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Economic Effects of Land Value Taxation in an Urban Area with Large Lot Zoning: an Urban Computable General Equilibrium Approach

Ki-Whan Choi

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ECONOMIC EFFECTS OF LAND VALUE TAXATION IN AN URBAN AREA WITH LARGE LOT ZONING: AN URBAN COMPUTABLE GENERAL EQUILIBRIUM APPROACH

BY

Ki-Whan Choi

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree
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ACCEPTANCE

This dissertation was prepared under the direction of the candidate's Dissertation Committee. It has been approved and accepted by all members of that committee, and it has been accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Economics in the Andrew Young School of Policy Studies of Georgia State University.

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ABSTRACT

ECONOMIC EFFECTS OF LAND VALUE TAXATION IN AN URBAN AREA WITH LARGE LOT ZONING: AN URBAN COMPUTABLE GENERAL EQUILIBRIUM APPROACH

By

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August 2006

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Major Department: Economics

LVT (Land Value Tax), unlike other taxes, causes no distortions in economic decision-making and therefore does not compromise the efficiency of a market economy. While there have been various challenges to this conclusion, it seems that the neutrality of LVT has been proven in the literature. Although it has been established conceptually that LVT is non-distortive, it is important to empirically test the effects of LVT reform in diverse aspects.

Unlike other studies, this dissertation examines the economic, spatial, and welfare effects of LVT reform in a second-best situation employing an urban (and spatial) CGE (Computable General Equilibrium) model. In addition, it examines the distributional effects among different income groups and the short-term aspects of LVT as well. The

feature that the present dissertation incorporates as the second-best situation includes LLZ (Large Lot Zoning). The computation and the assumptions about parameters for the current CGE model are made based on demographic, physical, and economic features of the Atlanta urban area in Georgia.

The results suggest the following: (1) LVT reform is economically feasible, (2) the tax on land rent stabilizes prices and contracts the CBD (Central Business District) and urban boundary in the economy where the CBD and urban area are endogenously determined, while the tax on land rent is purely neutral in the economy where the CBD and urban area are fixed, (3) LVT reform increases the money-metric welfare of residents by about 20% of the tax revenue in the economy where residents are landowners, while LVT reform increases the money-metric welfare of residents by about 45% of the tax revenue in the economy where the lands are owned by absentee, (4) LVT reform more increases the money-metric welfare of the less-income groups that own the smaller land area, which is contrary to the case of LLZ, (5) LLZ and property tax can cause the sprawl of an urban area, but at a very low elasticity of substitution between land and the other factors (0.1), even switching from the land tax to the property tax (or graded property tax) can contract the urban area, (6) LLZ, in the long-term during which housing capital and urban boundary are not fixed and in the economy where residents are landowners, can improve the welfare of households, while LLZ worsens the welfare of households both in the economy where the lands are owned by absentee and in the short-term during which housing capital is immobile in any economy, (7) When we consider that housing capital is immobile, the increase in the money-metric welfare due to LVT reform becomes weak, compared to the case with perfectly mobile housing capital.

CHAPTER ONE

INTRODUCTION

The analysis of land value taxation (LVT) has a long history. Many classical and neoclassical economists advocated the heavy taxation of rent or land values (or the increments in land values), including Adam Smith, James Mill, John Stuart Mills, H.H. Gossen, Alfred Marshall, Leon Walras, John R. Commons, H.G. Brown, A.C. Pigou, and Harold Hotelling.[1] These economists recognized that, in theory, LVT, unlike other taxes, causes no distortions in economic decision-making and therefore does not lower the efficiency of a market economy. While there have been various challenges to this conclusion,[2] it seems that the neutrality of LVT has been proven.

There are two types of studies of LVT. One tries to prove the neutrality of LVT, and the other shows the empirical significance of the effects of switching from a distortionary tax system to a LVT reform. While there are many studies about LVT, there are relatively few that have been done within urban contexts, and very few studies that have used urban computable general equilibrium (CGE) models. Unlike non-urban models or non-CGE models, urban CGE models allow us to include many interesting or

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[1]. Kris A. Feder,"Issues in the Theory of Land Value Taxation." Ph.D. Dissertation, Temple University, 1993.

[2] Ibid. Or look at Helen F.Ladd, ed. *Local Government Tax and Land Use Policies in the United States: Understanding the Links*. (Cambridge(MA): Edward Elgar in association with Lincoln Institute of Land Policy, 1998). Chapter 2.

complex features such as large lot zoning (LLZ), commuting costs of residents, multiple income groups, etc. These features add realism to model.

Land use regulations such as LLZ distort decisions in land and housing markets, which affects the size of urban area and all other variables, and that the LLZ has been considered an issue to explore by economists. The practice of LLZ is very common in U.S. cities, so it is of interest to explore how LLZ alters the effects of LVT reform in the present dissertation as well. The adoption of multiple income groups allows us to examine the distributional effects among different income groups of LVT reform. There are few studies that consider the distributional effects of LVT reform. In addition, this paper examines the effects of LVT reform in an urban area with immobile housing capital and only partially mobile housing capital as well. Most urban models assume that housing capital is perfectly mobile. The current dissertation shows that the effects of LVT reform with a perfectly mobile housing capital differ from those when housing capital is not perfectly mobile.

In addition, almost all urban models have assumed that an absentee landlord owns the whole land area in an economy. However, unlike other urban models, the current study assumes that the residents own land, which is the more realistic assumption. For the welfare analyses, this paper compares the results assuming resident-land-ownership with those assuming absentee-land-ownership. The computation and the assumptions about parameters for the current CGE model are made based largely on demographic, physical, and economic features of the Atlanta, Georgia urban area

There are well-known advantages to adopting a CGE model in this type of research. These include: (1) numerical representations of economic theory and intuition,

(2) ability to address a broad range of policy issues, (3) ability to track the distributional consequences of policy choices across factors and locations. There are also disadvantages to the use of CGE models, particularly their complexity and heavy data demands.

The main questions addressed in the dissertation are as follows:

1. How does LVT (or any degree of graded property tax) reform affect the economic efficiency and welfare of residents in an urban area with and without LLZ?

2. How does LVT (or any degree of graded property tax) reform affect the urban spatial structure such as the size of urban area and CBD size, and other spatial variables such as population density, land rent, and housing service price under the settings described above?

3. Assuming that there are three income groups (high income households, middle income households, low income households) in the urban economy, how does LVT (any degree of graded property tax) reform affect the residence location, the welfare, and other spatial variables of each income group?

4. Considering that housing capital are immobile or only partially mobile, how do the answers to questions 1 and 2 change?

There are many interesting findings from the study, including: (1) LVT reform is economically feasible, (2) the tax on land rent stabilizes prices and contracts the CBD (Central Business District) and urban boundary in the economy where the CBD and urban area are endogenously determined, while the tax on land rent is purely neutral in the economy where the CBD and urban area are fixed, (3) LVT reform increases the money-metric welfare of residents by about 20% of the tax revenue in the economy where residents are landowners, while LVT reform increases the money-metric welfare of residents by about 45% of the tax revenue in the economy where the lands are owned by absentee, (4) LVT reform more increases the money-metric welfare of the less-income groups that own the smaller land area, which is contrary to the case of LLZ, (5) LLZ and property tax can cause the sprawl of an urban area, but at a very low elasticity of substitution between land and the other factors (0.1), even switching from the land tax to the property tax (or graded property tax) can contract the urban area, (6) LLZ, in the long-term during which housing capital and urban boundary are not fixed and in the economy where residents are landowners, can improve the welfare of households, while LLZ worsens the welfare of households both in the economy where the lands are owned by absentee and in the short-term during which housing capital is immobile in any economy, (7) When we consider that housing capital is immobile, the increase in the money-metric welfare due to LVT reform becomes weak, compared to the case with perfectly mobile housing capital.

The remainder of the dissertation proceeds as follows. Chapter 2 reviews the literatures on both LVT and urban CGE models that consider LVT. Chapter 3 describes the basic model, presents the model formulation, and discusses the data and calibration. Chapter 4 reports the results for the basic model under various counterfacture assumptions. Chapter 5 describes the model with three income groups and a short run version of the model having housing capital adjustments and immobility, and reports results for the extensions. Chapter 6 discusses the welfare effects of LVT and conducts sensitivity analyses. Finally, Chapter 7 concludes the dissertation.

CHAPTER TWO

A REVIEW OF LITERATURE

The literature review has two major parts: a review of the issues associated with land value tax (LVT), and a review of the urban computable general equilibrium (CGE) models that study LVT. We also review the literature on non-urban CGE models that study LVT in order to show the empirical results about the effects of LVT reform.

It is important to first introduce the issues of LVT and related studies, since the current dissertation places a major focus on LVT. The literature that deals with the neutrality and efficiency of LVT will be reviewed, exploring in particular how the neutrality of LVT has been theoretically established. Since the current dissertation adopts an urban CGE model for the study of LVT, the existing urban CGE models that study LVT will be carefully reviewed.

Major Issues of LVT and Selected Literature Review

There are two major arguments used to support the adoption of LVT: (1) a tax on land value is neutral and efficient. There have been long debates on this issue. (2) LVT is fair in the sense that the landowner as an exclusive taxpayer is also the person who derives the benefits and takes the rent from using land.[3] Although most economists do not dispute that tax on land value is neutral, there have been several objections raised regarding the adoption of LVT. The objections include: LVT is not fair because it singles out landowners for taxation;[4] Switching to LVT will have no notable effects on economic activity;[5] LVT will not yield enough revenue to finance today's government because the value of all taxable land might be too low; [6] LVT is not administratively feasible because it is not possible to empirically divide property value between land value and building value. [7] Additional interest centers on the effect of LVT on land speculation.[8] The literature about LVT is vast, however I restrict my attention to the studies about the neutrality of LVT and spatial aspects of the effects of LVT.

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[3] Henry George, *Progress and Poverty*. (London: Kegan Paul Trench Trubner & Co. Ltd, 1923), and C. Loweli Harriss, "An Address on Land Taxation as an Evasion-Proof Revenue Source." In *American Journal of Economics & Sociology*, 53, 97: Blackwell Publishing Limited, 1994.etc.

[4] Murray N. Rothbard, "The Single Tax: Economic and Moral Implications and a Reply to Georgist Criticisms." In *The Logic of Action One: Applications and Criticisms from the Austrian School*. (London: Edward Elgar, 1997)

[5] Steven C. Bourassa, "Land Value Taxation and Housing Development: Effects of Property Tax Reform in Three Types of Cities." *American Journal of Economics and Sociology* 49 (1990): 101-111.

[6] Joseph A. DiMasi, "The Effects of Site Value Taxation in an Urban Area: A General Equilibrium Computational Approach." In *National Tax Journal*, 40, 577: National Tax Association, 1987.

[7] Alex Anas, "Taxes on Buildings and Land in a Dynamic Model of Real Estate Markets." In *The Property Tax, Land Use and Land Use Regulation*, ed. Netzer Dick. (Cambrideg: Edward Elgar in association with Licoln Institute of Land Policy, 2003) and,
E.S. Mills, ed. *Land Value Taxation: Can It Will Work Today?* (Cambridge(MA): Lincoln Institute of Land Policy, 1998)

[8] Harry G. Brown, "Land Speculation and Land-Value Taxation." *The Journal of Political Economy* 35, no. 3 (1927): 390-402.

Literature That Studies the Neutrality of LVT

The LVT has been proved to be neutral. But the proof depends upon properly defining LVT. According to Tideman (1982)[9] and Georgists' idea, the definition of LVT is a tax on the present value of all present and future rents of land. The valuation is the current, annual, perfect market rental value of the land alone, disregarding buildings and other improvements. Tideman (1999) again defines the value of land as the opportunity cost of leaving used land unused, to point out that the base of LVT must be independent of land use decision. A subsequent work, Arnott (2005),[10] contributes to the clarification of the LVT base by distinguishing 'raw site value' from 'residual site value'. Arnott wrote:

> A pure land value tax — one which is imposed on the 'intrinsic' value of the land, independent of the developer's decision concerning the timing and density of development — is neutral. … The essential difference between raw site value and residual site value taxation should now be apparent. Post-development raw site value is unaffected by the density of development, while in the neighborhood of the optimum post-development residual site value is increasing in the density of development. Thus, imposition of a raw site value tax has no effect on the development density condition, while imposition of a residual site value tax discourages density. (Arnott 2005, 36)

Arnott (2005) has shown that in a first-best world LVT is efficient in that it does not affect the timing and level of development and the tax is fully capitalized in land price. Arnott considers a model which is an extension of Arnott and Lewis (1979),[11] and

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[9] T. Nicolaus Tideman, "Taxing Land Is Better Than Neutral: Land Taxes, Land Speculation, and the Timing of Development." In *Land Value Taxation: The Equitable and Efficient Source of Public Finance*, ed. K.C. Wenzer. Armonk, New York: SHARPE, 1999.

[10] Richard J. Arnott, "Neutral Property Taxation." In *Journal of Public Economic Theory*, 7, 27: Blackwell Publishing Limited, 2005.

[11] Richard J. Arnott, and D. Lewis Frank, "The Transition of Land to Urban Use." *Journal of Political Economy* 87 (1979): 161-169.

starts by considering the landowner-developer's problem in the absence of taxation. A landowner owns a unit of undeveloped land area, and must decide when to develop the land and at what density to build the structure. It is assumed that once built, the structure does not depreciate, and that the landowner makes his/her decision under perfect foresight. Arnott assumes for simplicity that land prior to development generates no rent. Here are the definitions of each variable he adopted.

t	time (t = 0 today)
T	development time
K	development density (the capital-land ratio)
Q(K)	structure production function
r(t)	rent per unit of structure at time t
p	price per unit of capital
n(t)	site rent
V(t)	pre-development market value of (vacant) land
P(t)	post-development property value
S(t)	residual site value
RS(t)	raw site value

The developer's problem in the absence of taxation is

$$\max_{T,K} \prod (T, K) = \int_T^{\infty} r(t) \cdot Q(K) \cdot e^{-it} dt - p \cdot K \cdot e^{-iT} \qquad (2.1)$$

The first-order conditions are

$$T \ : \quad (-r(t) \cdot Q(K) + ipK) = 0 \qquad (2.2)$$

$$K \ : \quad (\int_{T}^{\infty} r(t) \cdot Q^{'}(K) \cdot e^{-i(t-T)} dt - p) \cdot e^{-iT} = 0 \tag{2.3}$$

Equation (2.2) means that, with K fixed, development time is chosen at the time point where the marginal benefit from postponing construction one period (the one-period opportunity cost of construction funds) equals the marginal cost (the rent forgone). Equation (2.3) means that, with T fixed, capital should be added to the land up to the point where the increase in rental revenue due to an extra unit of capital, discounted to the development time, equals the cost of the unit capital.

To see that tax on raw land value (or rent) is neutral, it is important to define several concepts. First, regarding land rent, prior to development, site rent equals the market rent on vacant land. Post-development site rents equals property rent minus amortized construction cost. Here, the rent prior to development and that of post-development are not equal to each other. If the government levies a tax on this residual site rent or value, the developer will change development time (T) and density (K) so as to maximize profits (2.1) and satisfy the equations (2.2) and (2.3), which are to be adjusted with the tax. In other words, because of the tax, the marginal benefit from postponing construction one period (the one-period opportunity cost of construction funds) may be reduced when K is fixed, and the density of housing (K) may be reduced when T is fixed.

Regarding (2.4), predevelopment site rent is the market rent on vacant land, which was assumed to be zero. Post-development site rent equals the property rent minus amortized construction cost.

$$n(t) = \begin{cases} 0 & t < T \\ r(t) \cdot Q(K) - i \cdot p \cdot K & t > T \end{cases} \tag{2.4}$$

Regarding (2.5), predevelopment residual site value is the predevelopment market value of land. Post-development residual site value equals property value minus depreciated structure value in which the depreciation rate was assumed to be zero.

$$S(t) = \begin{cases} V(t) & t < T \\ p(t) - p \cdot K & t > T \end{cases} \tag{2.5}$$

Regarding (2.6), pre-development raw site value is the market value of vacant land. Post-development raw site value is what the site would sell for were there no structure on it even though there in fact is. Thus, the site value by this definition does not change but is constant regardless of development, so the tax on raw site value is neutral because the tax payable is independent of the developer's decisions.

$$RS(t) = \begin{cases} V(t) & t < T \\ \Omega(t) = V(t) & t > T \end{cases} \tag{2.6}$$

The neutrality and efficiency of LVT relies on the fact that the supply of land is fixed. Taxes on wages and profits distort behavior, leading to welfare losses. With land, however, the obligation to pay rent to the community ultimately falls exclusively on the owner, because the supply of land is fixed. The fixity of land supply and the resultant neutrality of LVT are guaranteed on the condition that a central government applies a uniform rate of tax on perfectly competitive market based land rents throughout the whole area of an economy with a fixed boundary.

There are authors who claim that LVT is not neutral, but their claims are based on an incorrect definition of LVT. Tideman (1999), for example, argues that some economists, including Shoup (1970),[12] Skouras (1974),[13] and Bentick (1982)[14] have failed to define the base of LVT correctly, which has lead to wrong conclusions about the neutrality and efficiency of LVT. For example, Bentick (1982) claimed that taxes on the value of land distort land development decisions by advancing the time of development. According to Bentick, if the land tax depends on the current market value of the land and developers have to choose among mutually exclusive development projects with different time streams, the tax raises the carrying cost of the land and increases the attractiveness of current relative to future development. Tideman (1999) concluded that these authors have made logical errors regarding the definition of LVT base. If the value of land for tax purposes were based not on its chosen use but on its highest and best use, the LVT would not distort the timing of investment decisions. Feder (1993) in his Ph.D. dissertation also confirmed the neutrality of LVT clearly and similarly to that of Tideman (1999). Feder exposed that the Shoup (1970) model can’t be interpreted as a proof of non-neutrality of LVT because, according to Feder, Shoup failed to distinguish between full development value and after-tax development value and Shoup’s model was set up so that landowner can reduce his (or her) tax by controlling development timing.

Ladd also added a good comment on this:

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[12] Donald C. Shoup, "The Optimal Timing of Urban Land Development." *Papers of the Regional Science Association* 25 (1970): 33-44.

[13] Athanassios Skouras, "The Non-Neutrality of Land Taxation." *Public Finance* 30 (1978): 113-134.

[14] Brian L. Bentick, "A Tax on Land Value May Not Be Neutral." In *National Tax Journal*, 35: National Tax Association, 1982.

> True believers in the neutrality of the LVT argue that a tax affecting the timing of the development decision should not be called a LVT, but rather should be referred to as a tax on the present value of planned net income. In practice, the neutrality of any specific tax on land values will depend on how the tax assessors determine the value for tax purposes. (Ladd 1998, Chapter 2, 27)

<u>Literature That Includes Study about the Urban or Spatial Aspects of LVT</u>

There are three notable papers that address the effects of LVT in a spatial setting. These include Brueckner (1986, 2003)[15] and Colwell and Turnbull (2003)[16]. These papers are relevant since the present dissertation concerns the spatial effects of LVT.

Brueckner (1986) analyzed the incidence effects of LVT, employing a simple model with housing, capital and land markets and conducting comparative-statics analyses not found in the previous studies of LVT. We can discuss this more efficiently by looking at the major algebraic expressions of his model. Following are the definitions of variables and parameters he adopted.

H : Housing supply

h : Housing supply per-acre-of-land

p : Price of housing

S : Improvements per acre

r : Net land rent

τ : Tax rate on improvements

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[15] Jan K. Brueckner, "A Modern Analysis of the Effects of Site Value Taxation." In *National Tax Journal*, 39, 49: National Tax Association, 1986. And Jan K. Brueckner, and Hyun-A Kim, "Urban Sprawl and the Property Tax." *International Tax and Public Finance* 10, 2003: 5-23.

[16] Peter F. Colwell, and Geoffrey K. Turnbull, "Frontage Tax and the Optimally Compact City" in *The Property Tax, Land Use, and Land Use Regulation*, ed. Netzer Dick. Cambridge(MA): Edward Elgar, in association with Lincoln Institute of Land Policy, 2003.

θ : Tax rate on land rent

i : Net rental price of capital

N : Capital

L : Land

σ : The elasticity of substitution between capital and land in housing production

μ : Land's factor share

Assuming that housing price (p) is fixed, the level of housing supply per acre of land is

$$H(N,L)/L \equiv H(N/L,1) \equiv h(S) \tag{2.7}$$

Profit per acre for a housing producer operating in the tax zone is

$$\pi = p \cdot h(S) - (1+\tau) \cdot i \cdot S - (1+\theta) \cdot r \tag{2.8}$$

The first order condition to maximize the profit is

$$p \cdot h^{'}(S) - (1+\tau) \cdot i \tag{2.9}$$

Maximized profit per acre of land is

$$p \cdot h(S) - (1+\tau) \cdot i \cdot S - (1+\theta) \cdot r = 0 \tag{2.10}$$

Brueckner conducted comparative statics to derive the effects of LVT. By totally differentiating (2.9) and (2.10), he suggests the following four equations:

$$\frac{\partial S}{\partial \tau} = \frac{i}{p \cdot h^{"}} < 0 \tag{2.11}$$

$$\frac{\partial S}{\partial \theta} = 0 \tag{2.12}$$

$$\frac{\partial r}{\partial \tau} = \frac{-i \cdot S}{1+\theta} < 0 \tag{2.13}$$

$$\frac{\partial r}{\partial \theta} = \frac{-r}{1+\theta} < 0 \tag{2.14}$$

Equation (2.11) shows that an increase in τ reduces improvements (housing) per acre, equation (2.12) shows the land tax has no impact on the density of structure, equation (2.13) shows the higher tax on structure depresses land rent, and equation (2.14) shows that the higher land tax lowers land rent and the higher land tax is fully capitalized, leaving $(1+\theta)\cdot r$ unchanged. To reserve the tax revenue ($(\tau \cdot i \cdot S + \theta \cdot r)$) for equal yield analyses, the derivative (change) of revenue with respect to land tax must be zero. With this condition and by total differentiating revenue with respect to land tax rate, Brueckner suggests the following:

$$\frac{\partial \tau}{\partial \theta} = \frac{-r}{i \cdot S} \cdot (1 - \frac{(1+\theta)\cdot \tau \cdot \sigma}{(1+\tau)\cdot \mu}) \tag{2.15}$$

The sign of (2.15) is ambiguous, and so a revenue-preserving (or revenue-neutral) change in tax rate on structure due to a change in land tax rate may either decrease or increase. However, when σ is a very small number, the sign of (2.15) is negative, while when σ is sufficiently large, the sign of (2.15) is positive. Brueckner suggests that a negative sign would be more plausible. In addition, from equations (2.13), (2.14), and (2.15), we find the following relationship.

$$\frac{dr}{d\theta} = \frac{\partial r}{\partial \theta} + \frac{\partial r}{\partial \tau} \cdot \frac{\partial \tau}{\partial \theta} \mathop{\lesseqgtr} 0 \quad as \frac{\partial \tau}{\partial \theta} \mathop{\lesseqgtr} 0 \tag{2.16}$$

Equation (2.16) implies that when the housing price is fixed, in the plausible case

($\frac{\partial \tau}{\partial \theta} < 0$) the higher land tax causes the higher land value under the revenue reserving condition.

Until now, we have discussed the analyses for the case of exogenous housing price. But for the case of endogenous housing price, the housing market clearing condition is added to the system above. After deriving the same derivatives with this new system, Brueckner finds that when housing demand is not elastic, graduation toward land tax depresses land value in a revenue-preserving tax system. Finally, Brueckner concludes his paper by discussing short-run gains and losses by distance from the CBD in a metropolitan area. Here 'short-run' means that unlike 'long-run', the levels of 'S' and 'r' are fixed at their equilibrium levels. His conclusion is that in the short-run, as a result of the land tax, the most intensively developed parcels (near the CBD) suffer windfall losses in the form of higher taxes, assuming that the area near the CBD has a relatively higher land value, while the least intensively developed parcels (far from the CBD) benefit from windfall gains. Since his model is a partial equilibrium model, some other important features such as labor-leisure choice and transportation costs that affect the gradient of land value in an urban area are not reflected.

In another paper, Brueckner (2003) explored the connection between the property tax and urban sprawl, by considering the effect on urban size from switching from the property tax to a pure land tax in a simple spatial model. Following is the definition of some variables in his model.

x : Distance from CBD (Central Business District)

p : Price of housing, the rental price per square foot of floor space

S : Improvements per acre

r : Urban land rent

r_a : Agricultural land rent

τ : Land tax rate

i : Net rental price of capital

Most relevant to this dissertation is his finding that when agricultural land rent (r_a) is zero, the land tax does not affect urban size. Under the condition that developer's profit (per acre of land) function with land tax is

$$p \cdot h(s) - i \cdot S - (1+\tau) \cdot r = 0 \tag{2.17}$$

The first order condition for choice of S is given by

$$p \cdot \frac{\partial h(s)}{\partial S} = i \tag{2.18}$$

Note that the profit in (2.17) is zero, since the model assumes perfect competition.

According to (2.18), S is independent of land tax rate (τ), and land rent (r) can be derived from (2.17) as follows. Solving (2.17) for r to get

$$r = \frac{[p \cdot h(s) - i \cdot S]}{(1+\tau)} \tag{2.19}$$

Then, differentiating (2.19) yields

$$\frac{\partial r}{\partial \tau} = \frac{-r}{(1+\tau)} \tag{2.20}$$

The equation (2.20) means that when land rent (r) is zero, its partial derivative with respect to the land tax rate (τ) is also zero. Hence, if agricultural land rent (r_a) is assumed to be zero, the land tax does not affect urban size, because the land tax does not change urban land rent at the distance point where land rent ($r = 0$) is equal to agricultural land rent ($r_a = 0$). However, when agricultural land rent (r_a) is positive, the land tax does affect urban size.[17]

Next, I briefly summarize the effect of the property tax on urban size. There are two opposing effects regarding the urban size effect of the property tax: the improvement effect, and the dwelling size effect. The improvement effect suggests that land is developed less intensively under property taxation. Less intensive land development means a larger land area per dwelling unit to accommodate a fixed population in an urban area; as a result, the property tax contributes to urban sprawl. On the other hand, the dwelling size effect suggests that a tax on both land and structure is partly shifted forward to households (consumers), leads to a higher price of housing floor space, and decreases dwelling size in response. Brueckner's numerical examples and analyses using CES preference also suggest that at low (plausible) elasticity of substitution between housing and non-housing goods, the improvement effect dominates the dwelling size effect.

