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Revenue-Recycling and the Efficiency and Spatial Distributional Impacts of Development Taxes

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Abstract

Recent studies that compare the efficiency and distributional impacts of alternative instruments to curb sprawl typically ignore what to do with the revenues from anti-sprawl policies, such as development taxes. This paper extends first-best analysis of development taxes aimed at preserving land at the urban fringe to account for interactions with other distortions within the urban system. By incorporating urban decline at the city core, which in turn, generates negative neighborhood spillover effects and extra pressure for development at the urban fringe, we provide a more complete framework to evaluate the efficiency and distributional impacts of development taxes. We consider three potential alternative schemes to recycle the revenues: lump sum recycling, earmarked revenues to purchase conservation easements that permanently save open space and earmarked revenues to subsidize a revitalization program at the city core. In this setting, when revenues from the development tax are earmarked to fund a conservation easement there is an additional welfare gain (relative to the lump sum case) because the threat of future conversation of open space is fully eliminated. Similarly, when revenues are earmarked to fund a revitalization program at the city core, there are additional sources of welfare that make this policy preferred relative to the lump-sum recycling scheme. Finally, we also explore the spatial distributional impacts of these three alternative recycling schemes.

Keywords: Urban Sprawl, Revenue-Recycling, Regional Coordination, Spatial Modeling
JEL: Q31, R14, R38

1. Introduction

Because of its potential to preserve open space and promote revitalization of the urban core in declining cities, 'smart growth' strategies to curb urban sprawl have become a major U.S. public policy issue. Examples of anti-sprawl policies include: urban growth boundaries that limit development at the urban fringe, development taxes, subsidies to infill development, and increases in the rate of the property tax to finance the purchase of open space.[1]

Recently, many analysts have cast doubt on the effectiveness of these policies. Such critics argue that the potential for smart growth initiatives hinges on the ability of different jurisdictions in a metropolitan area to coordinate their strategies to manage growth (Downs, (2003)). The failure of jurisdictions to coordinate can only translate into the displacement of growth from one jurisdiction to another, which in turn can exacerbate the externalities associated with sprawl, such as increases in commuting. Taken to its extreme, the argument of coordination implies the creation of a metropolitan wide agency responsible for the 'vision' of urban growth for that metropolitan area.[2] There are at least two reasons that may justify regional coordination: First, an efficiency argument based on the fact that housing submarkets are linked throughout the city, and therefore policies enacted in one area will produce spillover effects across the entire metro region. These spillover effects create a rational for giving the power to regulate land to metropolitan wide agencies, as opposed to just local agencies. Second, there is a distributional argument based on the fact that the costs and benefits of anti-sprawl policies will vary across different communities,

[1] For a review of smart growth principles and policies already implemented across the U.S., see Getting to Smart Growth: 100 Policies for Implementation, a document jointly produced by the City/County Management Association (ICMA), the U.S. Environmental Protection Agency (EPA) and the Smart Growth Network.

[2] There are already several examples of metropolitan wide initiatives and attempts to coordinate. For example, in Minneapolis – St. Paul a regional tax sharing has been in place since 1971; In the State of Maryland, legislation since 1998 designates priority funding areas that target state funds to municipalities and planned growth areas. Finally, several localities in Pennsylvania use a split-rate property tax system to encourage development on vacant and blighted pieces of land in existing communities.

depending on their spatial location. Therefore, spatial distributional considerations may also justify a metropolitan wide regulatory agency.

In this coordination scenario, one potential policy would be a metropolitan wide development tax per unit of land developed. Whenever a new tax is implemented, the issue of what to do with its revenues becomes important. One could envision revenues earmarked to purchase permanent conversation easements at the urban fringe. Alternatively, revenues from a development tax could finance various programs at the city core that could alleviate pre-existing distortions that contribute to sprawl. One example would be a revitalization program in the inner city, especially if sprawl is also a result of a flight to the suburbs due to the decline of the city core. Indeed, an important practical question of interest to policymakers is whether the revenues from development taxes are better allocated at the city core, the fringe, or a combination of both. A related important issue is the measurement of the trade offs between efficiency and distributional impacts associated with these alternative forms of revenue-recycling.

This paper addresses the following questions: What are the efficiency effects of metropolitan wide development taxes under alternative recycling schemes? What are the (spatial) distributional impacts of these recycling options? That is, who wins and loses - and by how much- under each policy?

To properly address these questions, there is a need to develop a consistent, spatially explicit framework that simultaneously captures the key aspects of the problem: the benefits of open space preservation at the urban fringe, the benefits of urban revitalization at the city core, and the connections between the various housing submarkets throughout a metro area and their various spillover effects.

We extend prior literature on the economics of urban sprawl (e.g. Brueckner (2001) and Bento et. al (2006)) by developing a more complete, spatially-explicit framework that captures

several causes of urban sprawl[3]. First, unlike existing studies that have examined the effects of policies to curb sprawl (e.g. Bento et al. (2006) and Brueckner (2001)), we model two localized externalities - underprovision of open space at the urban fringe (similar to previous studies) and urban decline at the city core that creates pressure for development at the urban fringe.[4] The existence of urban decline at the city core provides a rationale for recycling the revenues of development taxes through a subsidy to improvements of the existing blighted housing stock. This form of revenue-recycling from development taxes can play an important role, as cities are struggling more and more to find sources of revenue to match federal funds to finance revitalization projects. Similarly, the underprovision of open space at the urban fringe also provides a rationale for recycling the revenues of development taxes through purchases of conservation easements at the fringe to permanently protect open space from future development[5].

Second, we provide a careful treatment of the housing market, which integrates the production of new housing at the fringe and alterations of the existing housing stock in the rest of the city. In our model, alterations of the existing housing stock occur through additions and improvements. With the exception of Arnott et al. (1999) previous studies on durable housing

[3] There is a growing body of literature on the economics of urban sprawl surveyed in Glaeser and Khan (2004) and Nechyba and Walsh (2004). For important contributions to the modeling of the causes of sprawl, see Brueckner (2000), Cheshire and Sheppard (2002), Cheshire and Sheppard (2003), Burchfield et al. (2006) and Wu (2006). Wu and Platinga (2003) examined the effects of public open space policies on urban spatial structure; Bento et al. (2005) examined the impacts of sprawl on vehicle ownership, vehicle miles traveled and public transit ridership. Wash (2007) evaluates open space policies in a locational equilibrium model that incorporates the endogeneity of both privately held open space and land conversion decisions. Platinga and Bernell (2005), and Eid et al. (2007) examined the link between urban sprawl and obesity.

[4] In related work, Anas and Rhee (2006) provide a numerical appraisal of congestion tolls and UGBs in a city that is congested but differs substantially from the standard monocentric model. Their city has dispersed, instead of centralized, employment, and intracity travel consists of both commuting and shopping trips. Brueckner (2007) re-examined the effectiveness of UGBs as second-best instruments in a monocentric congested city. In a companion paper, Bento et al (2008) examine the welfare effects of development taxes and urban growth boundaries in a model similar to the one developed in this paper.

[5] Empirical evidence suggests that permamently preserved open space is substantially more valuable than temporary preserved open space. See, Irwin (2002) for further discussion.

ignore the production of new housing supply and do not address alterations or replacements of the existing housing stock.

Third, because the existing housing stock is heterogeneous, we are able to analyze how different landowners (depending on their spatial location) respond to a development tax when revenues are earmarked to finance a subsidy to improvements. In addition, we are also able to capture the effects that improvement subsidies targeted at blighted areas indirectly produce in other housing markets as residential rents adjust. A key feature of our model is the presence of neighborhood effects, which influence landowners when deciding on the level of improvements on the existing housing stock. This feature is relevant to measure the potential investment multiplier effect that emerges from a subsidy on improvements, as empirical work suggest that maintenance behavior of individual homeowners is influenced by those of their neighbors (e.g. Galster (1987), Spivack (1991), Ioannides (2002)).

Our analytical model compares the efficiency effects of three alternative revenue-recycling policies: purchase of conservation easements, subsidizing revitalization at the city core, and the 'textbook' approach of recycling revenues lump sum to all landowners in the economy. The introduction of a development tax generates two primary sources of welfare. First, the *capitalization effect*, which is the efficiency gain associated with households responding to the higher level of open space by increasing their bids for housing. Second, the *size-effect*, which represents the primary cost associated with the reduction in the total amount of land developed at the urban fringe. When the revenues from the development tax are returned lump sum, these are the two only welfare effects of the development tax, confirming previous findings by Brueckner (2001) and Bento el al. (2006). In this case, the optimal development tax should be set at the point where the *capitalization effect* net of *the size effect* equals zero and corresponds to the traditional Pigouvian tax. It should be note that, as a result of the development tax, some owners of land at the urban fringe decide not to convert land, and therefore, there is an increase in the *temporary*

level of open space. We use the term temporary here to stress the fact that, under this policy, nothing prevents developers from future conversion of open space into residential development.

However, to the extent that households place an additional premium on permanently preserved land relative to temporary open space, as suggested by empirical literature (e.g. Irwin (2002)), when revenues from the development tax are instead earmarked to fund a conservation easement program, the *capitalization effect* is higher under this policy than when revenues are returned in a lump sum fashion, implying a higher optimal development tax. This is because under a conservation easement program, there is no threat of future conversion of the preserved open space.

