critical habitat at a distance of 32 miles from the center of the region

		Radians of critical habitat					
	Baseline	$\pi/4$	$\pi/3$	$\pi/2$	$2\pi/3$	π	$3\pi/2$
A. Geography							
Critical habitat area (mi^2)	0.00	73.23	98.12	148.67	200.25	306.64	474.84
Built-Up Area (mi^2)	3794.21	3729.58	3707.60	3663.00	3617.49	3523.63	3375.27
Percentage of Land Designated	0.00%	1.93%	2.58%	3.90%	5.25%	8.01%	12.33%
Miles to Urban-Rural Boundary	34.75	34.79	34.81	34.83	34.86	34.92	35.01
B. Change in Annual Rents to Land Owners							
Previously Developed Lands	$0	$7,295,025	$9,769,164	$14,783,460	$19,888,489	$30,384,504	$46,899,824
Newly Developed Lands	$0	$1414	$2420	$5006	$8086	$14,264	$17,186
Critical Habitat Lands	$0	−$1,032,135	−$1,375,967	−$2,063,014	−$2,748,885	−$4,115,247	−$6,143,381
All Lands	$0	$6,264,304	$8,395,617	$12,725,452	$17,147,689	$26,283,520	$40,773,630
C. Change in Average Annual Land Rents Per Acre							
Previously Developed Lands	$0.00	$9.28	$12.51	$ 19.18	$26.14	$41.04	$66.06
Newly Developed Lands	$0.00	$0.89	$1.19	$1.81	$2.44	$3.75	$5.82
Critical Habitat Lands	$0.00	−$66.74	−$66.40	−$65.70	−$65.00	−$63.54	−$61.26
All Lands	$0.00	$7.80	$10.45	$15.81	$21.27	$32.49	$50.14
D. Annual Equivalent Variation to Residents							
Aggregate	$0	−$7,674,396	−$10,283,654	−$15,581,273	−$20,987,160	−$32,137,845	−$49,768,378
Per Household	$0.00	−$19.19	−$25.71	−$38.95	−$52.47	−$80.34	−$124.42

square mile in its alternative use. The loss to the owners of these lands is just over $2,000,000 a year, or about $65 per acre of would-be housing in the critical habitat. As a result of this regulation, the built-up region extends marginally further to about 34.8 miles in the rest of the region (i.e., in the $3\pi/2$ radians outside the designated area), creating roughly four square miles of new housing. The gain to the owners of these newly converted lands is about $5,000 a year or about $2 an acre on average. The owners of land that would have been developed regardless of the critical habitat designation gain because they develop their lands more intensively—since land is now scarcer. The annual change in rents on these lands is $14.8 million or about $19 per acre. The aggregate rents to all lands has increased by approximately $12.7 million, or just under $16 per acre. While overall landowner welfare has increased, consumers are made worse off. Consumer utility has decreased because higher land prices translate into higher housing prices. Total losses to consumers, as measured by the equivalent variation of the critical habitat imposition, are just over $15.5 million or about $39 per household per year.

Table 1 displays the economic effects of designating other amounts of critical habitat, by varying the number of radians of critical habitat but keeping the distance to critical habitat constant at 32 miles. As the number of radians devoted to critical habitat increases, the area of the critical habitat designation increases. The change in rents to lands which would otherwise have been developed regardless of the designation vary by as much as an order of magnitude, depending on the level of critical habitat designation.

Table 2 displays the impacts of various distances to the critical habitat designation, assuming a constant "width" of $\pi/2$ radians. When the boundary of the critical habitat is moved closer to the center of the region (holding the number of radians of critical habitat constant) the area designated as critical habitat increases. Increases in rents to land owners are large for those who occupy developable land. For those unfortunate enough to own land designated as critical habitat, the losses can become quite substantial.

5.1. Partial vs. general equilibrium impacts of critical habitat designation

This section describes how this model of the general equilibrium effects of critical habitat designation compares to a partial equilibrium assessment of the effects of critical habitat. A partial equilibrium approach assumes that no other prices change in response to the designation.[9] In such a world, the only welfare effects of critical habitat designation are the lost land rents to the owners of designated lands. The residents that would otherwise live in critical habitat lands instead move outside of the region.