Colwell and Turnbull (2003) examined the relationship between residential land use and city size, focusing on the roles of lot dimensions and total area of land developed in the market. They studied the consequences of differential taxes on lot dimensions and

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[17] Actually, in his paper, there is no discussion of the urban size effect of land tax in the case that agricultural land rent is positive. But I found that land tax could affect the size of urban area. Email discussions with Dr. Brueckner confirmed that when agricultural land rent is positive, the land tax reduces the size of urban area. Brueckner also mentioned that when land tax is imposed on differential land rent (urban land rent minus agricultural land rent), the neutrality of land tax with respect to urban size is maintained, even when agricultural land rent is positive.

their relationships with property and land taxes. Although they did not determine the effects of land tax (tax on 'raw site value') directly, one of their results indirectly suggests an effect of the tax on land in an urban feature. They distinguish 'developable land' from 'raw land'. Developable land is land with infrastructure such as a water irrigation system, while raw land is land without any improvements. The supply of the developable land depends on lot dimension. The basic equations of their model are as follows:

$$u = u(y, k, q) \tag{2.21}$$

$$h = h(k, q) \tag{2.22}$$

$$C = \alpha + \beta \cdot F + \delta \cdot F \cdot D \tag{2.23}$$

$$\{q(p, r, m); k(p, r, m); y(p, r, m)\} \equiv \arg\max\{u(y, k, q)\} s.t. m = y + rk + pq \tag{2.24}$$

where

m : money income,

p : price of land consumed,

r : price of housing capital,

k : housing capital applied to developable land in the form of structure,

q : land consumption,

u : utility of a household

h : housing production

y : non-housing consumption

F : Frontage

D : Depth

C : The cost of preparing a parcel of land for development

α, β, δ : Parameters in the cost function C

Equations (2.21) and (2.22) are standard and general type of equations for household utility and housing production. Equation (2.23) implies that the cost of preparing a parcel of land for development depends on frontage and area. Equation (2.24) implies that the demand for land, housing capital, and non-housing good are derived from the maximization of utility subject to budget constraint. They then draw the effects of various taxes including frontage tax, area tax, and tax on developable land conducting comparative statics analyses after total differentiating the above equations. One relevant result to the current dissertation is that shifting from a tax on developable land value to a tax on raw land value leads to a lower price of developable land, greater land consumption by households, and a larger urban area. I notice that since the tax on developable land value is not neutral and not efficient due to the involvement of improvements, the tax on raw land value should be still encouraged, as the tax on raw land value is neutral and efficient.

Recent Studies to Show the Significance of the Effects of LVT

I now turn to the literature that studies the economic efficiency and other economic effects of LVT using non-urban CGE models. The qualitative results of the studies are generally consistent with those of past theoretical studies.

Follain and Tamar (1986)[18] measured the effects of a reduction of the Jamaican income tax in favor of either a LVT or a capital value tax (CVT) using a static national level CGE model. This appears to be the first paper using a CGE model to directly study the issues of LVT. The model consists of three production factors - land, capital, and labor- an intermediate good, housing, and a non-housing composite final good. Consumers demand final goods as well as supply primary factors. Follain and Tamar assume perfect competition in factor and product markets, as most CGE models do, and analyzed both open and closed economy cases. Some of the major findings include the following: (1) A switch to LVT from income tax reduces the current excess burden by 36% of the tax revenue under the heaviest LVT,[19] while the excess burden is increased by the same amount under the heaviest CVT. (2) Both the income tax rates and the LVT rates necessary to raise the same level of real revenue are lower in an open economy than in a closed economy because the movement from an income tax to a LVT increases the supply of capital and labor in an open economy. (3) Housing becomes less expensive relative to the composite non-housing good and stimulates production as the LVT increases, while a CVT hurts production.

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[18] James R. Follain, and Tamar Emi Miyake, "Land Versus Capital Value Taxation: A General Equilibrium Analysis." In *National Tax Journal*, 39, 451: National Tax Association, 1986.

[19] The heaviest LVT case means when the land portion of tax revenue occupies the 30% of all property tax revenue, while the heaviest CVT case means when the land portion of tax revenue occupies the 20 % of the whole revenue of property tax.

Nechyba (1998)[20] developed a static one-sector CGE model to pursue the land tax issues within the entire U.S. He addresses the issues of land taxation in the context of a reform package that lowers taxes on capital in a small and open economy. His focus is on the impact of such tax reforms under various assumptions about the nature of land in production and the degree of heterogeneity of land across space. The production function consists of land and capital and has a CES functional form. Capital is assumed to be perfectly mobile while land is taken as perfectly immobile. His major findings include: (1) land taxes are more efficient than capital taxes (i.e., output is larger); (2) land values rise for many types of land under a reform policy aimed at replacing capital income taxes with taxes on land rents; (3) results depend critically on the elasticity of substitution between capital and labor; and (4) distributional consequences are not very clear and depend on the elasticity of substitution between capital and labor. His qualitative findings are consistent with most other studies.

Nechyba (2001)[21] extended his earlier work (Nechyba 1998) to encompass state level effects and interactions among states, by assuming that each state is a small and open economy. The paper simulated general equilibrium impact of revenue neutral tax reforms that raise tax on unimproved land rent and decreased tax on improvement. His major findings include: (1) the impact of such reforms varies widely across states that face different economic conditions and that rely on different sources of current tax

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[20] Thomas J. Nechyba, "Replacing Capital Taxes with Land Taxes: Efficiency and Distributional Implications with an Application to the United States Economy." In *Land Value Taxation: Can It Will Work Today?* ed. Netzer Dick. Cambridge(MA): Lincoln Institute of Land Policy, 1998.

[21] Thomas J. Nechyba, *Prospects for Land Rent Taxes in State and Local Tax Reforms*. Duke University and NBER, 2001.

revenues; (2) under plausible yet conservative assumptions, reforms of tax systems toward greater taxation of land rent hold promise for substantial efficiency gains in the states, especially when states undertake such reforms unilaterally; (3) states that have relatively low initial output and make heavy use of taxes on capital are likely to benefit the most from tax reforms that increase the tax on land. One of the strengths of his study is that he assumes heterogeneity of land across the states (but not within a state). In other words, the model allows for different types of land to have different expected future rents.

Tideman (2002)[22] attempted to measure the excess burden of the current U.S. tax system using a dynamic national level CGE model. Their production function has three factors (land, labor, and capital) and a CES functional form. The household receives utility in a given period from three goods (private goods, public goods, and leisure). Their findings include: (1) significant increases in the efficiency of the U.S. economy could be attained by flattening the income tax and by shifting from land and capital taxes to a land tax; (2) in the short run, the greatest increase in after-tax wages is achieved by shifting taxes from wages to land while in the long run the greatest increase in wages is achieved by shifting taxes from capital to land; (3) even if conservative estimates of parameters are used, the potential gains are estimated at 6.6% of NDP (Net Domestic Product) per year and rise to 9.9% of NDP per year after 30 years.

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[22] T. Nicolaus Tideman, "The Avoidable Excess Burden Pf Broad-Based U.S.Taxes." *Public Finance Review* 30, no. 5 (2002): 416-441.

Urban CGE Models That Deal with the Issues of LVT

This section considers those papers that are most closely related to the approach taken in this dissertation. It shows not only the significance of the effects of LVT, but also presents the model descriptions in detail. The urban CGE models can reflect migration, transportation costs, zoning regulations, and housing characteristics, which add realism. There are three studies that we review: DiMasi (1987),[23] Sullivan (1985, 1984).[24] Each paper is discussed separately, and the differences among their models are summarized.

DiMasi (1987) generalized and extended the long-run analysis of Brueckner (1986) through the use of an urban spatial general equilibrium model with an endogenous amount of land in urban use. Because his model is the closest to the basic model used herein, it is reviewed in detail. Although the study was published in 1987, DiMasi's model is still unique in the sense that his model is an urban spatial general equilibrium model that studies LVT. There have been many CGE models or simple urban general equilibrium models constructed, but only three spatial and urban CGE models that consider LVT. DiMasi uniquely tried to incorporate an urban space in his model to measure the effects of LVT reform.

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[23] Joseph A. DiMasi, "The Effects of Site Value Taxation in an Urban Area: A General Equilibrium Computational Approach." In *National Tax Journal*, 40, 577: National Tax Association, 1987.

[24] Arthur M. Sullivan, "The General Equilibrium Effects of the Industrial Property Tax: Incidence and Excess Burden." *Regional Science and Urban Economics* 14, no. 4 (1984): 547. And "The General-Equilibrium Effects of the Residential Property Tax: Incidence and Excess Burden." *Journal of Urban Economics* 18, no. 2 (1985): 235.

Basically, DiMasi's model is a mono-centric urban model of spatial location. The urban area in his model consists of a set of concentric rings, the first being relatively large and meant to encompass a CBD (Central Business District) and the rest being residential and of equal thickness. There are three sectors: industry, residence, and agriculture. The industrial sector produces a composite non-housing good while the residential sector produces housing services. The rent on agricultural land is exogenously given. The assumed economic activities include production, consumption, renting of lands, and taxation. The price of non-housing good is exogenously given with the assumption that the urban economy is small enough for the price to be set at a national market. The urban area contains a fixed population of identical households with identical preferences and labor skills. He adopted a non-nested CES (Constant Elasticity of Substitution) functional form for production and utility functions, and calibrated parameters using data from the Boston area.

Table 1 presents information about tax rates on land and capital, tax bases, and differential land rent[25] for both the base case and the optimal case. The latter is the case of a graded property tax system that generates a maximum welfare to households while raising the required tax revenue. We see that there is a difference between land in residential use and land in industrial use regarding effective tax rates in Boston. The difference is given from the benchmark (base case). We also see that compared with the base case, in the optimal case the wage increases, the tax on land increases, the tax on

[25] Differential land rent means the difference between actual land rents in the urban area and what they would be if all land in urban use were rented to the agricultural sector.

capital decreases, the land tax base decreases, but the capital tax base increases. The graded property tax stimulates the demand for labor and results in an increased wage. In other words, to provide a maximum welfare to residents, the tax on land should increase considerably while the tax on capital should decrease. LVT is not feasible in DiMasi's model, since it does not generate sufficient revenue to fully replace the existing property tax revenue.

Table 1. Wage rate, tax rates, and some outcomes (DiMasi)

	Base Case	Optimal Case
Wage rate ($/hr)	7.18	7.21
Effective tax rate on land in residential use (%)	24.7	67.9
Effective tax rate on capital in residential use (%)	24.7	22.6
Effective tax rate on land in industrial use (%)	33.9	93.3
Effective tax rate on capital in industrial use (%)	33.9	31.1
Residential land tax base ($)	288,161,000	220,360,000
Residential capital tax base ($)	3,735,646,000	3,798,084,000
Industrial land tax base ($)	72,725,000	50,502,000
Industrial capital tax base ($)	2,005,493,000	2,062,411,000
Non-housing good industry bid land rent ($)	12,052	8,369
Differential land rent ($)	262,843,000	187,206,000

His results (Table 2) imply that there are considerable incentive effects of switching to a site value tax. In other words, when a local government adopts the graded property tax system in which land is more heavily taxed than improvements, land and housing prices fall while the improvement per unit of land in housing and population density rises, and the boundary of city contracts due to the graduation of property tax. Thus, the welfare gain of residents for a metropolitan-wide move to the graded tax system was found to be 6.6% of the tax revenue. For the measures of welfare changes, compensating and equivalent variation measures were adopted. He included the change in differential land rents created by moving from a general property tax system to the graded property tax system in the overall welfare measures, which according to DiMasi, generated a greater level of household welfare.[26] In addition, the results show that the graded property tax suppresses urban expansion.

Table 2. Comparisons between base case and optimal case (DiMasi)

Ring	Population Density (Households per acre of land)		K/L rations for housing (Units of capital per acre of land)		Housing service Prices (Dollars per unit of housing services per year		Residential land Rent (Dollars per acre per year)	
	Base	Optimal	Base	Optimal	Base	Optimal	Base	Optimal
1	0	0	0	0	6523	6444	6794	5250
2	20.9	21.48	586.97	612.27	6517	6439	6719	5193
12	17.65	18.17	494.02	516.28	6404	6327	5339	4136
22	14.72	15.19	410.94	430.38	6292	6215	4177	3245
32	12.12	12.54	337.4	354.12	6180	6105	3210	2502
42	9.83	10.19	272.64	287.04	6069	5995	2417	1891
52	7.83	8.15	216.49	228.67	5959	5887	1777	1397
62	6.1	6.38	168.34	178.5	5850	5778	1271	1004
72	4.64	4.87	127.65	136	5742	5671	879	699
82	3.43	3.62	93.93	100.63	5634	5565	584	468
87	2.91		79.49		5581		467	

There are two papers similar to DiMasi’s in the structure of their models, although they do not directly explore the effects of LVT but indirectly capture the efficiency of LVT. Sullivan (1985) analyzed the incidence and excess burden of the residential

[26] It seems that DiMasi considered the residents who own land in calculating welfare. However, according to our study, since LVT lowers land rent, which results in decrease in residents’ income, the simple addition of the differential land rent in the welfare calculation is not justified.

property tax in an urban CGE framework. Because a land tax is non-distortionary, Sullivan takes the approach of measuring incidence effects and excess burden when an urban economy switches from a pure LVT to the property tax. While DiMasi's model assumes a relatively larger but closed metropolitan area where the number of households is fixed, Sullivan's model assumes a small and open city in the sense that the number of households is not fixed but the welfare level is. Sullivan also analyzes the inter-city interactions under the alternative setting that there are three cities with the same structure in a closed region. In Sullivan's model, a full labor market is considered so that both labor supply and demand are endogenously determined, while in DiMasi's model labor supply is fixed. While DiMasi's model has numerous but variable number of residential rings, Sullivan's model has only one residential ring for a city. Another difference of Sullivan's model is that it employs a Cobb-Douglas (CD) function in the household's utility while DiMasi's model employs a CES (Constant Elasticity of Substitution) utility function. The elasticity of substitution of CD functions is one, while the elasticity of substitution in the CES function can vary. Both CD and CES functions can be flexibly specified in the amount of returns to scale. However the studies reviewed here assume functions with the characteristics of constant returns to scale (CRTS) or the first degree of homogenous function. Altmann (1981)[27] mentions that the model with CD functions produces greatly different results than the model with CES functions, even if there is no qualitative difference between the two cases.

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[27] James L. Altmann, "Analysis and Comparison of the Mills-Muth Urban Residential Land-Use Simulation Models." *Journal of Urban Economics* 9, no. 3 (1981): 365.

Major findings of Sullivan (1985) for the simple open city case in which the emigrants simply disappear into the rest of the world when there is an incentive to do so include: (1) the property tax reduces the aggregate labor supply causing the city’s wages and population to decrease; (2) since the city is open and labor is fully mobile, landowners bear the entire burden of both property tax and land tax; (3) the property tax reduces the net return on land by an amount equal to 164.9% of total tax revenue, so landowners are worse off with the adoption of the property tax. On the other hand, the major findings for the case with three cities in a closed region include: (1) the other two cities that employ the non-distortionary land tax grow at the expense of the city that switched to the property tax; (2) housing prices increase everywhere, with the largest increase in the city that employs the property tax; the welfare loss of regional residents totals 100.1% of the city’s property tax revenue; (3) the net return of landowners in the city that employs the property tax decreases by 2.2%, while the net returns on landowners in the other cities that employ the land tax increase by 2.99%; (4) in the aggregate, the property tax generates an excess burden equal to 6.5% of the city’s property tax revenue.

Sullivan (1984) is almost the same as the later article (Sullivan 1985) in model structure and research questions. The differences are: (1) Sullivan (1984) measures the incidence effects and excess burden of industrial property tax in which taxes are levied on capital and land in industrial sector only; (2) the production factors of the industrial sector include equipment capital in addition to structural capital, land, and labor; (3) taxes are levied on land and structural capital. However, the model does not properly reflect differences between the two types of capital with respect to durability and mobility because the model is static and the characteristics of durability and mobility can be properly reflected in a dynamic setting. The results are consistent with his other work (Sullivan, 1985). The urban CGE models described above clearly shows the efficiency effects of LVT reform in an urban area.

The present study is different from the previous research in the following ways. First, it considers a model in which there exists a LLZ in some of the suburban areas, which may alter the effects of LVT. Second, by adopting three income groups (rich, middle, and poor) in the model, the distributional effects of LVT can be captured. Third, this paper assumes that the residents of the economy own a fixed amount of land and capital, while the studies above assume an absentee landowner. Fourth, it considers a model with immobile housing capital and only partially mobile housing capital, one of the short-term features. Table 3 summarizes the differences of the present model from the above models. Each item bears its own implication. For example, the resident landownership means that the rental income of a household is endogenously determined, while the absentee landownership means that there is no land rental income for households. The additions, changes, and extensions to the existing studies will enrich both the literature of the urban model and the literature of LVT.

Table 3. Comparisons of model specifications among studies

	DiMasi (1987)	Sullivan (1985)	Sullivan (1984)	The Current Dissertation
Sectors	Housing sector, Non-housing good sector	Housing sector, export good sector	Housing sector, Non-Housing good sector	Housing sector, Non-housing good sector
Land ownership	Absentee	Absentee	Absentee	Resident owns fixed amount of land
Capital ownership	Absentee	Absentee	Absentee	Resident owns fixed amount of capital
Production function type	CES	CES	CES	CES
Utility function type	CES	C-D	C-D	Nested CES
CBD size	Fixed	Variable	Variable	Variable
Urban size, residential rings	Variable, many residential rings, endogenous ring number	Variable, one residential ring	Variable, one residential ring	Both fixed and variable (2 cases), fixed number of residential rings, endogenous ring width
Trade	Not explicitly considered	Not explicitly considered	Not explicitly considered	Explicitly considered
Data and Model area	Boston area, metropolitan area	Artificial data, small city area	Artificial data, small city area	Atlanta area, metropolitan area
Labor-leisure choice	Fixed amount of labor	Labor-leisure choice is applied	Labor-leisure choice is applied	Labor-leisure choice is applied
Income groups	Single income group	Single income group	Single income group	Single and Multiple income groups
Mobility of housing capital	Perfectly mobile	Perfectly mobile	Perfectly mobile	Perfectly mobile, and Variable degrees of mobility
Population level	Fixed	Not fixed	Not fixed	Fixed
Other characteristics	Property tax	Residential property tax	Industrial property tax, division of equipment capital and structural capital	Large lot zoning, Land tax, Property tax

CHAPTER THREE

THE BASIC MODEL

Chapter 3 describes the basic model that is developed, discusses issues directly related to the basic model and discusses data for benchmark, and formulates the model using specific functional forms.

An Outline of the Economy to Be Modeled

This subsection describes general features of the metropolitan economy to be modeled.

The metropolitan area is located in a flat featureless plain, so that the land in any ring is assumed to be homogenous in quality. There are ten residential rings and one central business district (CBD) in the urban economy. The CBD is surrounded by much smaller rings where the households of the urban area live. It is assumed that within each ring, there would be no gradient of land rent. The boundary of the CBD and that of the urban area are endogenously determined. In other words, the boundary of CBD is determined at the distance point where the land rent of the 1st residential ring is equal to the land rent of the CBD, while the boundary of the urban area is determined at the distance point where the land rent of the last (i.e. 10th) residential ring is equal to an exogenously given agricultural land rent. When the boundary of the urban area expands, the thickness of each ring increases, and when the boundary of the urban area contracts, the thickness of each ring becomes narrower.[28] All residential rings are assumed to have an equal thickness.

There are two explicit production sectors in the urban economy: housing sector, and composite non-housing good sector. There is also an agricultural sector. The agricultural sector is not explicitly modeled, and the land rent for the agricultural use is exogenously given. All non-housing good production occurs in the center of the CBD. The capital, one of the production factors, is supplied perfectly elastically to the urban area at a fixed price. Thus, capital can be either exported or imported, depending on the size of demand for capital relative to the amount of capital endowment of the urban residents. The non-housing good can be exported. Details about the housing sector and non-housing good sector are discussed in the next subsections.

In this economy, the endowment of land and capital need not be equal to the demand of land and capital; this is not true for labor. That is because both capital and land are trade goods. Regarding the trade of land, the urban area may expand or contract due to economic policies, but the endowment of land is fixed, and so some land can be rented to (or from) the people outside the urban area. Although the endowment of land and capital might be equal to the demand for land and capital, the sum of the endowments for both land and capital (minus transport cost) must be equal to the sum of the demands of both land and capital plus export amount for non-housing good with respect to dollar value to meet the economy's budget constraint (or close the model). It is assumed that net

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[28] DiMasi (1986) programmed the model differently to reflect the endogenous boundary of urban area. He made the number of rings variable so that when the urban area expands, the number of rings increases, while when the urban area contracts, the number of rings decreases. One the other hand, Sullivan (1985, 1984) has one CBD and one residential area, and the width of each area becomes wider or narrower due to policy changes. There is no standard rule to program the feature.

import of factors (land or capital) is financed by net export of non-housing goods. Net exports of factors are assumed to prohibit, since factor endowments are parts of the household income and factors will be used primarily for satisfying the demands of residents. In other words, the model assumes that the urban economy is a net importer of factors in sum. The reason for this is that allowing imports of the non-housing good requires solving for the price of the non-housing good in a national market, which is outside the scope of the model.

The urban area has a fixed number of households, and households costlessly choose places to live within the urban area. The assumption of the fixed number of households implies that the urban area is closed in a sense, although the urban area is open in the sense that there is a trade between the economy and the rest of the world. Since this dissertation analyzes the effect of a universal use of the land tax for the Atlanta urban area, not interactions among small cities such as changes in population location and total population level due to a tax policy, the closed urban area approach with respect to the number of households is appropriate.[29] Every worker residing in a given ring is treated, for commuting purposes, as if he (or she) lives at the midpoint of the ring. In other words, within each ring, it is assumed that commuting distance from any point in a ring to the CBD is considered as the distance from the midpoint of the ring to the CBD. Each worker makes a round trip per day to the center of CBD. The transportation network is assumed to be radial and dense, so that all trips follow a linear pattern. In some rings of the suburban area a large lot zoning (LLZ) regulation is promulgated.

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[29] See Brueckner (2003), page 12.

Household

It is assumed that a household consists of one worker. Each worker is assumed to supply a certain amount of labor by choosing between labor and leisure within a fixed available time. The total time of workers is allocated to leisure, work, and commuting. Each household (worker) owns a fixed amount of capital and land. Each household owns an equal amount of land in the CBD and in each residential ring. Thus, the disposable income for household (worker) consists of income from time endowment, rental income from land, and rental income from capital, and equally distributed tax revenue, net of commuting time and money costs. The amount of land and capital endowments for each household is set at a benchmark level (or little bit greater than the benchmark level) and remains fixed.

Workers are assumed to maximize utility over housing services, a composite non-housing good, and leisure. The choice problem facing a household residing in ring j is to maximize

$$U(x_N^j, x_H^j, l^j) \tag{3.1}$$

Subject to the following budget and time constraints:[30]

The budget constraint can be expressed with the following two cases. Case 1 suggests that when the land endowment of household is greater than the actual land demand for residential and industrial purposes, the excessive land near urban boundary will be sold to farmers. On the other hand, case 2 simply suggests that when the land endowment is smaller than the actual demand, there is no extra land for selling.

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[30] Note that each household owns a fixed amount of land, which is averaged with all location and all population. So, each household's land endowment is neutral to location.

Case 1: The endowment of land is greater than the urban area

$$
\begin{aligned}
& P_N \cdot x_N^j + P_H^j \cdot x_H^j + P_W \cdot l^j \\
& = P_W \cdot T + \frac{\sum_j r_L^j \cdot L^j}{N} + \overline{r_A} \cdot \left(\frac{A - \sum_j L^j}{N}\right) + \overline{r_K} \cdot \overline{K} + Tax - c \cdot D^j - P_W \cdot \Gamma \cdot D^j \\
& = Y(D)
\end{aligned}
\tag{3.2}
$$

Case 2: The endowment of land is smaller than the urban area. Note that $\sum_j r_L^j \cdot L^j = A$.

$$
\begin{aligned}
& P_N \cdot x_N^j + P_H^j \cdot x_H^j + P_W \cdot l^j \\
& = P_W \cdot T + \frac{\sum_j r_L^j \cdot L^j}{N} + \overline{r_K} \cdot \overline{K} + Tax - c \cdot D^j - P_W \cdot \Gamma \cdot D^j \\
& = Y(D)
\end{aligned}
\tag{3.2'}
$$

$$
l^j + W^j + \Gamma \cdot J^j = T \tag{3.3}
$$

Here, j = 1, 2,3 ---. Note that ring 1 is CBD.

x_N^j Consumption of non-housing good by the household who resides in ring j

x_H^j Consumption of housing services by the household who resides in ring j

l^j Amount of leisure enjoyed by the household's worker

P_N Price of a unit of the non-housing good

P_H^j Price of a unit of housing services per year in ring j

P_W Hourly wage rate

r_L^j Rental rate of land for ring j

$\overline{r_A}$ Agricultural land rent (exogenous)

$\overline{r_K}$ Fixed rental rate of capital

W^j Hours supplied by a worker

c The fixed roundtrip money cost per mile

$Y(D)$ Income net of transportation cost

$\frac{A}{N}$ Land endowment per capita (fixed and averaged for all locations)

L^j Total land demand in ring j

$\overline{K}$ Capital endowment per capita (fixed)

Tax Equally distributed tax revenue

$\boldsymbol{\Gamma}$ Round trip time for work per mile

D^j Distance in miles from the midpoint of ring j to the city center

T Time endowment for leisure, work, and commuting

N Number of households

For ease of exposition, we consider case 1 only in what follows.