Alternatively, when revenues are used to subsidize a revitalization program at the urban core, there are three additional sources of welfare: first the *revenue-recycling effect*, which represents the efficiency gain associated with using the revenues from the development tax to subsidize improvements of the existing housing stock in the blighted areas; second, two interaction effects: The *city-suburb* and *city-fringe interaction effects*. When development tax revenues are earmarked to finance the improvements of the existing housing stock at the city core, the price of housing in neighborhoods near the city boundary is reduced. This occurs because households' utility from living in neighborhoods far from the blighted area decreases when housing decline at the city core is reduced. This impact on housing prices has two opposing efficiency effects. First it produces a loss in residential land values for neighborhoods located between the city core and the urban fringe. We denote this effect the negative *city-suburb interaction effect*. Second, the pressure to convert land into residential use at the city boundary is reduced, and thus so are the costs of saving open space. This additional efficiency gain is the positive *city-fringe interaction effect*. Under plausible parameter values, we find that the *revenue-recycling effect* and positive *city-fringe interaction effect* dominate the negative *city-suburb interaction effect*. As a consequence, the second best development tax should be set above its Pigouvian level.

We also compare the distributional effects for the three policies using a calibrated simulation model. Under a lump sum recycling policy, residential landowners throughout the city bear the costs of the policy, while non-residential landowners receive a benefit from revenue-recycling. Under a conservation easement policy, residential landowners near the urban boundary receive the benefit of the easements, while urban landowners nearer the city center bear the cost of the tax. Finally, under a revitalization subsidy, landowners in the urban core receive a large benefit from a revitalized housing stock, while landowners near the urban boundary bear both the cost of the tax and the decrease in rents due to the negative *city-suburb interaction effect.* It is clear that these alternative policies differentially affect communities throughout the metro area. Because none of the policies considered improve welfare for all landowners, regional coordination is necessary to achieve the potential efficiency benefits from a recycled development tax. Regional planners can expect support from those communities that benefit from a particular recycling policy, and resistance from those bearing the cost of the policy.

The rest of the paper is organized as follows. Section 2 analytically decomposes the efficiency channels of a development tax under the three alternative recycling policies. Section 3 supplements the analytical model with a simulation model. Section 4 presents our results and finally, section 5 offers conclusions.

2. Analytical Framework

2.1. Model assumptions

We develop a static model of an open city in which a representative household enjoys utility from housing (H), a composite consumption good (Z), open space $(O(x))$ and is adversely affected by neighborhood decline $(D(x))$. The household utility function is represented by:

$$U(u(H,Z),O(x),D(x)) \tag{2.1}$$

where $U(\cdot)$ is continuous, quasi-concave and weakly separable in $u(\cdot)$, $O(x)$ and $D(x)$.[6] The household budget constraint is given by:

$$Z + pH = y - tx \tag{2.2}$$

where p is the rental price of H, y is household income, t is the transportation cost per mile and x is distance, in miles, from the place of residence to the place of work. For simplicity, we set the price of the composite good equal to unity. Households choose x, Z and H to maximize utility (2.1) subject to the budget constraint (2.2), taking the level of open space and neighborhood decline as given. From the resulting first-order conditions and (2.2) we obtain the uncompensated demand functions for the composite good and housing, condition on x:

$$Z(y, t, p, x) \text{ and } H(y, t, p, x) \tag{2.3}$$

Substituting these equations into (2.1) gives the indirect utility function:

$$V(y, t, p, O(x), D(x), x) \tag{2.4}$$

For any given structure of housing prices in the city, households prefer those locations that provide the highest level of utility. In equilibrium, the usual spatial arbitrage argument implies all locations that are occupied by households must have rents that allow a common level of utility $\overline{V}$ to be achieved. Therefore, a representative household chooses x that maximizes (2.4) and p adjusts so that:

$$V(y, t, p, O(x), D(x), x) = \overline{V} \tag{2.5}$$

Equation (2.5) implicitly defines the housing bid rent function as:

$$p(y, t, O(x), D(x), \overline{V}, x) \tag{2.6}$$

Equation (2.6) describes the maximum rent per unit floor area that a household is willing to pay at distance x from the CBD if it is to receive a given level of utility $\overline{V}$. The slope of the housing bid rent function (2.6) is given by:

[6] The separability restriction implies the demands for H and Z do not vary directly with changes in $O(x)$ and $D(x)$.

$$\frac{\partial p(\cdot,x)}{\partial x} = \frac{1}{H(x)}\left[-t + \frac{\partial U/\partial O(x)}{\partial U/\partial Z(x)}\frac{\partial O(x)}{\partial x} + \frac{\partial U/\partial D(x)}{\partial U/\partial Z(x)}\frac{\partial D(x)}{\partial x}\right] \tag{2.7}$$

While higher commuting costs make more distant locations less attractive, higher benefits from open space have the reverse effect. In addition, if central city decline increases demand for non-urban housing, housing bid rents will continue to rise in the suburbs. Therefore, the bid-rent function (2.7) can have a positive or negative slope over distance from the CBD.

Open space

Consistent with the empirical evidence (e.g. Irwin (2002), Geoghegan (2002), Geoghegan et al. (2003)), the valuation of open space depends on its accessibility and on whether it is developable or protected from future development:

$$O(x) = \begin{cases} 0 & for \quad 0 \le x < \bar{x} - x_o \\ \mu O j(\bar{x} - x) & for \quad \bar{x} - x_o \le x \le \bar{x}, \quad \mu \ge \mu_d > 0 \end{cases} \tag{2.8}$$

where $\bar{x}$ denotes the urban boundary and x_O is the distance from the urban boundary up to where open space amenities exist. $j(\cdot)$ is the rate at which open space amenities decline with distance.[7] O is the total amount of open space and μ represents the value of the open space to households. If O is developable $\mu = \mu_d$; if O is permanently protected $\mu > \mu_d$.

Neighborhood decline

A neighborhood is defined as a ring of houses at distance x miles from the CBD. Neighborhood decline ($D(x)$) depends on the physical deterioration of the neighborhood's housing stock ($Q(x)$) and on the neighborhood's proximity to blighted areas ($A(x)$):

$$D(x) = D(Q(x), A(x)) \tag{2.9}$$

[7] This function satisfies $\partial j(\cdot)/\partial x \ge 0$, $\partial^2 j(\cdot)/\partial x^2 > 0$, $j(\bar{x} - x) = 0$ for all $x \in [0, \bar{x} - x_O]$ and $j(0) = 1$.

where $D(\cdot)$ is a continuous convex function. We assume that $\frac{\partial^2 D(x)}{\partial Q(x)\partial A(x)} > 0$, which implies a complementarity relationship between the physical deterioration of the neighborhood's housing stock ($Q(x)$) and the neighborhood's proximity to blighted areas ($A(x)$).

We define the blighted area as a set of neighborhoods which exhibit positive physical deterioration $Q(x)$. The physical deterioration of the housing stock $Q(x)$ occurs because of age and lack of improvements to quality. The average physical deterioration of the blighted area produces spillovers to surrounding neighborhoods that decrease with distance from the blighted area. Households within the blighted area feel the full negative effects of spillovers. Outside the blighted area, spillovers can negatively affect utility for households in adjacent neighborhoods up to x_A miles from the CBD, and spillovers can positively affect utility for households beyond x_A. This increase in utility from living far from the blighted area results in a flight to the suburbs. The spillover effects from proximity to the blighted area are represented by:

$$A(x) = \frac{\int_0^{x_B} Q(z) 2\pi z dz}{\pi x_B^2} \begin{cases} 1 \quad if \quad 0 \le x \le x_B \\ f(x - x_B) \quad if \quad x > x_B \end{cases} \tag{2.10}$$

where x_B is the geographic extent of the blighted area. $f(\cdot)$ is the rate at which spillovers from the blighted area decrease with distance and is such that $f(x - x_B) > 0$ for $x_B \le x \le x_A$ and is $f(x - x_B) < 0$ for $x > x_A$.[8]

Production of housing

There are two types of housing stock in our model: an existing housing stock and a new housing stock. The presence of an existing housing stock can be explained by the durable nature of housing itself. There are two types of land use: residential and agriculture. We assume that

[8] This function satisfies $\partial f(\cdot)/\partial x \le 0$ and $\partial^2 f(\cdot)/\partial x^2 > 0$.

land and the housing stock are owned by absentee landowners and that the agricultural rent per unit of land is exogenous and equal to r_a.

When land is allocated to residential use, the landowner combines land (L) with capital (K) to produce housing. Assuming constant returns to scale in the housing production function, we can express the housing supply as a function of the capital-to-land ratio:

$$S = \frac{K}{L} \tag{2.11}$$

S is a proxy for housing density or building height and $h(S)$ is a concave function representing housing supply per unit of land.

Existing housing stock

The existing housing stock in a neighborhood is exogenous and exhibits a level of physical deterioration given by the level of deterioration of the housing stock net any improvements to quality ($I(x)$):

$$Q(x) = \underline{Q}\delta(x) - I(x) \text{ with } 0 \le Q(\cdot, x) \le \underline{Q} \tag{2.12}$$

where $\underline{Q}$ is the maximum physical deterioration of the existing housing stock. $\delta(x)$ is the exogenous rate at which physical deterioration decreases with distance. Given (2.12), improvements to quality satisfy:

$$0 \le I(x) \le \underline{Q}\delta(x) \text{ with } \partial\delta(x)/\partial x < 0 \tag{2.13}$$

When $\delta(x) = 0$ buildings have no physical deterioration and there is no need for improvement activity ($I(x) = 0$). When $0 < \delta(x) \le 1$, buildings exhibit some degree of deterioration and there

is room for improvement ($I(x) > 0$) up to a maximum $\underline{Q}\delta(x)$.[9] Total improvements in the blighted area are given by:

$$\bar{I} = \int_0^{x_B} I(x) 2\pi x dx \tag{2.14}$$

Given (2.6), (2.9), (2.11) and (2.13), at each distance x from the CBD, both improvements at that distance, $I(x)$, and total improvements in the blighted area, $\bar{I}$, are capitalized into housing prices:

$$\frac{\partial p(\cdot, x)}{\partial D(x)} \frac{\partial D(x)}{\partial Q(x)} \frac{\partial Q(x)}{\partial I(x)} > 0 \tag{2.15}$$

and

$$\begin{cases} \dfrac{\partial p(\cdot, x)}{\partial D(x)} \dfrac{\partial D(x)}{\partial A(x)} \dfrac{\partial A(x)}{\partial \bar{I}} > 0 & if \quad 0 \le x \le x_A \\ \dfrac{\partial p(\cdot, x)}{\partial D(x)} \dfrac{\partial D(x)}{\partial A(x)} \dfrac{\partial A(x)}{\partial \bar{I}} < 0 & if \quad x > x_A \end{cases} \tag{2.16}$$

From (2.15), an increase in the level of improvements at distance x from the CBD decreases the physical deterioration of the neighborhood's housing stock ($\frac{\partial Q(x)}{\partial I(x)} > 0$), which reduces neighborhood decline, $\frac{\partial D(x)}{\partial Q(x)} < 0$. This in turn, increases housing prices at distance x from the CBD, $\frac{\partial p(\cdot, x)}{\partial D(x)} < 0$.