In contrast, in our "closed region" model, we assume that the region's residents do not move out of the system. These displaced residents then change the demand for land and housing in the remainder of the region, causing price changes throughout the system. These price changes lead to other welfare losses in addition to the lost rents which would otherwise be earned on the designated lands.

As Table 3 shows, the partial equilibrium approach estimates the total impacts of critical habitat designation to be −$2,063,014, while the general equilibrium approach estimates the total impacts to be −$2,855,821, a difference of 38 percent. This is a substantial difference. The most important limitation of a partial equilibrium approach, however, is that it ignores the large transfers that may result from critical habitat designation. The general equilibrium approach shows

[9] This is formally equivalent to the "open region" assumption discussed in the introduction.

Table 2
The economic impacts of designating $\pi/2$ radians of critical habitat at varying distances from the center of the region

		Miles to critical habitat					
	Baseline	34.0	33.0	32.0	30.0	28.0	25.0
A. Geography							
Critical Habitat Area (mi^2)	0.00	41.73	95.92	148.67	249.87	345.40	478.20
Built-Up Area (mi^2)	3794.21	3756.87	3708.96	3663.00	3577.05	3499.21	3398.11
Percentage of Land Designated	0.00%	1.10%	2.52%	3.90%	6.53%	8.98%	12.34%
Miles to Urban-Rural Boundary	34.75	34.77	34.80	34.83	34.90	34.98	35.13
B. Change in Annual Rents to Land Owners							
Previously Developed Lands	$0	$3,737,778	$9,052,662	$14,783,460	$27,575,410	$42,271,828	$68,183,620
Newly Developed Lands	$0	$317	$1869	$5006	$17,605	$41,894	$111,552
Critical Habitat Lands	$0	−$149,240	−$822,827	−$2,063,014	−$6,350,188	−$13,224,394	−$28,831,659
All Lands	$0	$3,588,856	$8,231,704	$12,725,452	$21,242,827	$29,089,329	$39,463,514
C. Change in Average Annual Land Rents Per Acre							
Previously Developed Lands	$0.00	$4.71	$11.58	$ 19.18	$36.75	$57.82	$96.76
Newly Developed Lands	$0.00	$0.46	$1.11	$1.81	$3.40	$5.25	$8.58
Critical Habitat Lands	$0.00	−$16.93	−$40.62	−$65.70	−$120.33	−$181.28	−$285.47
All Lands	$0.00	$4.47	$10.24	$15.81	$26.28	$35.83	$48.20
D. Annual Equivalent Variation to Residents							
Aggregate	$0	−$3,928,283	−$9,526,959	−$15,581,273	−$29,163,934	−$44,892,367	−$72,971,753
Per Household	$0.00	−$9.82	−$23.82	−$38.95	−$72.91	−$112.23	−$182.43

Table 3
Partial vs. general equilibrium impacts of baseline critical habitat designation: the designation of $\pi/2$ radians of critical habitat at 32 miles from the region's center

Including impacts on ...	Approach		Economic impact
	Partial	General	
Critical Habitat Lands	√	√	−$2,063,014
Previously Developed Lands		√	$14,783,460
Newly Developed Lands		√	$5006
Consumers		√	−$15,581,273
Total	−$2,063,014	−$2,855,821	

that the total impacts are greater than they would be under the partial equilibrium approach, but, more importantly, it also shows that there are nearly $15 million dollars transferred from consumers to non-critical-habitat-owning landowners in the region. This underscores an important part of the analysis of the impacts of critical habitat designation: the net impacts are small in comparison to the wealth transfers created by the policy.[10]