Preferences can be expressed in the indirect utility function that is derived by solving the maximization problem (3.1) that is subject to (3.2) and (3.3), as follows:

$$V^j(P_N, P_H^j, Y) =$$

$$V^j(P_N, P_H^j, P_W \cdot T + \frac{\sum_j r_L^j \cdot L^j}{N} + \overline{r_A} \cdot (\frac{A - \sum_j L^j}{N}) + \overline{r_K} \cdot \overline{K} + Tax \text{-} \mathrm{c} \cdot D^j - P_W \cdot \Gamma \cdot D^j)$$

(3.4)

Consumers choose the ring that maximizes V^j. It must be true that in equilibrium, for all rings j =2,3---, $V^j = V$. Taxes on land and capital in the production sectors will affect the price of housing services and the wage rate. Taxes are imposed on producers, not on renters, so tax variables do not enter the worker's budget constraint directly. The expression for the housing-rent gradient follows from the differentiation of (3.4) with respect to *D*, (note that superscript j is suppressed in the following equations):

Note that the wage rate (P_W) and land holding ($\frac{\sum_j r_L^j \cdot L^j}{N} + \overline{r_A} \cdot (\frac{A - \sum_j L^j}{N})$) in the equation (3.4) do not vary with distance (*D*) by assumption. Hence,

$$dV = 0 = V_{P_N} \cdot dP_N + V_{P_H} \cdot dP_H + V_Y \cdot dY \qquad (3.5)$$

$$dV = 0 = V_{P_H} \cdot dP_H + V_y \cdot (-P_W \cdot \Gamma \cdot dD - c \cdot dD) \qquad (3.6)$$

Then, we get the following, by inverting with respect to $\frac{dP_H}{dD}$.

$$\frac{dP_H}{dD} = (c + \Gamma \cdot P_W) \cdot \frac{V_y}{V_{P_H}} \qquad (3.7)$$

The gradient of housing service price with respect to distance depends on the signs and magnitudes of $\frac{V_Y}{V_{P_H^j}}$. The sign of $\frac{V_Y}{V_{P_H^j}}$ is negative according to Roy's identity. Thus, the sign of the equation (3.7) is unambiguously negative. The negative sign of the gradient of housing price means that housing price decreases by distance from the CBD.

Housing Production Sector

The producers of housing are profit maximizers. All markets in each ring, including factor and product markets, are taken to be perfectly competitive. Thus, equilibrium profit is zero. In addition, the production function has constant returns to scale (CRTS) technology. It is assumed that housing services in a ring are produced using capital and land in that ring. Thus, the aggregate quantity of housing services in ring j is given by the following production function:

$$S_H^j = S_H^j(K_H^j, L^j) \tag{3.8}$$

where $j = 2, 3, 4, ---$

S_H^j Housing supply in ring j

K_H^j Amount of capital used in the production of housing services in ring j

H Housing sector.

Therefore, aggregate profits to producers of housing in ring j can be expressed as follows:

$$\Pi_H^j = P_H^j \cdot S_H^j - (1+\theta) \cdot \overline{r_K} \cdot K_H^j - (1+\omega) \cdot r_L^j \cdot L^j = 0 \tag{3.9}$$

where

$\boldsymbol{\Pi}_H^j$ Economic profits of housing producers from operations in ring j

L^j Land used for production in ring j

$\boldsymbol{\theta}$ Tax on capital rental

ω Tax on land rent.

Capital is assumed to be rented in a national market at fixed price and we assume that it can be transported at no cost within the urban area.

We can express a cost function for housing services as follows:

$$C_H^j = C_H^j((1+\omega)\cdot r_L^j, (1+\theta)\cdot \overline{r_K}, S_H^j) = S_H^j \cdot \hat{C}_H^j((1+\omega)\cdot r_L^j, (1+\theta)\cdot \overline{r_K}) \qquad (3.10)$$

where

C_H^j Cost of housing services in ring j

$\hat{C}_H^j$ Average housing production cost in ring j, and the second equality holds because the production function was assumed to exhibit constant returns to scale.

The housing land rent (r_L^j) takes all profits, given the fixed price of capital, so that the profits of housing service sector are zero in a competitive equilibrium. The price of housing service in a ring must equal the average cost of producing housing in that ring. Hence, algebraically,

$$P_H^j = \hat{C}_H((1+\omega)\cdot r_L^j, (1+\theta)\cdot \overline{r_K}) \qquad (3.11)$$

The bid-rent function for land in ring j can be obtained by inverting (3.10) with respect to r_L^j.

Manufacture Sector (Composite Non-housing Good)

It is assumed that some of the composite non-housing goods can be traded to the people outside the urban area. It is assumed that the export price is the same as the domestic price set in a competitive market. The aggregate quantity of the non-housing good from producers in the urban area can be defined as follows:

$$S_N = S_N(K_N, L^1, W_N) \qquad (3.12)$$

where

K_N Amount of capital used in the production of the non-housing good

L^1 Amount of available land for non-housing good production within the CBD area used in the production of the non-housing good

N Non-housing good sector

W_N Amount of labor used in the production of the non-housing good.

Therefore, profits in aggregate to producers of the non-housing good can be expressed as follows:

$$\Pi_N = P_N \cdot S_N - (1+\theta)\cdot \overline{r_K} \cdot K_N - (1+\omega)\cdot r_L^1 \cdot L^1 - P_W \cdot W_N \qquad (3.13)$$

where

Π_N Economic profits of non-housing good producers from operations in the CBD

As for the non-housing good sector, since the land rent of the CBD (r_L^1) takes all the profits, given the perfectly competitively determined wage rate (P_W) and the nationally determined capital rental ($\overline{r_K}$), the price of non-housing good (P_N) is just the average cost which can be derived from the equation (3.13). We can also derive the rental price for the CBD land (r_L^1) by inverting the average cost function.

Land Ownership and Land Markets

It is assumed that the residents own the land of the urban area. However, whether the urban area expands or contracts, the amount of landholding for each household as an endowment is fixed. The fixed pattern of landownership is necessary, since otherwise it biases the evaluation of policies that increase the size of urban area. How to treat landownership is an important issue in urban economic models and might even change the direction of welfare change. For example, this dissertation finds that LVT reduces the size of the urban area and increases the welfare of residents. If we allow the amount of landholding for each household to vary with the size of urban area, we may produce the result that LVT would reduce the welfare of residents and that a distortionary property tax would improve the welfare.

Generally, in analytical models, absentee landownership is adopted to avoid analytical difficulties. The absentee landownership means that all land areas are rented to users, so that the change of land rent does not affect the income of household, but affect the production costs of housing and non-housing goods. There are two representative studies that take different (but more realistic) approaches to landownership than absentee landownership. Pines and Sadka (1986)[31] and Sasaki (1987)[32] assume that urban

[31] Pines, David, and Efraim Sadka. "Comparative Statics Analysis of a Fully Closed City." *Journal of Urban Economics* 20, no. 1 (1986): 1.

[32] Sasaki, Komei. "A Comparative Static Analysis of Urban Structure in the Setting of Endogenous Income." *Journal of Urban Economics* 22, no. 1 (1987): 53.

residents take land rent as a part of their income, so that the income of urban residents becomes endogenous,[33] since the rental income from land is endogenous.

Pines and Sadka (1986) assumes that an absentee landowner owns the whole urban land, but urban residents take all differential land rents[34]as a part of their income. This approach has the same implication as the approach that urban residents own the whole land within an urban area. As discussed above, this type of landownership treatment should be taken cautiously. For example, when an urban area expands from a benchmark level, the urban residents take the extra land due to the expansion as rental income by subtracting the amount of agricultural land rent only, while when a city contracts, the reduced amount of land due to the contraction are to be taken away from the residents and given back to non-residents. Agricultural land rent is assumed to be fixed, and so economic policies encouraging urban sprawl might increase the welfare of urban residents by providing more rental income from land to the urban residents.

Sasaki (1987) avoids the problem mentioned above by taking a slight different approach, although he deals with the similar landownership issue to Pines and Sadka (1986). Sasaki assumes that urban residents own a fixed amount of land (A), and the income of urban residents is determined as follows.

$$y = y_o + \frac{2\pi}{N}\int_0^b r(u,t,y,k)\cdot t \cdot dt + \frac{\mathrm{s}\cdot(\mathrm{A} - \pi \cdot \mathrm{b}^2)}{N} \qquad (3.14)$$

Where

y The income level of urban residents

[33] Existing analytical urban studies that adopt absentee landownership assumes that the income of urban residents is exogenous.

[34] Differential land rent was defined as residential land rent minus agricultural land rent.

y_o	Exogenous income given initially
N	Population level
t	Location (distance from CBD)
b	Urban fringe
r	Urban land rent
u	Utility level
k	Transportation cost per mile
s	Agricultural land rent
A	The amount of land that urban residents own

From the equation (3.14), we recognize that the land endowment of urban residents covers not only the whole urban land, but also some agricultural land area. Note that the amount of landholding does not vary with urban size, and that the income of urban residents is determined endogenously in a fully closed model.

This dissertation's approach regarding landownership is consistent with Sasaki's approach in the following senses: (1) the income of residents is endogenously determined; (2) the amount of landholding for each household is fixed. The difference from Sasaki's approach is that this dissertation additionally includes endogenous wage income, rental income from capital holding, and income from export.

Findings from Sasaki (1987) suggest that some comparative statics results from the urban model with resident landownership and endogenous income can be different from traditional findings from the urban model with absentee landownership and exogenous income. One of the examples is that the increase of commuting cost may increase the welfare of residents in the endogenous income setting due to the increase of rental income from land, while in the exogenous income setting with absentee landownership, the increase of commuting cost unambiguously decreases the welfare of residents.

There are three types of land use: use for the production of non-housing good, use for the production of housing service, and use for an agricultural sector. Landowners in each ring maximize their income by renting only to the highest bidder. To close the production side of the model, we assume that the rent offered for land anywhere in the ring by the agriculture sector is given exogenously, and that the agricultural sector is untaxed. A fixed bid rent for land by the agricultural sector will allow for the determination of the size of urban area without taking the agricultural market explicitly into account. On the other hand, the highest bid rent for land at the 1st ring by the housing sector will allow for the determination of CBD size.

Foreign Sector

Although the benchmark SAM (Social Accounting Matrix) in the next section is constructed without trade, it allows the possibility that some capital and/or land is rented from non-residents, in case that any deficit of those factors happens due to a tax policy. We have assumed that the net value of capital and land rented from non-residents is positive or zero, and further assume that firms finance the import of the resources (land and capital) by exporting the non-housing good to the non-residents. This condition can be expressed as follows.[35]

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[35] See Appendix 2 for the derivation of (3.15)

$$Ex - \sum_j n^j \cdot \mathrm{c} \cdot D^j = r_L^1 \cdot L^1 + \sum_j r_L^j \cdot n^j \cdot L^j + \overline{r_K} \cdot K$$
$$- \sum_j r_L^j \cdot A^J - \overline{r_K} \cdot \overline{K} \tag{3.15}$$

where

Ex The value of export of non-housing good

n^j The number of households in ring j

Large Lot Zoning (LLZ)

Arnott and MacKinnon et al. (1977)[36] mention in their conclusion that land use controls probably result in increases of housing prices in U.S. cities. Pasha (1994)[37] and Sullivan (1996) explore the effects of a LLZ on the urban structure such as population density and the size of an urban area but under a no-tax and no-full-general-equilibrium model setting. Recently, Glaeser and Gyourko (2002)[38] and Saks (2005)[39] also found that zoning is a big cause of price increases of housing and one of the explanatory factors about why the supply of housing has been inelastic with respect to the price of housing. Given that LLZ is so common and has been an important factor to explain urban

[36] Richard J. Arnott, and James G. MacKinnon, "The Effects of the Property Tax: A General Equilibrium Simulation." *Journal of Urban Economics* 4, no. 4 (1977): 389.

[37] Hafiz A. Pasha, "Suburban Minimum Lot Zoning and Spatial Equilibrium." *Journal of Urban Economics* 40 (1996): 1-12.

[38] Edward L. Glaeser, and Joseph Gyourko. "Zoning's Steep Price." In *Regulation*, 25, 24: Cato Institute, 2002.

[39] Raven E. Saks, "Job Creation and Housing Construction: Constraints on Employments Growth in Metropolitan Areas." In *Dissertation Fellowship Symposium*. Cambridge(MA), Lincoln Institute of Land Policy, 2005.

phenomena, exploring the effects of LVT in the presence of LLZ is a meaningful extension.

A binding LLZ is promulgated in some parts of the residential area by assumption. Due to the binding LLZ, housing producers lose their flexibility to use the various mixes of land and capital for the production of housing to maximize their profits. In particular, housing producers are forced to use at least a minimum input of land. Households who want to live in the rings with LLZ must consume the housing with the minimum lot size. The binding LLZ distorts decisions of housing producers to use the efficient combination of inputs (land and capital).

To apply the binding LLZ to housing production, we need per-capita (household) housing production function. The per-household housing production function is obtained by dividing equation (3.8) by the number of households (n^j) in a zoned ring. Then, because we assume that the housing production function has the characteristics of constant returns to scale, we get the following:

$$\frac{S_H^j}{n^j} = \frac{1}{n^j} \cdot S_H(K_H^j, L^j) = S_H\left(\frac{K_H^j}{n^j}, \frac{L^j}{n^j}\right) \tag{3.16}$$

So, for the rings having the LLZ, the following constraint is added to the first-order conditions for maximizing the profit function for housing.

$$\frac{L^j}{n^j} \geqslant \overline{L^j} \tag{3.17}$$

If (3.17) is binding, then $\frac{L^j}{n^j}$ is replaced by $\overline{L^j}$ in the production function. This will affect the land rent for housing (r_L^j) and other variables in the urban area.

Although this dissertation does not adopt the following approach, for reference, let us discuss a similar approach regarding land use constraint as follows. Instead of LLZ, some authors such as the Moss (1977, page 416)[40] and Pogodzinski and Sass (1990, page 302)[41] discuss imposing a maximum capital density constraint. Although LLZ is not exactly the same as the maximum density constraint, those are in nature similar. Under this constraint, equation (3.8) is transformed into equation (3.18):

$$\frac{S_H^j}{L^j} = \frac{1}{L^j} \cdot S_H(K_H^j, L^j) = S_H \cdot \left(\frac{K_H^j}{L^j}, 1\right) = S_H\left(\frac{K_H^j}{L^j}\right) \tag{3.18}$$

Then, a ceiling on the capital/land ratio is imposed on the profit function of housing as an additional constraint.

$$\frac{K_H^j}{L^j} \leqslant \overline{\mathrm{C}} \tag{3.19}$$

If (3.19) is binding, we get

$$K_H^j = \overline{\mathrm{C}} \cdot L^j \tag{3.20}$$

Then, the equation (3.20) is substituted into the production function, and would affect the land rent for housing (r_L^j) and equilibrium conditions.

Government

The government can be thought of as a taxing authority. In the benchmark, the tax is the standard capital-land property tax in which land and improvement (capital) are

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[40] William G. Moss, "Large Lot Zoning, Property Taxes, and Metropolitan Area." *Journal of Urban Economics* 4, no. 4 (1977): 408.

[41] J. Michael Pogodzinski, and Tim R. Sass, "The Economic Theory of Zoning: A Critical Review." In *Land Economics*, 66, 294: University of Wisconsin Press, 1990.

taxed equally. The alternative taxes considered are a pure LVT in which land is taxed while improvements are not and a graded property tax in which land is taxed at a higher rate than improvements. Hence, when the government switches from the capital property tax to a LVT or a graded property tax, we can check who gains and who loses because of the tax reform. This paper does not consider how the expenditure of tax revenues would affect the economy, so it assumes that tax revenues are distributed to all households equally.[42]

On the Equilibrium of the Model

This subsection briefly provides what conditions must be met to solve the model. The equilibrium land rent at location j equals the maximum of the bid-rents of the manufacture sector, housing sector, and agriculture. Thus,

$$r_L = Max\{r_L^1, r_N^j, \overline{r_A}\} \tag{3.21}$$

The land allocations are consistent with available supplies.

$$L_D^1 = L_S^1 \tag{3.22}$$

$$L_D^j = L_S^j \quad \text{for j =2,3,4 ---} \tag{3.23}$$

where

r Rent

L Land

A Agricultural sector

---

[42] In other words, the equal distribution of tax revenue makes the expenditure side neutral, so that we can capture the effects of tax policies only.

D Demand

S Supply

Equation (3.22) means that in the CBD, the supply of land is equal to the demand for land for the production of non-housing good, while equation (3.23) means that in each and every residential ring, the supply of land is equal to the demand for land for the production of housing.

In other expressions, for any vector of price ∇p,

$\nabla p = \left(P_W, P_N, P_H^j, r_L^j \cdot (1+\omega), r_N^1 \cdot (1+\omega), \overline{r_K} \cdot (1+\theta)\right)$, the demand and the supply of land in each ring must be equated.

Having allocated all land to uses, we can now find supplies and demands of other factors conditional on the vector ∇p. The aggregate demand for housing in each ring must be equal to the supply in each ring in equilibrium. The sum of the number of households for all residential rings must equal the total fixed number of households in the urban area. The equilibrium condition of 'zero excess demand' for labor must also be satisfied, conditional on the vector ∇p.

Importantly, regarding the equilibrium of residential location (expressed with ring and distance), in equilibrium, all households attain the same utility level in all rings, and the savings in housing cost of moving further from the CBD is exactly offset by the additional commuting costs that will be incurred. The boundary of the CBD is determined at the point where the land rent for the non-housing good sector is equal to that for housing sector at the 1st residential ring, while the city boundary is determined at the point where the land rent for housing sector is equal to the land rent for agriculture.

Formulation of the Basic Model

According to the methodology explained in the appendix, the basic model is specified using algebra in a complementary format. Workers are assumed to maximize utility over housing service, non-housing good, and leisure. The utility of household is formulated using a nested function. First, the preference between leisure and the other two goods is a CES (Constant Elasticity Substitution) function. Second, as a subsystem, the preference between non-housing good and housing is also a CES function but with a different elasticity of substitution. The use of the (nested) CES function is common in CGE modeling, since they are relatively easy to handle and flexible to change parameters. However, the use of CES function requires us to know the value of the elasticity of substitution. Usually, such information is hard to get for a specific study, and so researchers often end up assuming a value for the parameter. By taking the nested function, it is possible to reflect the difference between the elasticity of substitution between housing and non-housing good and that between leisure and all other choices. For the housing and non-housing good production functions as well, the paper uses CES functions.

Now, the algebraic formulation of the basic model is provided using specific functions. Following are the definitions of all parameters and variables in Table 4 and Table 5.

Table 4. Parameters for the basic model

$\overline{L_H(j)}$	Total benchmark land area for housing in each ring
α	Intensity of leisure preference over the other goods
β	Intensity of capital use over land in housing sector
$\overline{L_{CBD}}$	Total benchmark land area for CBD
δ	Elasticity of substitution among factors in housing production function
$\overline{K}$	Total, fixed capital endowment
λ	Elasticity of substitution among factors in non-housing good production function
π	Intensity of land use in non-housing good sector
$\overline{r_K}$	Price of capital, fixed, capital is perfectly elastically supplied
j	Parameter to represent a residential ring (total 10 residential rings)
σ	Elasticity of substitution between leisure and the other goods in utility function
ξ	Elasticity of substitution between housing and non-housing goods
TPOP	Total, fixed population level
TTIME	Total time available for leisure, labor, and commuting per capita (fixed)
μ	Scale parameter of non-housing good production function
ψ	Scale parameter of housing production function
ν	Intensity of housing preference over non-housing goods
ω	Intensity of capital use over land and labor uses in non-housing goods sector

Table 5. Variables for the basic model

Ex	Total value of export
L_{CBD}	Total area for CBD
$D(j)$	Distance from CBD in each ring
$H(j)$	Housing (per capita) in each ring
K	Total capital demand for all uses
$K_H^D(j)$	Capital demand for housing production in each ring (per capita)
$LEIS(j)$	Leisure demand in each ring (per capita)
$L_H^D(j)$	Land demand for housing production in each ring (per capita)
$M(j)$	Income level net of commuting cost in each ring (per capita)
$N(j)$	Number of households in each ring
$NH(j)$	Total non-housing goods demand in each ring (per capita)
NH^E	Total export demand of non-housing good
$PH(j)$	Housing price in each ring
$r_L(j)$	Land rent for housing production in each ring
r_{LN}	Land rent of CBD
PN	Price of non-housing good

Table 5. – coninued.

PU(j)	Unit welfare price, minimum expenditure to enjoy unit level of utility in each ring
TAX	Total tax revenue raised in the economy
$M\cos t(j)$	Monetary commuting cost in each ring
TKN	Total capital demand for the production of non-housing goods
tl	Tax rate on land rent
TLN	Total land demand for the production of non-housing goods
ts	Tax rate on capital rental
U(j)	Utility level in each ring (per capita)
USTR	Equilibrium utility level across all rings (per capita)
W	Wage rate
WL(j)	Labor demand for non-housing goods production (per capita)
x	Half of the distance between the centers of two contiguous rings

As a reminder, there are two production sectors (housing and non-housing good), one type of household, one CBD, and ten residential rings. Algebraically, the utility function of a representative in each ring can be expressed as follows

$$(\alpha \cdot LEIS(j)^{(\sigma-1/\sigma)} + (1-\alpha)\cdot(\nu \cdot H(j)^{(\xi-1)/\xi} + (1-\nu)\cdot NH(j)^{(\xi-1)/\xi})^{\xi/(\xi-1)})^{(\sigma-1/\sigma)})^{(\sigma/\sigma-1)} \tag{3. 24}$$

Housing production in each ring is performed using the following technology

$$\psi \cdot (\beta \cdot K_H^D(j)^{(\delta-1)/\delta} + (1-\beta)\cdot L_H^D(j)^{(\delta-1)/\delta})^{\delta/(\delta-1)} \tag{3. 25}$$

Non-housing goods are produced using the following technology

$$\mu \cdot (\omega \cdot TKN^{((\lambda-1)/\lambda} + \pi \cdot TLN^{(\lambda-1)/\lambda} + (1-\varpi-\pi)\cdot WS^{(\lambda-1)/\lambda})^{\lambda/(\lambda-1)} \tag{3.26}$$

The equations (3.24), (3.25) and (3.26) along with budget constraints are used to derive the expenditure function, cost functions, and demand functions for output and input. Note that since the rental price of capital is fixed, no supply side function is needed.

