Institute of Business and Economic Research

Fisher Center for Real Estate and Urban Economics

PROGRAM ON HOUSING AND URBAN POLICY

WORKING PAPER SERIES

WORKING PAPER NO. W08-003

LAND USE REGULATION WITH DURABLE CAPITAL

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August 2009

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Journal of Economic Geography **10** (2010) pp. 9–26
Advance Access Published on 31 August 2009
doi:10.1093/jeg/lbp039

Land use regulation with durable capital

John M. Quigley and Aaron M. Swoboda**†*

Abstract

This article compares the level and distribution of the welfare changes from restricting land available for residential development in a city. We compare the economic costs when residential capital is durable with the costs when capital is perfectly malleable and those when population is also freely mobile. Our simulation, based on the stylized specification of an urban location model, suggests that in a more realistic setting with durable capital, the costs of regulation are substantially higher than they are when capital is assumed to be malleable or when households are assumed to be fully mobile. Importantly, the extent of wealth redistribution attributable to these regulations is much larger when these more realistic factors are recognized. When capital is durable, the results also imply that far more new development takes place on previously undeveloped land at the urban boundary, sometimes resulting in an increase in total land under development.

Keywords: malleable capital, durable capital, open city, closed city
JEL classifications: L51, R14, O21
Date submitted: 8 October 2008 **Date accepted:** 6 July 2009

1. Introduction

The economic impacts of regulations in the housing market depend crucially upon the ability of consumers and producers to anticipate and to adapt to the changed market conditions brought about by those regulations. Consumers' willingness to pay for alternate housing depends on their ability to relocate within the affected region or else to move to new regions altogether. The response of suppliers in the housing market is dependent on the ability of producers to reallocate capital over space, as well as their expectations about future changes in economic conditions and in regulatory regimes. Policymakers attempting to measure the impacts of proposed policies must make assumptions concerning these important elements of behavior. Is the city open or closed? What is the cost of redevelopment? Can housing producers foresee changes in regulation? Or are they surprised?

More generally, the implications of household mobility, of the durability of capital and of foresight for economic models of urban development have been emphasized by many authors, and a careful survey of these issues was provided by Brueckner (2000). In the simplest formulation, originally developed in the 1960s (e.g. Muth, 1968), capital is assumed to be malleable. Households may be mobile across cities (the 'open city' model) or within cities (the 'closed city'), and the model solves for the

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spatial distribution of population and housing, rents and capital intensities. A richer formulation, in which investment in housing capital is irreversible and developers have myopic expectations was developed by Anas (1978). This was extended to the case of perfect foresight (in which developers correctly anticipate the future evolution of urban rents and agricultural rents in making current investment decisions) by Capozza and Helsley (1989).

Until quite recently, these models had not been employed to analyze the implications of land use regulation, except in the very simplest cases. In this article, we extend the application of these models in evaluating an increasingly common form of land use restriction. We consider two crucial issues about the impact of land use regulation: who is affected by the regulations; and where are the impacts located within the region? As noted below, previous work has concentrated on the special case of a fully open city and on the case of perfectly malleable capital. We extend the analysis to consider a closed city with durable capital. Of particular interest is the question of how much new development occurs as a response to the regulation; does protecting some area result in the development of an even larger area somewhere else?

Wu and Plantinga (2003) assess the impacts of open space preservation on the urban spatial structure by modeling an open city with perfectly malleable housing capital in which the local government purchases land to create a park-like 'amenity.' They assume that consumers prefer to live close to this amenity. Their model suggests that the creation of park-like open space increases the demand for nearby lands, and it may foster non-contiguous ('leap-frog') development. Wu and Plantinga conclude that the population influx can increase the acreage of total development if the amenity value is sufficiently large. Their work does not disaggregate the revenue and expenditure impacts of the policy.

In this article, we abstract from local amenities fostered by regulation. We consider instead land use policies emanating from higher levels of government. These types of policies are important and they are distinct from local land use regulation in at least three ways. First, they can be very large: as part of the 'Critical Habitat' provision of the US Endangered Species Act, the United States Fish and Wildlife Service prohibited development of four million acres of land in California to protect one species, the red-legged frog (Federal Register, 2001). Second, the public goods nature of species preservation leads to a separability of the impacts of implementation. The benefits of the preservation will be enjoyed by residents across the state, the nation or the world community, and they can be treated as separate from the local housing impacts. Third, these policies are typically implemented by fiat rather than through the purchase of land or development rights, typically fostering local opposition to the policies. These features can lead to situations in which environmental interests sue the national government to set aside lands for environmental preservation,[1] while groups of local land owners sue to prevent the implementation of these same policies.[2] In such circumstances, the regulated lands are not transformed into park-like areas, and in our model we do not assume that the regulations create a local amenity for housing consumers.

1 For one clear example, see *Center for Biological Diversity v. Norton*, 240 F.Supp.2d 1090 [D. Ariz. 2003].

2 See, for example, *New Mexico Cattle Growers Ass'n v. US Fish and Wildlife Service*, 248 F.3d 1277 [10th Cir. 2001].

Until quite recently the costs of preserving land from development under the US Endangered Species Act were estimated simply as the changes in the capitalized rental values of the land whose usage is affected by the regulation. (See Economic and Planning Services, 2002.) This is appropriate only under the assumption of a fully 'open' local economy in which mobility is costless across regions and local housing markets. In this special case, all economic costs are reflected in the reduction in aggregate rents generated on those lands which are affected directly by the regulations.[3]

Quigley and Swoboda (2007) analyzed the impacts of density restrictions in a closed urban economy, comparing the impacts upon the owners of regulated and unregulated land and upon consumers in the region. In this framework, the intensity of land use throughout the entire region is modified in response to regulations imposed in one part of the region. These prior results are, however, subject to a rather important limitation. The assumption of long-run equilibrium means that the density of housing and other salient features of the existing capital stock throughout the region can be modified costlessly in response to regulation affecting the use of land in one part of the region. The model is static and capital is malleable.