From (2.16) the effect of total improvements in the blighted area is felt throughout the city. In particular, an increase in the overall level of improvements within the blighted area has two opposing effects. First, the reduction in the aggregate level of housing decline within the blighted area increases housing prices within and in the proximity of the blighted area up to x_A miles from

[9] The function $\delta(x)$ also satisfies $\partial^2 \delta(x) / \partial x^2 < 0$, $\delta(0) = 1$ and $\delta(x_B) = 0$. Therefore, assuming cities tend to develop from the center outwards over time, absent of improvement activities the most deteriorated structures are found at the city center.

the CBD. Second, reducing housing decline also reduces households´ utility gain from living far from the blighted area, which implies a smaller suburban flight effect and therefore, a decrease in housing prices past x_A miles from the CBD.

Landowners who own existing housing stock decide the level of new structural density and the level of improvements to quality in order to maximize their total rent per unit of land subject to the level of physical deterioration (2.12) while taking the rental price (2.6) and total improvements (2.14) as given. For these landowners, total rent per unit of land, $r_e(y,t,O(x),S_e(x),Q(I(x)),A(x),\overline{V},x)$, is given by:

$$r_e(\cdot,x) = \underset{S_n(x),I(x)}{Max}\ p(\cdot,x)h(S_e(x)+S_n(x)) - C^S(S_n(x)) - C^I(S_e(x),I(x)) \qquad (2.17)$$

where $C^S(S_n(x))$ are total convex construction costs and $C^I(S_e(x),I(x))$ are total convex improvement costs. $S_n(x)$ is the new structural density and $S_e(x)$ the existing structural density. The marginal productivity of $S_n(x)$ is assumed to be decreasing with $S_e(x)$, reflecting the increasing difficulty of adding new units of housing as density increases.[10]

Note from (2.16) that, because aggregate improvements are positively capitalized into housing prices up to x_A miles from the CBD, a landowner's marginal return of housing improvements within the blighted area increases with aggregate improvements. Therefore, each individual improvement decision yields external benefits which enhance the profitability of other individual's housing improvements, implying $\frac{dI(x)}{d\bar{I}} > 0$. Because landowners take aggregate improvements as given, they are not able to recognize this investment externality when deciding their individual housing improvement. However, we assume landowners can revise a posteriori their improvements decisions once the new aggregate housing improvement is known.

[10] The rationale for this type of adjustment costs of the housing stock is given in Lucas (1967) and Hochman and Pines (1982).

In the absence of government intervention, we assume the optimal choice of improvements is zero for all landowners:

$$I^*(\cdot, x) = 0\,,\ 0 \le x \le x_B \tag{2.18}$$

New housing stock

The new housing stock results from new construction activities in the outer neighborhoods of the urban area. Because landowners choose the land use that maximizes the return of their plot of land, if the return in agriculture is less than the return in residential, a plot of land is converted into residential use. For landowners who produce new housing, total rent per unit of land, $r_n(y, t, O(x), A(x), \overline{V}, x)$, is given by:

$$r_n(\cdot, x) = \underset{S_n(x)}{Max}\ p(y, t, O(x), A(x), \overline{V}, x)h(S_n(x)) - C^S(S_n(x)) \tag{2.19}$$

Closing conditions

Finally, the two closing conditions of the model require that the residential land rent must equal the exogenous agricultural rent at the urban boundary ($\bar{x}$):[11]

$$r_n(y, t, \mu O, A(\bar{x}), \overline{V}, \bar{x}) = r_a \tag{2.20}$$

The city limit is established in the land market and is implicitly determined by (2.18) as:

$$\bar{x}(y, t, \mu O, A(\bar{x}), \overline{V}, r_a) \tag{2.21}$$

Note from (2.20) and (2.21) that due to its externalities, the concentration of physical deterioration at the city core influences bid rents at the urban boundary and hence the city's

[11] Note that $O(\bar{x}) = \mu O j(\bar{x} - \bar{x}) = \mu O$.

spatial size. Furthermore, landowners do not take into account all the benefits of open space when converting land into residential use, which reinforces urban sprawl.[12]

The second closing condition of the model requires that the city population N fits inside the urban boundary:

$$\int_0^{\bar{x}} \frac{h(x)}{H(y,t,p(\cdot,\bar{V},x),x)} 2\pi x dx = N \tag{2.22}$$

where $\frac{h(x)}{H(y,t,p(\cdot,\bar{V},x),x)}$ is the population density at distance x miles from the CBD.

Given an exogenous utility level, $\bar{V}$, the price of housing is determined for each location by (2.6). Given $p(\cdot,\bar{V},x)$ and the stock of housing, $h(x)$, the number of households accommodated in the city as a whole is determined by (2.22).

Figure 1 illustrates the spatial layout of the city. Up to $\bar{x}_E$ miles from the CBD there is an existing housing stock exhibiting suboptimal quality up to x_B miles. Conversion of agricultural land into residential use occurs up to $\bar{x}$ miles from the CBD.

2.2. Welfare Measurement

With this framework, we can now calculate the efficiency impacts of a policy intervention. We note that prior to a policy intervention, total value of land in the city, R, is given by the sum of total value of land in residential use with total value of land in agriculture use:

$$R = \int_0^{\bar{x}_E} r_e(\cdot,x) 2\pi x dx + \int_{\bar{x}_E}^{\bar{x}} r_n(\cdot,x) 2\pi x dx + \int_{\bar{x}}^{\bar{m}} r_a 2\pi x dx \tag{2.23}$$

[12] The social value of the land around the city includes the agricultural rent it earns and all the open space benefits it generates: $r_a + \int_0^{\bar{x}} \frac{\partial U / \partial O(x)}{\partial U / \partial Z(x)} N(x) 2\pi x dx$, where $N(x) = \frac{h(x)}{H(x)}$.

where $\overline{m}$ denotes the geographic extent of potentially developable land. The efficiency impacts of the policy are calculated as changes in the value of land resulting from the policy intervention.

2.3. Development tax with Lump Sum revenue-recycling

First consider the impact of a development tax with revenues returned lump sum to all landowners. Let t_D be a tax per unit of land developed. The efficiency effects of a marginal increase in t_D can be expressed as:

$$\frac{dR}{dt_D} = \underbrace{\left[\int_{\bar{x}_{t_D}-x_O}^{\bar{x}_{t_D}} \mu_d \frac{\partial p(\cdot)}{\partial O(x)} \frac{\partial O(x)}{\partial \bar{x}_{t_D}} h(S_e(x) + S_n^*(\cdot, x)) 2\pi x dx\right] \frac{d\bar{x}_{t_D}}{dt_D}}_{dR^C} + \underbrace{\left[r_n[\cdot, \mu_d O, \bar{I}(\cdot, g), \bar{x}_{t_D}] - r_a\right] 2\pi \bar{x}_{t_D} \frac{d\bar{x}_{t_D}}{dt_D}}_{dR^S} \tag{2.24}$$

where $\bar{x}_{t_D}$ is the geographic extent of the city under the lump sum development tax and $S_n^*(\cdot, x)$ is the optimal new structural density. The term labeled dR^C in (2.24) represents the *capitalization effect*. The *capitalization effect* equals the sum of the willingness to pay for open space by each household who increase their bids for housing. The term labeled dR^S in (2.24) represents the *size effect*. This effect is the cost associated with the reduction in the total amount of land developed and is given by the reduction in the return of land due to the change in land use induced by the policy. Because only households near the urban fringe benefit from open space, the *capitalization effect* will only benefit those households. Furthermore, because revenues are returned lump sum, there is a wealth transfer from landowners with developed land to those with undeveloped land.