<Distance from each ring to CBD >

Assuming that the shape of the city is a circle, we can have the following distance from the CBD relationship. The distance from the CBD at each ring (j) is expressed as miles from the center of the CBD to the midpoint of each ring.

$$D(j) = (L_{CBD}/3.14)^{1/2} + x \cdot (2 \cdot j - 1) \tag{3.27}$$

<Monetary commuting cost from each ring to CBD>

As stated in the next section, in the Atlanta urban area, average monetary commuting cost per household is 73 cents per mile.[43] The roundtrip monetary commuting cost can be expressed as follows.

$$M\cos t(j) = 2 \times 0.73 \times D(j) \tag{3.28}$$

<Residential area in each ring>

$$A(j) = 3.14 \times (D(j) + x)^2 - 3.14 \times (D(j) - x)^2 \tag{3.29}$$

<Zero Profit Inequalities>

For all the inequalities below in this subsection, the left-hand-side represents unit cost (or unit expenditure), and the right-hand-side represents market price per unit. To derive the unit (minimum) cost function which is the function of only factor prices, we need to minimize the production cost function expressed as the sum of the products of each factor and its price, then derive factor demand functions from the first order conditions, and finally substitute the factor demand functions into the objective function. For welfare (utility), we derive an (minimum) expenditure function to satisfy unit utility level in the same way. Note that the CES utility function has characteristics of the first degree of homogeneity, and we can express the function as an intensive form, which

[43] See Table 12. An average total monetary commuting cost per mile is 0.517 dollars and average household size is 2.65, and worker to population ratio is 0.536, thus 51.7 ×0.536 × 2.65 = 73.4

denotes unit value. In the unit cost function, there is no output variable in the functional form, since the unit cost represents the minimum average cost and is taken to be the price of output. The expenditure function has a similar form to an indirect utility function with the first degree of homogenous preference, so that it can be divided by utility and then be the function of commodity prices only. Finally, we get the following inequalities. The unit cost function for housing production is as follows

$$\frac{1}{\psi}\cdot(\beta^{\delta}\cdot(\overline{r_K}\cdot(1+ts))^{(1-\delta)}+(1-\beta)^{\delta}\cdot(r_L(j)\cdot(1+tl))^{(1-\delta)})^{\frac{1}{(1-\delta)}}\geq PH(j) \qquad (3.30)$$

The unit cost function for non-housing good production is as follows

$$\frac{1}{\mu}\cdot(\omega^{\lambda}\cdot(\overline{r_K}\cdot(1+ts))^{(1-\lambda)}+\pi^{\lambda}\cdot(r_{LN}\cdot(1+tl))^{(1-\lambda)}+(1-\varpi-\pi)^{\lambda}\cdot W^{(1-\lambda)})^{\frac{1}{(1-\lambda)}}\geq PN \qquad (3.31)$$

The unit expenditure function for welfare is as follows.

$$(\alpha^{\sigma}\cdot W^{(1-\sigma)}+(1-\alpha)^{\sigma}\cdot(\nu\cdot PH(j)^{(1-\xi)}+(1-\nu)\cdot PN^{(1-\xi)})^{(1-\sigma)/(1-\xi)})^{\frac{1}{(1-\sigma)}}\geq PU(j) \qquad (3.\ 32)$$

<Market Clearance Inequalities>

For all the inequalities below in this subsection, the left-hand-side represents supply, and the right-hand-side represents demand. Taking a partial derivative of expenditure functions or cost functions with respect to each price derives demand functions. The supply-demand inequality for housing sector is as follows

$$H(j)\ \geq\ U(j)\cdot\nu\cdot\frac{((1-\alpha)\cdot PU(j))^{\sigma}\cdot(\nu\cdot PH(j)^{(1-\xi)}+(1-\nu)\cdot PN^{(1-\xi)})^{(\xi-\sigma)/(1-\xi)}}{PH(j)^{\xi}} \qquad (3.\ 33)$$

The supply-demand inequality for non-housing good is as follows

$$NH(j) \geq$$

$$U(j)\cdot(1-\nu)\cdot\frac{((1-\alpha)\cdot PU(j))^{\sigma}\cdot(\nu\cdot PH(j)^{(1-\xi)}+(1-\nu)\cdot PN^{(1-\xi)})^{(\xi-\sigma)/(1-\xi)}}{PN^{\xi}}\cdot+\frac{Ex}{PN}\cdot\frac{1}{TPOP}$$

(3.34)

The supply-demand inequality for leisure is as follows

$$LEIS(j) \geq U(j)\cdot\frac{(\alpha\cdot PU(j))^{\sigma}}{W^{\sigma}} \tag{3.35}$$

The capital demand for the production to satisfy per capita housing demand is as follows.

$$K_H^D(j) = \frac{HD(j)}{\psi}\cdot\left(\frac{\beta\cdot\psi\cdot PH(j)}{(1+ts)\cdot\overline{\overline{r_K}}}\right)^{\delta} \tag{3. 36}$$

The total capital demand for non-housing good production is as follows

$$TKN = \frac{\sum_j N(j)\cdot NH(j)}{\mu}\cdot\left(\frac{\omega\cdot\mu\cdot PN}{(1+ts)\cdot\overline{\overline{r_K}}}\right)^{\lambda} \tag{3.37}$$

Total capital demand for all production is as follows

$$K = \sum_j N(j)\cdot K_H^D(j) + TKN \tag{3. 38}$$

The land demand for the production to satisfy per capita housing demand in each ring is as follows

$$L_H^D(j) = \frac{HD(j)}{\psi}\cdot\left(\frac{\psi\cdot(1-\beta)\cdot PH(j)}{(1+tl)\cdot r_L(j)}\right)^{\delta} \tag{3.39}$$

The land supply-demand inequality for housing production in each ring is as follows

$$A(j) \geq N(j)\cdot L_H^D(j) \tag{3.40}$$

The land demand for the production to satisfy total non-housing good demand is as follows

$$L_{CBD} = TLN = \frac{\sum_j N(j) \cdot NH(j)}{\mu} \cdot \left(\frac{\mu \cdot \pi \cdot PN}{(1 + tl) \cdot r_{LN}} \right)^{\lambda} \qquad (3.41)$$

The labor demand for the production to satisfy total non-housing good demand is as follows

$$WL(j) = \frac{NH(j)}{\mu} \cdot \left(\frac{\mu \cdot (1 - \varpi - \pi) \cdot PN}{(1 + tl) \cdot W} \right)^{\lambda} \qquad (3.\ 42)$$

Per capita utility is as follows

$$U(j) = \frac{M(j)}{PU(j)} \qquad (3.\ 43)$$

<Closed city condition with respect to the number of households >

The condition for a closed city is as follows

$$\sum_j N(j) = TPOP \qquad (3.44)$$

<Equal utility condition across rings >

The condition to satisfy that all households must obtain an equal utility in equilibrium can expressed as follows

$$U(1) = U(2) = U(3) = \cdots = USTR \qquad (3.\ 45)$$

<Tax revenue raised in the economy>

Tax revenue raised in the economy is as follows

$$TAX = K \cdot \overline{r_K} \cdot ts + (r_{LN} \cdot tl \cdot L_{CBD}) + (\sum_j r_L(j) \cdot tl \cdot L_H(j)) \qquad (3.46)$$

<Income Balance Equation>

Per capita income in each ring is as follows. Note that commuting time cost is cancelled out in the equation (3.47).

$$M(j) = LEIS(j)\cdot W + WL(j)\cdot W + \frac{\overline{r_K}\cdot\overline{K}}{TPOP} + \frac{\sum_j r_L(j)\cdot\overline{L_H(j)}}{TPOP} + \frac{r_{LN}\cdot\overline{L_{CBD}}}{TPOP}$$
$$+ \frac{TAX}{TPOP} - M\cos t(j)$$

(3. 47)

<Export Value>

$$Ex = P_N \cdot NH^E \tag{3. 48}$$

<Trade Restriction>

The following trade restriction is imposed to close the model.

$$Ex - \sum_j N(j)\cdot M\cos t(j) = r_{LN}\cdot L_{CBD} + \sum_j r_L(j)\cdot N(j)\cdot L_H^D(j) + \overline{r_K}\cdot K$$
$$-\sum_j r_L(j)\cdot\overline{L_H(j)} - \overline{r_K}\cdot\overline{K} \tag{3. 49}$$

Data

The CGE models of this dissertation are developed with the standard mono-centric city framework. The available data such as land rent, housing prices for the representative household is approximately average data in the Atlanta urban region. It is assumed that the benchmark data obtained represent those for the representative household who lives in the 5th ring of the present model.

As mentioned in a previous section, the current study is for the Atlanta urban region in Georgia, which consists of ten counties, including Cherokee, Clayton, Cobb, Dekalb, Douglas, Fayette, Fulton, Gwinnett, Henry, and Rockdale. This area covering the ten counties is close to the urbanized area of Georgia as defined in the U.S. Census. The Benchmark data and SAM reflect the basic features of the Atlanta urban area in Georgia.

The basic features include the number of households, land area, housing price, land price, wage rate, the level of property tax. Table 6 shows the distributions of the number of households and land area across the region. The total number of households in the urban area is 1,385,865. Some counties such as Fulton (340,342) and Dekalb (263,296) have conspicuously high numbers of households. Fulton (526.5 square miles) and Gwinnett (432.6 square miles) have relatively larger land areas. We also see that rural areas such as Cherokee have much sparser population density than other central areas such as Dekalb. Along with the land value data in Table 11, the density pattern in the table shows to some degree that the Atlanta region roughly fits in the mono-centric city framework. The whole urban land area is 2,981 square miles. Assuming that the shape of each ring is a circle, the radius is about 31 miles.

According to data obtained from ARC (Atlanta Regional Commission), we get 43.04 % (1,274 square miles) for residential use, 7.57 % (224 square miles) for CBD, and 49.39 % (1,462 square miles) for the other uses such as parks and roads. Actually, there is a parcel of land for agricultural use (633 square miles). However, the current model covers only urban area, and so the land area for agricultural use is subtracted from the total land area, reducing to the total area of 2,960 square miles, which is the study area for this dissertation.

Table 6. Household and land area distribution of Atlanta region

Name of county in Atlanta region	Number of Households	Land Area (square miles)	Density (per square mile of land)	*Density (per square mile of residential land)
Cherokee	60,634	423.6	0.22	0.55
Clayton	91,142	142.6	1.00	2.44
Cobb	240,490	339.4	1.11	2.71
DeKalb	263,696	268.2	1.54	3.76
Douglas	39,356	199.3	0.31	0.75
Fayette	34,711	195.3	0.28	0.68
Fulton	340,342	526.5	1.01	2.47
Gwinnett	234,210	432.6	0.85	2.07
Henry	55,030	322.7	0.27	0.65
Rockdale	26,254	130.3	0.31	0.77
Total	1,385,865	2,981.0	0.73	1.78

Source: 2004 Atlanta Regional Commission, "Table A2 A. Housing Units, Occupancy, and Household Size, Counties, April 1, 2000 and 2004", and "Table A1 A. Total Population, Race, and Density, Counties, April 1, 2000 and 2004". *Estimated values

Table 7. Land use type of the Atlanta region (10 counties)

Land Use	Area (Square miles)	Share (%)
CBD	223.98	7.57
Residence	1,274.22	43.04
Government	92.34	3.12
The other uses (Park, Roads, etc)	1,369.91	46.27
Total	2,960.44	100.00

Source: 2003 Atlanta Regional Commission, Land Use by type, internal data

To construct a rectangular SAM for the current model, we first need to determine the money income for a representative household for the designated ten counties. Currently, the data for an average household income is available only until the year 2000. On the other hand, for the Atlanta MSA (twenty counties), the data for an average household income is available until the year 2003. Thus, the strategy is to estimate the average household income for the ten counties and for the year 2003, by reflecting the percentage difference between the average household income of the Atlanta MSA (twenty counties) and the average household income of the ten counties for year 2000. However, although the average household income data is not available until year 2003, for the Atlanta MSA (twenty counties) the annual average expenditure data by a consumer unit is available until recently. Thus, the strategy is to estimate household income data for year 2003 (ten counties), by taking the following steps. First step is to update the average household income for the Atlanta MSA (twenty counties) from year 2002 to year 2003, by reflecting the percentage difference between the two average expenditure data[44] $60,529 (year 2003) and $53,936 (year 2000) in Table 8. Second step is to transform the estimated average household income data for the Atlanta MSA (year 2003) to that for the ten county region (year 2003), by reflecting the percentage difference between the average household income data[45] $67,535 for the Atlanta MSA and $69,490 for the ten counties (year 2000). After having taken these steps, the result is in Table 9.

Table 8. Annual average expenditure for the Atlanta MSA

Item	2002-2003 (dollars)	1999-2000 (dollars)
Income before taxes	60,529	53,936
Average annual expenditures	39,549	37,624
Housing	14,548	13,663
All others	25,001	23,961

Source: U.S. Department of Labor (Bureau of Labor Statistics), "Table 23. Selected southern metropolitan statistical: Average annual expenditures and characteristics (Consumer Expenditure Survey)".

[44] This survey was done for 'consumer units' according to the glossary in the website of consumer expenditure survey. There is no 'household unit expenditure survey', and so I will apply the shares of housing and non-housing expenditures to 'average household income' to estimate household expenditure share for housing and the other.

[45] Average household income data came from 'America Facts Finder' of the website, www.census.gov accessed in May 2004.

Table 9. Annual average household income and expenditure for the Atlanta region (10 counties) (estimated)

Item	2002-2003 (dollars)
Household Income before taxes	77,988
Average annual expenditure	50,957
Housing	18,744
All others	32,213

Households may save or borrow money to spend. However the current model dose not consider ‘saving’ or ‘borrowing’. As mentioned in a previous section, it is assumed that households would spend the whole income inclusive of leisure value on housing, non-housing goods, leisure, and transportation. The current model considers property tax, and the property tax is already reflected in the ‘annual average expenditure’. The annual average expenditure ($50,957) is the benchmark household income.

However, the $50,957 does not include leisure value. In the SAM, total income should be inclusive of leisure value. To include the leisure value, we need to know total leisure time and unit value of it for a representative household. The annual total workday is assumed to be 250. According to Table 10, among 24 hours, daily sleeping time is 8.58 hours, so total daily amount of time available for work, leisure, and commuting is calculated as $24 – 8.58 = 15.42$ hours. Among the 15.42 hours, at the benchmark, daily non-sleeping work-hour is 7.38, and annual work-hour is $7.38 \times 250 = 1,845$. And daily average commuting time is $30.5 \times 2 = 61$ minutes, according to ARC (2004). So, daily leisure time is $15.42 – 7.38 – 61/60 = 7.02$ hours, and annual leisure time is $7.02 \times 250 = 1,755$ hours. To calculate the value of the leisure time, we need to multiply 1,755 by an hourly value of leisure (or labor). In this model, labor income comes from the sector of non-housing good only. This assumption inevitably makes the value and portion of wage income smaller than the actual values of wage income. The current model assumes that all households owned fixed amount of land and capital. This additional assumption allows the total amount of income to be maintained at the actual income in the study area by compensating the reduced wage value. Thus, the hourly rate we should apply to determine the value of leisure must be derived from the labor portion of non-housing good production. As you will see in one of the next discussions, the labor portion of non-housing good is $20,294. So, the hourly rate for labor is calculated as $11.0 through dividing $20,294 by (250 × 7.38). Then, total annual leisure expenditure is 1,755 × 11.00 = $19,305. Finally, total average income inclusive of leisure value is estimated to $19,305 + $50,957 = $70,262.

Table 10. National surveys: American time use

Occupation	Average Hours per day for each occupation
Total work	7.38
Work (main job)	7.54
Work (other jobs)	7.50
Sleeping time	8.58

Source: Bureau of Labor Statistics, America Time Use Survey, Summary Table 2-A. Number of persons and average hours per day by detailed activity classification, 2003 annual averages, unpublished

The portion of housing expenditure is $18,744 for the representative household. The housing expenditure ($18,744) is inclusive of property tax. Thus, we need to separate the portion of property tax from the housing expenditure to construct SAM. For metro Atlanta, it is reported that statutory property tax rates range from 22.20 to 54.31 mills.[46]

[46] The Property tax here is an Ad valorem tax. "Ad valorem taxes are stated in terms of mills, or the amount to be paid per each $1,000 of the real property's assessed valuation. Mills are valued the same in each county and municipality for commercial land and buildings, equipment and inventory, as well as personal property. In most areas, the assessed valuation is 40 percent of what is judged as the property's fair market value". (Metro Atlanta Chamber of Commerce; Business Taxes and Related Regulations; www.metroatlatachamber.com, or http://www.echolsgroup.com/echolswriting/Corptaxes.pdf).

We need to calculate and apply the ‘effective’ property tax rate. The effective property tax rate is the product of statutory property tax rate and assessment ratio. The assessment rate is 40%. Then, effective property rate ranges from 8.88 to 21.72 mills. 16 mills is chosen as approximately average effective mills[47] for the whole urban area and applied to the model. Note, however, that the property tax base is not the annual housing cost, but the market value of housing. Assuming that an interest rate is 7%, we can calculate a new effective property tax rate with the base of annual cost of housing ($0.016 \div 0.07 = 0.229$). Then, dividing \$18,744 by 1.229, we can generate the housing cost net of the tax (\$15,251). Thus, the remaining part is the portion of annual property tax for housing (\$18,744 - \$15,251 = \$3,493).

Next task is to divide the annual housing cost (\$15,251) into two parts: land value and structure value. Table 11 provides average land value per acre and the portion of land value per residence for the Atlanta ten county region. The original raw data to calculate the information in the table could be obtained from the official website of Georgia Department of Revenue. According to the Table 11, average land value for residence is \$127,299, that for commerce are \$238,928, and that for agriculture are \$23,318. We see that the land value and the portion of land value vary by distance from the CBD. The variances are consistent with our intuition for the mono-centric city framework. For instance, Atlanta midtown’s commercial land value is \$7,127,073, which is very high, the city of Atlanta’s residential land value is \$251,021, and Nelson in Cherokee county has \$70,175 as an average land value. And also with the residence, the percentage portion of

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[47] We have not enough information to calculate a weighted average property tax rate accurately.

land value is relatively higher in Atlanta than in Nelson and Duluth. Duluth in Gwinnett county, which is located roughly at the middle of Atlanta metro, has $141,336 as an average land value. For the present study, we take the average lot size and the average land value for Duluth, since we will make 5th ring of ten rings in the model have the benchmark land value and lot size.[48]

Table 11. Average lot size and land value for Atlanta metro (10 counties)

Lot Type	Average Land Value per acre ($)	Ave. Portion of Land Value per Housing (%)
Residence	127,299	25.15
Nelson	70,175	19.70
Duluth	141,336	24.70
Atlanta	251,021	29.80
Commerce	238,928	19.19
Atlanta/Buckhead	5,928,895	26.81
Atlanta, Midtown, CID	7,127,072	22.96
Agriculture	23,318	25.57

Source: Georgia Department of Revenue, calculated from raw data (2004).

Since land price embodies expenditure for non-building capital invested in the land, we follow Muth's[49] practice of reducing it by one-half to obtain a price for raw land. The price of raw land per acre is estimated as $71,000. Since we have the information for the percentage portion of land value, we can successfully divide the annual expenditure for housing ($15,251) into the value of raw land (=$15,251 × 0.2470 = $3,767) and that of structure ($15,251 - $3,767 = $11,484). When we assume that 100 is the unit amount of capital, the rental price per unit of capital is $114.84.[50]

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[48] Here, for easier application, we take $142,000 as a land value for benchmark, after rounding $141,336.

[49] Richard F. Muth, *Cities and Housing*. Chicago: University of Chicago Press, 1967, DiMasi,1987

[50] There is no standard measure to determine 'unit capital'. Thus, in the current dissertation, I take '100' as unit amount of capital.

Next, we need to divide the expenditure for non-housing good ($32,213) into three factors. The three factors consist of the portions of labor, land, and capital that are used to produce non-housing goods. From the input-output table for the Atlanta urban region,[51] for all goods except housing, 63% ($20,294) of total value added belongs to labor, and 37% ($11,919) of it belongs to the other two factors. Note that the values of land and capital include the value of property tax. I mentioned that the new effective property tax rate with the base of annual cost in the Atlanta urban area is 22.9 mills. So, dividing $11,919 by $1.229 gives us the land and capital value net of tax, which is $9,698. We can also successfully divide the $9,698 into the two parts. According to the Table 11, for commerce, the average percentage of land value is 19.19 %. Hence, applying 20 %, we get the land portion ($9,698 × 0.2 = $1,940) and the capital portion ($9,698 - $1,940 = $7,758).

Turning to the issue of transportation cost, according to Table 12, an average total transportation cost per mile is 51.7 cents, and average daily commute mileage per capita is reported as 30.53 miles.[52] According to the information from ARC (Atlanta Regional Commission),[53] average household size is 2.65 and worker to population ratio is 0.536 for year 2003. Thus, the monetary transportation cost for a representative household is 30.53 × 2.65 × 0.517 × 0.536 = $22.42 per day, and annual average monetary commuting cost for a household is calculated to $22.42 × 250 = $5,605. We need to add the annual value of commuting time to this monetary cost ($5,605). The average one-way

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[51] For extracting this information, I referred to the following databases. 1) IMPLAN 2) U.S.Department of Commerce (Bureau of Economic Analysis); Input-Output Accounts Data

[52] ARC(Atlanta Regional Commission). "Atlanta Region Transportation Planning: Fact Book 2004." 2004.

[53] http://www.atlantaregional.com accessed in May 2004.

commuting time per day in the metro Atlanta is taken as 30.5 minutes, so round-trip commuting time per year is 2 × 30.5/60 × 250 = 254 hours. Then the value of commuting time per year is 254 × $11 (wage rate per hour) = $2,794 dollars per year. Finally, total annual transportation cost per household is calculated as $5,605 + $2,794 = $8,399.

Table 12. Transportation costs in America

	2003	2000
Average total cost per mile (current ¢)	51.7	49.1
Gas and oil	7.2	6.9
Gas and oil as a percent of total cost	13.9	14.1
Maintenance	4.1	3.6
Tires	1.8	1.7
Average total cost per 15,000 miles (current $)	7,754	7,363
Variable cost	1,965	1,829
Fixed cost	5,789	5,534
*Daily Vehicle mileage traveled per capita (staff/employee) in Atlanta area (miles)	30.53	-

Source: www.bts.dot.gov/publications/national_ transportation_statistics/2004/excel/Table_03_14.xls accessed in May 2004, and *Atlanta Regional Commission

Now, let us discuss choosing parameter values for setting up utility and production functions using specific functional forms such as CES (Constant Elasticity of Substitution) functions. Regarding the elasticity of substitution for the production of non-housing good, according to a recent study, Pessoa and Rob (2005), the elasticity of substitution between capital and labor in aggregate is estimated as 0.7. We take this value for our production function of non-housing good. Regarding the elasticity of substitution between capital and land for housing production, according to Conder (1998), literature suggests that the value ranges between 0.6 and 0.8 for it. We assume a value of 0.7 for the current housing production function.

Regarding the elasticity of substitution in the nested utility function, the present dissertation reflected the possible differences of the elasticities of substitution among the choices to be more realistic than other studies, although there is still an arbitrary portion. At the first level, there are no published studies of the elasticity of substitution between leisure and non-leisure goods. Generally, studies adopt Cobb-Douglas function when they cannot find the elasticity of substitution for their studies. However, adopting Cobb-Douglas function means that they arbitrary choose 1 as the elasticity of substitution for their studies. For this dissertation, instead of choosing 1, 0.7 is used. This is arbitrary, but existing studies such as DiMasi (1987) treated the elasticity of substitution among leisure, housing, and non-housing goods as the same, which is also arbitrary and less realistic than the present study. At the second level, for the elasticity of substitution between housing and non-housing goods of the utility function, according to Yang (2005), it is reported as 0.145 for the elasticity of substitution of utility function in his study. The number 0.145 is very inelastic. This paper uses a value of 0.2 for the present utility function.

The data above generates the following rectangular SAM, Table 13. Note that the following tables work as a primary benchmark. The following tables do not provide all the information for all the rings of the Atlanta urban area, but provide a consistent data set for a representative household who lives in a given ring. The benchmark result that provides information for all the rings should be produced within the model using the primary benchmark. It is discussed in the next section.

Table 13. Rectangular SAM for the base model (per year)

Markets	H(r)	NH(r)	U(r)	TTIME	Household (r)
PH(r)	18,744		-18,744		
PN		32,213	-32,213		
PU(r)			70,262		-70,262
PL(r)	-3,767				3,767
PLN		-1,940			1,940
PK	-11,484	-7,758			19,242
WS(r)		-20,294		20,294	
LEIS(r)			-19,305	-28,693	47,998
Tax	-3,493	-2,221			5,714
Tracost(r)				8,399	-8,399

Calibration

We can calibrate function coefficients by inverting the factor demand or product demand functions using benchmark data. Note that in the benchmark data, the export of non-housing good (*Ex*) assumed to be zero, and the variable *Ex* is not shown in the following equations of calibration.

Calibration of Utility Function

From the product demand functions redefined above, divide (3.34) by (3.33), to get

$$\frac{NH(j)}{H(j)} = \frac{(1-\nu)}{\nu} \cdot (\frac{PH(j)}{PN})^{\xi} \tag{3.50}$$

By solving (3.50) for ν, we get

$$\nu = \frac{PH(j)^{\xi} \cdot H(j)}{NH(j) \cdot PN^{\xi} + PH(j)^{\xi} \cdot H(j)} \tag{3.51}$$

Next, dividing (3.34) by (3.35), we get

$$\frac{NH(j)}{LEIS(j)} = \left(\frac{(1-\alpha)\cdot W}{\alpha}\right)^{\sigma} \cdot \frac{(1-\nu)\cdot(\nu\cdot PH(j)^{(1-\xi)} + (1-\nu)\cdot PN^{(1-\xi)})^{(\xi-\sigma)/(1-\xi)}}{PN^{\xi}}$$

(3.52)

By solving (3.52) for α and substituting (3.51) for ν, we get

$$\alpha = \frac{W}{\left(\frac{NH(j)\cdot PN^{\xi} + PH(j)^{\xi}\cdot H(j)}{LEIS(j)}\cdot\left(\frac{NH(j)\cdot PN + PH(j)\cdot H(j)}{NH(j)\cdot PN^{\xi} + PH(j)^{\xi}\cdot H(j)}\right)^{(\sigma-\xi)/(1-\xi)}\right)^{1/\sigma} + W}$$

(3.53)

<u>Calibration of Housing Production Function</u>

Dividing (3. 36) by (3.39) yields

$$\frac{K_H^D(j)}{L_H^D(j)} = \left(\frac{\beta\cdot(1+tl)\cdot r_L(j)}{(1-\beta)\cdot(1+ts)\cdot \overline{r_K}}\right)^{\delta} \tag{3.54}$$

Then, by solving (3. 54) for β, we get

$$\beta = \frac{(1+ts)\cdot\overline{r_K}\cdot\left(K_H^D(j)/L_H^D(j)\right)^{1/\delta}}{(1+tl)\cdot r_L(j) + (1+ts)\cdot\overline{r_K}\cdot\left(K_H^D(j)/L_H^D(j)\right)^{1/\delta}} \tag{3.55}$$

For the scale parameter of housing production function, we can get as follows by solving the equation (3.25) for ψ.

$$\psi = HS(j)\cdot(\beta\cdot K_H^D(j)^{((\delta-1)/\delta)} + (1-\beta)\cdot L_H^D(j)^{((\delta-1)/\delta)})^{\delta/(1-\delta)} \tag{3. 56}$$

<u>Calibration of Non-housing Good Product Function</u>

Dividing (3.37) by (3.41) yields

$$\frac{TKN}{TLN} = \left(\frac{\omega\cdot(1+tl)\cdot r_{LN}}{\pi\cdot(1+ts)\cdot\overline{r_K}}\right)^{\lambda} \tag{3. 57}$$

Using (3. 37) and (3.42), we get

$$\frac{TKN}{\sum_j WL(j)} = \left(\frac{\omega \cdot W}{(1-\omega-\pi)\cdot(1+ts)\cdot \overline{r_K}}\right)^{\lambda} \tag{3.58}$$

Finally, using (3.38) and (3.42), we get

$$\frac{TLN}{\sum_j WL(j)} = \left(\frac{\pi \cdot W}{(1-\omega-\pi)\cdot(1+tl)\cdot r_{LN}}\right)^{\lambda} \tag{3.59}$$

By solving (3.57), (3.58) and (3.59) for ω and π, we get the following.

$$\omega = \frac{(1+ts)\cdot \overline{r_K} \cdot \left(\frac{TKN}{\sum_j WL(j)}\right)^{1/\lambda}}{W + (1+ts)\cdot \overline{r_K} \cdot \left(\frac{TKN}{\sum_j WL(j)}\right)^{1/\lambda} + (1+tl)\cdot r_{LN} \cdot \left(\frac{TLN}{\sum_j WL(j)}\right)^{1/\lambda}} \tag{3.60}$$

and

$$\pi = \frac{(1+tl)\cdot r_{LN} \cdot \left(\frac{TLN}{\sum_j WL(j)}\right)^{1/\lambda}}{W + (1+ts)\cdot \overline{r_K} \cdot \left(\frac{TKN}{\sum_j WL(j)}\right)^{1/\lambda} + (1+tl)\cdot r_{LN} \cdot \left(\frac{TLN}{\sum_j WL(j)}\right)^{1/\lambda}} \tag{3. 61}$$

And finally, by solving (3.26) for the scale parameter (μ), we get

$$\mu = NH \cdot \left(\omega \cdot KT^{(\lambda-1)/\lambda} + \pi \cdot LT^{(\lambda-1)/\lambda} + (1-\varpi-\pi)\cdot WL^{(\lambda-1)/\lambda}\right)^{\lambda/(1-\lambda)} \tag{3. 62}$$

Table 14. Calibrated values for some parameters

α	0.275, Intensity of leisure preference over the other goods
β	0.831, Intensity of capital use over land in housing sector
π	0.032, Intensity of land use in non-housing good sector
μ	2.3, Scale parameter of non-housing good production function
ψ	0.739, Scale parameter of housing production function
ν	0.368, Intensity of housing good preference over non-housing good
ω	0.23, Intensity of capital use over land and labor in non-housing good sector

CHAPTER FOUR

EMPIRICAL RESULTS FOR THE BASIC MODEL

This chapter provides empirical results and their interpretation of the basic model [54] both for the case with fixed CBD (Central Business District) and urban boundaries and for the case with endogenous CBD and urban boundaries. For each case there are sub-analyses, the analysis of taxes on land rent only and the analysis of graded property taxes. In addition, the analyses for the case with LLZ (Large Lot Zoning) are also included and compared to the case without LLZ. All results are generated under the equal tax revenue setting.