In contrast, Turnbull (2005) examined the impact of prohibiting development in a true dynamic framework. He assumed landowners have choices over the timing of development and the capital intensity of development. His model of regulation is stochastic; landowners do not know which lands will be regulated, or when. The threat of regulation is thus an additional cost of waiting to develop and motivates landowners to develop their lands sooner than otherwise. The solution to the Turnbull model of development depends crucially, however, upon assumptions about landowners' expectations for the future course of regulation. In addition, this model is not readily adaptable to address the overall impacts of regulation on consumers and the owners of unregulated land as well as regulated land.

We adopt instead a model with durable capital and myopic land owners, an extension of a closed city model with malleable capital. Thus, the model we analyze and the conclusions we draw do not depend on specific assumptions about the formation or revision of landowners expectations. This is both an advantage and a disadvantage. It is a generalization of previous work (most specifically Anas, 1978), and thus it permits a comparison of the importance of durable capital in drawing welfare implications about regulation. Our work is silent, however, on the role of changed expectations on the behavior of landowners and their investment decisions. Thus, our perspective is more appropriate for the analysis of one-off regulations prohibiting development (say, in response to a judicial determination of the critical habitat necessary for the preservation of a species) rather than for a program of regulation introduced over time in an urban area.

3 In a small open economy, the well-being of local residents is exogenous, so a reduction in permitted densities will cause consumers to be reallocated among a large number of regions, having negligible impact elsewhere. Thus, changes in the welfare of local landowners caused by the policy can be measured quite simply—by the reduction in aggregate rents accruing to the landowners at the time the policy is introduced.

The basic economic model is sketched out in Section 2. We illustrate the impacts of regulation under three distinct sets of assumptions: when residents can relocate costlessly to other regions, when capital is malleable and when capital is durable. When consumers can costlessly relocate to other regions, there are no spillover effects from regulation, and all of the costs of regulation are borne by the owners of regulated land. In the other cases, displaced residents alter the demand for development on neighboring land and lead to spillover effects from the regulation. We analyze the impact of land use regulation in three components: the direct impacts on the owners of regulated lands, the impacts on the owners of unregulated lands and the impacts of regulation on consumer welfare.

Our results suggest that significant economic effects of density restrictions typically occur outside of the area designated by the regulation. Incomes are redistributed across landlords, and the well-being of housing consumers is reduced through these linkages. In Section 3 we provide a comparison of the welfare effects of density regulations under different assumptions of consumer mobility and capital durability. Simulations with plausible economic parameters demonstrate that the economic impacts of density restrictions are larger than in the simpler and more stylized representations which have been used to analyze policy choices. The results suggest that simple models of regulatory impact greatly underestimate the social cost of the regulations. These models underestimate the costs to consumers and the substantial redistribution of wealth attributable to these rules.

Our results also reiterate the importance of measuring the spillover effects from land use regulation. When policy makers protect some lands from development, the displaced residents will have a non-marginal impact on demand for development in other parts of the region. In the case of malleable capital, when producers have the largest ability to respond to the regulation, the area of new development may often be smaller than the regulated area, leading to a reduction in the aggregate land used for development. However, in the case of durable capital, when owners of previously developed lands are constrained in their ability to respond to the changing demand for housing, regulation may often lead to an increase in land under development in the region. This contrasts with the results of Wu and Plantinga (2003), who concluded that large local amenities were generally needed to increase the total area of development.

2. A simple model with durable capital

Consider a 'standard' Muth-Mills model of an urban area composed of identical households who work in the central business district (CBD) and who commute to their residences, arrayed in a circle around the CBD which extends to the agricultural hinterland. (See Brueckner, 1987, for the canonical treatment.) Land is used more intensively close to the CBD, and the capital intensity of housing output declines with distance from the center. The price of housing declines along any radius from the CBD, just enough so that households who commute longer distances are compensated with lower rents and achieve a common level of well-being.

Land rents, $r(x, \bar{u}_0)$, housing production, $h(x, \bar{u}_0)$, and housing demand $q(x, \bar{u}_0)$, vary with distance to the CBD, x, and depend on the equilibrium citizen utility level, $\bar{u}_0$. The prevailing population density at any location is then $h(x, \bar{u}_0)/q(x, \bar{u}_0)$. The intermediate

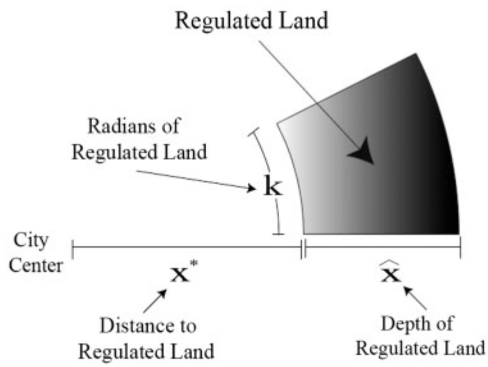

Figure 1. Geography of regulated land.

steps necessary to solve the basic model can be found in the Appendix. The solution is established by Equations (1) and (2),

$$N = \int_0^{\bar{x}_0} 2\pi \frac{h(x, \bar{u}_0)}{q(x, \bar{u}_0)} \mathrm{d}x \tag{1}$$

and

$$r(\bar{x}_0, \bar{u}_0) = r_a. \tag{2}$$

Equation (1) requires that the population of the region, N, be located within the city's endogenously determined urban–rural boundary, $\bar{x}_0$, and Equation (2) requires that all land in the built-up region ($x < \bar{x}_0$) earn rents greater than the opportunity cost of land, r_a.