2. 4. Development tax with revenues used to subsidize improvements in the city core

Now consider the effects of the development tax with revenues used to subsidized improvements in the city core. The efficiency effects of a marginal increase in t_D under this recycling policy are given by (see Appendix A):

$$\begin{aligned}\frac{dR}{dt_D} = & \underbrace{\int_{\bar{x}_{t_D}-x_O}^{\bar{x}_{t_D}} \mu_d \frac{\partial p(\cdot)}{\partial O(x)} \frac{\partial O(x)}{\partial \bar{x}_{t_D}} h(S_e(x)+S_n^*(\cdot,x))2\pi x dx \frac{d\bar{x}_{t_D}}{dt_D}}_{dR^C} \\ & + \underbrace{\left[r_n[\cdot,\mu_d O,\bar{I}(\cdot,g),\bar{x}_{t_D}]-r_a\right]2\pi\bar{x}_{t_D}\frac{d\bar{x}_{t_D}}{dt_D}}_{dR^S} \\ & + \underbrace{\left[\int_0^{x_A}\frac{\partial p(\cdot,x)}{\partial \bar{I}}h(S_e(x)+S_n^*(\cdot,x))2\pi x dx - g\right]\frac{d\bar{I}}{dt_D}}_{dR^R} \\ & + \underbrace{\int_{x_A}^{\bar{x}_{t_D}}\frac{\partial p(\cdot,x)}{\partial \bar{I}}h(S_e(x)+S_n^*(\cdot,x))2\pi x dx\frac{d\bar{I}}{dt_D}}_{dR^{CS}} \\ & + \underbrace{\left[r_n[\cdot,\mu_d O,\bar{I}(\cdot,g),\bar{x}_{t_D}]_{g>0}-r_n[\cdot,\mu_d O,\bar{I}(\cdot,g),\bar{x}_{t_D}]_{g=0}\right]2\pi\bar{x}_{t_D}\frac{d\bar{x}_{t_D}}{dt_D}}_{dR^F}\end{aligned} \tag{2.25}$$

where g is the subsidy per unit of housing improvement and $\bar{x}_{t_D}$ the geographic extent of the city under the development tax. The overall increase in housing improvements is given by:

$$\frac{d\bar{I}}{dt_D} = \int_0^{x_B}\frac{\partial I(\cdot,x)}{\partial g}\frac{dg}{dt_D}2\pi x d\left[1-\int_0^{x_B}\frac{\partial I(\cdot,x)}{\partial \bar{I}}2\pi x d\right]^{-1} \tag{2.26}$$

A comparison of (2.24) and (2.25) suggests that, when revenues of development taxes are earmarked to subsidize improvements in the city core, both policies produce the same *capitalization effect* and *size effect*. However, the overall efficiency effects of a revitalization policy differ from the lump sum return in two important dimensions. First, in contrast to the lump sum policy, revitalization also produces an additional welfare effect given by dR^R in (2.25). We denote this effect, the *revenue-recycling effect*, which is the welfare gain from development taxes that results from earmarking the revenues to revitalization in the city core. This equals the wedge

between the marginal social benefit of improvements and the subsidy multiplied by the overall increase in housing improvements. Note from (2.26) that the overall increase in housing improvements has two terms. The first term on the right-hand side of (2.26) represents the direct increase in individual improvements induced by the subsidy on improvements. The second term captures the investment multiplier generated by the positive feedback of aggregate improvements into individual improvements ($\frac{\partial I(\cdot, x)}{\partial \bar{I}} > 0$), which magnifies the impact of the subsidy on housing improvements. Also note that the benefits of revitalization are explicitly spatial, as landowners up to x_A benefit from improved neighborhood quality.

The second difference is that spatial connectivity between housing submarkets creates interaction effects beyond the city center. dR^{CS} and dR^{F} represent the *city-suburb* and *city-fringe interaction effects*, respectively. When development tax revenues are earmarked to finance the improvements of the existing housing stock at the city core, both the demand and the price for housing in neighborhoods beyond x_A miles from the CBD is reduced. This occurs because households' utility from living in neighborhoods far from the blighted area decreases when housing decline at the city core is reduced. This impact on housing prices has two opposing efficiency effects. First it produces a loss in residential land values for neighborhoods located between x_A and $\bar{x}_{t_D}$ miles from the CBD. This efficiency loss is captured by the term dR^{CS} in (2.25) and we denote this effect as the negative *city-suburb interaction effect*. Second, it reduces the pressure to convert land into residential use at the city boundary and thus, the cost of saving open space. This additional efficiency gain is captured by the term dR^{F} ; the positive *city-fringe interaction effect.*

Thus, when comparing a lump sum return to a revitalization policy, it is clear that if the net benefits of revitalization are positive, $dR^{R} + dR^{CS} + dR^{F} > 0$, a revitalization policy is more efficient than a lump sum policy. Furthermore, even if there are no benefits from preserving open

space, $dR^C = 0$, if the net benefits of revitalization cover the *size effect*, $dR^R + dR^{CS} + dR^F > dR^S$, a revitalization policy would still be welfare improving. To summarize the distributional impacts of this policy, all landowners with developed land pay the development tax, landowners near the city center receive a benefit from the *revenue-recycling effect*, while landowners near the fringe gain from the *capitalization effect* but lose from the *city-suburb interaction effect*.

2.5. Development tax with revenues used to purchase conservation easements

Finally, consider the impacts of the development tax when revenues are used to purchase conservation easements. The efficiency effects of a marginal increase in the development tax in this case can be represented by (see Appendix A):

$$\frac{dR}{dt_D} = \underbrace{\left[\int_{\bar{x}_{t_D} - x_O}^{\bar{x}_{t_D}} \mu \frac{\partial p(\cdot)}{\partial O(x)} \frac{\partial O(x)}{\partial \bar{x}_{t_D}} h(S_e(x) + S_n^*(\cdot, x)) 2\pi x dx\right] \frac{d\bar{x}_{t_D}}{dt_D}}_{dR^{CE}} + \underbrace{\left[r_n[\cdot, \mu O, \bar{I}^*(\cdot, g), \bar{x}_{t_D}]_{g=0} - r_a\right] 2\pi \bar{x}_{t_D} \frac{d\bar{x}_{t_D}}{dt_D}}_{dR^S} \tag{2.27}$$

There are two key differences between this policy and the two previous policies. First, a comparison between (2.24), (2.25) and (2.27) shows that the *capitalization effect* of a development tax when revenues are used to purchase conservation easements (the term dR^{CE} in (2.27)) is higher than the *capitalization effect* produced by the lump return or revitalization policy. This is because when revenues are allocated to purchase conversation easements, open space will be permanently preserved and therefore its value to households is higher. Under the other policies, individuals perceive that open space is only temporarily preserved and therefore their willingness to pay is lower, reflecting the potential threat of future development.

Second, the *size effect* of this policy is greater than the *size effect* of the lump sum policy, and greater than the *size effect* under a revitalization policy. Because conservation easements raise the value of land, restricting development comes at a greater cost. Thus, both benefits and costs of land preservation under conservation easements have increased.[13] In contrast to the lump sum return, undeveloped land receives no wealth transfer and landowners who sell their development right are exactly as well off as they were in the absence of the policy.

A comparison of (2.24), (2.25) and (2.27) also reveals that the efficiency of a development tax depends greatly on how revenue is recycled. A priori, however, it is not possible on efficiency grounds to determine from the analytical model whether revenues should be earmarked to finance improvements in the city core or used to purchase conservation easements. Nor is it possible to determine the distributional impacts of each policy. In the calibrated simulation model we are able to quantify the magnitude of the different *capitalization*, *size* and *revenue-recycling effects* and therefore rank the instruments. Using a simulation model, we also look at a cross-section of the metro area and determine the spatial impacts of each policy both in terms of who benefits/loses, and the relative magnitudes of the effects.

3. Simulation Model

In this section we discuss the parameter values used to calibrate our simulation model and the solution algorithm. The simulation model allows us to rank the revenue-recycling instruments and also allows us to determine the distributional impacts of each policy. In addition to the three policies considered in the analytical section, we also consider a "hybrid" policy where development tax revenues are used to purchase conservation easements, with the remaining revenue used for revitalization. The parameter values discussed in sub-section 3.1 are based on the empirical literature and on Census Data (2000). We then describe in sub-section 3.2 the

[13] Though a formal proof is not provided here, the increase in capitalization should outweigh the increase in costs if the benefits of open space are non-point ($x_O \neq \bar{x}_{t_D}$)

computation of the equilibrium algorithm, which consists of two nested algorithms-a strategic behavior algorithm and a policy algorithm.

3.1. Parameter Values

Table 1 summarizes the parameter values used in our benchmark.

Valuation of Open Space: Despite several studies on the value of farmland (McConnell and Walls (2005)), there is still uncertainty over an average willingness-to-pay (WTP) for farmland preservation. For our benchmark, we set $\gamma = 0.00004$ and $\phi = 0.5$ to generate an average aggregate WTP of \$20 per acre for developable farmland, approximating the conservative values suggested in McConnell and Walls (2005). In addition, we set $\mu = 24$ so that the total average WTP for one acre of permanent protected farmland is three times greater than for one acre of developable farmland (Irwin (2002), Geoghegan (2002)). Finally, we set $x_O = 2$ and $\lambda = 1$ so that the spillover effects of open space amenities are concentrated within the first 2 miles from the open space area (McConnell and Walls (2005)).

Valuation of improvements: There is also uncertainty regarding households WTP for housing improvements, due to a lack of empirical studies.[14] Given the aggregate nature of the model, we calibrate the WTP for housing improvements consistent with the values provided by studies that use property value gains as a proxy for benefits of housing rehabilitation programs (Schill et al. (2002), Ellen et al. (2003)). For our benchmark, we set $v = 0.000004$ and $\theta = 2$ to generate a moderate aggregate WTP for housing improvement equal to \$1.25 per dollar of subsidy spent.[15] In order to capture the positive feedback of aggregate improvements into individual improvements as suggested by the empirical literature (Ioannides (2002), Ioannides and Zabel (2003)), we set $\varphi = 2$.

[14] See DiPasquale (1999) for a review on the main themes in the empirical literature on housing supply.
[15] For exemple, Ellen et al. (2003) find that an expenditure of \$3.7 billion dollars in total public subsidies resulted in a property value increase of \$6.8 billion dollars, meaning, for every dollar of subsidy spent, it resulted in \$1.84 increase in property values.

Flight to the suburbs: In our benchmark, we set $\xi = 0.5$ so that the positive spillover at the city boundary due to blight flight is equal to that of the negative spillover at x_B.[16]

Physical decay parameter (δ): While we are unaware of any studies that explicitly measure the decay of housing stock with respect to distance from a central business district, a data-oriented snapshot from the 2001 American Housing Survey-National Sample of the characteristics of the existing housing stock in 2000 provides some insight into the choice of δ.[17] A value of $\delta = 0.5$ captures the basic features of this snapshot, with older decayed units concentrated in the city center, and newer housing units as we approach the edge of the blighted area.