The tax reform of switching from the current property tax to LVT (Land Value Tax) only might be appeared as a politically difficult option to implement in the short term in which the urban boundary does not change, since more than 80% of the user cost of land must be taxed to meet the current benchmark tax revenue. However, in the long term in which the urban boundary does change, our results suggest that the pure LVT reform can be a possible option to adopt in the sense that the required land tax rate to meet the current benchmark tax revenue is greatly reduced.

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[54] The case of fixed CBD and urban boundaries can be considered as one of the short-term spatial features. As time passes, the boundaries of the CBD and urban area should change. In chapter 5, additional short-term analyses with variable mobility of housing capital are conducted.

The variables provided in each table include the area of the CBD, the radius of the urban area, per capita annual tax revenue, annual average non-housing good production, the price of the non-housing good, the wage rate, the value of total domestic consumption, export value, total income for the economy, income per household, residential land rent, annual housing service price, capital-land ratio (housing capital density), and population density. The non-housing good, capital, and housing service are either composite goods or composite services, and so the choice of quantity unit for each of them was arbitrarily made.

The Benchmark

Table 15 contains the benchmark results obtained when the model was solved with the benchmark data (Table 13) and other demographic and geographic data for the Atlanta urban area. The Atlanta urban area is not strictly mono-centric in the sense that there are also scattered business districts in the suburban areas. However, the differences in land rent, housing service price, and population density by location show that the Atlanta urban area has the characteristics of the mono-centric city to a considerable degree. As we can recall from Table 6 and Table 11, the average land values and population densities by location are consistent with our intuition for the mono-centric city framework; areas closer to the center of the Atlanta urban region have the higher land values and housing prices and denser population. The 5th ring in Table 15 represents the land rent of a middle area such as Duluth ($4,970), [55] and annual housing service price paid by an average household ($15,251) of the Atlanta urban area (see Chapter 3). On

[55] In Chapter 3, it turned out that an average raw land value was $71,000. The land rent $4,970 was obtained through multiplying $71,000 by the assumed interest rate of 7%.

one hand, the benchmark simulation was successful in reflecting the real area of CBD and the radius of urban area (Table 7); On the other hand, the benchmark does not closely reflect the land gradient.

Table 15. Benchmark result: ‘tax on land = 22.9%, tax on capital = 22.9%’

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
323.31	30.58	4,510.75	198.78	100.00	11.00	47,975.61	1,146.05	64,753.32 (46,747.73)

Ring[56]	Residential land rent per acre of land	Annual Housing service price	K/L ratio capital amount per acre of land	Population density per acre of land
1	8,807.75	17,132.80	19.68	1.42
2	7,703.66	16,655.33	17.92	1.31
3	6,699.65	16,177.86	16.25	1.21
4	5,789.47	15,714.43	14.67	1.11
5	4,970.00	15,251.00	13.19	1.01
6	4,234.98	14,815.66	11.79	0.92
7	3,578.15	14,366.27	10.48	0.83
8	2,996.39	13,944.98	9.25	0.74
9	2,483.44	13,523.68	8.11	0.66
10	2,033.04	13,102.38	7.05	0.58

[56] Note that ring 1 is one of the residential rings, not the CBD.

The Effects of Tax on Land Rent

In this subsection, we investigate the effects of replacing the capital property tax with an equal yield LVT under both LLZ and no LLZ. The results are contained in Tables 16 through 21. Tables 16 through 18 are for the fixed CBD and urban boundaries, while Tables 19 through 21 are for the endogenous CBD and urban boundaries. Tables 17, 18, 20, 21 are the results when a binding LLZ is imposed on suburban rings. Regarding the imposition of LLZ, there are two sub-cases: (1) a binding LLZ on 6th and 7th rings, (2) a binding LLZ on 6th to 9th rings.

Let's first compare Table 15 with Table 16. Table 15 is the benchmark result with the taxes (22.9%) on both land and capital, while Table 16 is the result in which the tax rate on land is 409% and the tax rate on capital is zero, with fixed CBD and urban boundaries. Note that the land tax rates in the tables are calculated under the assumption that the liability of tax belongs to land users, and the land rents reported in the tables are net of taxes and the land rents that owners receive. In other words, for example, if land rent is $1.00 and the land tax rate is 400 percent, the land rent that users pay is $5.00 ($1.00 to the owner plus $4.00 in taxes). Note also here that if the liability of tax belongs to landowners, the land tax rate is calculated to 80%.

The first observation is that since the land tax rate 409% means that more than 80% of the user cost of land must be collected in the short term to meet the benchmark tax revenue ($4,510 per capita), the LVT reform seems to be close to the confiscation of land. Applying the information from Table 11 and Muth's practice to get 'raw'[57] land value (see Chapter 3), the percentage portion of housing value that is land value lies

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[57] Here 'raw' refer to the state that there is not any improvement such as water irrigation in land itself.

between 10% and 15%;[58] the remaining 85% to 90% is the value of capital (i.e. improvements). Hence, it is not surprising to get this observation. However, the tax revenue ($4,510 per capita) has a greater purchasing power for government to use, since the prices have decreased due to the tax reform, as can be seen from the tables.

The land rent and the price of housing service for the benchmark (Table 15) are overall much greater than those of the case with the tax on land rent only (Table 16). For example, for the 1st ring, the land rent for the benchmark is $8,807.75 while that for the LVT simulation is only $2,814.98, and the housing service price for the benchmark is $17,132.80 compared to $14,478.62 in Table 16. The same tendency holds true for the other rings as well. Unlike other taxes, landowners bear the entire burden of the tax on land rent, since there is no way for landowners to avoid the tax when the boundaries of the CBD and urban area do not change. Thus, consistent with the theory, the tax on land rent is fully capitalized into land rents, and the capitalized land rents results in the lower housing service prices.

The elimination of the tax on capital increases the housing capital density (the ratio of capital to land). For the 1st ring, the housing capital density of the benchmark (19.68) is smaller than the other case (20.52). The same holds true for the other rings as well. The tax reform (switching from the capital property tax to land tax) lowers the user cost of capital,[59] but the user cost of land does not change due to the full capitalization of land tax, which provides an incentive to adopt more capital for the production of non-

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[58] In Table 11, the percentage range of land value was reported between 20% and 30%. But this percentage range still includes improvements, so Muth's practice suggests cutting the values in half.

[59] Note that although the rental price of capital ($\overline{r_K}$) was fixed as a numeraire, the user cost of capital ($\overline{r_K} \cdot (1+ts)$) is not constant because of the tax (ts).

housing good and housing. Furthermore, the lowered user cost of capital means a lower cost of production, and as a result the production (or efficiency) in the economy increases. The adoption of more capital can mean taller housing or any other improved housing service. Population density remained constant in both cases, since the boundaries of the CBD and urban area have been fixed as a short-term feature.

Total income after the tax reform has also been reduced from $64,753.32 million (Table 15) to $56,416.68 million (Table 16), while the annual average non-housing good production to satisfy the demand per capita increased from 198.78 (Table 15) to 201.98 (Table 16). The result suggests that switching from the benchmark property tax to a land tax lowered the overall price level and also enhanced an efficiency of the economy.

Note that the wage rate has decreased from $11.00 (Table 15) to $9.72 (Table 16) because of the tax reform. We need to be careful in judging whether the real user cost of labor decreased or increased. Because of taxes, the relative user cost of labor in equilibrium can be different from the nominal wage rate. Assuming that the fixed rental price of capital is one, the user cost of capital is 1.229[60] at the benchmark while the user cost of capital is one after the tax reform. Thus, the user cost of labor relative to capital cost before the tax reform is $11 ÷ 1.229 = $8.95, while the user cost of labor relative to capital cost after the tax reform is $9.72 ÷ 1 = $9.72. Hence, the user cost of labor relative to capital cost in equilibrium increased after the tax reform, although the nominal wage rate decreased.

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[60] The benchmark property tax rate (22.9%) is applied here. Although the rental price of capital is fixed as numeraire, the user cost of capital with the property tax is 1.229 since capital is perfectly elastically supplied. In other words, the tax on capital generates ‘inflation effect’.

Regarding the change of wage rate, there are two countervailing forces: the replacement effect and the efficiency effect. The replacement effect suggests that the reduced user cost of capital due to the tax reform would replace some labor with capital to the point that the elasticity of substitution allows. This decreases labor demand and wage rate. On the other hand, the efficiency effect suggests that the reduced cost of production due to the reduced user cost of capital increases demand for labor and wage rate. Depending on relative sizes of the two forces, the wage rate relative to capital cost can either increase or decrease as a result of the tax reform. Here, the efficiency effect applies to all production factors. All households in the current model are landowners and laborers, and the reduced land rents and wages resulted in a decrease in income. If the households were not landowners, the efficiency effect would have more greatly dominated.[61]

Of course, the supply side of each factor must also be considered to determine change in the user costs of each factor. For land, the supply curve is vertical, so any increase in demand leads to an increase of land rent, while for capital, the supply curve is horizontal at an international price level, so the change in demand for capital does not affect the rental price of capital. The supply status of labor lies between land and capital. In our case, the efficiency effect dominated and led to the increase of wage rate relative to capital cost, although the nominal wage rate decreased.[62]

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[61] There is a big difference (even qualitatively) in the change of efficiency due to economic policy between resident landowners and absentee landowners. The details are described in Chapter 6.

[62] This is due to the elimination of 'inflation effect' that is from the elimination of the tax on capital.

Now, compare Table 16 to Table 17. Table 16 contains the results with LLZ on 6th and 7th rings under the fixed CBD and urban boundaries. Due to the LLZ, to meet the equal tax revenue condition, the required land tax rate with the LLZ (271%) is much lower than the case without the LLZ (409%). It is also observed that the increased land rent due to the LLZ contributes to the increase of total income from $51,416.68 million (Table 16) to $57,685.91 million (Table 17). This increased income would allow households to demand more housing and non-housing goods, and again allow firms to demand more factors. Let's call this effect the 'positive income effect' of LLZ.

The imposition of the LLZ increases the demand for land in all rings. For the rings with the LLZ, households consume housing services with the larger lot size,[63] while for the rings without the LLZ, the immigrants from the rings with the LLZ add to the number of existing residents by increasing the aggregate demand for residential lots. As a result, the land rents in all rings increase due to the LLZ.[64] Let's call this 'migration effect'. The positive income effect combined with this migration effect contributed to the increase in prices: the land rent of the 1st ring increased from $1,835.99 (Table 16) to $2,814.98 (Table 17); wage rate increased from $9.72 (Table 16) to $9.93 (Table 17); the price of non-housing good increased from $86.75 (Table 16) to $88.01 (Table 17). Another result is that the housing capital density (K/L ratio) in the rings with the LLZ decreased, but that in the rings without the LLZ increased, as would be expected. The housing capital densities of the 1st ring and (one of the rings without the LLZ) the 6th ring

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[63]The migration does not reduce the land rent in the rings with the LLZ, since the remained households in the rings with the LLZ would demand a larger lot size. And also, in the current model, the markets between for house and apartment are not separated, so that the household competes for only single-family housing.

[64] This finding is consistent with Moss (1977).

(one of the rings without the LLZ) for the absence of the LLZ (Table 16) are 20.52 and 12.26, while those for the presence of the LLZ (Table 17) are 22.19 and 8.13. The same pattern holds true for the other rings as well. This result is consistent with another result that the rings with LLZ have lower household (population) densities while the rings without the LLZ have higher household (population) densities, as compared to the case with the LLZ. Table 18 contains the results with the LLZ in 6th, 7th, 8th, and 9th rings and LVT. The results are qualitatively the same as when the LLZ is imposed in just 6th and 7th rings. Since LLZ was imposed on a larger area, the migration effect and the positive income effect became strengthened.

Now, let's discuss the results of the same counterfactual cases but under endogenous CBD and urban boundaries (Tables 19 to 21). Note that the benchmark is still the same, and so all tables can be compared to Table 15. Unlike the cases of fixed CBD and urban boundaries, the tax on land rent is not neutral in the case of endogenous CBD and urban boundaries. The tax on land rents lowers land rents in all rings, and the areas near the urban boundary would shift to agricultural use.[65] Due to the change of land area in the economy, the tax on land rent is not purely neutral.

Comparing Table 15 (the benchmark) with Table 19, due to the increase in the tax on land and the elimination of the tax on capital (i.e. improvements), the urban boundary contracted from 30.58 miles to 25.69 miles. The tax reform reduces land rents in all location and thus land at the edge of the urban area shifts to agricultural use, contracting the CBD area and the urban boundary, as we have discussed. Brueckner (2003) found that there are two countervailing effects of the property tax regarding the urban size: the

[65] This possibility was discussed in Chapter 2, when we reviewed Brueckner (2003).

improvement effect and the dwelling size effect. The improvement effect suggests that the property tax depresses improvements, reduces population density, and spurs the spatial expansion of the metropolitan area, while the dwelling size effect suggests that the property tax is partly shifted forward to consumers (households), leads to a higher price of housing service, decreases dwelling sizes in response, and contracts the urban size as a result. In this case, the improvement effect of the capital property tax dominated, so that switching from the capital property tax to the LVT contracts the CBD and the urban area.

Consistent with the above, comparing the benchmark (the capital property tax) to the case with just a LVT, the land rent and the housing service price of the 1st ring, for example, decreased from $8,807.75 and $17,132.80 in Table 15 to $5,373.48 and $15,672.30 in Table 19, respectively. However, as mentioned, the tax on land rent is not neutral in the case of endogenous boundary, which makes consumers bear a slight portion of the land tax, and so the decrease in land rent and housing service price is not as great as in the case of the fixed boundary.[66]

The required land tax rate to meet the equal tax revenue ($4,510.75 per capita) in the endogenous CBD and urban boundaries is 172%, which is much lower than the 409% in the fixed CBD and urban boundaries. We see here that the LVT reform can be adopted as a tax reform with less difficulty, since the 172% is about less than 60% of the user cost of land. Since the CBD and urban boundaries change, the revenue effect of land tax becomes improved.[67] Due to the spatial contraction of the urban area and the replacement

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[66] In the fixed boundaries case, the land rent and housing service price in the 1st ring were $1,835.99 and $14,127.54, respectively.

[67] Note that although the current discussion involves something about tax revenue, the current dissertation and models were not designed to explore the revenue effects of land tax.

effect due to the elimination of the tax on capital, the housing capital density (28.09) of the 1st ring (Table 19) became greater than in Table 16 (20.52). The same holds true for the other rings. Consistent with the other results, the population density (1.81 in Table 19) of the 1st ring also became greater than that (1.42 in Table 16) in the case of fixed CBD and urban boundaries.

Let's now compare Table 19 with Table 20. The latter is the result of the case with LLZ on 6th and 7th ring. The increase in income due to the residential landownership and LLZ increased the land rents in all locations: for example, the land rent of the 1st ring increased from $5,373.48 (Table 19) to $6,199.21 (Table 20). For the rings without the LLZ, the migration effect (emigrants from the rings with the LLZ) contributed to the increase in land rents. The increase of land rents increases production cost, and so the prices of housing service and the non-housing good also increased: the housing service price of the 1st ring increased from $15,672.30 (Table 19) to $15,742.51 (Table 20); the price of non-housing good increased from $93.44 (Table 19) to $95.26 (Table 20). The same holds true for the other rings as well.

The positive income effect due to the LLZ (combined with the replacement effect[68]) also increased the wage rate from $10.50 (Table 19) to $10.76 (Table 20), and increased the production of non-housing good from 206.31 (Table 19) to 211.18 (Table 20). Consistent with these results, the area of the CBD and the urban radius also increased from 256.46 square miles and 25.69 miles in Table 19 to 258.03 square miles and 27.28 miles in Table 20, respectively.

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[68] The increase of land rent due to the LLZ makes firms to substitute labor and capital for land, to the point that the elasticity of substitution allows. This effect also contributes to the increase of wage rate.

Table 21 contains the results for the case with the LLZ in the 6th to 9th rings, which is a larger area than the 6th and 7th rings. The imposition of the LLZ on the larger area makes more people in the rings with the LLZ move to the rings without the LLZ, which further pushes up the land rents and the prices of housing service. The increased land rent due to the LLZ results in an increase of household income.[69]

Regarding the changes in the CBD and urban boundaries, since the increase in land rents are larger due to the imposition of the LLZ on the larger area, the radius of the urban area increased from 27.28 miles (Table 20) to 28.57 miles (Table 21). However, the area of the CBD decreased from 258.03 square miles (Table 20) to 257.25 miles (Table 21). These results occur because the LLZ makes the residential area expand in both directions, i.e. into the CBD and the agricultural area.

[69] Under the absentee landownership, LLZ made the welfare of all households be reduced. For details, refer to Chapter 6.

Table 16. Results for ‘tax on land = 409%, tax on capital = 0%’ (fixed CBD and urban area) under the equal tax revenue

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
323.31	30.57	4,510.75	201.98	86.75	9.72	41,568.33	998.14	56,416.68 (40,729.21)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	1,835.99	14,127.54	20.52	1.42
2	1,604.54	13,720.28	18.68	1.31
3	1,394.98	13,327.07	16.94	1.21
4	1,204.19	12,933.86	15.28	1.11
5	1,032.16	12,554.69	13.71	1.01
6	878.90	12,175.52	12.26	0.92
7	741.28	11,810.40	10.87	0.83
8	619.30	11,445.27	9.59	0.74
9	512.95	11,094.19	8.41	0.66
10	419.12	10,743.11	7.30	0.58

Table 17. Results for ‘tax on land = 271%, tax on capital = 0%’ (fixed CBD and urban area) under the equal tax revenue and LLZ on 6th and 7th rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
323.31	30.57	4,510.75	204.97	88.01	9.93	42,340.94	1,474.67	57,685.91 (41,645.51)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	2,814.98	14,478.62	22.19	1.51
2	2,470.93	14,071.36	20.25	1.40
3	2,158.15	13,664.11	18.43	1.29
4	1,873.52	13,270.90	16.69	1.19
5	1,613.92	12,877.69	15.03	1.09
6	1,382.47	12,498.52	8.13	0.60
7	1,176.04	12,119.35	8.01	0.60
8	991.50	11,754.22	10.69	0.81
9	825.73	11,389.10	9.40	0.72
10	681.85	11,038.02	8.23	0.64

Table 18. Results for 'tax on land = 201%, tax on capital = 0%' (fixed CBD and urban area) under the equal tax revenue and LLZ on 6th, 7th, 8th and 9th rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
323.31	30.57	4,510.75	208.06	89.40	10.15	43,223.08	1,947.09	59,076.68 (42,649.56)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	3,844.01	14,829.70	23.84	1.59
2	3,387.36	14,408.40	21.82	1.48
3	2,971.37	13,987.10	19.91	1.37
4	2,589.78	13,579.85	18.08	1.26
5	2,242.60	13,186.64	16.35	1.16
6	1,932.95	12,793.43	8.29	0.60
7	1,651.45	12,414.26	8.16	0.60
8	1,398.11	12,035.09	8.02	0.60
9	1,176.04	11,669.96	7.91	0.60
10	978.99	11,318.88	9.15	0.70

Table 19. Results for 'tax on land = 172%, tax on capital = 0% ' (endogenous CBD and urban area) under the equal tax revenue

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
256.46	25.69	4,510.75	206.31	93.44	10.50	45,808.66	1,568.21	62,217.52 (44,917.05)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	5,373.48	15,672.30	28.09	1.81
2	4,885.55	15,321.22	26.27	1.71
3	4,432.03	14,970.13	24.55	1.62
4	4,009.78	14,633.10	22.89	1.53
5	3,612.56	14,296.06	21.27	1.44
6	3,246.61	13,959.02	19.74	1.35
7	2,905.68	13,621.98	18.27	1.26
8	2,589.78	13,313.03	16.85	1.18
9	2,298.90	12,990.03	15.50	1.10
10	2,033.04	12,681.08	14.22	1.02

Table 20. Results for 'tax on land = 140%, tax on capital = 0%' (endogenous CBD and urban area) under the equal tax revenue and LLZ on 6th and 7th rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
258.03	27.28	4,510.75	211.18	95.26	10.76	46,327.05	2,313.70	63,285.74 (45,688.23)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	6,199.21	15,742.51	28.44	1.81
2	5,570.53	15,349.30	26.38	1.70
3	4,988.77	14,942.05	24.42	1.60
4	4,453.92	14,562.88	22.56	1.49
5	3,956.61	14,183.71	20.77	1.39
6	3,499.96	13,804.54	8.77	0.60
7	3,080.84	13,439.42	8.65	0.60
8	2,699.25	13,074.29	15.89	1.11
9	2,348.94	12,723.21	14.42	1.02
10	2,033.04	12,372.13	13.03	0.94

Table 21. Results for 'tax on land = 119%, tax on capital = 0%' (endogenous CBD and urban area) under the equal tax revenue and LLZ on 6th, 7th, 8th and 9th rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
257.25	28.57	4,510.75	215.30	96.79	11.00	46,997.14	2,935.83	64,456.57 (46,533.49)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	6,990.53	15,854.86	28.99	1.82
2	6,224.23	15,405.48	26.73	1.71
3	5,517.36	14,970.13	24.56	1.59
4	4,869.91	14,548.84	22.51	1.48
5	4,275.64	14,127.54	20.55	1.37
6	3,734.54	13,720.28	8.81	0.60
7	3,240.35	13,327.07	8.67	0.60
8	2,796.21	12,933.86	8.55	0.60
9	2,392.73	12,540.65	8.41	0.60
10	2,033.04	12,161.48	12.21	0.88

The Effects of Graded Property Taxes

In this section, we discuss the results with graded property taxes where land is more heavily taxed than capital, under endogenous CBD and urban boundaries. In this subsection, we discuss the tax reforms that can be highly practically adopted. First, compare Table 19 with Table 22. Table 19 is, as we already mentioned, the result of the case with the tax on land rent only (172%), while Table 22 is the result of the case with the graded property tax where land is taxed at 80%[70] and capital is taxed at 10%. Both cases collect the same tax revenue.

The 10% increase in the tax on capital increases the nominal income of households from $62,217.52 million (Table 19) to $63,141.16 million (Table 22). I call it 'nominal income', since the increase of the nominal income does not imply an increase of production (or efficiency). Due to the 10% tax on capital, the production of non-housing good decreased from 206.31 (Table 19) to 202.88 (Table 22). Note that the tax on capital carries an inflation effect. Because the rental price of capital is fixed, the tax on capital increases the user cost of capital by the amount of tax. As a result, the other prices in the economy are adjusted accordingly. Provided that the base rental price of capital (and the old user cost of capital) is one as an example, the new user cost of capital increased to 1.1 due to the tax on capital. In this situation, for example, the old wage rate relative to capital cost is $10.50 ÷ 1 = $10.50 (Table 19), while the new wage rate relative to capital cost is $10.72 ÷ 1.1 = $9.75 (Table 22). For another example, the old price of non-housing good relative to capital cost is $93.44 ÷ 1 = $93.44 (Table 19), but the new price of non-housing good relative to capital cost is $96.09 ÷ 1.1 = $87.35 (Table 22). We also

[70] The 80% is about 40% of the user cost of land.

see that the housing service price in the 1st ring increased from \$15,672.30 to \$16,163.81, but the housing service price relative to capital cost in the 1st ring decreased from \$15,672.30 ÷ 1 = \$15,672.30 to \$16,163.81 ÷ 1.1 = \$14,694.37. The same pattern holds true for the other rings as well.

Switching from the land tax to the revenue-preserving graded property tax where capital is taxed at 10% increases land rents in all locations. We can provide insight into this finding by first considering a reduction in land tax rate to zero, followed by an increase in the tax on capital to recover the lost revenue. Reducing land tax rate to zero pushes up the land rents in all locations. We recall that the imposition of a land tax in an urban economy makes landowners bear the whole burden of the tax in the short-term, or makes landowners bear most of the tax burden in the long term.[71] Then, regarding the second step, Brueckner (2003) finds that the imposition of a property tax on a mono-centric urban economy may depress land rents up to a certain distance from the center, and then increase land rents beyond that point, i.e., there is counter-clockwise rotation of the land rent curve. Here, that point is the distance at which the equality of net returns to the landowner hold.[72] According to Brueckner (2003), it is complex to derive a full relationship between land rent and property tax. So, it is not straightforward to catch the reason for the relationship. Summing the two effects, for our case, the land rents in all locations increased. The depressive effect of the property tax on land rent did not exceed the positive effect of reducing the land tax.