Suppose the density of some specified area in the city is regulated; for example, suppose housing is prohibited in the regulated area to protect some endangered species. What are the economic effects upon consumers and landowners of mandating open space in this way?[4] For convenience only, the regulated land is depicted as k radians of an annulus located at distance x^* from the CBD and a depth of $\hat{x}$. The area is then $k\hat{x}(x^* + \hat{x}/2)$, which is increasing in all three parameters. Figure 1 presents the regulated area geographically.

The economic effects of this type regulation depend heavily on the type of economy in the region, specifically on the costs of mobility for residents across regions and the ability of housing producers to reallocate capital. The economic effects of the density restriction can be computed and compared for three cases:

1. The 'open city' model, in which mobility across cities is costless.
2. The 'closed city' model, in which mobility is costly between cities but capital may be transformed costlessly.

4 We assume that neither landowners nor consumers benefit directly from the prohibition on development in a region. In many cases, of course, environmental protection is merely an excuse used by some to enjoy the amenity of open space at the expense of the owners of that regulated land. See Mills, 1979, for a forceful statement.

3. The more realistic ‘closed city’ model in which mobility between cities is costly and residential capital is durable.

The impacts of prohibiting housing on the regulated lands can be calculated by adding up the changes in land rents across the regulated area,

$$\Delta R_{REG} = \int_{x}^{x^*+\hat{x}} kx[r'(x) - r(x, \bar{u}_0)]\mathrm{d}x, \tag{3}$$

where $r'(x) - r(x, \bar{u}_0)$ is the difference between the rental rate of land after regulation and the pre-regulation equilibrium rental rate at location x.

The regulation will also displace those who would have resided on the regulated lands. The number of people displaced depends upon the size, location and population density of the regulated lands. A regulation prohibiting housing on k radians of land from distance x^* to $x^* + \hat{x}$ will displace M residents, where

$$M = \int_{x^*}^{x^*+\hat{x}} kx \frac{h(x, \bar{u}_0)}{q(x, \bar{u}_0)} \mathrm{d}x. \tag{4}$$

In an ‘open city,’ the displaced residents move to other regions without loss of welfare. They are unable to live elsewhere within the region because to do so would require expanding the city’s built-up region, or else increasing the population density in the existing built-up area. But either of these activities would reduce consumer welfare. The only effects upon the metropolitan area from regulation in an open city are a population decline of M households and a loss of rents to the owners of regulated land, ΔR_{REG}. The remaining households and unregulated lands are unaffected by the regulation.

Now consider the ‘closed city’ where the M households who would have resided in the regulated lands are relocated elsewhere within the city. These residents must either live on previously undeveloped lands, or else compete with existing residents for housing in already developed areas, either of which causes the equilibrium utility level of residents to decline. The increase in demand for housing in unregulated areas increases housing prices and the capital intensity of housing in unregulated areas. Equilibrium housing density, housing prices and land prices all increase outside of the regulated area. This encourages a supply response from housing producers. New housing is produced on previously undeveloped lands that are now more valuable in housing than in the alternate use. Additional housing may also be produced on previously developed lands through redevelopment.

Assume first that land owners can freely adjust the capital intensity of their lands in response to the increased consumer demand for housing. The equilibrium capital intensity is endogenously determined, along with consumer utility and the geographic size of the region. This can be seen by modifying Equation (1) to reflect the prohibition of housing construction on the regulated lands (note that $\bar{x}_1$ and $\bar{u}_1$ reflect the new equilibrium urban–rural boundary and utility level for the residents as a result of the regulation). The new equilibrium condition is,

$$N = \int_{0}^{x^*} 2\pi x \frac{h(x, \bar{u}_1)}{q(x, \bar{u}_1)} \mathrm{d}x + \int_{x^*}^{x^*+\hat{x}} (2\pi - k)x \frac{h(x, \bar{u}_1)}{q(x, \bar{u}_1)} \mathrm{d}x + \int_{x^*+\hat{x}}^{x_1} 2\pi x \frac{h(x, \bar{u}_1)}{q(x, \bar{u}_1)} \mathrm{d}x. \tag{5}$$

The effects of the regulation are confined to the regulated lands under a system of free mobility, but will spread beyond the regulated lands when the displaced residents cannot simply move to another city to avoid a loss of welfare. In particular, residents will be worse off as the displaced residents increase competition for housing services, and the owners of unregulated land will be better off from the increases in land rents that result. Equation (6) indicates the change in rents across newly developed lands, where $r(x, \bar{u}_1)$ represents the land rental rate after the spillover effects from the regulation regime,

$$\Delta R_{ND} = \int_{\bar{x}_0}^{\bar{x}_1} 2\pi x[r(x, \bar{u}_1) - r_a]\mathrm{d}x. \tag{6}$$

Similarly, the aggregate impact to rents on previously developed lands is

$$\begin{aligned} \Delta R_{PD} = &\int_0^{x^*} 2\pi x[r(x, \bar{u}_1) - r(x, \bar{u}_0)]\mathrm{d}x + \int_{x^*}^{x^*+\hat{x}} (2\pi - k)x[r(x, \bar{u}_1) - r(x, \bar{u}_0)]\mathrm{d}x \\ &+ \int_{x^*+\hat{x}}^{\bar{x}_0} 2\pi x[r(x, \bar{u}_1) - r(x, \bar{u}_0)]\mathrm{d}x. \end{aligned} \tag{7}$$

Finally, the impacts upon the region's residents can be calculated using standard techniques estimating the equivalent variation of the regulation.