Spillover effects of the blighted area (ρ): Our spillover effects were calibrated to mimic studies by Ellen et al. (2002, 2003) and Schill et al. (2002) which suggest that the impact of the disamenity in blighted areas becomes quite small at a distance of 2000 feet, and disappears as one move even further away from the blighted region. Ellen et al. (2002) investigated the neighborhood price impacts of the Nehemiah program and the Housing Partnership program in New York City during the 80's and 90's. They identified a positive home price impact for both programs, with the impact attenuating over distance from the developments: 11% within 500 feet, 6% at 1000 feet and 3% at 2000 feet, which would imply that $\rho = 1$.[18]

3.2. The Equilibrium Algorithm

The computation of the equilibrium consists of two nested algorithms: a strategic behavior algorithm and a policy algorithm. The strategic behavior algorithm solves for a Nash equilibrium

[16] Note that $A(\bar{x}_{t_d}) = [\xi / 1 - \xi][-A(x_B)]$.

[17] We focused on housing units built 82 years or more ago (old units) and compared their characteristics with those of units built after 1990 (as new units).

[18] On the other hand, Ellen et al. (2003) find that prices in the blighted area were 28% lower, at 500 feet 20% lower, at 1900 feet 5% lower, and at 2000 feet around 2% lower, corresponding to $\rho = 2$. Adopting a larger ρ would slightly diminish the *revenue-recycling effect* as fewer households benefit from recycling.

amongst landowners, who optimize their profits with respect to densities and improvements. In the spirit of Lucas and Rossi-Hansberg (2002), we numerically solve for the equilibrium improvement function that maximizes residential land rent at each location within the blighted area, which yields equilibrium housing bid rents and residential land rents for the system. This solution is then nested within the larger policy algorithm and is used to compute the welfare impacts of a development tax for different amounts of land saved. The sequence of interactions from the policy algorithm concludes when 1) no household would prefer to live in a ring other than the one it actually lives in; 2) land is allocated to its most profitable use; 3) no landowner has incentive to deviate from his improvement level choice; 4) the government budget constraint is balanced; and 5) the number of households equals the population of the city.

Figure 2 provides a graphical example of the strategic behavior algorithm convergence. Consistent with the analytical model, the curve $I^0(x)$ represents landowners' initial improvement decision in response to the subsidy. The subsequent curves, $I^n(x)$, represent landowners' iterative response to aggregate improvements, until the process converges to the equilibrium curve $I^*(x)$.The bell shape of the improvements function is due to neighborhood effects and the heterogeneity of the existing housing stock.[19]

4. Numerical Results

This section presents results from the numerical model. Section 4.1 and 4.2 compare the marginal welfare effects of the different revenue-recycling policies and the spatial distribution of total benefits to landowners located at different distances from the CBD. Though we have carefully calibrated the simulation model, it should be noted that our emphasis is on qualitative rather than quantitative differences across policies.

[19] Near the CBD, a large existing housing density implies large costs of improvements and additional new construction. Near the edge of the blighted area, marginal benefits of improvements are small, due to a low level of decline.

4.1. Marginal Welfare Effects

We first examine the marginal welfare effects to landowners of alternative anti-sprawl policies. In figure 3, the horizontal axis measures the percentage of land saved and the vertical axis measures the marginal welfare effect, where a positive value indicates a benefit and a negative value a cost. The main goal of this figure is to decompose the different sources of efficiency discussed in section 2 and discuss their contribution to the overall welfare of the different policies.

MW^{LS} represents the marginal welfare effect of a lump sum development tax. This curve represents the two opposing efficiency channels exploited by this instrument: the *capitalization* and *size effects*. This curve has a positive intercept due to the capitalization of open space, and is downward sloping, reflecting the increasing marginal cost of saving land. The crucial point from this curve is that while the *capitalization effect* is significant for low levels of saved land, the contribution of the *size effect* to the costs of the policy quickly increases. This increase in the *size effect* quickly drives benefits to zero. This is not surprising, because as more land gets saved, we more towards the city center where housing prices are higher and thus residential land is more valuable. From the figure, the optimal level of land preservation under lump sum return is approximately 3.5%, where the MW^{LS} intercepts the horizontal axis. After 3.5% the costs of preserving land would outweigh the benefits.

MW^{CE} shows the marginal welfare effect of saving land under the development tax when revenues are used to purchase conservation easements. The vertical distance between this curve and the MW^{LS} isolates the increase in *capitalization effect* due the permanent nature of the open space that is saved through the easement. Consistent with empirical evidence (Irwin (2002)), if households perceive that open space will be permanently preserved, their willingness to pay is about 2.5 times higher. As a consequence, the optimal level of savings under this policy is 8%.

MW^I shows the marginal welfare effect of a development tax when revenues are used for revitalization through financing improvements at the city core. The vertical difference between this curve and MW^{LS} reflects the combination of the *revenue-recycling effect* – which is the additional benefits generated from reducing urban decline at the city center – the decrease in benefits due to the negative *city-suburb interaction effect*, and the increase in benefits from the *city-fringe interaction effect* due to a decrease in the flight-to-the suburbs. For lower amounts of land saved, the differences in welfare of this policy relative to the lump sum highlight the large benefits of revitalizing the city core. However, as more and more funds are diverted to the city center, the additional gains from improvements rapidly decrease. The optimal level of land saved under this policy is about 7%, about 2.33 times higher than under the lump sum return. On the other hand, the optimal amount of land saved under this policy is less than under a conservation easement policy, though the total benefits of the revitalization policy (the integral of the areas under the curves in figure 3) exceed those under the conservation easement policy. Because of the large benefits of financing improvements in the city core, even if the benefits of preserving open space are equal to zero, our simulations suggest that one should still save about 6.5% of land through development taxes just to raise revenues to revitalize the city core.

Finally, the curve MW^{CE+I} gives the marginal welfare effect of a development tax under the "hybrid" policy of conservation easements and subsidies to improvements. An identical amount of revenue is raised by this policy relative to the pure revitalization policy; however a fraction of that revenue is used to purchase permanent conservation easements, while the remaining revenue is used to fund revitalization. The difference between MW^{CE+I} and MW^I represents the additional benefits from purchasing conservation easements net the decrease in benefits from less money going towards revitalization. This policy has the greatest total benefits and largest optimal amount of land saved of around 8.5%.

4.2 Distributional Impacts

We now consider the distribution of total gross benefits to different landowners across the metro from saving 8% of land. 8% was chosen as a point of comparison because it is the optimal level of land savings under the conservation easement policy. Choosing a different level of savings merely alters the magnitudes, but not the relative structure of the distribution effects. Figure 4a compares the total gross benefits across policies to different landowners inside the city (up to 4 miles from the CBD). We remind the reader that the blighted area consists of 3.5 miles. Figure 4b looks at landowners beyond 4 miles from the CBD (the suburbs and urban fringe, roughly speaking).

GB^I shows the distribution of total benefits throughout the city under the development tax when revenues are used to finance a revitalization program. This curve highlights several important features of the model: First, housing stock improvements only take place between 2.5 and 3.5 miles from the CBD, as shown through the large benefits to those landowners. To the left of 2.5 miles and to the right of 3.5 miles the total growth benefits of the policy are still positive reflecting the spillover benefits from improvements. Looking at Figure 4b, suburban landowners experience a loss due to the tax and the decrease in rents due to a decrease in flight to the suburbs. Finally, landowners who switch land uses from residential to farmland experience the loss in the triangle from 6.85 to 7.15 miles.

GB^{CE+I} gives the distribution of total benefits throughout the city under the development tax when revenues are combined to finance a revitalization program and purchase conservation easements. This curve illustrates that the loss in total gross benefits at the city center from allocating part of the revenues to conservation easements is negligible. This is not surprising since the amount of money allocated to purchase the easement (that is the *size effect* at the urban fringe) only represents 4% of the total amount of revenues generated; or in other words, it is not

extremely expensive to purchase 8500 acres of easements.[20] Because the development right of land beyond 6.85 miles has been purchased through the easement, landowners there are exactly as well off as they were before.

GB^{LS} and GB^{CE} denote, respectively, the gross benefits under the lump sum and conservation easement policies. Because the benefits of preserving open space are concentrated in the suburbs, these policies produce no benefit in the city center. As the conservation easement produces greater capitalization benefits, landowners receive greater benefits of preserving open space than under the lump sum policy. Comparing the total effect to landowners nearer the city center, we see that the conservation easement has a much smaller cost to those landowners than the lump sum policy. This is because the conservation easement only needs to raise enough revenue to purchase the development rights corresponding to 8% of land saved, while the lump sum policy needs to increase the tax until the landowner corresponding to 8% of land saved is indifferent between residential and agricultural use. Finally, while the conservation easement has no impact on agricultural owners, the lump sum policy of returning revenues to all landowners has the effect of subsidizing agricultural land at the expense of developed residential land.

Figures 4a and 4b make clear that each policy has a very different spatial imprint on the metro area. The revitalization and "hybrid" revitalization policies concentrate benefits near the CBD and losses in the suburbs and urban fringe. The conservation easement and lump sum policies on the other hand, produce benefits for landowners far from the city center (suburban landowners for the conservation easement and agricultural landowners for the lump sum) at the expense of urban landowners. Given these distributions of benefits and costs, it is clear that coordination will be difficult, as no policy is Pareto improving for all landowners. Thus, these results echo the call by analysts for a regional coordination entity capable of setting urban policy across metro jurisdictions.

[20] The purchase of the conservation easement only entails the purchase of the development right, which is equal to the difference between the returns from residential and agricultural use.