6. Extension: urban growth boundary

This section extends the model to the case in which the critical habitat designation completely surrounds the region and forces the displaced residents to live within the previously developed and unregulated lands. In this case, the critical habitat designation is analogous to a growth boundary. In Section 4 we modeled critical habitat designation impacts as a function of the distance to the designation, x^* and the radians of critical habitat, k. In this section we examine the impacts of a policy that sets $k = 2\pi$, in other words, a policy that prevents all development beyond an urban growth boundary located at x^*. Under such a policy, the boundary of the built up region is determined by $\bar{x} = x^*$. The land rents at the urban boundary are no longer forced to be equal to the alternate use, so Eq. (2) is no longer an equilibrium condition. The equilibrium condition for the economy is given by

$$\int_0^{x^*} 2\pi x D(x, u)\,\mathrm{d}x. \tag{12}$$

Table 4 displays the impacts of growth boundaries imposed at differing distances from the center of the region rather than the unconstrained boundary of 34.5 miles from the center. The table shows results similar to Tables 1 and 2; the losses to regulated lands are the most intense, but there are much larger effects upon consumers and the owners of unregulated land.

Brueckner [4] is a closely-related examination of growth control boundaries. Brueckner's model concentrates on land rather than housing, so (as indicated in footnote 5) his model generates larger losses to final consumers than the model presented here. His analysis of policy solutions to combat "urban sprawl" highlights the difficulties of using these regulations to correct market failures in the urban economy. He notes that overzealous enaction of growth boundaries

[10] Of course, if the residents owned the land in common, the wealth transfers reported in Table 3 would be substantially reduced. More realistically, about a third of metropolitan residents are renters, and they are made substantially worse off by the policy.

Table 4
The economic impacts of growth boundaries at varying distances from the center of the region

	Distance to growth boundary (in miles)				
	34	33	32	30	25
% of Developed Area Regulated	4.3%	9.8%	15.2%	25.5%	48.3%
Change in Annual Rents to Land Owners					
Inside Growth Boundary	\$16,234,093	\$39,387,454	\$64,442,270	\$120,695,100	\$302,164,590
Outside Growth Boundary	−\$597,382	−\$3,293,790	−\$8,258,693	−\$25,423,977	−\$115,471,490
All Lands	\$15,636,711	\$36,093,664	\$56,183,578	\$95,271,127	\$186,693,100
Change in Average Annual Land Rents Per Acre					
Inside Growth Boundary	\$21.17	\$54.51	\$94.85	\$202.12	\$728.65
Outside Growth Boundary	−\$17.40	−\$41.81	−\$67.75	−\$124.52	−\$298.65
All Lands	\$20.39	\$49.95	\$82.69	\$159.54	\$450.20
Annual Equivalent Variation to Residents					
Aggregate	−\$17,102,303	−\$41,695,390	−\$68,585,851	−\$130,076,900	−\$340,561,470
Per Household	−\$42.76	−\$104.24	−\$171.46	−\$325.19	−\$851.40

may create larger costs than benefits and recommends the use of development fees and congestion taxes to internalize the externalities of sprawl. Our model extends this work from land to housing without considering externalities from urban development. It reinforces the finding that the costs from exogenously imposed growth boundaries can be quite high indeed.

7. Conclusion

This paper analyzes the economic consequences of designating land as critical habitat, thus restricting its economic uses by imposing regulations to protect plant or animal species. When the amount of land so designated is significant, and the lands would otherwise have been used to produce housing, the regulations will have effects upon the equilibrium of the local economy, its land and housing markets. The reduction in the land available for development means that other land, which would not have been developed for housing, can now be profitably developed. Still other land, which would have been developed at lower densities, is instead developed more intensely. These lands increase in value, and the rents to land owners increase, offsetting in part, the reduced value and rent of lands designated as critical habitat. The well being of consumers declines as housing prices and densities increase.

We present a flexible general equilibrium model of these interactions. The model is highly stylized: the built-up area is initially circular; and land designated as critical habitat is modeled as some portion of an annulus of a given width at a given distance from the center of the region. In this way, the economic effects of devoting more land to critical habitat, or of devoting more valuable land (closer to the center) to critical habitat, can be investigated. We assume that the region is a closed economy, meaning that the population is exogenous and fixed, and we compare static equilibria with and without lands designated as critical habitat. The model focuses upon the impacts within the region from changes in the supply of land and their resulting impacts throughout the economy. The model does not include other benefits that may accrue to the region, such as increased utility from the preservation of endangered species.