Against this benchmark, the economic impacts of regulation when capital is durable can be deduced. The equilibrium is no longer determined by Equation (1) or (5) but is instead modified to represent the fixed housing production on previously developed lands, as in Equation (8) below. The equilibrium condition can be adjusted to reflect the new urban–rural boundary, $\bar{x}_2$, and the regulation-adjusted utility level, $\bar{u}_2$,

$$\begin{aligned} N = &\int_0^{x^*} 2\pi x \frac{h(x, \bar{u}_0)}{q(x, \bar{u}_2)}\mathrm{d}x + \int_{x^*}^{x^*+\hat{x}} (2\pi - k)x \frac{h(x, \bar{u}_0)}{q(x, \bar{u}_2)}\mathrm{d}x \\ &+ \int_{x^*+\hat{x}}^{\bar{x}_0} 2\pi x \frac{h(x, \bar{u}_0)}{q(x, \bar{u}_2)}\mathrm{d}x + \int_{\bar{x}_0}^{\bar{x}_2} 2\pi x \frac{h(x, \bar{u}_0)}{q(x, \bar{u}_2)}\mathrm{d}x. \end{aligned} \tag{8}$$

In Equation (8), $h(x, \bar{u}_0)/q(x, \bar{u}_2)$ refers to the population density at locations with previously built housing while $h(x, \bar{u}_2)/q(x, \bar{u}_2)$ refers to the population density on lands with newly built housing. Note that because capital is durable, structural density (i.e. the capital land ratio) cannot be changed on developed land, but population density (i.e. the intensity of use by households) can. The shifting population leads to changing rents on newly developed lands as shown in Equation (9) and previously developed lands in Equation (10), where $r(x, \bar{u}_2)$is the rent function under regulation with durable capital.

$$\Delta R_{ND} = \int_{\bar{x}_0}^{\bar{x}_2} 2\pi x[r(x, \bar{u}_2) - r_a]\mathrm{d}x. \tag{9}$$

$$\begin{aligned} \Delta R_{PD} = &\textstyle\int_0^{x^*} 2\pi x[r(x, \bar{u}_2) - r(x, \bar{u}_0)]\mathrm{d}x + \int_{x^*}^{x^*+\hat{x}} (2\pi - k)x[r(x, \bar{u}_2) - r(x, \bar{u}_0)]\mathrm{d}x \\ &+ \textstyle\int_{x^*+\hat{x}}^{\bar{x}_0} 2\pi x[r(x, \bar{u}_2) - r(x, \bar{u}_0)]\mathrm{d}x. \end{aligned} \tag{10}$$

The impact of regulation with durable capital will necessarily lead to larger aggregate economic impacts. The intuition for this is clear. With malleable capital, owners of unregulated land are able to change the capital intensity of development in response to the increased demand for housing in unregulated areas. When landowners' abilities to respond to the changing demand are restricted, this will lead to larger welfare impacts. Less housing outside of the regulated area is available in convenient locations and consumers must make do with less housing or else move to less convenient locations. The inability to respond to the changing economic conditions brought about by the regulation increases the demand for undeveloped land at the urban fringe. In some circumstances, the increased demand for previously undeveloped land as a result of the regulation may result in an area of new development larger than the originally regulated area.

To clarify the analytics and timing of our model, suppose that housing capital and households are about to be distributed around a central workplace according to the plan described in the six-equation model (Equations A2, 3, 6, 7, 9, 10) presented in detail in the appendix. After committing to this plan, a regulation is imposed making it impossible to distribute housing capital and households on some specific part of the land. If capital is 'malleable,' then the entire plan can be modified before any capital is allocated to land in the city. Equivalently, the capital intensity of land throughout the region can be re-optimized to take into account the regulation which is imposed. If capital is 'durable,' in contrast, this durability prevents modification of the original plan; capital intensities on the land allowed for development are unchanged. Additional land is converted to urban use at the periphery. Residential densities may change, but not capital intensities.

With 'malleable' or with 'durable' capital, the model can be solved for an 'open city' (with an exogenously specified level of utility and an endogenous population), or for a 'closed city' (with an exogenously specified population and an endogenous level of utility).

3. How important is durable capital?

The quantitative importance of the durability of capital upon the regulatory outcome can be quite large indeed. We illustrate the magnitudes using simple but widely used assumptions about household preferences and housing production. In particular, we assume the household utility function is Cobb-Douglas in housing and the numeraire good and households spend 25% of their incomes on housing (see Goodman, 1989). Analogously, we assume the production function for housing is Cobb-Douglas in land and non-land inputs and that land represents 30% of housing output (see Oates and Schwab, 1997; Thorsnes, 1997).

These assumptions, together with three parameters—the cost of travel time ($400/mile/year),[5] the real price of capital (3% per year) and the opportunity cost of urban land ($250,000/square mile/year, in 'agriculture')—allow the model to be solved completely for a stylized urban area—defined in terms of the number of households

5 This figure, combining time and money costs of travel, is based upon IRS Publication 463, 2006, specifying $0.445/mile, an average wage rate of $30/hour, a travel speed of 35 miles/hour and a valuation of commuting time at one-half the wage rate.

and their annual incomes. For this simulation, we assume a stylized region of 400,000 households[6] with incomes of \$60,000 each, with 33% of urban land allocated to housing (see Hartshorn, 1991). Under these assumptions, the equilibrium city radius is 34.75 miles.[7]

In this stylized metropolitan area, we mandate that about 4% of land area be set aside for open space (or be set aside as 'critical habitat' under the ESA).[8] Specifically, we set aside $\pi/2$ radians of land with a depth of 2.75 miles at a distance of 32 miles from the city center (3.9% of the original 3794 square miles).