5. Conclusions

This paper uses consistent, spatial analytical and numerical simulation models to demonstrate the efficiency and distributional effects of a metro-wide development tax with alternative recycling policies. We analytically decompose the welfare effects of a development tax when revenues are recycled under three scenarios: lump sum return to all landowners, purchase of conservation easements, and subsidy of improvements in the urban core. The analytical results highlight the importance of spatial connectivity of housing submarkets throughout the city, leading to interaction effects between urban, suburban, and fringe housing markets.

Because of the benefits of revenue-recycling, the lump sum return policy performs the worst, with an optimal land saved of only 3%. Conservation easements and revitalization policies create additional benefits, and therefore generate larger amount of optimal land saved: 8% and 7% respectively. When revenues from the development tax are used to purchase conservation easements at the fringe, the resulting *capitalization effect* is higher than when revenues are returned lump sum. In turn, if revenues finance a revitalization program at the city core, the development tax exploits three additional sources of welfare (all absent in the two previous policies): the *revenue-recycling effect*, which is the additional welfare gain from using the revenues of development taxes to subsidize improvements in the blighted areas of the city-core; the *city-suburb interaction effect*, which is a welfare loss that results from the reduction in residential rents in the suburbs; and the *city-fringe interaction effect*, which is the welfare gain that results from removing the pressure for development at the fringe, reducing the costs of saving land. Since the combination of these three effects is to produce a welfare gain, development taxes with revenues used to finance an improvements subsidy should be set above its first best Pigouvian level.

This result has a clear implication for policy analysis and suggests that, even when there is uncertainty about the benefits of open space, just the revenue-raising characteristic of the

development tax per se justifies a tax that saves 3.5% of land, suggesting that the second best development tax should be set above its Pigouvian level. Our results also suggest that the bulk of the gains from anti-sprawl policies come primarily from the *revenue-recycling effect* and less so from the benefits of saving open space.

The simulation model also compares the distributional impacts of the alternative policies. Revitalization concentrates benefits at the city center, while the lump sum and conservation easement policies produce benefits much farther from the CBD. No policy is welfare improving for all landowners, suggesting that regional coordination bodies would be needed to capture the potential gains from revenue-recycling suggested by the analytical model and marginal welfare simulations.

There are a number of limitations to our analysis that might be worth relaxing in future work. First, we abstract from zoning regulations and redevelopment restrictions. It would be useful to explore how these pre-existing policies may restrict the density adjustments predicted by our model and therefore affect the benefits from the *revenue-recycling effect*. While we suspect that pre-existing zoning regulations will not alter the main findings of our work, they will certainly affect the magnitude of the welfare gains from the *revenue-recycling effect*. The impacts of zoning may also vary across space, altering the distributional impacts as well.

Second, we could allow for other causes of urban sprawl and distortions within the urban system, such as traffic congestion and agglomeration economies, and perhaps a polycentric urban spatial structure. For example, it would be useful to examine the efficiency and distributional effects of development taxes and urban growth boundaries and consider recycling policies that may alter the transportation network capacity. Similarly, we abstract from the fact that housing is subsidized through tax exemptions for imputed income and that the current tax system fails to charge developers for complementary infrastructure inputs. In part, some of these pre-existing distortions are offset by property taxes.

Third, we abstract from city open space, and therefore, do not consider the potential substitution between open space inside the city, open space at the fringe and lot size. However, as documented in Anderson and West (2006), the value of different kinds of open space interacts with densities, distance to the central business district and other spatial amenities. While we suspect that a more careful treatment of open space will not change the qualitative results of our work, it is certainly the case that the resulting urban spatial structure of the city will be different.

Appendix A.

Deriving equations (2.25) and (2.26)

The government budget constraint when the revenues from the development tax are earmarked to fund subsidies to housing rehabilitation satisfies:

$$g\bar{I} = t_D \bar{x}_{t_D}^2 \tag{A.1}$$

For landowners who own the existing housing stock, total rent per unit of land can be written as:

$$r_e^{t_D}(\cdot, x) = \underset{S_n(x), I(x)}{Max}\ p(\cdot, x)h(S_e(x) + S_n(x)) - C^S(S_n(x)) - C^I(S_e(x), I(x)) - t_D + gI(x) \tag{A.2}$$

where $p(\cdot, x)$ is given by (2.6). From the first-order conditions of the maximization problem on the right-hand side of (A.2) we obtain the supply of structural density and housing improvements, conditional on x:

$$S(y, t, O, S_e(x), \bar{I}, g, x) \tag{A.3}$$

$$I(y, t, O, S_e(x), \bar{I}, g, x) \tag{A.4}$$

For landowners who produce new housing, the return per unit of land is given by:

$$r_n^{t_D}(\cdot, x) = \underset{S_n(x)}{Max}\ p(y, t, O(x), \bar{I}, x), \overline{V}, x)h(S_n(x)) - C^S(S_n(x)) - t_D \tag{A.5}$$

By setting (A.5) evaluated at $x = \bar{x}_{t_D}$ equal to the agricultural rent and eliminating $\bar{x}_{t_D}$ from (A.5) using (A.1), we derive:

$$r_n[y, t, O, \bar{I}, \overline{m}, \overline{V}] - t_D = r_a \tag{A.6}$$

which implicitly defines t_D as a function of *O*. Therefore, in order to evaluate the efficiency effect of a development tax, the choice variable can be view as *O* instead of t_D, with a particular *O* corresponding to a particular t_D. Differentiating the city total aggregated land value (2.23) with

respect to O while taking into account (A.1)-(A.6), yields the efficiency effects of a development tax expressed as (2.25). By differentiating (2.13) while taking (A.4) we obtain (2.26).

Appendix B.

Functional Forms of the Simulation Model

Households' preferences are represented by a Cobb-Douglas utility function:

$$U(H(x),Z(x),O(x),D(x)) = H(x)^{\alpha} Z(x)^{(1-\alpha)}(1+\gamma O(x)^{\phi})(1-\nu D(x)^{\theta}) \tag{B.1}$$

where α denotes the percentage of income net of transportation costs spent on housing; γ and ν represent, respectively the household valuation of open space and neighborhood decline; and ϕ and θ are respectively, the elasticity of utility with respect to open space amenities and neighborhood decline. The amenities from open space are represented by:

$$O(x) = \begin{cases} \mu O\left[\dfrac{x-(\bar{x}-x_o)}{x_o}\right]^{\lambda} & if \quad \bar{x}-x_o \le x \le \bar{x} \\ 0 & if \quad 0 \le x < \bar{x}-x_o \end{cases} \tag{B.2}$$

where λ is the rate at which open space amenities decline with distance.

The subutility for neighborhood decline is represented by a C.E.S. function:

$$D(x) = \left[Q(x)^{1-1/\varphi} + A(x)^{1-1/\varphi}\right]^{1/(1-1/\varphi)} \tag{B.3}$$

where φ is the degree of complementarities between private improvements. The physical deterioration of the existing housing stock is given by:

$$Q(x) = \underline{Q}\left[\frac{x_B - x}{x_B}\right]^{\delta} - I(x) \tag{B.4}$$

where δ is the rate at which physical deterioration decreases with distance. The spillover effects of the blighted area are computed as:

$$A(x) = \frac{1}{\pi x_B^2}\int_0^{x_B} Q(z)2\pi z dz * \begin{cases} 1 & if\ 0 \le x \le x_B \\ \dfrac{e^{-\rho(x-x_B)} - \xi}{1-\xi} & if\ x_B \le x \le \bar{x} \end{cases} \tag{B.5}$$

where ρ is the rate at which the negative spillovers from the blighted area decrease with distance. ξ is a parameter that captures household valuation for suburban residence. The value of $\xi/(\xi-1)$ gives the positive effect of living near the city boundary.[21]

[21] Note that $\lim_{x\to+\infty} e^{-\rho(x-x_B)} = 0$.

The housing floor area produced per unit of land is described by a CES function:

$$h(S) = \left[\beta S^{\frac{\sigma-1}{\sigma}} + (1-\beta) \right]^{\frac{\sigma}{\sigma-1}}, \sigma \neq 1 \quad \text{(B.6)}$$

where β is the share of capital in the production of housing and σ is the elasticity of substitution between capital and land in the production of housing.

Total costs of improvements are quadratic and convex, following Hall (2004):

$$C^I(S_e(x), I(x)) = p_I h(S_e(x)) I(x) + \omega h(S_e(x)) I(x)^2 \quad \text{(B.7)}$$

where ω is the improvement cost adjustment factor per square feet of existing housing stock and p_I is the price of improvements per square feet of existing housing stock.

Construction costs are linear and given as.[22]

$$C^S(S_n(x)) = p_k S_n(x) \quad \text{(B.8)}$$

where p_k is the price of capital per unit of capital.