The model is calibrated using plausible functional forms and initial conditions, and the model is exercised using stylized facts. The simulation results illustrate the importance of the indirect effects in assessing the costs of critical habitat. If more than a small percentage of the region's land is designated as critical habitat, then the most important economic consequences of the regulations are not their effects upon lands so designated. Rather, the most important consequences are the increases in the rents and prices of land which would have been developed anyway. This leads to losses to consumers who must face higher housing prices.

The simulation results suggest that the designation of critical habitat can cause a large and significant redistribution of welfare among land owners and consumers in a metropolitan region. When critical habitat is located close to the periphery of the region, the loss to the owners of the critical habitat region may be three or four times larger, per acre of land, than the gains of the owners of land which would have been developed anyway. However, even when the area devoted to critical habitat is only a few percent of the land area of the region, the aggregate gain to owners of land which would have been developed anyway—in the absence of critical habitat regulations—is much larger than the aggregate loss to the owners of critical habitat land. These results mirror the impacts to consumers: although the economic effects upon each consumer are small, in aggregate they may overshadow the economic effects upon lands designated as critical habitat.

As the land designated as critical habitat is moved closer to the center, the land designated has a higher opportunity cost, since it would otherwise have been used more intensely for housing production. Thus, the losses to the owners of these lands are much larger. But, in the simulations explored in this paper, in the aggregate these losses are still a good bit less than the aggregate gains of the owners of other land which would have been developed anyway.

The principal distributional effect of these regulations is to reduce the well being of housing consumers in the region. When small amounts of land are designated as critical habitat, and when these lands are located near the periphery, it is nevertheless true that the aggregate losses to consumers are approximately seven-to-eight times larger than the losses to critical habitat landowners. This relative relationship is maintained when the land designated is located closer to the center, but the aggregate losses are much larger when more valuable land is designated as critical habitat.

We should emphasize that this analysis says little or nothing about the wisdom of designating land as critical habitat for the preservation of endangered species. Presumably, the value of species preservation, the aggregation of a small individual willingness to pay over a large number of individuals in the national (or world) economy, is large. Presumably, the location of designated lands is a "technical" matter. However, conditional upon these political and technical decisions, the distributional effects of critical habitat may be quite large indeed.

This paper shows the importance of examining the designation of critical habitat in a general equilibrium framework. The numerical results vary with the particular scenarios which are simulated. However, even when reasonably small areas of the region are designated, and even when these areas are located close to the periphery, the numerical results predict that the losses to consumers in the region are not negligible. This underscores the basic fact that policy makers wishing to compare the economic costs of critical habitat designation with its benefits must not only examine the impacts upon the regulated landowners, but also the region's residents, who are affected through higher prices of housing, and other landowners who benefit from increased demand for their land.

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Appendix A. Solving the model with Cobb–Douglas utility and production functions

Assume the following Cobb–Douglas functional forms for household utility and housing production:

$$U(c,q) = c^{1-\alpha} \cdot q^{\alpha}, \quad 0 < \alpha < 1, \tag{A.1}$$

$$h(S) = A \cdot S^{\gamma}, \quad 0 < \gamma < 1. \tag{A.2}$$

With this formulation, households spend fraction α of their incomes on housing services, the income elasticity of housing is one, and land expenditures represent a constant fraction γ of total housing production costs. Using these utility and production functions, Eqs. (A.3) and (A.4) represent the equilibrium of the consumer. The marginal rate of substitution between housing and other goods equals their price ratio (A.3); identical consumers of income y achieve the same level of utility (A.4). Equations (A.5) and (A.6) represent the equilibrium of housing producers.

The marginal product of capital in production is equal to the cost of capital (A.5); all producers earn normal profits (A.6). Equations (A.7) and (A.8) are described in the text as Eqs. (2) and (3).