Table 1 indicates the impact of this regulation upon the owners of regulated lands, on the owners of newly developed lands (which had otherwise been in agriculture), on the owners of land which had previously been developed, and on the renters in this metropolitan housing market. The table presents the aggregate impact of the regulation on each of these groups in thousands of dollars.

In an open city, all the costs are borne by the owners of the land on which development is prohibited. Using Equation (3), we find that the aggregate rent lost by prohibiting development on these 144 square miles of land is \$2.07 million/year. With costless mobility across regions, the approximately 4000 households who would otherwise have lived on that land move elsewhere and obtain the same level of well-being. No land is bid away from agriculture for urban development, and previously developed land is unaffected by the regulation.

In a closed city with malleable capital, the same \$2.07 million is lost by the owners of land on which development has been prohibited. In addition, using Equation (7), we find that the owners of land which had been previously developed gain a total of \$14.4 million annually. This is because the displaced residents bid up the rent for

Table 1. Annual impact of prohibiting development near the urban–rural boundary[a] (thousands of dollars)

Costs imposed on	Open city	Closed city	
	Malleable capital	Malleable capital	Durable capital
Owners of regulated land	−\$2065	−\$2065	−\$2065
Owners of newly developed land	0	\$6	\$46
Owners of previously developed land	0	\$14,394	\$38,630
Resident renters	0	−\$15,173	−\$40,734
Total	−\$2065	−\$2838	−\$4123

Note: [a]Prohibition of building on $\pi/2$ radians of land with a depth of 2.75 miles located 32 miles from metropolitan center: ~4% of metropolitan area.

6 Assuming an average household size of 2.5 people means our economic region has a total population of ~1,000,000 people.
7 This is roughly the size and density of the Louisville Metropolitan Statistical Area.
8 This stylized example can be compared with real data from Zabel and Paterson (2006); they report that, in 118 designated places in which land had been set aside for critical habitat, the median (mean) set-aside was 6.9% (15.3%) of land area.

housing on previously developed lands, and producers are able to reallocate capital to meet the increased demand for housing services. In addition, Equation (6) shows that owners of land which is converted from agriculture to urban land gain about \$6000 a year. Residents of the region lose \$15.2 million a year due to the decrease in equilibrium utility levels.

In the third column, we again assume that the region is closed, but also that capital is durable once put in place. The prohibition on building removes the same amount of land from development, but the durable capital stock on previously developed land cannot be adjusted. The housing on this land cannot be made more capital intensive, but due to the increased demand it is used more intensively. Because the capital intensity of previously developed land cannot be adjusted, more land is converted at the boundary from agriculture to housing, and the city expands. The expansion of the city is consistent with the increase in the price of housing, the decline in demand and the reduction in consumer welfare.

As indicated in Table 1, the durability of the capital stock leads to considerably higher aggregate costs of the land use regulation. When capital is malleable in a closed city, the economic costs of this regulation are 37% higher than in a completely open city (i.e. \$2.84 million/year instead of \$2.07 million per year). When capital is durable, however, the economic costs of the land use regulation increase by another 45%, to \$4.11 million. Importantly, with durable capital, the transfers from resident renters to the owners of previously developed lands are substantially larger. When capital is durable, the cost of the regulation imposed on renters is about \$40.73 million a year; this is 2.7 times as large as the costs when capital is malleable. The benefits to landlords of previously developed land are about 2.7 times as large, as well.

Figure 2 compares the economic cost of the regulation when the amount of regulated land is increased at the same distance from the city center. (In these simulations the distance to the regulated land is kept at 32 miles, the depth is kept at 2.75 miles while the radians of regulated ranges from 0 to 2π.) Figure 2A presents the net economic costs of the land use prohibition. The costs are much larger in a closed city model and they are very much larger when capital is durable. When $3\pi/2$ radians are regulated (11.4% of the metropolitan area, instead of 3.9%), the economic costs when capital is durable are \$13.1 million/year; they are \$8.8 million/year when capital is malleable. The regulations impose much higher costs on consumers when more land is regulated, and they greatly increase the rents to land owners. When $3\pi/2$ radians of land are regulated, the costs to renters are \$43.2 million/year if capital is malleable and \$122.1 million/year if capital is durable. With this larger regulated area, aggregate rents to the owners of previously developed lands are much higher, \$43 million when capital is malleable, and \$115 million when capital is durable.

The difference in total impact between the lowest and highest costs associated with the regulation can be quite substantial. In fact, in these circumstances, the economic costs in a closed city with durable capital are roughly twice as large as the costs in an open city. This is seen more dramatically in Figure 2B. The figure shows clearly that the marginal cost of regulated land is increasing as more land is regulated. This is an important distinction between the models of regulatory impact. The inappropriate use of a partial equilibrium model will imply that the marginal costs of more extensive regulation are constant while a general equilibrium analysis correctly shows that marginal costs increase with the extent of the regulation.