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Figure 1: Spatial Layout of the City

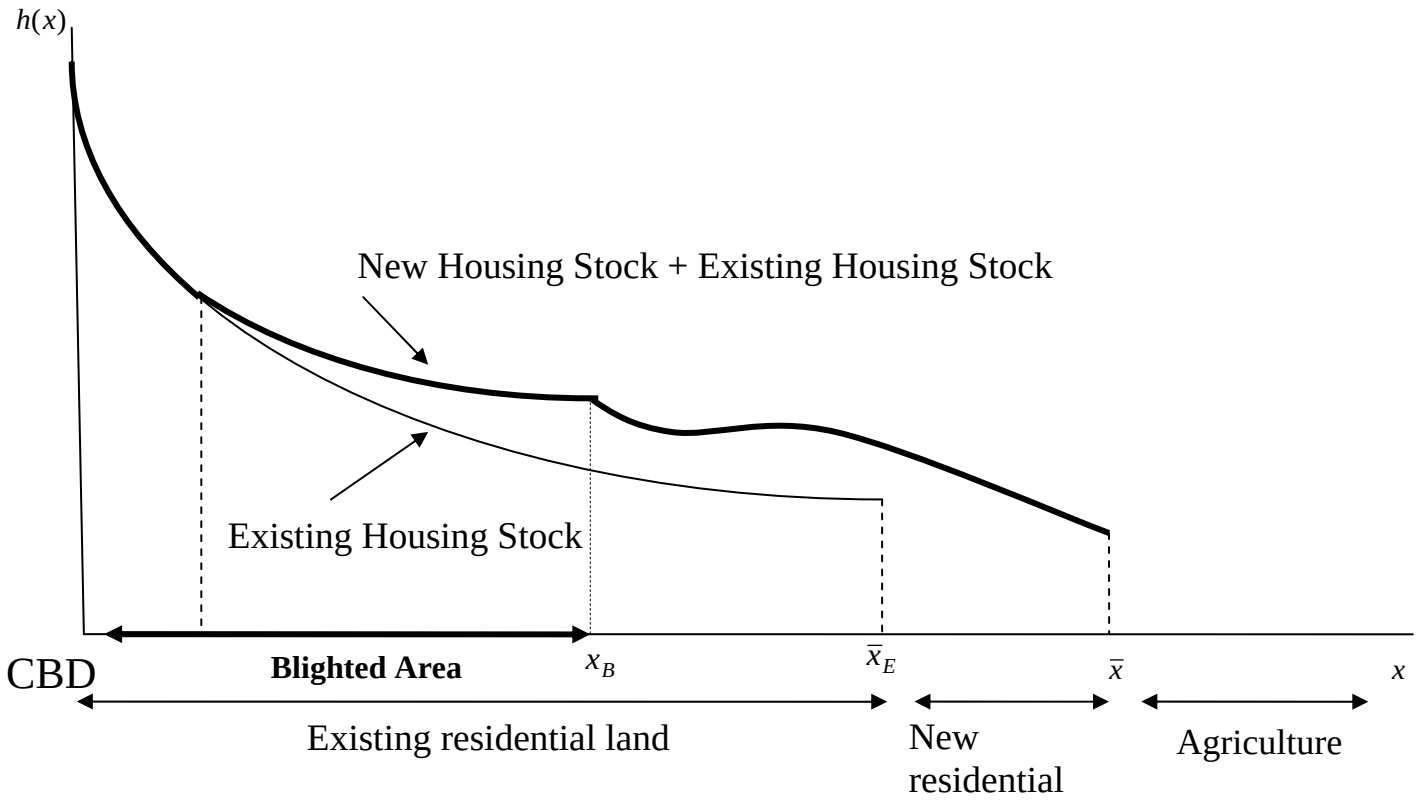

Figure 2: Improvements in the Blighted Area

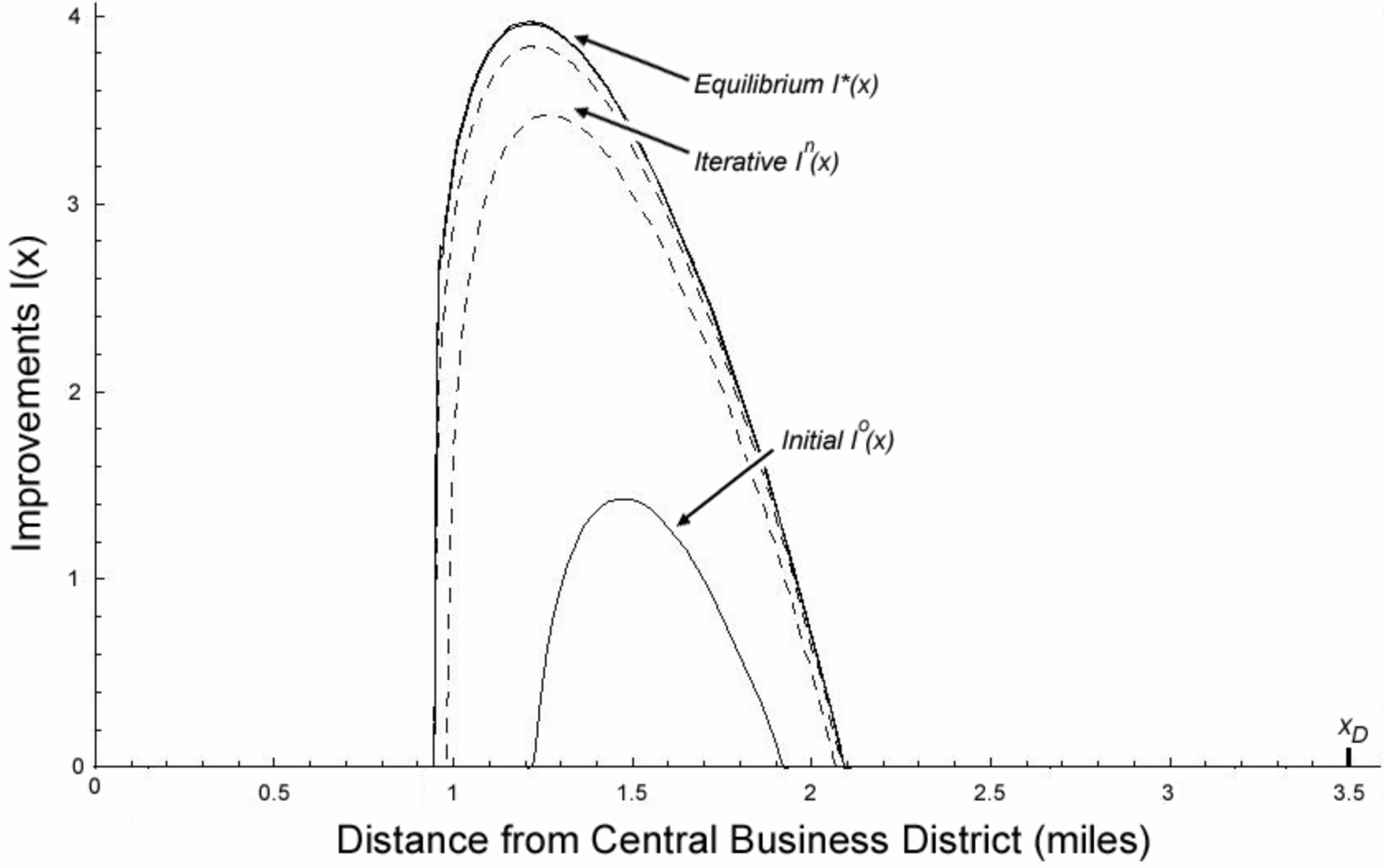

Figure 3: Marginal Welfare Effects

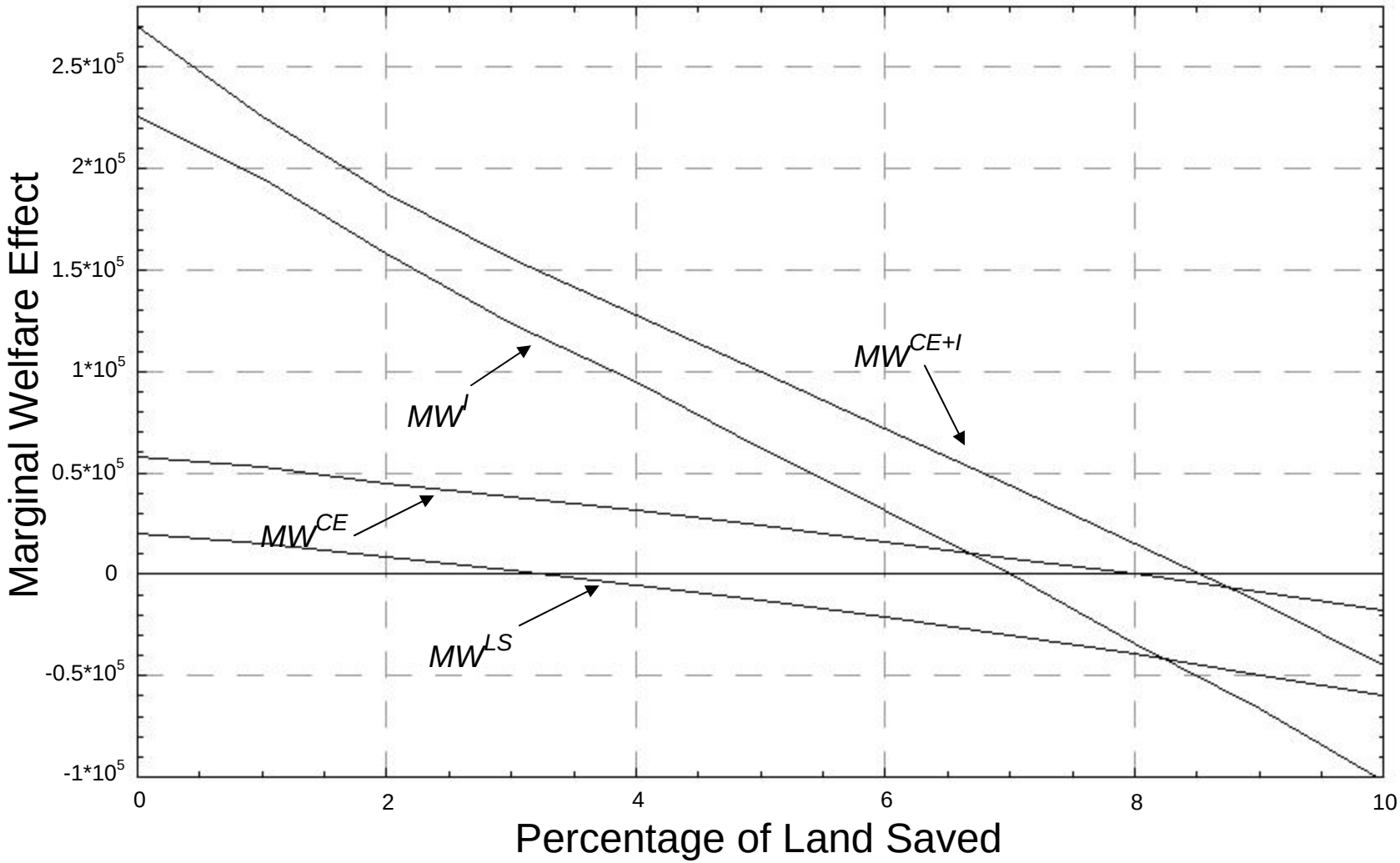

Figure 4a: Total Gross Benefits in City Center

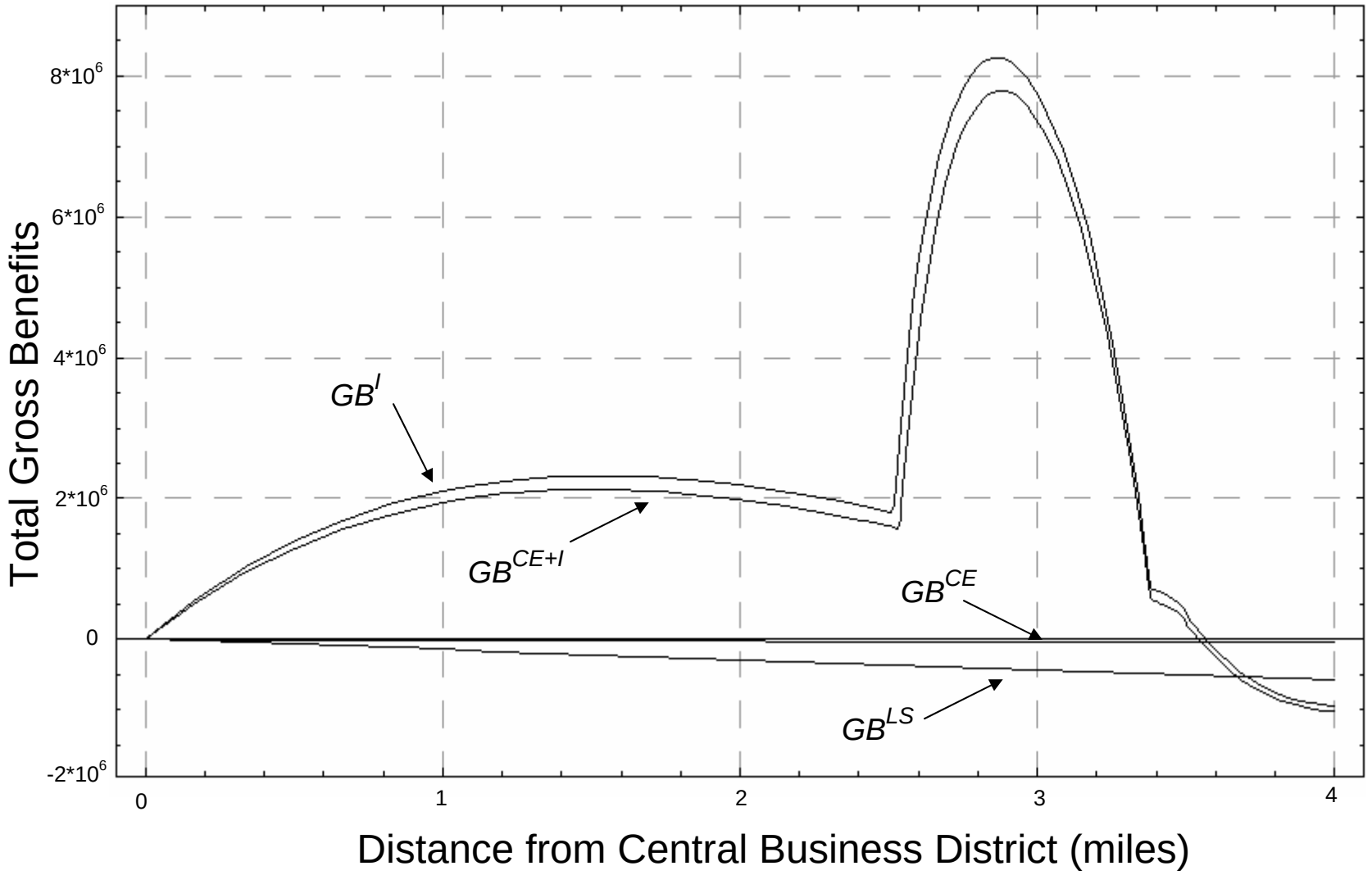

Figure 4b: Total Gross Benefits in Suburbs

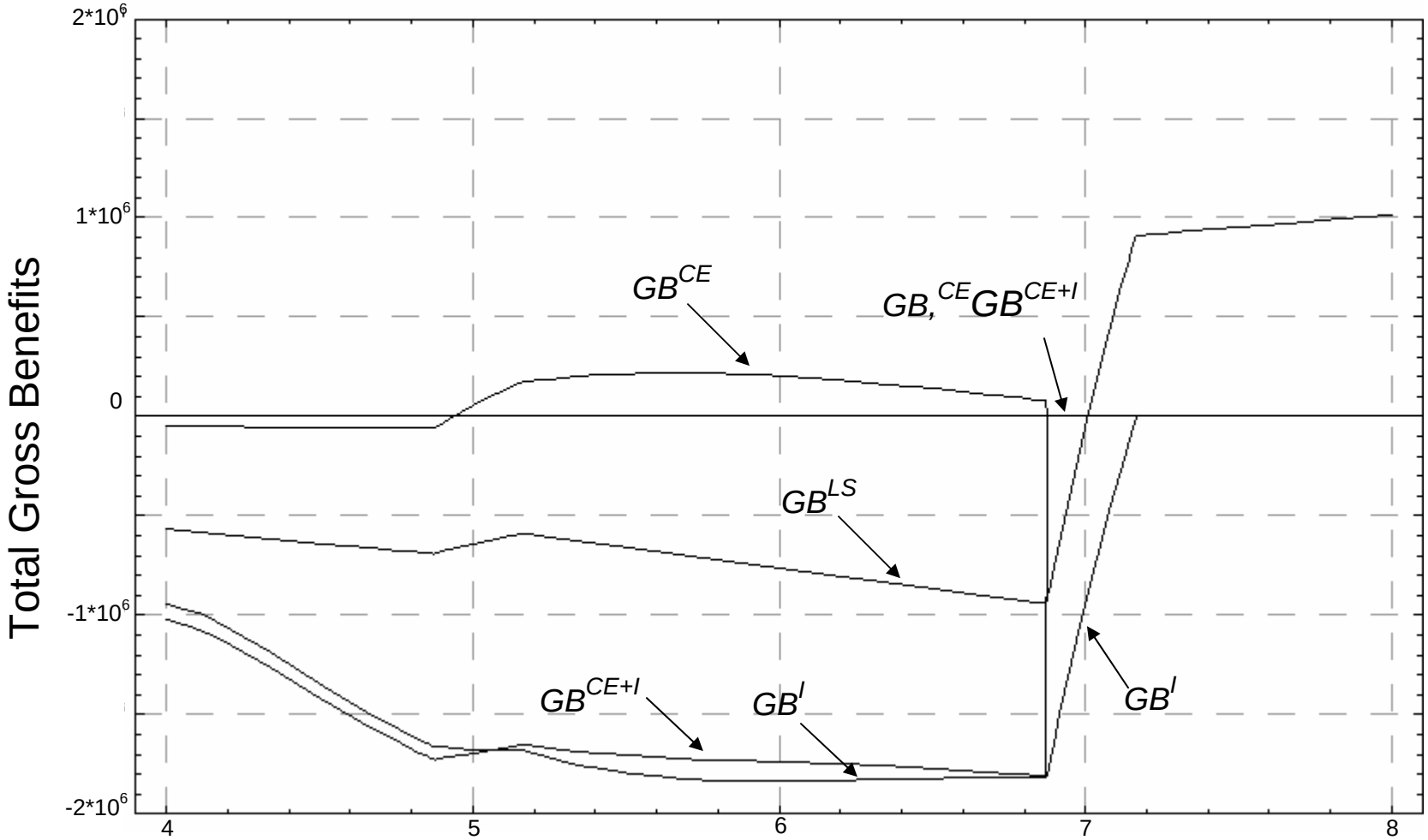

Table 1: Parameters used to calibrate the model

Description of the Parameter	Parameter	Value
Geographic extent of the existing housing stock	$\bar{x}_E$	5.2 mi.
Historical household income	$\bar{y}_E$	\$39,000
Household income	y	\$40,000
Transportation cost per mile	t	\$600
Percentage of income net of transportation costs spent on housing	α	0.4
Household valuation of open space	γ	0.00004
Elasticity of utility with respect to open space amenities	ϕ	0.5
Distance from urban boundary up to where open space amenities exist	x_O	2 mi.
Rate at which open space amenities decline with distance	λ	1
Elasticity of utility with respect to neighborhood decline	θ	2
Household valuation of neighborhood decline	v	0.000004
Geographic extent of the blighted area	x_B	3.5 mi.
Rate at which physical deterioration decreases with distance	δ	0.5
Geographic extent of negative spillovers from the CBD	x_A	4.5 mi.
Maximum physical deterioration of the existing housing stock	$\underline{Q}$	100
Rate at which negative spillovers from decline decrease with distance	ρ	1
Degree of complementarity between private improvements	φ	2
Household valuation of suburban flight	ξ	0.6
Elasticity of substitution between capital and land in the production of housing	σ	0.8
Share of capital in the production of housing	β	0.99
Price of capital per unit of capital	p_k	\$9
Price of improvements per square feet of existing housing stock	p_I	\$0.28
Improvement cost adjustment factor per square feet of existing housing stock	ω	\$0.000005
Agricultural rent per acre	r_a	\$80
Exogenous utility level	$\bar{V}$	7380
Geographic extent of potentially developable land	$\overline{m}$	10 mi.

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