$$\frac{U_2(y-p(x)q(x)-tx,q(x))}{U_1(y-p(x)q(x)-tx,q(x))}=p(x)=\frac{\alpha c(x)^{1-\alpha}q(x)^{\alpha-1}}{(1-\alpha)c(x)^{1-\alpha-1}q(x)^{\alpha}}, \tag{A.3}$$

$$U\big(c(x),q(x)\big)=\bar{u}=c(x)^{1-\alpha}*q(x)^{\alpha}, \tag{A.4}$$

$$p(x)h'\big(S(x)\big)=i=p(x)A\gamma\big[S(x)\big]^{\gamma-1}, \tag{A.5}$$

$$p(x)h\big(S(x)\big)-iS(x)=r(x)=p(x)A\big[S(x)\big]^{\gamma}-iS(x), \tag{A.6}$$

$$r(\bar{x})=r_a, \tag{A.7}$$

$$\int_0^{\bar{x}}2\pi x\frac{h(S(x))}{q(x)}\,\mathrm{d}x=N=\int_0^{\bar{x}}2\pi xA\big[S(x)\big]^{\gamma}q(x)^{-1}\,\mathrm{d}x. \tag{A.8}$$

The economic model consists of six equations in six unknowns: four functions, $p(x)$, $r(x)$, $S(x)$, and $q(x)$; and two constants, $\bar{x}$ and $\bar{u}$. The values which solve this system describe the spatial pattern of housing prices, land rents, capital intensity of housing, and housing density. The model also solves for the physical size of the built up region and the common level of utility of the residents. Housing prices decline with distance from the center. Land prices decline more steeply than housing prices. Population density decreases with distance from the center.

We can use Walras' Law and successive substitution to render Eqs. (A.3)–(A.6) as a function of $\bar{u}$ and exogenous parameters. Walras' Law states that total expenditures must equal total income

$$c(x)+p(x)q(x)=y-tx\quad\Rightarrow\quad c(x)=y-tx-p(x)q(x). \tag{A.9}$$

When substituted into (A.3), and rearranged, this yields

$$q(x)=\alpha(y-tx)\big[p(x)\big]^{-1}. \tag{A.10}$$

Now substitute this result into (A.4) to solve for $p(x)$ as a function of $\bar{u}$:

$$p(x)=\alpha(1-\alpha)^{(\frac{\alpha-1}{\alpha})}(y-tx)^{(\frac{1}{\alpha})}\bar{u}^{(\frac{-1}{\alpha})}. \tag{A.11}$$

When combined with (A.10), this yields $q(x)$ as a function of $\bar{u}$:

$$q(x)=(1-\alpha)^{(\frac{\alpha-1}{\alpha})}(y-tx)^{(\frac{\alpha-1}{\alpha})}\bar{u}^{(\frac{1}{\alpha})}. \tag{A.12}$$

Together, (A.11) and (A.12) describe the equilibrium consumer behavior. Substituting (A.11) into Eq. (A.5) yields $S(x)$ as a function of $\bar{u}$:

$$\big[p(x)\big]\gamma A\big[S(x)\big]^{\gamma-1}=i, \tag{A.13}$$

$$\Big[\alpha(1-\alpha)^{(\frac{\alpha-1}{\alpha})}(y-tx)^{(\frac{1}{\alpha})}\bar{u}^{(\frac{-1}{\alpha})}\Big]\gamma A\big[S(x)\big]^{\gamma-1}=i, \tag{A.14}$$

$$S(x)=\Big[\alpha(1-\alpha)^{(\frac{1-\alpha}{\alpha})}(y-tx)^{(\frac{1}{\alpha})}\bar{u}^{(\frac{-1}{\alpha})}A\gamma i^{-1}\Big]^{\frac{1}{1-\gamma}}. \tag{A.15}$$

Substitute this result into (A.6) to get $r(x)$ as a function of $\bar{u}$:

$$\big[p(x)\big]A\big[S(x)\big]^{\gamma}-i\big[S(x)\big]=r(x), \tag{A.16}$$

$$\Big[\alpha(1-\alpha)^{(\frac{\alpha-1}{\alpha})}(y-tx)^{(\frac{1}{\alpha})}\bar{u}^{(\frac{-1}{\alpha})}\Big]A\Big[\Big(\alpha(1-\alpha)^{(\frac{1-\alpha}{\alpha})}(y-tx)^{(\frac{1}{\alpha})}\bar{u}^{(\frac{-1}{\alpha})}A\gamma i^{-1}\Big)^{\frac{1}{1-\gamma}}\Big]^{\gamma}$$
$$-i\Big[\alpha(1-\alpha)^{(\frac{1-\alpha}{\alpha})}(y-tx)^{(\frac{1}{\alpha})}\bar{u}^{(\frac{-1}{\alpha})}A\gamma i^{-1}\Big]=r(x). \tag{A.17}$$