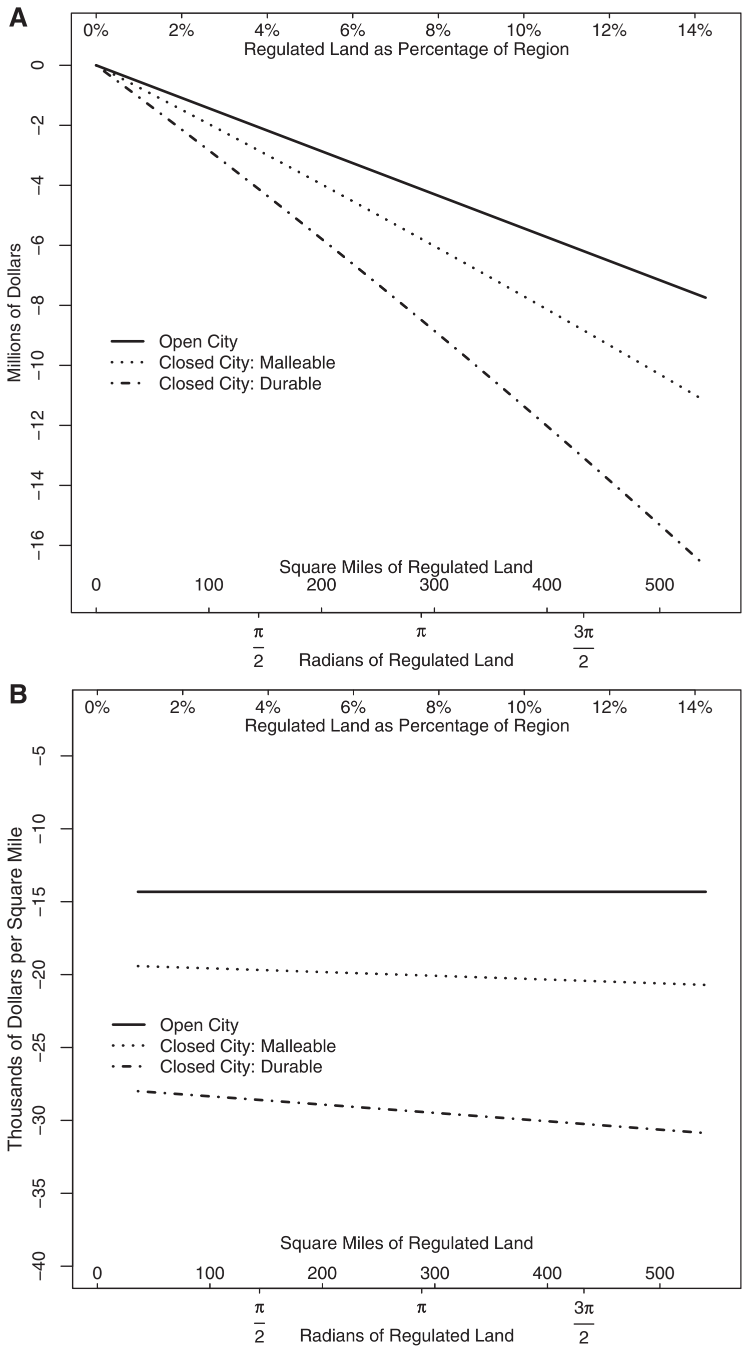

Figure 2. Annual economic cost of prohibiting housing development when the extent of the prohibition is increased. (**A**) Total costs. (**B**) Cost per unit of regulated land. Regulated land is computed by varying the radians covered by the prohibition on building, at a distance of 32 miles to the CBD and a depth of 2.75 miles.

Table 2. Annual economic impacts of prohibiting development on interior lands[a] (thousands of dollars)

Costs imposed on	Open city	Closed city	
		Malleable capital	Durable capital
Owners of regulated land	−$16,637	−$16,637	−$16,637
Owners of newly developed land	0	$19	$137
Owners of previously developed land	0	$24,761	$66,218
Resident renters	0	−$26,202	−$70,115
Total	−$16,637	−$18,059	−$20,396

Notes: [a]Prohibition of building on $\pi/2$ radians of land with a depth of 2.75 miles located 24 miles from metropolitan center, ~2% of the metropolitan area.

Table 2 displays results of regulating lands in the interior of the developed region, in this case regulating $\pi/2$ radians of land with a depth of 2.75 miles at a distance of only 24 miles from the region's center. In the absence of regulation, these lands would be developed much more intensely than land closer to the urban–rural border. In fact, the total impact of the regulation is between 6 and 8 times larger than that reported in Table 1, even though less land is regulated.[9] The larger total impact in Table 2 as compared to Table 1 is due to the impact upon regulated lands ($16.64 million vs. $2.07 million). As compared to the costs computed from an open city model, those computed from a closed city model with malleable capital are larger by 8–9% (to a total of about $18 million). With durable capital, the economic costs of the same regulation increase 'by an additional 17%.'

Figure 3 shows the impact of regulating land more distant from the urban–rural boundary. In this figure, the radians of regulated land are constant at $\pi/2$ and the depth of regulated land is constant at 2.75 miles, but the distance of the regulated land from the city center varies from 22 to 32 miles. When lands located closer to the center of the city are regulated, the total impact is larger even though the total regulated area decreases. In Figure 3A, the differences among the three models are less distinct, although the durable capital model still indicates that costs are more than 20% higher than under the partial equilibrium framework. The location of the regulated lands within the city is crucial in determining the aggregate effects of the regulation, whether the city is open or closed, or whether capital is malleable or durable. Figure 3B reports the intensity of the impact of regulating land at different locations within the region. It again shows that while there are differences among the models, the location of the regulated lands is crucial.

However, the economic effect of the regulation becomes substantially larger when capital is more durable. Durable capital generally results in twice the amount of new development as malleable capital. Indeed, when the regulated lands are located approximately halfway between the city center and the urban–rural boundary, more land is newly developed than is preserved from development by the regulation. These

9 $\pi/2$ radians and a depth of 2.75 miles represents 110 square miles at a distance of 24 miles from the city center and 144 miles at a distance of 32 miles.