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[71] Here, short term means the period of no change in the urban boundary, while long-term means the period that allows change in the urban boundary.

[72] Brueckner (2003) also finds that the result comes out when the improvement effect is greater than the dwelling size effect, in other words when the elasticity of substitution between housing and non-housing good is very low. Also refer to page 14 of his paper.

Furthermore, the tax on capital generates a larger burden on locations with large capital-land ratios (or higher housing capital densities), and so the gap between the pre-tax and the post-tax land rent curves increases as one approaches the rings near the CBD. The following numerical result confirms this finding. Compare the results in Table 19 to those in Table 22. For the 1st ring, the land rent increased by 26.54% (($6,799.74 - $5,373.48) ÷ $5,373.48 × 100 = 26.54%), but for the 9th ring, the land rent increased by only 3.76% (($2,385.35 - $2,298.90)÷ $2,298.90 × 100 = 3.76%). The same pattern holds true for the other rings as well. Consistent with the result for the land rent increase, the radius of the urban area and the area of the CBD also increased from 25.69 miles and 256.46 square miles in Table 19 to 28.32 miles and 294.57 square miles in Table 22, respectively.

Now, assume that a LLZ is imposed on some suburban rings. First of all, when we imposed a LLZ on 6th and 7th rings, the required land tax rate to meet the equal tax revenue decreased from 80% (Table 22) to 69% (Table 23), while the capital tax rate was kept at 10%. The existence of the LLZ increased the land rents in all locations, thus allowing the tax on land rent to be reduced. When a LLZ is imposed on the larger area (6th ring to 9th ring), the required land tax rate further decreased to 62% to meet the equal tax revenue (Table 24). We see that the LLZ favors landowners. Compare Table 22 to Table 23. For the 1st ring, the land rent increased by 11.64% (from $6,799.74 in Table 22 to $7,591.06 in Table 23), for the 6th ring, the land rent increased by 6.21% (from $3,675.11 in Table 22 to $3,903.44 in Table 23), and for the 9th ring, the land rent increased by 1.62% (from $2,385.35 in Table 22 to $2,424.01 in Table 23). So, we also see that the existence of the LLZ makes the gradient of land rent steeper. The emigrants from the rings with the LLZ put upward pressures on the land rent in the rings without the LLZ, and even greater upward pressures in the land rent in the rings nearer the CBD. Note that the land rents of the rings with the LLZ also increased, since the land markets[73] in the current economy are not distinguished and separated by characteristics and the LLZ does not diminish the demand for housing and land in the rings with the LLZ as well.[74] As a result, the LLZ shifts up the land rent curve for residential land in all locations. The preference of households for housing size is not fixed, either, but depends on the income of households, which is endogenous. The household income increased due to the LLZ, which increased the demand for housing and non-housing good, which again increased the demand for land, raising land rents even higher. The imposition of the LLZ on the larger area (Table 24) strengthened the effects described above.

In addition, the wage rate increased from $10.72 in Table 22 to $10.94 in Table 23 to $11.11 in Table 24 and the price of non-housing good increased from $96.09 to $97.91 to $99.02, due to the increase in income. Consistent with the increase in land rents, the radius of the urban area increased from 28.22 miles in Table 22 to 29.29 miles in Table 23 to 30.03 miles in Table 24, but the area of the CBD decreased from 293.57 square miles in Table 22 to 288.29 square miles in Table 23 to 284.24 square miles in Table 24, since the increased residential land rent of 1st ring outbid the extant land rent of the CBD. Note that for the cases in Table 23 and Table 24 the rings with the LLZ have

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[73] For example, land market for apartment, land market for single-family house, etc.

[74] If housing and land markets were separated, land value for single family home would decrease, but land value for apartment would increase. Hence, LLZ would make home residents gain but apartment residents lose. In the current model, although some residents are excluded from the rings with the LLZ, the minimum per-capita dwelling land size required by the LLZ did not diminish the demand for land in the rings with the LLZ as well.

lower housing capital density and population density while the rings without the LLZ have higher housing capital density and population density than reported in Table 22.

Now, let the government raise the tax on capital to 20% from 10% that allowed the land tax rate to decrease to 32% from 80% to meet the equal tax revenue. The results are reported in Table 25. With the imposition of the LLZ on the 6^{th} and 7^{th} rings (Table 26), the required land tax rate further decreased to 15%, and with the imposition of the LLZ in the larger area (6^{th} ring to 9^{th} ring), the required land tax rate again further decreased to 14% (Table 27). We see that at the 20% capital tax, the imposition of the LLZ in the current economy results in the land tax rate that is less than the tax rates on capital here. Hence, we draw the implication that the imposition of the LLZ in suburban rings makes a graded property tax more feasible in the sense that the government can further lower capital tax rate, without making land tax rate unreasonably high. Moreover, as we will see in Chapter 6, when the residents of an urban economy are landowners, the imposition of a LLZ may enhance the welfare of households. [75] Therefore, the combined policy of a graded property tax and a LLZ can be desirably pursued in some specific situations.

[75] However, as can be seen in the Chapter 6, when the residents are renters of land, the imposition of the LLZ reduces the welfare of the households.

Table 22. Results for 'tax on land = 80%, tax on capital = 10%' (endogenous CBD and urban area) under the equal tax revenue

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
293.57	28.22	4,510.75	202.88	96.09	10.72	46,619.93	1,317.97	63,141.16 (45,583.86)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	6,799.74	16,163.81	23.17	1.58
2	6,064.71	15,742.51	21.39	1.48
3	5,389.12	15,335.26	19.69	1.38
4	4,766.70	14,942.05	18.07	1.28
5	4,197.44	14,548.84	16.53	1.19
6	3,675.11	14,169.67	15.06	1.10
7	3,202.82	13,790.50	13.68	1.01
8	2,771.19	13,425.37	12.36	0.93
9	2,383.35	13,060.25	11.12	0.84
10	2,033.04	12,695.12	9.95	0.77

Table 23. Results for ‘tax on land = 69%, tax on capital = 10%’ (endogenous CBD and urban area) under the equal tax revenue and LLZ on 6th and 7th rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
288.29	29.29	4,510.75	206.59	97.91	10.94	47,230.03	1,910.21	64,222.21 (46,364.30)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	7,591.06	16,332.33	23.96	1.61
2	6,715.29	15,882.95	21.99	1.50
3	5,911.45	15,447.61	20.11	1.39
4	5,176.43	15,012.26	18.33	1.29
5	4,510.22	14,576.92	16.64	1.19
6	3,903.44	14,155.62	8.25	0.60
7	3,356.08	13,748.37	8.13	0.60
8	2,865.02	13,355.16	12.12	0.90
9	2,424.01	12,947.90	10.78	0.82
10	2,033.04	12,568.73	9.53	0.73

Table 24. Results for ‘tax on land = 62%, tax on capital = 10%’ (endogenous CBD and urban area) under the equal tax revenue and LLZ on 6th, 7th, 8th and 9th rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
284.24	30.03	4,510.75	209.19	99.02	11.11	47,789.37	2,315.10	65,129.90 (47,019.59)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	8,191.59	16,472.77	24.57	1.64
2	7,206.34	15,995.29	22.47	1.52
3	6,302.42	15,531.87	20.45	1.41
4	5,482.95	15,068.44	18.56	1.29
5	4,741.67	14,605.01	16.76	1.19
6	4,069.21	14,169.67	8.29	0.60
7	3,468.68	13,734.33	8.16	0.60
8	2,930.70	13,313.03	8.03	0.60
9	2,455.29	12,891.73	7.91	0.60
10	2,033.04	12,484.47	9.27	0.71

Table 25. Results for ‘tax on land = 32%, tax on capital = 20% (endogenous CBD and urban area) under the equal tax revenue

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
318.02	30.12	4,510.75	199.66	99.16	10.93	47,649.09	1,175.04	64,361 (46,464.21)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	8,347.97	16,894.06	20.30	1.45
2	7,331.45	16,430.64	18.53	1.34
3	6,402.51	15,967.21	16.86	1.24
4	5,558.02	15,517.82	15.27	1.14
5	4,797.97	15,068.44	13.78	1.04
6	4,109.87	14,647.14	12.36	0.95
7	3,493.70	14,211.80	11.03	0.86
8	2,946.34	13,804.54	9.79	0.77
9	2,461.54	13,397.29	8.63	0.69
10	2,033.04	12,990.03	7.55	0.62

Table 26. Results for 'tax on land = 15%, tax on capital = 20%' (endogenous CBD and urban area) under the equal tax revenue and LLZ on 6th and 7th rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
310.11	30.85	4,510.75	202.53	100.70	11.13	48,261.51	1,637.55	65,369.16 (47,192.33)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	9,057.97	17,104.71	21.09	1.49
2	7,906.96	16,599.15	19.17	1.37
3	6,859.16	16,107.64	17.36	1.26
4	5,914.58	15,630.17	15.65	1.15
5	5,063.83	15,152.70	14.04	1.05
6	4,300.66	14,689.27	7.84	0.60
7	3,621.94	14,239.88	7.72	0.60
8	3,021.41	13,790.50	9.78	0.77
9	2,492.82	13,355.16	8.55	0.68
10	2,033.04	12,933.86	7.41	0.60

Table 27. Results for 'tax on land = 14%, tax on capital = 20%' (endogenous CBD and urban area) under the equal tax revenue and LLZ on 6th, 7th, 8th and 9th rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income million $) (average income per household, $) net of transport cost
306.28	31.21	4,510.75	203.96	101.39	11.22	48,631.51	1,859.54	65,941.43 (47,605.47)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	9,430.18	17,203.02	21.49	1.51
2	8,207.22	16,683.41	19.50	1.39
3	7,100.00	16,177.86	17.62	1.27
4	6,099.12	15,686.34	15.84	1.16
5	5,201.45	15,194.83	14.17	1.06
6	4,400.75	14,717.36	7.87	0.60
7	3,687.62	14,253.93	7.74	0.60
8	3,058.94	13,790.50	7.61	0.60
9	2,511.59	13,355.16	7.49	0.60
10	2,033.04	12,905.77	7.34	0.60

CHAPTER FIVE

EXTENSIONS TO THE BASIC MODEL

This chapter provides two extensions for the basic model to further draw meaningful results. The extensions include the model with three income groups, and the model with immobile housing capital and only partially mobile housing capital. The former allows us to additionally capture the distributional effect of the LVT, while the latter allows us to capture the short-term effects.

The Model with Three Income Groups

The Model Description

This extension involves three income groups - a high-income group, a middle-income group and a low-income group - with the other features being the same as in the basic model. The resources that provide income to the households consist of time for work and leisure, land, and capital. The different income groups are associated with different wage rates, land holdings, and capital holdings. More specifically, it is assumed that the high-income group has one and half times of the endowment for the middle-income group, the low-income group has half of the endowment for the middle-income group. The labor markets for each income group are distinguished so that the wage rate for each income group is separately determined. In this dissertation, it is assumed that the labor type 1 is from the high-income group; the labor type 2 is from the middle-income group; the labor type 3 is from the low-income group. Regarding the size for each income group, the high-income group occupies 21 % of all households; the middle-income group occupies 34 %; and the low-income group occupies 45 % of all households. This percentage share was determined at the level that best helps to make the benchmark (Table 29) close to the economic, demographic and physical data of the Atlanta urban economy. The determined percentage share for the size of each income group is consistent with the fact that there are fewer wealth people than poor people. The tax revenues are distributed to each income group according to the percentage share of the endowment of each income group, but are equally distributed to each household within each income group.[76]

Table 28 is the numerical representation of the model with the three income groups, and expressed in the form of a SAM. The data used for building the SAM is from the same sources as in the basic model. The SAM is used to calibrate parameters to produce Table 29, which is the benchmark result for the model with the three income groups. In Table 28, the top row lists 'quantity' terms, the first column lists 'price' terms, and the numbers are monetary values, which are the 'quantity' term multiplied by 'price' term. In the SAM, 'HOUS1' represents a high-income household, 'HOUS2' represents a middle-income household, and 'HOUS3' represents a low-income household. The 'UI', 'U2', 'U3' represent the utilities of each income group. The definitions of the other terms are included within the table.

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[76] The reason why the tax revenue has to be distributed in this way is to make the expenditure side of government neutral so that the effects of tax policy only are captured. If we distribute the tax revenue to each household equally ignoring income groups, it means that the expenditure of the tax revenue is performed on a pro-poor people basis, which does not make the expenditure side neutral.

This three-income group model can experiment in solving the model with the existence of LLZ more meaningfully in the sense that LLZ in some suburban rings is promulgated by preference of the higher income group that may have a greater political power. The extended model is also solved under the condition of endogenous CBD and urban boundaries and equal tax revenue setting.

Table 28. The benchmark SAM with three income groups (per year)

Markets	H(r) (Housing)	NH (Non-Housing)	U1(r) (Utility)	U2(r)	U3	WL1(r) (Labor supply)	WL2(r)	WL3(r)	HOUS1(r)	HOUS2(r)	HOUS3(r)
PH(r) (Housing price)	56,232		-28,116	-18,744	-9,372						
PN (Price of non-housing)		96,639	-48,320	-32,213	-16107						
PU1(r) (Utility price)			105,393						109,593		
PU2(r)				70,262						-70,262	
PU3(r)					35,131						-35,131
PL(r) (Residential land price)	-11,301								5,651	3,767	1,884
PLN (Non-residential land price)		-5,820							2,910	1,940	970
PK (Capital price)	-34,452	-23,274							28,863	19,242	9,621
W1S (Wage for labor)		-30,441				30,441					
W1 (Wage for leisure)			-28,958			-43,039.5			71,997		
W2S		-20,294					20,294				
W2				-19,305			-28,693			47,998	
W3S		-10,147						10,147			
W3					-9,653			-14,347			23999
TAX(r)	-10,479	-6,663							8,571	5,714	2,857
Tracos(r) (Commuting cost)						12,599	8,399	4,200	-12,599	-8,399	-4,200

The Result

Table 29 shows the newly constructed benchmark result for the three-income group model. As in the benchmark for the basic model, the 5th ring represents the land rent and housing service price from the primary benchmark data in Chapter 3, and the rings nearer the CBD show the higher land rents and housing service prices. The population is denser in the rings nearer the CBD compared to the other rings. In addition, the rich (the high income group) live in suburbs (6th to10th rings); the poor (the low income group) live in rings near the CBD (1st and 2nd rings), and the middle live between them (3rd to 5th rings). Regardless of the reasons, what the benchmark result suggests regarding the pattern of residence by income is broadly consistent with the fact that the poor live in the central cities while the rich live in suburbs, even though there is also some suburban poverty.[77] Table 30 to Table 32 belong to the group of results with the absence of LLZ for the pure LVT reform, while Table 33 to Table 35 belong to the group of results with the presence of LLZ. With the sense that the hidden purpose of LLZ is to exclude lower income people, it is assumed that the government imposes a binding LLZ on the 2nd, 3rd and 6th rings - the rings having two of the three income groups mixed - while the others are the rings having the income groups segregated.[78] For the benchmark result (Table 29), the middle and the poor in the 2nd ring are mixed, and the rich and the middle in the 6th ring are mixed.

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[77] Refer to Glaeser, Edward L., Matthew E. Kahn, and Jordan Rappaport. " Why Do the Poor Live in Cities?" Harvard University, 2000, Working Paper.

[78] In the benchmark result, the 3rd ring was not the area where the poor and the middle live together. But in the first counterfactual case, the 3rd ring became the area where the poor and the middle live together

The general finding for each tax reform policy is that as the tax on land rent under the revenue preserving condition increases, the level of each price decreases,[79] the densities of housing capital (K to L ratio) and population become higher, the CBD and urban area contract, and the lower income households enjoy the larger benefit. The details and reasons for the finding are provided as follows. First compare Table 29 (the benchmark) with Table 30 (the first counterfactual case). Recall that the benchmark is the case with the tax rate of 22.9 % on both land and capital, while the first counterfactual case is the case with the tax on land rent only. Switching from the benchmark (capital property tax) to the first counterfactual case (tax on land rent only) depresses, for the 1st ring, the land rent exclusive of the tax and housing service price from $10,001 and $17,766 in Table 29 to $4,537 and $16,414 in Table 30 respectively. The same pattern holds for the other rings as well. The wage rates also decrease from $16.50 (Table 29) to $14.04 (Table 30) for the rich; from $11.00 (Table 29) to $10.14 (Table 30) for the middle; and from $5.50 (Table 29) to $5.27 (Table 30) for the poor. The decrease of land rent and wage rate is partly due to the elimination of 'inflation effect'[80] of removing the tax on capital (22.9%). The land tax itself also has the effect of decreasing land rent (and other prices) by making landowners bear the tax burden. Consistently, the price of the non-housing good due to the tax reform also decreases from $100 (Table 29) to $88.42 (Table 30).

Further look at the change of wage rates relative to capital cost for each income group. This analysis partly shows the incidence of the LVT reform. Regarding the more

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[79] However, the price level relative to capital cost increases, as the discussion is followed.

[80] In Chapter 4, I mentioned that since the rental price of capital is fixed as numeraire, the tax on it increases the user cost of it by the tax amount, raising all other price levels.

comprehensive incidence analysis among the three income groups, it is discussed in Chapter 6 (Welfare analyses). Assuming that the rental price of capital is $1, the user cost of capital before the tax reform is $1.229 and that after the tax reform is $1. Then the wage rate relative to capital cost for the rich increased by 4.5% (from $16.50 ÷ 1.229 = $13.43 in Table 29 to $14.04 ÷ 1 = $14.04 in Table 30); that for the middle increased by 13.3% (from $11.00 ÷ 1.229 = $8.95 in Table 29 to $10.14 ÷ 1 = $10.14 in Table 30); and that for the poor increased by 17.8% (from $5.50 ÷ 1.229 = $4.475 in Table 29 to $5.27 ÷ 1 = $5.27 in Table 30). The efficiency effect, due to the switching from the capital property tax to the LVT, dominated, the demand for each labor as a result increased, and finally the wage rates relative to capital cost of each income group increased. In addition and notably, the LVT reform increased the wage rate relative to capital cost for the lower income laborer. Although the urban land area is endogenously determined, the required tax on land to meet the required tax revenue makes the landowners bear almost all of tax burden, also eliminating the excess burden of the tax on capital.

Now examine the per capita income relative to capital cost by each income group. In the benchmark (Table 29), per capita incomes for each income group are $93,524.71 for the rich, $50,685.18 for the middle, and $23,175.93 for the poor. Assuming that the rental price of capital is $1, the per capita incomes relative to capital cost for each income group in Table 29 are $93,524.71 ÷ 1.229 = $76,098.22 for the rich, $50,685.18 ÷ 1.229 = $41,240.99 for the middle, and $23,175.93 ÷ 1.229 = $18,857.55 for the poor. On the other hand, after the tax reform, the per capita incomes relative to capital cost in Table 30 are $82,578.20 ÷ 1= $82,578.20 for the rich, $47,097.29 ÷ 1 = $47,097.29 for the middle, and $22,071.56 ÷ 1 = $$22,071.56 for the poor, respectively. Who gained most because of the tax reform is determined by dividing each income relative to capital cost after the tax reform by that before the tax reform: $88,578.20 ÷ $76,098.22 = 1.09 for the rich, $47,097.29 ÷ $41,240.99 = 1.14 for the middle, and $22,071.56 ÷ $18,857.55 = 1.17 for the poor, respectively. Again the LVT reform favored the poor and the middle more than did the rich.

The LVT reform contracted the area of CBD and the radius of urban area from 327.69 square miles and 30.95 miles in Table 29 to 250.08 square miles and 25.00 miles in Table 30 respectively. On the other hand, the distribution percent of households in the rings near the CBD goes down after the tax reform, it is because the contraction of the CBD and urban area reduces the residential area for each ring (due to the decrease of ring width) and makes the households in some rings near the CBD spread over the more rings.[81] Consistent with this contraction of the CBD and urban area, the LVT reform contributed to the denser housing structures (or higher K (Capital) to L (Land) ratio) and the denser population for all income groups. In addition, the LVT reform allowed all income groups to be relocated to the more central rings. Particularly, some low-income households lived in the 3rd ring before the tax reform, but they moved to the 1st and 2nd rings after the tax reform. The land tax reduced land rents, made the edge land near the

[81] Note that the poor did not live in the ring 3 before the LVT reform (Table 30), but live after the reform (Table 31).

urban boundary shift to agricultural uses, reduced the price of housing service accordingly,[82] and provided an incentive to move to the rings closer to the CBD.

Consider the effects of the graded property taxes in which the tax on capital increases by 11% points in Table 31 and 20% points in Table 32 under the equal tax revenue setting, while the required tax rates on land rent to meet the required tax revenue are 94% and 35% respectively. The land rent of the 1st ring increased from $4,537.29 (Table 30) to $6,876.84 for the 11% tax on capital (Table 31) and $9,213.94 for the 20% tax on capital (Table 32). The same pattern holds true for the other rings as well. The increase of the tax on capital depresses land rents for some rings near the CBD,[83] but the simultaneous decrease of the tax on land to meet the equal tax revenue ended up with increasing the land rents for all the rings. Because the land is a production factor for housing (and non-housing good), the increase of the land rent means an increase of production cost, which is the cause for the increased housing service price. For the 1st ring, the price of housing service increases from $16,414.89 (Table 30) to $16,762.72 (Table 31) for the 11% tax on capital and $17,498.52 (Table 32) for the 20% tax on capital. The same pattern holds true for the other rings as well. The price of the non-housing good also increases with the same reason.

As the tax on capital increases under the equal tax revenue condition, the area of CBD and the radius of urban area expand from 250.08 square miles and 25.0 miles

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[82] Since housing capital density (K to L ratio) is denser in the rings nearer the CBD, the tax reform to eliminate the tax on capital reduces the prices of housing service in the rings nearer the CBD more than in other rings.

[83] Any distortionary tax can depress an economy. As mentioned in Chapter 4, Brueckner (2003) finds that the imposition of property tax may reduce land rents on some locations near the CBD but increase land rents on the other locations. Also mentioned in Chapter 4 that Brueckner noted that the simple statement about why this result is not available.

(Table 30) to 298.72 square miles and 28.47 miles (Table 31) for the 11% tax on capital, and to 322.07 square miles and 30.44 miles (Table 32) for the 20% tax on capital in respectively. This is because the increased land rents outbid the extant land rents near the CBD and urban boundaries. Consistent with this result, the population and housing capital have become sparser than before, as can be seen from the tables.

Regarding the change of wage rate, we can further explain with the following effects: (in) efficiency effect, replacement effect, inflation effect, and income effect. The inefficiency effect suggests that as the tax on capital increases, the production cost increases, the production as a result decreases, the demand for factors decreases, and finally the wage rate also decreases accordingly. The replacement effect suggests that as the tax on capital increases, the user cost of capital relative to other costs increases, firms try to replace capital with labor (and land), and the wage rate increases accordingly. The inflation effect suggests that as the tax on capital increases, the user cost of capital increases by the size of tax rate since the rental price of capital is a numeraire and fixed, and the other prices in the economy are adjusted upwardly. In this economy, the nominal wage rates increased, due to the inflation effect and replacement effect, from \$14.04 for the rich, \$10.14 for the middle, and \$5.27 for the poor in Table 30 to \$15.05 for the rich, \$10.51 for the middle, and \$5.37 for the poor in Table 31, and \$14.98 for the rich, \$10.54 for the middle, and \$5.42 for the poor in Table 32. However, due to the inefficiency effect from the tax on capital, the wage rates relative to capital cost decreased from \$14.04 ÷ 1 = \$14.04 for the rich, \$10.14 ÷ 1 = \$10.14 for the middle and \$5.27 ÷ 1 = \$5.27 for the poor in Table 30 to \$15.05 ÷ 1.1 = \$13.68 for the rich, \$10.51 ÷ 1.11 = \$9.47 for the middle, and \$5.37 ÷ 1.11 = \$4.84 for the poor in Table 31, and \$14.98 ÷ 1.2

= \$12.48 for the rich, \$10.54 ÷ 1.2 = \$8.78 for the middle, and \$5.42 ÷ 1.2 = \$4.52 for the poor in Table 32. The incomes of each household also changed due to the change of the wage rates and land rents, but this positive income effect was not great enough to fully offset the other effects.

Regarding the per capita income relative to capital cost for each income group, as the tax on capital increases, the income relative to capital cost for the rich decreases by 5.5% from \$82,578.20 ÷ 1 = \$82,578.20 (Table 30) to \$86,600.20 ÷ 1.11 = \$78.018.20 (Table 31) for the 11% tax on capital, and decreases by 12.07% to \$91,687.00 ÷ 1.2 = \$76,405.83 (Table 32) for the 20% tax on capital; the income relative to capital cost for the middle decreases by 7.4% from \$47,097.29 ÷ 1 = \$47,097.29 to \$48,408.63 ÷ 1.11 = \$43,611.38 for the 11% tax on capital, and decreased by 4.3% to \$50,078.18 ÷ 1.2 = \$41,731.82 for the 20% tax on capital; and the income relative to capital cost for the poor decreases by 8.23% from \$22,071.56 ÷ 1 = \$22,071.56 to \$22,483.82 ÷ 1.11 = \$20,255.69 for the 11% tax on capital, and decreases by 5.4% to \$22,994.12 ÷ 1.2 = \$19,161.77 for the 20% tax on capital. Hence, we conclude that the increase of the tax on capital under the equal tax revenue condition hurts the poor and the middle more than does the rich. In other words, the decrease of the tax on capital favors the poor and the middle more than does the rich.