This expression simplifies to

$$r(x)=\Big[\alpha(1-\alpha)^{(\frac{1-\alpha}{\alpha})}(y-tx)^{(\frac{1}{\alpha})}\bar{u}^{(\frac{-1}{\alpha})}Ai^{-\gamma}\gamma\Big]^{\frac{1}{1-\gamma}}(\gamma^{-1}-1). \tag{A.18}$$

All that remains is to solve for $\bar{x}$ and $\bar{u}$. Substituting (A.18) into (A.7) yields

$$\Big[\alpha(1-\alpha)^{(\frac{1-\alpha}{\alpha})}(y-t\bar{x})^{(\frac{1}{\alpha})}\bar{u}^{(\frac{-1}{\alpha})}Ai^{-\gamma}\gamma\Big]^{\frac{1}{1-\gamma}}\big(\gamma^{-1}-1\big)=r_a, \tag{A.19}$$

or

$$\bar{u}=r_a^{-\alpha(1-\gamma)}\alpha^{\alpha}(1-\alpha)^{(1-\alpha)}(y-t\bar{x})A^{\alpha}i^{(-\alpha\gamma)}\gamma^{\alpha}(\gamma^{-1}-1)^{\alpha(1-\gamma)}. \tag{A.20}$$

Meanwhile, substituting (A.15) and (A.12) into (A.8) yields

$$N=2\pi A\Big[(1-\alpha)^{(\frac{1-\alpha}{\alpha})}\Big(\frac{\alpha\gamma}{i}\Big)^{\gamma}\Big]^{\frac{1}{1-\gamma}}\bar{u}^{(\frac{-1}{\alpha-\alpha\gamma})}\int_0^{\bar{x}}x(y-tx)^{(\frac{1-\alpha+\alpha\gamma}{\alpha-\alpha\gamma})}\,\mathrm{d}x. \tag{A.21}$$

Replacing equation $\bar{u}$ in (A.21) with the RHS of (A.20) yields Eq. (A.22), with only one unknown, $\bar{x}$.

$$N=2\pi r_a\alpha^{(\frac{\alpha-1}{1-\gamma})}\gamma^{-1}(\gamma^{-1}-1)^{-1}(y-t\bar{x})^{(\frac{-1}{\alpha-\alpha\gamma})}\int_0^{\bar{x}}x(y-tx)^{(\frac{1-\alpha+\alpha\gamma}{\alpha-\alpha\gamma})}\,\mathrm{d}x. \tag{A.22}$$

Equation (A.22) can be solved for the equilibrium $\bar{x}$ using integration by parts. This solution can then be used in Eq. (A.20) to find the equilibrium utility level, $\bar{u}$, and from this, the remaining functions p(x), q(x), S(x), and r(x) can be solved explicitly.

A.1. Critical habitat

Critical habitat removes some land, whose size is determined by x^* and k, from housing production. Under these circumstances, Eq. (A.8) becomes

$$\int_0^{x^*}2\pi x\frac{h(S(x))}{q(x)}\,\mathrm{d}x+\int_{x^*}^{\bar{x}}(2\pi-k)x\frac{h(S(x))}{q(x)}\,\mathrm{d}x=N, \tag{A.23}$$

or,

$$\int_0^{x^*}2\pi xA\big[S(x)\big]^{\gamma}q(x)^{-1}\,\mathrm{d}x+\int_{x^*}^{\bar{x}}(2\pi-k)xA\big[S(x)\big]^{\gamma}q(x)^{-1}\,\mathrm{d}x=N. \tag{A.24}$$

Substituting Eqs. (A.12), (A.15), and (A.20) into (A.24) again yields one equation and one unknown. This equation can be solved for the new equilibrium $\bar{x}$, the resulting $\bar{u}$, and functions $p(x)$, $q(x)$, $S(x)$, and $r(x)$.

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