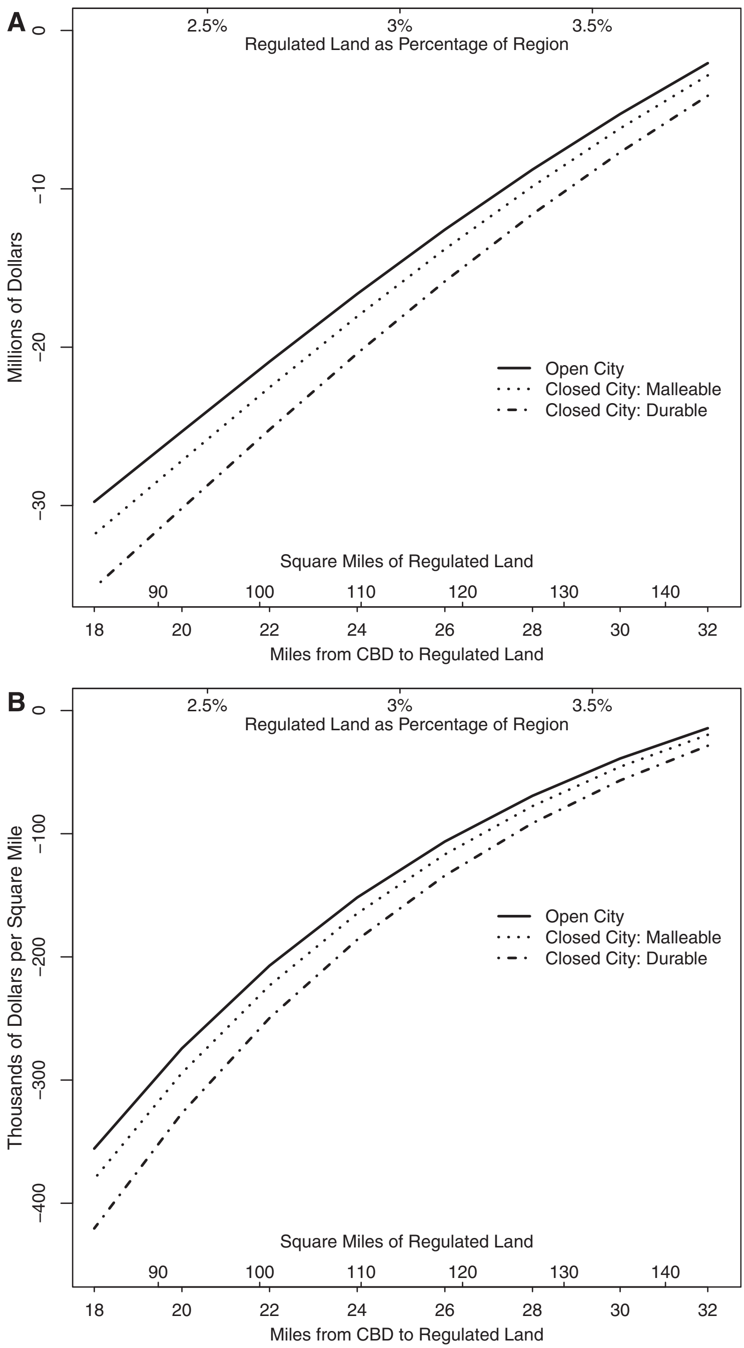

Figure 3. Annual economic cost of prohibiting housing development at various distances from the city center. (**A**) Total costs. (**B**) Cost per unit of regulated land. Regulated land is computed as $\pi/2$ radians with a depth of 2.75 miles at various distances to the CBD.

Table 3. Comparing the quantity of new land development[a]

Distance to regulated lands (miles)	Extent of prohibited development (mi^2)	Extent of new development (mi^2)		
		Open city	Closed city	
		Malleable capital	Malleable capital	Durable capital
32	144	0	17	46
30	136	0	20	53
28	127	0	23	61
26	118	0	26	70
24	110	0	29	79
22	101	0	33	88
20	92	0	37	98
18	84	0	40	108

Note: [a]Prohibition of building on $\pi/2$ radians of land with a depth of 2.75 miles located at varying distances from the metropolitan center.

results suggest that regulators should be cognizant of the effect of these types of regulation on aggregate land use—including land used for non-urban purposes.

Table 3 compares the quantity of land regulated with the quantity of land newly developed as a consequence of the regulation. To what degree does restricting development in one area simply push development somewhere else? This effect varies considerably depending on the durability of capital. When capital is malleable, the area of new land development ranges between 12% and almost 50% of the regulated area. However, with durable capital the area of newly developed land is often 2–3 times as large. In some of the simulations, the area of new development is actually larger than the regulated area, meaning that open-space preservation may lead to overall increases in the total area of development and less open space.

4. Conclusion

Recently, a great deal of attention has been paid to the efficiency of land use regulation and to the distributional implications of land use prohibitions. For example, Glaeser, Gyourko and Saks (2005) compared construction costs and selling prices for housing to measure the impact of density rules on the New York housing market. Malpezzi and Green (1996) used metropolitan measures of regulatory stringency to document the link between regulation and high rents paid by poor households. Quigley and Raphael (2005) showed that the rents and prices of owner-occupied housing are much higher in jurisdictions in California which restrict housing development.

The simulation results presented here document the importance of local land use restrictions in affecting house prices and rents on lands far removed from the site of the regulation. We compare the impacts of land use regulation that prohibits residential construction under a variety of assumptions about the ability of consumers and producers to react to the regulation. In the open city, displaced residents move to another region without loss of welfare. As a result, the only welfare impacts from the regulation are losses in land rents to the owners of regulated lands. Costless mobility from one region to another certainly represents an extreme assumption; whenever this assumption is violated, this approach will underestimate the total economic impact of the regulation, and it will ignore potentially large wealth transfers from residents to landowners.