The existence of the LLZ does not change the qualitative effects of the LVT and graded property tax. However, the imposition of the LLZ produces some special results. Tables 34 to 36 are the results with the LLZ on 2nd, 3rd and 6th rings for the same tax polices. Regarding the change of income due to the imposition of the LLZ, per capita income for the rich increases by 3.59% from \$82,578.20 in Table 30 (no LLZ) to

$85,544.11 in Table 33 (LLZ); per capita income for the middle increases by 2.03% from $47,097.29 in Table 30 to $48,057.59 in Table 33; and per capita income for the poor increases by 2.63% from $22,071.56 in Table 30 to $22,651,45 in Table 33. Thus, the imposition of the LLZ increases the income of each household and favors the rich more than does the middle and the poor.

Due to the imposition of the LLZ, the land rents of the 1st and 3rd rings increase from $4,537.29 and $3,686.55 in Table 31 to $6,715.49 and $5,121.57 in Table 34, respectively. The emigrants from the rings with the LLZ make the rings without the LLZ have more population and push up the land rents for the residential rings, which outbids the extant CBD and agricultural land rents. Here, the 1st ring is one of the rings without the LLZ, and the 3rd ring is one of the rings with the LLZ. The same pattern holds true for the other rings and tax policies as well. Remember that there is one type of housing market in the economy and the land rent of the rings with the LLZ also increases due to the LLZ. Even though the LLZ excludes some people from the rings with the LLZ, the increased per capita demand for land due to the LLZ and the increase in income are directly related to the higher land rents than before.

Due to the increase of land rent in all locations, the residential area expands toward into both the CBD and agricultural area. For example, when the revenue preserving LVT is imposed, the area of the CBD decreases from 250.08 square miles (Table 30) to 247.18 square miles (Table 33), but the radius of urban area increases from 25 miles (Table 30) to 28.60 miles (Table 33). The same pattern holds true for the other tax policies as well.

The wage rates for each income group increase from $14.04 (Table 30) to $14.98

(Table 33) for the rich, from \$10.14 (Table 30) to \$10.54 (Table 33) for the middle, and from \$5.27 (Table 30) to \$5.42 (Table 33) for the poor. The increased land rent due to the LLZ makes firms replace some land with labor, which increases wage rates. The same holds true for the other tax policies as well.

The rich live in the suburbs; the poor live in the areas near the CBD; and the middle live in-between. This means that the income elasticity of housing consumption (or land consumption) is greater than the income elasticity of commuting costs. Although a binding LLZ is, according to the preference of the higher income group, imposed on 2nd, 3rd, and 6th rings where multiple income groups are mixed, the middle in the 3rd ring moved to the farther suburban rings after the imposition of the LLZ, instead of excluding the poor in the 3rd ring. This result implies that in the long-term, the imposition of LLZ would change an original situation comprised of some variables such as income of household, and the households would behave differently from the expectation with a myopic eye that the income of household would be constant.

Table 29. Benchmark of three-income group model with ‘tax on land = 22.9%, tax on capital = 22.9%

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate 1 ($/hour)	Wage rate 2 ($/hour)	Wage rate 3 ($/hour)	Value of total domestic consumption net of leisure (export value) (million $)	Total income: group1 (average income per household), million $ ($) net of transport cost	Total income: group 2 (average income per household), million $ ($) net of transport cost	Total income: group 3(average income per household), million $ ($) net of transport cost
327.69	30.95	5,486.43	371.19	100.00	16.50	11.00	5.50	35,268.52 (14,938.49)	27,188.91 (93,524.71)	23,835.82 (50,685.18)	14,465.94 (23,175.93)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	Dist. of Household 1(%)	Dist. of Household 2(%)	Dist. of Household 3(%)	Population density per acre	K/L ratio for Household 1	K/L ratio for Household 2	K/L ratio for Household 3
1	10,001.12	17,766.08	0.00	0.00	52.09	3.22	0.00	0.00	59.97
2	8,526.98	17,123.93	0.00	2.99	47.91	2.78	0.00	17.87	53.63
3	7,192.20	16,481.78	0.00	31.40	0.00	1.19	0.00	15.86	0.00
4	6,008.98	15,853.01	0.00	30.88	0.00	1.07	0.00	13.99	0.00
5	4,970.00	15,251.00	0.00	29.94	0.00	0.95	0.00	12.24	0.00
6	4,060.59	14,662.36	20.40	4.79	0.00	0.51	10.63	10.63	0.00
7	3,229.40	14,046.97	22.88	0.00	0.00	0.39	9.06	0.00	0.00
8	2,522.89	13,444.96	21.02	0.00	0.00	0.33	7.62	0.00	0.00
9	1,931.28	12,869.70	18.96	0.00	0.00	0.28	6.32	0.00	0.00
10	1,442.35	12,307.82	16.75	0.00	0.00	0.24	5.15	0.00	0.00

Table 30. Results of three-income group model with 'tax on land = 266%, tax on capital = 0%' under the equal tax revenue

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate 1 ($/hour)	Wage rate 2 ($/hour)	Wage rate 3 ($/hour)	Value of total domestic consumption net of leisure (export value) (million $)	Total income: group1 (average income per household), million $ ($) net of transport cost	Total income: group 2 (average income per household), million $ ($) net of transport cost	Total income: group 3(average income per household), million $ ($) net of transport cost
250.08	25.00	5,486.53	371.72	88.42	14.04	10.14	5.27	32,322.23 (14,104.45)	24,006.61 (82,578.20)	22,148.54 (47,097.29)	13,776.61 (22,071.56)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	Dist. of Household 1(%)	Dist. of Household 2(%)	Dist. of Household 3(%)	Population density per acre	K/L ratio for Household 1	K/L ratio for Household 2	K/L ratio for Household 3
1	4,537.29	16,414.89	0.00	0.00	42.43	4.01	0.00	0.00	85.49
2	4,097.26	15,986.79	0.00	0.00	44.05	3.79	0.00	0.00	79.61
3	3,686.55	15,558.70	0.00	19.36	13.53	2.21	0.00	24.63	73.92
4	3,295.41	15,130.60	0.00	28.05	0.00	1.54	0.00	22.76	0.00
5	2,931.15	14,702.50	0.00	28.25	0.00	1.44	0.00	20.98	0.00
6	2,598.68	14,287.78	3.52	24.34	0.00	1.26	19.29	19.28	0.00
7	2,263.76	13,846.30	25.18	0.00	0.00	0.69	17.51	0.00	0.00
8	1,963.06	13,404.83	24.59	0.00	0.00	0.64	15.84	0.00	0.00
9	1,689.26	12,976.73	23.82	0.00	0.00	0.58	14.26	0.00	0.00
10	1,442.35	12,562.01	22.90	0.00	0.00	0.53	12.77	0.00	0.00

Table 31. Results of three-income group model with 'tax on land = 94%, tax on capital = 11%' under the equal tax revenue

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate 1 ($/hour)	Wage rate 2 ($/hour)	Wage rate 3 ($/hour)	Value of total domestic consumption net of leisure (export value) (million $)	Total income: group1 (average income per household), million $ ($) net of transport cost	Total income: group 2 (average income per household), million $ ($) net of transport cost	Total income: group 3(average income per household), million $ ($) net of transport cost
298.72	28.47	5,486.43	369.70	93.24	15.05	10.51	5.37	33,347.31 (14,328.47)	25,175.86 (86,600.20)	22,765.23 (48,408.63)	14,033.93 (22,483.82)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	Dist. of Household 1(%)	Dist. of Household 2(%)	Dist. of Household 3(%)	Population density per acre	K/L ratio for Household 1	K/L ratio for Household 2	K/L ratio for Household 3
1	6,876.84	16,762.72	0.00	0.00	47.17	3.44	0.00	0.00	68.07
2	6,018.76	16,227.60	0.00	0.00	48.39	3.18	0.00	0.00	62.03
3	5,236.47	15,705.85	0.00	26.88	4.44	1.48	0.00	18.74	56.28
4	4,512.85	15,184.11	0.00	29.51	0.00	1.22	0.00	16.89	0.00
5	3,862.57	14,675.74	0.00	29.11	0.00	1.12	0.00	15.14	0.00
6	3,278.29	14,167.38	12.31	14.50	0.00	0.79	13.51	13.51	0.00
7	2,720.91	13,645.63	24.07	0.00	0.00	0.50	11.85	0.00	0.00
8	2,231.98	13,137.26	22.76	0.00	0.00	0.44	10.32	0.00	0.00
9	1,809.05	12,628.90	21.26	0.00	0.00	0.39	8.90	0.00	0.00
10	1,442.35	12,147.29	19.59	0.00	0.00	0.34	7.60	0.00	0.00

Table 32. Results of three-income group model with ‘tax on land = 35%, tax on capital = 20%’ under the equal tax revenue

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate 1 ($/hour)	Wage rate 2 ($/hour)	Wage rate 3 ($/hour)	Value of total domestic consumption net of leisure (export value) (million $)	Total income: group1 (average income per household), million $ ($) net of transport cost	Total income: group 2 (average income per household), million $ ($) net of transport cost	Total income: group 3(average income per household), million $ ($) net of transport cost
322.07	30.44	5,486.50	370.72	98.19	16.12	10.87	5.46	34,728.14 (14,771.70)	26,654.66 (91,687.00)	23,549.90 (50,077.18)	14,352.45 (22,994.12)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	Dist. of Household 1(%)	Dist. of Household 2(%)	Dist. of Household 3(%)	Population density per acre	K/L ratio for Household 1	K/L ratio for Household 2	K/L ratio for Household 3
1	9,213.94	17,498.52	0.00	0.00	50.96	3.25	0.00	0.00	61.45
2	7,901.15	16,869.75	0.00	1.71	49.04	2.88	0.00	18.39	55.18
3	6,703.27	16,254.36	0.00	30.98	0.00	1.21	0.00	16.39	0.00
4	5,639.84	15,665.72	0.00	30.57	0.00	1.10	0.00	14.52	0.00
5	4,698.64	15,077.09	0.00	29.75	0.00	0.98	0.00	12.78	0.00
6	3,872.35	14,501.83	18.62	7.00	0.00	0.57	11.16	11.16	0.00
7	3,107.17	13,913.19	23.16	0.00	0.00	0.41	9.57	0.00	0.00
8	2,454.44	13,337.94	21.41	0.00	0.00	0.35	8.11	0.00	0.00
9	1,901.95	12,776.06	19.46	0.00	0.00	0.30	6.79	0.00	0.00
10	1,442.35	12,227.56	17.36	0.00	0.00	0.26	5.59	0.00	0.00

Table 33. Results of three-income group model with 'tax on land = 159%, tax on capital = 0%' under the equal tax revenue and LLZ on 2nd, 3rd, and 6th rings.

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate 1 ($/hour)	Wage rate 2 ($/hour)	Wage rate 3 ($/hour)	Value of total domestic consumption net of leisure (export value) (million $)	Total income: group1 (average income per household), million $ ($) net of transport cost	Total income: group 2 (average income per household), million $ ($) net of transport cost	Total income: group 3(average income per household), million $ ($) net of transport cost
247.18	28.60	5,486.43	385.88	92.28	14.98	10.54	5.42	30,932.82 (16,213.05)	24,868.84 (85,544.11)	22,600.14 (48,057.59)	14,138.57 (22,651.45)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	Dist. of Household 1(%)	Dist. of Household 2(%)	Dist. of Household 3(%)	Population density per acre	K/L ratio for Household 1	K/L ratio for Household 2	K/L ratio for Household 3
1	6,715.49	16,628.94	0.00	0.00	56.26	4.10	0.00	0.00	88.45
2	5,881.86	16,053.68	0.00	0.00	15.88	1.03	0.00	0.00	21.75
3	5,121.57	15,491.81	0.00	0.00	17.68	1.03	0.00	0.00	21.36
4	4,432.17	14,956.68	0.00	31.04	10.17	1.77	0.00	22.03	66.13
5	3,794.12	14,408.18	0.00	37.15	0.00	1.35	0.00	19.76	0.00
6	3,222.07	13,873.06	0.00	12.61	0.00	0.42	0.00	6.07	0.00
7	2,713.58	13,351.31	14.68	19.20	0.00	0.88	15.63	15.62	0.00
8	2,227.09	12,802.81	30.31	0.00	0.00	0.54	13.61	0.00	0.00
9	1,806.61	12,267.69	28.53	0.00	0.00	0.48	11.75	0.00	0.00
10	1,442.35	11,745.95	26.49	0.00	0.00	0.07	10.04	0.00	0.00

Table 34. Results of three-income group model with 'tax on land = 62%, tax on capital = 11%' under the equal tax revenue and LLZ on 2nd, 3rd, and 6th rings.

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate 1 ($/hour)	Wage rate 2 ($/hour)	Wage rate 3 ($/hour)	Value of total domestic consumption net of leisure (export value) (million $)	Total income: group1 (average income per household), million $ ($) net of transport cost	Total income: group 2 (average income per household), million $ ($) net of transport cost	Total income: group 3(average income per household), million $ ($) net of transport cost
273.62	31.17	5,486.43	385.79	98.67	16.36	11.00	5.56	32,819.35 (16,620.84)	26,716.05 (91,898.18)	23,590.56 (50,163.64)	14,578.29 (23,355.94)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	Dist. of Household 1(%)	Dist. of Household 2(%)	Dist. of Household 3(%)	Population density per acre	K/L ratio for Household 1	K/L ratio for Household 2	K/L ratio for Household 3
1	9,768.87	17,525.27	0.00	0.00	61.53	3.80	0.00	0.00	76.91
2	8,336.30	16,829.61	0.00	0.00	18.87	1.03	0.00	0.00	20.36
3	7,055.30	16,160.71	0.00	2.00	19.60	1.03	0.00	14.77	19.94
4	5,898.97	15,505.18	0.00	38.60	0.00	1.28	0.00	18.00	0.00
5	4,881.99	14,863.04	0.00	37.86	0.00	1.14	0.00	15.77	0.00
6	3,992.13	14,234.27	0.00	15.22	0.00	0.42	0.00	5.70	0.00
7	3,219.62	13,618.88	24.52	6.32	0.00	0.55	11.78	11.78	0.00
8	2,518.00	12,990.11	27.76	0.00	0.00	0.41	9.92	0.00	0.00
9	1,928.84	12,388.09	25.24	0.00	0.00	0.35	8.23	0.00	0.00
10	1,442.35	11,786.08	22.48	0.00	0.00	0.05	6.72	0.00	0.00

Table 35. Results of three-income group model with 'tax on land = 24%, tax on capital = 20%' under the equal tax revenue and LLZ on 2nd, 3rd, and 6th rings.

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate 1 ($/hour)	Wage rate 2 ($/hour)	Wage rate 3 ($/hour)	Value of total domestic consumption net of leisure (export value) (million $)	Total income: group1 (average income per household), million $ ($) net of transport cost	Total income: group 2 (average income per household), million $ ($) net of transport cost	Total income: group 3(average income per household), million $ ($) net of transport cost
289.18	32.40	5,486.46	386.09	104.22	17.56	11.40	5.65	34,778.80 (16,917.60)	28,462.47 (97,905.52)	24,504.02 (52,106.05)	14,938.02 (23,932.26)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	Dist. of Household 1(%)	Dist. of Household 2(%)	Dist. of Household 3(%)	Population density per acre	K/L ratio for Household 1	K/L ratio for Household 2	K/L ratio for Household 3
1	12,284.43	18,408.22	0.00	0.00	64.10	3.67	0.00	0.00	71.04
2	10,333.59	17,632.30	0.00	0.00	20.38	1.03	0.00	0.00	19.43
3	8,607.66	16,896.50	0.00	9.72	15.52	1.03	0.00	14.24	19.01
4	7,074.85	16,160.71	0.00	38.79	0.00	1.18	0.00	16.08	0.00
5	5,744.96	15,451.67	0.00	37.63	0.00	1.05	0.00	13.90	0.00
6	4,595.97	14,769.39	4.30	13.86	0.00	0.42	10.55	5.48	0.00
7	3,571.65	14,060.35	27.98	0.00	0.00	0.41	9.97	0.00	0.00
8	2,713.58	13,378.07	25.46	0.00	0.00	0.35	8.22	0.00	0.00
9	2,009.51	12,722.54	22.64	0.00	0.00	0.29	6.67	0.00	0.00
10	1,442.35	12,080.40	19.62	0.00	0.00	0.23	5.28	0.00	0.00

Immobile Housing Capital and Partially Mobile Housing Capital Adjustment

This section considers the model with immobile housing capital and only partially mobile housing capital. This extension assumes that in the short-term, the amount of housing capital, the boundary of CBD, and the boundary of urban area do not change. To reflect the features and get the results for the model with the features, the following procedure is followed. Note that the non-housing good capital is still perfectly elastically supplied to the economy.

1. Solve the basic model with the fixed boundaries of CBD and urban area for the benchmark property tax (22.9 % on both land rent and the rental price of capital).

2. Find the quantity of the housing capital for each ring, referring to it as K1(r).

3. Revise the model to fix the housing capital stock available in each ring at K1(r) and allow the rental price of housing capital in each ring to vary until the demand for the housing capital is equal to K1(r) in each ring. This version considers and assumes no adjustment and no mobility for housing capital.

4. Solve the revised model for 0% tax on capital under the equal tax revenue.

5. Solve again the original model for 0% tax on capital under the equal tax revenue, and find the quantities for the housing capital in each ring, referring to it as K2(r).

6. Redo the steps 3 and 4, but set $K(r) = K1(r) + 0.5 \times (K2(r) - K1(r))$ for each ring. This is the case with partially mobile housing capital.

7. Repeat the step 4 through step 6 but with LLZ, and compare results.

In this version, the housing capital is immobile or only partially mobile, and so the rental price of housing capital is not fixed and not the same across all the rings, but varies with the distance from CBD.

See Tables 36 to 39 that include the results for the model with immobile and only partially mobile housing capital under the fixed CBD and urban boundaries, and then compare them with Tables 16 to 18 that include the benchmark and the results for the basic model having perfectly mobile housing capital under the fixed CBD and urban boundaries. In the LVT reform, in which the land is more heavily taxed than before and the tax on capital is eliminated under the equal tax revenue setting, the land rent of the 1st ring decreases from $8,807.75 for the benchmark (Table 15) to $2,226.96 for the model with immobile housing capital (Table 36) to $2,020.53 for the model with partially mobile housing capital (Table 37) to $1,835.99 for the model with perfectly mobile housing capital (Table 16). Thus, the more mobile the housing capital is, the lower the land rent is. The same pattern holds true for the other rings as well. It is because the more mobile housing capital allows firms to use more capital when the rental price of capital decreases due to the tax reform. It has already been established that the decrease of land rent decreases the price of housing service.

Consistent with the result, the housing capital density becomes lower, as the housing capital becomes less mobile. For example, the housing capital density of the 1st ring for the model with perfectly mobile housing capital is 20.52 (Table 16); that for the model with partially mobile housing capital is 20.08 (Table 37); and that for the model with immobile housing capital is 19.64 (Table 36). The same pattern holds true for the other rings as well. Since the land area for each ring is fixed, the sparser housing capital means the less housing service. We conclude that the longer time span (the more mobile housing capital) allows households to enjoy more housing services at a lower housing service price.

The wage rate increases from $9.72 for the model with perfectly mobile housing capital (Table 16) to $9.74 for the model with partially mobile housing capital (Table 37) and to $9.78 for the model with immobile housing capital (Table 36). This result holds because the relatively higher land rent makes firms to replace some land with labor, which makes the wage rate higher. Consistent with the higher land rent and wage rate for the model with the less mobile housing capital, total income of household increases from $56,416.68 million for the model with perfectly mobile housing capital (Table 16) to $57,142.41 million for the model with partially mobile housing capital (Table 37) and to $57,959.53 million for the model with immobile housing capital (Table 36).

Note that the higher income in the model with the less mobile housing capital does not imply the higher production (or higher efficiency) in the model. Instead, the per capita production for the non-housing good is 201.98 for the model with perfectly mobile housing capital, 200.92 for the model with partially mobile housing capital, and 199.84 for the model with immobile housing capital. Thus, the production decreases as the housing capital becomes less mobile. The reason is that the higher user cost of factors for the model with the less mobile housing capital causes production to shrink, which is great enough to offset the positive effect of the increased income.

The same model was solved for the presence of LLZ as well, but could not find a qualitatively different result (Compare Table 17, Table 38 and Table 49).

Table 36. Results of immobile housing capital model with 'tax on land = 343%, tax on capital = 0%'

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income (average income per household), million $ ($) net of transport cost
321.31	30.57	4,510.75	194.82	87.03	9.78	42,867.46	970.73	57,959.53 (41,843.05)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	2,226.96	15,644.21	19.64	1.42
2	1,948.59	15,208.87	17.88	1.31
3	1,698.37	14,787.57	16.23	1.20
4	1,470.04	14,366.27	14.68	1.10
5	1,263.61	13,973.06	13.19	1.01
6	1,079.07	13,565.81	11.80	0.92
7	913.30	13,172.59	10.50	0.83
8	766.30	12,793.43	9.28	0.74
9	638.06	12,414.26	8.17	0.66
10	522.33	12,049.13	7.08	0.59

Table 37. Results of partially mobile housing capital model with 'tax on land = 375%, tax on capital = 0%'

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income (average income per household), million $ ($) net of transport cost
323.31	30.57	4,510.75	195.82	86.75	9.74	43,163.36	984.79	57,142.41 (41,253.14)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	2,020.53	14,843.74	20.08	1.42
2	1,767.18	14,436.49	18.27	1.31
3	1,538.85	14,029.23	16.59	1.21
4	1,329.30	13,621.98	14.97	1.11
5	1,141.63	13,228.77	13.44	1.01
6	972.73	12,835.56	12.02	0.92
7	822.60	12,456.39	10.69	0.83
8	688.11	12,091.26	9.42	0.74
9	572.38	11,726.14	8.29	0.66
10	469.16	11,375.06	7.22	0.58

Table 38. Results of immobile housing capital model with ‘tax on land = 220%, tax on capital = 0%’ under the existence of LLZ on 6th and 7th rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income (average income per household), million $ ($) net of transport cost
323.31	30.57	4,510.75	194.40	88.70	10.04	45,932.17	1,482.82	60,215.37 (43,471.62)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	3,562.51	16,880.02	20.89	1.51
2	3,134.01	16,430.64	19.08	1.40
3	2,739.91	15,981.25	17.34	1.29
4	2,383.35	15,545.91	15.72	1.19
5	2,061.19	15,110.57	14.20	1.09
6	1,770.31	14,703.31	7.68	0.60
7	1,510.70	14,282.01	7.57	0.60
8	1,276.12	13,888.80	10.13	0.81
9	1,069.69	13,481.55	8.94	0.73
10	885.15	13,102.38	7.82	0.65

Table 39. Results of partially mobile housing capital model with 'tax on land = 245%, tax on capital = 0%' under the existence of LLZ on 6th and 7th rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Export (million $)	Total income (average income per household), million $ ($) net of transport cost
323.31	30.57	4,510.75	195.88	88.28	9.96	44,785.41	1,478.17	58,839.16 (42,478.09)

Ring	Residential land rent per acre of land	Housing service prices per unit, per year	K/L ratio capital amount per acre of land	Population density per acre of land
1	3,162.16	15,602.08	21.53	1.51
2	2,777.44	15,166.74	19.67	1.40
3	2,427.14	14,745.44	17.88	1.29
4	2,111.23	14,324.14	16.23	1.19
5	1,820.35	13,916.89	14.61	1.09
6	1,563.88	13,523.68	7.91	0.60
7	1,329.30	13,130.47	7.79	0.60
8	1,122.86	12,751.30	10.41	0.81
9	938.33	12,372.13	9.17	0.72
10	775.68	11,992.96	8.03	0.64

CHAPTER SIX

WELFARE AND SENSITIVITY ANALYSES

This chapter includes the welfare results calculated in the form of a money-metric measure of utility for the various tax policies in the basic model and the two extensions, and includes the sensitivity analyses for examining the robustness for the results in the Chapter 4.

Welfare Analyses

Basic Methodology

The arithmetic sum of each (identical) individual's money-metric utility is used in calculating total welfare of the economy. The money-metric utility, $\mu(q; p, m)$ measures how much income the consumer would need at prices q to be as well off as he or she would be facing prices p and having income m.[84] The utility measure is used to calculate either EV (Equivalent Variation) or CV (Compensation Variation) to see the change in welfare. The former (EV) is the change in expenditure for the household to reach from an old utility level to a new utility level (or welfare) at old prices, while the latter (CV) is the change in expenditure for the household to keep the old utility level at new prices. Since the benchmark result (and the benchmark price) can be compared to the results for

[84] I followed the following textbook for the definitions of the money-metric utility function and EV in the equations (6.1) and (6.2). Hal R. Varian, *Microeconomic Analysis*. 3rd Ed.: W. W. Norton & Company, 1993.

various policy options, it is more appropriate to calculate and use EV. Hence, EV is adopted for the current welfare analyses.