In contrast, the closed city with durable capital lies at the other extreme. The economic impacts are highest under these circumstances because residents are unable to leave the region, and landowners cannot change the capital intensity on previously developed lands. Of course, neither of these two extremes is likely to be correct, and the truth lies somewhere between. Some displaced residents will likely live in other parts of the region while others will move elsewhere. Although neither of the models conforms strictly to reality, this comparison clearly indicates the important influence of capital durability on the welfare of urban renters. These results also suggest that empirical research should explore more carefully the distinction between 'open' and 'closed' regions and the importance of the durability of real capital.

Finally, the large transfers from renters to land owners reported in these simulations may be suggestive of the political motive for restrictive regulation by local home owners. These restrictions on housing supply may be more palatable when they are presented in terms of conservation or the protection of species and the environment. Future research should explore how the impacts of these regulations vary across owner-occupied communities.

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Appendix

Solving the model

This appendix presents the basic model which underlies the welfare comparisons in the text. It extends and generalizes the model developed by Quigley and Swoboda (2007) for a special case of land use regulation.

Consider a geographic region with N identical consumers of income y, whose well-being depends on their consumption of housing, q, at price, p, and a numeraire good, c. At any location, x, measured as the distance to the central place of employment, residents must pay commuting costs $t(x)$. For convenience, we assume transportation costs are linear, tx.

Each consumer acts to maximize a well-behaved utility function

$$U(c, q) = U(y - p(x)q(x) - tx, q(x)). \tag{A1}$$

Consumers choose a location and quantity of housing to consume at price $p(x)$. These two choices determine the total commute costs, and also the residual income to be spent on the numeraire good. In equilibrium, the marginal rate of substitution between housing and the numeraire good must equal the ratio of their prices,

$$\frac{U_2(y - p(x)q(x) - tx, q(x))}{U_1(y - p(x)q(x) - tx, q(x))} = p(x), \tag{A2}$$

where subscripts refer to partial derivatives. Since all consumers are assumed to be identical, they enjoy a common level of utility, $\bar{u}$.

$$U(y - p(x)q(x) - tx, q(x)) = \bar{u} \tag{A3}$$

Consumers enjoy the same utility level regardless of where they locate within the region. Consequently, the price and quantity of housing consumed must vary systematically by location. The schedules of prices and quantities at all locations are determined by the solution to Equations (A2–A3).

Now consider production and the supply of housing at all locations. We assume that developers are price-takers in the markets for land and capital, and that the cost of capital is constant throughout the region; the price of land varies endogenously. Let $K(x)$ represent the amount of capital and $L(x)$ represent the amount of land used in the production of housing at location x. Assume a housing production function, $H(K, L)$, characterized by constant returns to scale and concavity in input substitution. With a production technology exhibiting constant returns to scale, each producer chooses only the capital intensity, $s(x) = K(x)/L(x)$.

$$H(K, L) = L \cdot H(K/L, 1) = L \cdot h(s(x)). \tag{A4}$$

Profit π at any location can be written as

$$\pi = p(x)Lh(s[x]) - is(x)L - r(x)L = L[p(x)h(s[x]) - is(x) - r(x)], \tag{A5}$$

where i is the price of capital and $r(x)$ the price of land at location x. In equilibrium, the marginal revenue product is equal to the marginal cost of each input, and competitive producers will earn zero profits. Equation (A6) determines the capital-to-land intensity for profit maximizing producers while Equation (A7) represents the zero-profit condition for the competitive producers. These two equations fully characterize the production side of the model. The capital intensity of housing and the price of land vary systematically by location within the region.

$$p(x)h'(s[x]) = i \tag{A6}$$

$$p(x)h(s[x] - is(x)) = r(x) \tag{A7}$$

The region must also achieve an economic equilibrium in two other senses. Firstly, 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,

$$r(\bar{x}, \bar{u}) = r_a. \tag{A8}$$

The equation 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. Without loss of generality, assume that each household contains one individual, and recall that $h(s(x, \bar{u}))$ is the quantity of housing produced at location x, while $q(x, \bar{u})$ is the quantity of housing demanded by the representative consumer at any location. Then, $2\pi x dx \cdot h(s(x))/q(x)$ is the density of households at distance x, and integration over the entire region, a circle of radius $\bar{x}$, yields the population of the region, N,

$$\int_0^{\bar{x}} 2\pi x \frac{h(s(x, \bar{u}))}{q(x, \bar{u})} \mathrm{d}x = N. \tag{A9}$$

The system of equations in (A8) and (A9) can be solved by rearranging (A8) to solve for utility level as a function of the equilibrium distance to the urban–rural boundary and the model parameters, Γ

$$u(\bar{x}; \Gamma) = \bar{u}. \tag{A10}$$

Equation (A10) can then be substituted into (A9) and solved for the equilibrium distance to the urban–rural boundary.

The economy is fully characterized by six equations, two equations representing consumer choice, subject to the constraint that all consumers must have the same utility, two equations representing housing production, subject to the constraint that all producers earn identical normal profits. The equilibrium values for $\bar{x}$ and $\bar{u}$ yield the spatial pattern of housing prices, land rents, capital intensity of housing and housing density. The N residents of the region all obtain constant utility of $\bar{u}$. Housing prices decline with distance from the center. Land prices decline more steeply than housing prices. Population density decreases with distance from the center.

For the functional forms assumed in the text, Cobb-Douglas preferences and production functions, it is straightforward (but somewhat tedious) to derive the closed form relationships to be substituted into Equations (A1)–(A10).