The algebraic definition of EV is as follows.

$$EV = \mu(p^0; p^{'}, m^{'}) - \mu(p^0; p^0, m^0) = \mu(p^0; p^{'}, m^{'}) - m^0 \quad (6.1)$$

where

p^0 Old prices

$p^{'}$ New prices

m^0 Old income

$m^{'}$ New income

Then, the EV is expressed using the algebra in the current model. Taking $PU(r)^o$ as the benchmark utility price level and $PU(r)^n$ as the current utility price level,

$$EV = U(r)^n \cdot PU(r)^o - U(r)^O \cdot PU(r)^o \quad (6.2)$$

In Chapter 3, $U(r) \cdot PU(r)$ is defined as $M(r)$ (income) to achieve the utility ($U(r)$) in ring r. Hence, $U(r)^n \cdot PU(r)^o$ is the expenditure necessary to achieve the new utility level at the benchmark price level, while $U(r)^o \cdot PU(r)^o$ is the benchmark expenditure.[85]

Welfare Analysis for the Basic Model

This section discusses the welfare effects of LVT and graded property taxes. Table 40 is the money-metric welfare results for the basic model. In Table 40, when the

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[85] So, the numbers in the Tables 41 to 44 are generated, through the application of the definitions.

government switched from the capital property tax to the LVT, the money-metric welfare increased by 1.7% (from $64,753 million to $65,857 million) for the fixed boundary case, and increased by 2.14% (from $64,753 million to $66,139 million) for the endogenous boundary case. The increase in the money-metric welfare is expected, since switching from the avoidable tax base (capital) to the unavoidable or hard-to-avoid tax base (land) increases the efficiency of the economy. The increase in the money-metric welfare was larger for the case with the endogenous boundary than for the case with the fixed boundary. In understanding the result for the case with the endogenous boundary, there are two countervailing factors to be considered. Recall that for the case with the endogenous boundary, the land tax is not purely neutral. As a countervailing effect against the non-neutrality, the LVT contracts the urban size and allows households to save commuting costs due to the contraction. In this case, it turns out that the saved amount of commuting costs is greater than the burden of the tax. Hence, the endogenous boundary case generates a larger money-metric welfare improvement than the fixed boundary case did. The percents (1.7% and 2.14%) appear to be small. However, the monetary values of the changes for the money-metric welfare ($1,104 million and $1,386 million) are not negligible but record 17.7% and 22.2% of the tax revenue respectively in the economy.

As the tax on capital under the equal tax revenue setting increases, the welfare improvement from the benchmark weakens. When the tax on capital is 10% and the tax on land is 80%, the money-metric welfare is improved by 1.29% from the benchmark. When the tax on capital is 20% and the required tax on land is 32%, the money-metric welfare improvement from the benchmark is as low as 0.3%. This indirectly reconfirms that the heavier tax on land entails the greater efficiency.

The imposition of LLZ increases land rents and the income of household as a landowner, although the LLZ distorts the housing consumption of households. In the economy where the residents are landowners, there exist the two countervailing effects: the increase in income and the distortion in the choice of housing consumption. Table 41 shows that the positive income effect of the LLZ is greater than the distortive effect of the LLZ, so that the existence of the LLZ makes the welfare of households (as a landowner) further improved than the absence of the LLZ does. From the Table 40, for example, the money-metric welfare is improved by 3.43% from the benchmark under the existence of the LLZ on 6^{th} to 9^{th} rings for the LVT reform. In this case, the money-metric welfare change ($66,974.73 - $64,753.32 = $2,221.4 million) is 35.6% of the tax revenue in the economy. The same tendency holds true for the other tax policies as well.

Table 40. Welfare comparisons for the basic model

Policy Options			Land Tax Rate (%)	Capital Tax Rate (%)	Expenditure (evaluated at the benchmark price) ($ million)	EV ($ million)	% Change from Benchmark
Benchmark			22.9	22.9	64,753.32	-	-
LVT	No LLZ	Fixed Bou.	409	0	65,856.93	1,103.61	1.7
		Endo. Bound.	172	0	66,138.70	1,385.38	2.14
	LLZ on 6th and 7th rings	Fixed Bou.	271	0	66,016.56	1,263.24	1.95
		Endo. Bound.	140	0	66,518.60	1,765.28	2.73
	LLZ on 6th, 7th, 8th and 9th rings	Fixed Bou.	201	0	66,267.54	1,514.22	2.34
		Endo. Bound.	119	0	66,974.73	2,221.41	3.43
Graded Property Tax	No LLZ	Endogenous Boundaries	80	10	65,587.10	833.78	1.29
			32	20	64,945.12	191.80	0.3
	LLZ on 6th and 7th rings		69	10	65,849.34	1,096.02	1.69
			62	20	65,142.19	388.87	0.6
	LLZ on 6th, 7th, 8th and 9th rings		29	10	66,129.72	1,376.40	2.13
			27	20	65,294.51	541.19	0.84

Welfare Analysis for the Three-Income Group Model

This section discusses the welfare in the model with three income groups (Table 41). A notable result is that switching to the LVT and graded property taxes reduces the money-metric welfare of the rich, but improves those of the middle and the poor. This result suggests that although the LVT reform (or switching to graded property tax) can increase the money-metric welfare of landowners as well, the LVT reform may hurt the welfare of people with large-scale landholdings.

Numerically, the money-metric welfare of the rich decreases by 2.79% from the benchmark for the pure LVT reform, decreases by 1.44% for the 10% tax on capital, and decreases by 0.35% for the 20% tax on capital. On the other hand, the money-metric welfare of the middle increases by 1.21% from the benchmark for the pure LVT reform, increases by 0.91% for the 10% tax on capital, and increases by 0.25% for the 20% tax on capital. Furthermore, the money-metric welfare of the poor increases by 3.80% from the benchmark for the pure LVT reform, increase by 2.35% for the 10% tax on capital, and increase by 0.56% for the 20% tax on capital. The tax reforms improved the money-metric welfare of the poor most. In the current model, a household from the rich owns the largest land area, a household from the poor owns the smallest land area, and a household from the middle owns the level between them. Thus, the result suggests that the LVT discourages the large landholding.

However, the imposition of LLZ entails the reverse result pattern to what the LVT reform policy does. The LLZ makes the rich gain, but the middle and the poor lose for each tax policy. In other words, even under the existence of LLZ, switching to the LVT and graded property taxes increases the money-metric welfare of the economy, but the LLZ mitigates the decreasing tendency of the money-metric welfare of the rich and weakens the increasing tendency of the money-metric welfares of the middle and the poor. Numerically, due to the existence of the LLZ, the money-metric welfare decrease of the rich for the pure LVT reform is mitigated by 1.48% points (-2.79 – (-1.31) = 1.48); the money-metric welfare increase of the middle for the pure LVT reform weakens by 0.19% points (1.21-1.02 = 0.19); the money-metric welfare increase of the poor for the pure LVT reform weakens by 0.11% points (3.80-3.69 = 0.11). The same pattern holds true for the graded property taxes as well. The LLZ makes land rents increase by the migration effect, and the LLZ in itself favors the rich by excluding lower income groups. Hence, it is not surprising to get the result that the rich as a large-scale landowner get benefit from the LLZ, but the others lose.

Table 41. Welfare analyses for the three-income group model

		Benchmark (tl=ts=22.9%)	tl=266%, ts=0%	tl=94%%, ts=11%	tl=35%, ts=20%	tl=159%,tl= 0% with LLZ	tl=62%,tl= 11% with LLZ	tl=24%,tl= 20% with LLZ
The Rich	Expenditure (evaluated at the benchmark price)	27,188.91	26,430.87	26,796.07	27,093.68	26,832.34	27,223.96	27,528.56
The Middle		23,835.82	24,124.71	24,052.43	23,895.35	24,078.58	23,912.14	23,737.74
The Poor		14,431.78	14,980.36	14,770.89	14,512.11	14,964.44	14,658.97	14,388.38
The Rich	EV ($ million)	-	-758.04	365.20	297.61	-261.34	391.62	304.60
The Middle		-	288.89	-72.28	-157.08	183.23	-166.44	-174.40
The Poor		-	548.58	-209.47	-258.78	452.33	-305.47	-270.59
The Rich	% Change from the Benchmark	-	-2.79	-1.44	-0.35	-1.31	0.13	1.25
The Middle		-	1.21	0.91	0.25	1.02	0.32	-0.41
The Poor		-	3.8	2.35	0.56	3.69	1.57	-0.3
Total	($ million)	65,456.51	65,535.94	65,619.40	65,501.14	65,875.37	65,795.07	65,654.67
% Change from the Benchmark		-	0.12	0.25	0.07	0.64	0.52	0.3

Welfare Analysis for the Model with the Immobile and Partially Mobile Housing Capital

This section discusses the welfare result (Table 42) in the model with immobile and only partially housing capital, and compares the results for each to the result in the model with the perfectly mobile housing capital. The benchmark welfare for the model here is also $64,753.32 million, which is the same as that in Table 42. The result of the model with perfectly mobile housing capital is from the Table 40.

The LVT reform improves the money-metric welfare of households even when the housing capital is immobile and only partially immobile. The more mobile the housing capital is, the greater the welfare is: the money-metric welfare under the immobile housing capital version is $65,108.28 million; that under the only partially mobile housing capital version is $65,490.72 million; that under the perfectly mobile housing capital version is $65,856.93 million. In other words, in the absence of LLZ, the money-metric welfare for the immobile housing capital version increases by 0.55%, that for the partially mobile housing capital version increases by 1.14%, and that for the perfectly mobile housing capital version increases by 1.70%. The same pattern holds true in the presence of LLZ as well. Given that the land area for each ring is fixed as a short-term feature, it turns out that the higher mobility of the housing capital provides the more flexibility to use the amount of capital in establishing housing services, which causes the increase of economic efficiency. In other words, when the housing capital as well is fixed due to the immobility, the immobility of housing capital works as a restriction, which causes inefficiency.

Table 42. Welfare analyses for the model with immobile and partially mobile housing capital

Policy Options		Land Tax Rate (%)	Capital Tax Rate (%)	Expenditure (evaluated at benchmark price) $ million	EV ($ million)	% Change from Benchmark
Benchmark		22.9	22.9	64,753.32	-	-
Immobile Housing Capital	No LLZ	343.0	0	65,108.28	354.96	0.55
	LLZ on 6th and 7th rings	220.0	0	64,896.03	142.71	0.22
Partially Mobile Housing Capital	No LLZ	375.0	0	65,490.72	737.40	1.14
	LLZ on 6th and 7th rings	245.0	0	65,446.42	693.10	1.07
Perfectly Mobile Housing Capital	No LLZ	409.0	0	65,856.93	1,103.61	1.7
	LLZ on 6th and 7th rings	271.0	0	66,016.56	1,263.24	1.95

Sensitivity Analyses

In this section, the sensitivity analyses for the basic model are performed by varying a key assumption and some key parameters such as the elasticity of substitution between factors and that between goods. The purpose of the analyses is to see whether any change of an assumption or a parameter would change some qualitative results for the LVT or graded property taxes. The focus is on discussing the differences among scenarios.

First, change the assumption that all households are landowners into the new assumption that the residents are not landowners. Households under the assumption of the absentee landownership do not make an income from land. Table 43 reports the result under the absentee landownership condition. The first notable result is that the change (increase) of the money-metric welfare for each tax reform is more significantly greater than that with the resident landownership. For example, switching to the LVT under no LLZ improves the money-metric welfare of households by 5.30%, which is 45.3% of the tax revenue in the economy and great enough to note. Another notable result is that the imposition of LLZ no longer improves the money-metric welfare of households, but decreases the money-metric welfare. For example, for the LVT reform, the money-metric welfare improvement weakens by 0.08 percentage points (from 5.30% to 5.22%) due to the presence of LLZ on 6th and 7th rings, and weakens by 0.32 percentage points (from 5.30% to 4.98%) due to the presence of LLZ on 6th to 9th rings. The same holds true for the graded property taxes as well.

Table 43. Welfare comparisons for the basic model with the absentee landownership

Policy Options		Land Tax Rate (%)	Capital Tax Rate (%)	Expenditure (evaluated at benchmark price) $ million	EV ($ million)	% Change from Benchmark
Benchmark		22.9	22.9	53,422.21	-	-
LVT	No LLZ	152	0	56,251.48	2,829.27	5.3
	LLZ on 6th and 7th rings	128	0	56,211.05	2,788.84	5.22
	LLZ on 6th to 9th rings	110	0	56,080.66	2,658.45	4.98
Graded Property Tax	No LLZ	73	10	55,054.73	1,632.52	3.06
		31	20	53,810.06	387.85	0.73
	LLZ on 6th and 7th rings	65	10	54,982.19	1,559.98	2.92
		29	20	54,965.12	1,542.91	2.89
	LLZ on 6th to 9th rings	60	10	53,677.97	255.76	0.48
		28	20	53,627.59	205.38	0.38

Next, we varied the elasticity of substitution (λ) between factors for the production of non-housing good, that (δ) for the production of housing, and that (ξ)

between housing and non-housing good for the utility function. Note that the original elasticity of substitution between factors is 0.7, and that between housing and non-housing good is 0.2. The experimented scenarios are:

(1) $\lambda = \delta$ =0.1, LVT reform (Table 44),

(2) $\lambda = \delta$ =0.1, the revenue preserving tax on capital = 20% (Table 45),

(3) $\lambda = \delta$ =0.1, LVT reform with LLZ on 6th and 7th rings (Table 46),

(4) $\lambda = \delta$ =0.1, the revenue preserving tax on capital = 20% with LLZ on 6th and 7th rings (Table 47),

(5) ξ = 1.2, LVT reform (Table 48),

(6) ξ = 1.2, the revenue preserving tax on capital = 20% (Table 49).

Note that for each scenario, the other features are the same as in the basic model. Note also that the change of the elasticity of substitution between production factors means the change of technology, while the change of the elasticity of substitution between goods means the change of taste. Because of the smaller λ and δ, the CBD area (734.88 square miles) and the radius of urban area (35.76 miles) in Table 44 for the scenario (1) are greater than 256.46 square miles and 25.68 miles in Table 19 at the higher (original) elasticity of substitution (0.7). As mentioned before, the tax on land rent in endogenous city is not totally neutral but makes households bear a slight burden of the tax. So, under the land tax being imposed, the land does not well substitute the other factors at a low elasticity of substitution. With this background in mind, it turns out that the CBD and urban area at $\lambda = \delta$ =0.1 is larger than those at $\lambda = \delta$ =0.7. Along with the larger CBD and urban area, it turn out that land rent, the price of housing service, the price of non-housing good, and wage rate at $\lambda = \delta$ =0.1 are lower than those at $\lambda = \delta$ =0.7, as can be seen from Tables 44 and 19.

On the other hand, the production of non-housing good at $\lambda = \delta$ =0.1 is 227.69 (Table 44), while that at $\lambda = \delta$ =0.7 is 206.31 (Table 19), which is lower than the other. But, the money-metric welfare ($64,762.92 million in Table 44) at $\lambda = \delta$ =0.1 is smaller than that ($66,138.70 million in Table 19) at $\lambda = \delta$ =0.7. Note that the production of non-housing good includes the export of non-housing good as well, but the welfare is for the residents only in the urban economy. Thus, the larger CBD and urban area at the lower elasticity of substitution (0.1) means the more export of non-housing good which results in the higher production in non-housing good. When taste (the elasticity of substitution) changes, the higher production level is not necessarily equal to the higher efficiency. For the money-metric welfare comparison, it makes sense that the higher flexibility in factor combination due to the higher elasticity of substitution can lead to the efficiency (welfare) gain. The result pattern described above holds true for the other scenarios (2), (3), and (4) as well.

From now on, differences only among the scenarios (1), (2), (3), and (4) are discussed. A notable result is found between the scenarios (1) and (2). As the revenue preserving tax on capital increases to 20% from zero while the tax on land rent decreases accordingly, the CBD and urban area contract from 734.88 square miles and 35.76 miles in Table 44 to 726.09 square miles and 35.61 miles in Table 45. The same holds true for the relationship between Table 46 (scenario 3) and Table 47 (scenario 4) as well. This result pattern is opposite to that at the original case of $\lambda = \delta$ =0.7. Recall that there are dwelling size effect and improvement effect in relation to the capital property tax. Due to the capital property tax, the former has the force that reduces the dwelling size and urban area, while the latter has the force that reduces the level of improvements per dwelling size. Regarding the improvement effect, to accommodate a fixed population in an urban area, the reduced improvement due to the property tax means the larger space per housing, which causes the spatial expansion of urban area.[86] In the scenario (2), the dwelling size effect dominates so that switching from the land tax to the graded property tax contracts the urban radius. Hence, our result adds the finding that at a low elasticity of substitution between factors (0.1), switching from land tax to graded property tax makes the urban area contract, instead of making it expand. Note that this result is strong in the sense that the dwelling size effect outweighed not only the improvement effect but also the expansion effect due to the elimination of the tax on land. In addition, since the elasticity of substitution between factors (0.1) is very low and the replacement effect[87] is very weak, even the nominal wage rate decreases from $8.86 (Table 44) to $8.63 (Table 45) although the tax on capital increases. The same holds true for the relationship between Table 46 (scenario 3) and Table 47 (scenario 4) as well. The scenarios (3) and (4) are the results with LLZ added to the scenarios (1) and (2). There are no different qualitative result for the scenarios (3) and (4) from the discussion we have done. The LLZ raises all price levels, expands the CBD and urban area, and does not reduce welfare.

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[86] Brueckner (2003) found that at a low elasticity of substitution between housing and non-housing good in a utility function, the improvement effect dominated, so that the capital property tax encouraged the urban expansion. However, Brueckner's analytical model does not have full production features and the tax was imposed on residential land and improvement only. On the other hand, in this case, taxes are imposed on all land types (but agricultural land) and improvements.

[87] As the tax on capital increases, the user cost of capital increases by the capital tax amount (20%). Then firms would replace some capital with labor and land.

Now, consider the scenarios (5) and (6) (See Tables 48 and 49). The production of non-housing good (230.28 in Table 48) at $\xi = 1.2$ is greater than that (206.31 in Table 19) at $\xi = 0.2$. The higher production of non-housing good represents the higher demand for non-housing good relative to the demand for housing. This means that at $\xi = 0.2$, households wanted to enjoy the more housing service relative to the non-housing good than at $\xi = 1.2$, but at $\xi = 1.2$, households substituted the non-housing good for some of the housing service due to the change of taste. Consistent with this result, the CBD area (294.01 square miles in Table 48) at $\xi = 1.2$ is greater than that (256.46 square miles in Table 19) at $\xi = 0.2$, while the radius of urban area (24.38 miles in Table 48) at $\xi = 1.2$ is smaller than that (25.69 miles in Table 19) at $\xi = 0.2$.[88] Due to the higher demand for non-housing good relative to the demand for housing at $\xi = 1.2$, the demand for factors to produce the non-housing good at $\xi = 1.2$ should also be greater than for the other case ($\xi = 0.2$). As a result, the wage rate (\$16.14 in Table 48) at $\xi = 1.2$ is also greater than that (\$10.50 in Table 19) at $\xi = 0.2$. In addition, at $\xi = 1.2$, the land rent of the 1st ring (\$6,145.09 in Table 48) is also greater than that (\$5,373.48 in Table 19) at $\xi = 0.2$.[89]

Regarding the relationship between the scenarios (5) and (6), there are no different qualitative results from the effects of switching from LVT to a graded property tax for the original benchmark elasticity (0.2).

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[88] The larger CBD area indirectly implies that the labor demand increased.

[89] Note that the land rent of 1st ring is the same as the CBD land rent.

Table 44. Results with ‘tax on land = 93%, tax on capital = 0%’ at $\lambda = \delta = 0.1$

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Welfare, Export (million $)	Total income million $, (average income per household, $) net of transport cost
734.88	35.76	4,510.75	227.67	84.94	8.86	39,623.13	64,767.92 4,176.69	55,046.58 (39,740.09)

Ring	Residential land rent per acre of land ($)	Housing service prices per unit, per year ($)	K/L ratio capital amount per acre of land	Population density per acre of land
1	4,579.03	14,801.62	10.58	0.86
2	4,272.51	14,450.53	10.51	0.85
3	3,969.12	14,113.49	10.43	0.84
4	3,671.98	13,790.50	10.35	0.84
5	3,384.23	13,467.50	10.27	0.83
6	3,099.60	13,144.51	10.17	0.82
7	2,824.36	12,835.56	10.08	0.81
8	2,552.25	12,526.60	9.97	0.80
9	2,289.52	12,217.65	9.87	0.79
10	2,033.04	11,922.74	9.76	0.78

Table 45. Results with ‘tax on land = 27%, tax on capital = 20%’ at $\lambda = \delta = 0.1$

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Welfare, Export (million $)	Total income million $, (average income per household, $) net of transport cost
726.09	35.61	4,510.75	214.64	87.31	8.63	40,752.69	63,445.23 3,398.93	55,735.34 (40,237.33)

Ring	Residential land rent per acre of land ($)	Housing service prices per unit, per year ($)	K/L ratio capital amount per acre of land	Population density per acre of land
1	5,989.65	16,023.38	10.24	0.87
2	5,504.85	15,658.26	10.15	0.87
3	5,029.43	15,307.17	10.06	0.86
4	4,569.65	14,956.09	9.96	0.85
5	4,116.12	14,619.05	9.85	0.84
6	3,678.24	14,282.01	9.75	0.82
7	3,249.74	13,944.98	9.63	0.81
8	2,830.62	13,621.98	9.49	0.80
9	2,427.14	13,298.98	9.35	0.79
10	2,033.04	12,975.99	9.19	0.77

Table 46. Results with 'tax on land = 86%, tax on capital = 0%' at $\lambda = \delta$ =0.1 with LLZ on 6th and 7th rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Welfare, Export (million $)	Total income million $, (average income per household, $) net of transport cost
736.43	36.51	4,510.75	231.37	85.91	9.02	39,911.84	64,890.54 4,606.78	55,656.23 (40,180.21)

Ring	Residential land rent per acre of land ($)	Housing service prices per unit, per year ($)	K/L ratio capital amount per acre of land	Population density per acre of land
1	4,823.00	14,871.83	10.59	0.86
2	4,482.07	14,520.75	10.52	0.85
3	4,150.53	14,155.62	10.44	0.84
4	3,825.24	13,804.54	10.35	0.83
5	3,509.34	13,467.50	10.27	0.82
6	3,199.69	13,130.47	7.46	0.60
7	2,896.30	12,793.43	7.47	0.60
8	2,599.16	12,470.43	9.96	0.79
9	2,314.54	12,147.44	9.85	0.78
10	2,033.04	11,824.44	9.72	0.77

Table 47. Results with 'tax on land = 25%, tax on capital = 20%' at $\lambda = \delta = 0.1$ with LLZ on 6^{th} and 7^{th} rings

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Welfare, Export (million $)	Total income million $, (average income per household, $) net of transport cost
726.01	36.34	4,510.75	218.05	88.56	8.78	41,138.06	63,544.86 3,821.15	56,450.50 (40,753.63)

Ring	Residential land rent per acre of land ($)	Housing service prices per unit, per year ($)	K/L ratio capital amount per acre of land	Population density per acre of land
1	6,299.30	16,177.86	10.27	0.87
2	5,773.83	15,798.69	10.18	0.87
3	5,264.01	15,419.52	10.09	0.86
4	4,763.57	15,040.35	9.99	0.85
5	4,275.64	14,675.23	9.88	0.83
6	3,800.22	14,324.14	7.08	0.60
7	3,340.44	13,973.06	7.10	0.60
8	2,890.04	13,621.98	9.50	0.80
9	2,455.29	13,284.94	9.35	0.78
10	2,033.04	12,947.90	9.17	0.77

Table 48. Results with 'tax on land = 176%, tax on capital = 0%' at $\xi = 1.2$

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Welfare, Export (million $)	Total income million $), (average income per household, $) net of transport cost
294.01	24.38	4,510.75	230.28	106.69	12.59	49,854.77	65,605.81 1,603.90	68,036.22 (49,117.77)

Ring	Residential land rent per acre of land ($)	Housing service prices per unit, per year ($)	K/L ratio capital amount per acre of land	Population density per acre of land
1	6,145.09	16,174.01	31.68	2.39
2	5,522.59	15,762.21	29.40	2.21
3	4,956.68	15,350.40	27.26	2.04
4	4,434.05	14,967.00	25.21	1.88
5	3,961.35	14,583.59	23.30	1.73
6	3,528.60	14,214.39	21.49	1.59
7	3,135.79	13,859.38	19.78	1.46
8	2,779.60	13,504.38	18.18	1.34
9	2,456.70	13,177.77	16.68	1.22
10	2,163.76	12,851.17	15.26	1.12

Table 49. Results with 'tax on land = 33%, tax on capital = 20%' at $\xi = 1.2$

Area of CBD (square miles)	Radius of urban area (miles)	Per capita annual tax revenue ($)	Annual average non-housing goods production to satisfy the demand per capita	Price of non-housing good ($)	Wage rate ($/hour)	Value of total annual domestic consumption (million $) leisure (excluded)	Welfare, Export (million $)	Total income million $, (average income per household, $) net of transport cost
360.12	28.38	4,510.75	222.59	113.39	13.14	51,977.95	64,548.38 1,255.10	70,621.65 (50,984.29)

Ring	Residential land rent per acre of land ($)	Housing service prices per unit, per year ($)	K/L ratio capital amount per acre of land	Population density per acre of land
1	9,806.85	17,480.43	23.24	1.96
2	8,465.31	16,926.62	20.96	1.76
3	7,276.91	16,387.01	18.86	1.57
4	6,224.98	15,861.61	16.90	1.40
5	5,299.56	15,364.60	15.10	1.25
6	4,487.31	14,896.00	13.44	1.11
7	3,778.27	14,427.39	11.92	0.98
8	3,162.42	13,987.18	10.52	0.86
9	2,626.48	13,561.18	9.24	0.75
10	2,163.76	13,149.37	8.07	0.65

CHAPTER SEVEN

CONCLUSIONS

The following models and their results for LVT and graded property tax reforms have been discussed: the static model with one income group, the static model with three income groups, the model with immobile housing capital, and the model with only partially mobile housing capital. In addition, chapter 6 discussed the welfare effects of LVT and conducted sensitivity analyses by varying an assumption or key parameters such as the elasticity of substitution. This chapter provides the summary of the findings and suggests future extensions.

Summary of Findings

The pure LVT reform is feasible although the high land tax rate to meet the current tax revenue needs to be imposed in the short-term during which the CBD and urban boundary do not change. However, the LVT reform in the long-term can become a more practical tax reform option for an urban economy to adopt in the sense that the government does not need to make the tax on land rent unreasonably high, while taking the advantages that the LVT provides. Moreover, when most of the residents are landowners, the combined policy with a LLZ would make the LVT reform even more practical and desirable.

Regarding the effects of LVT, unlike other taxes, landowners bear the whole burden of the tax on land rent, since there is no way for landowners to avoid the tax when the boundaries of the CBD and urban area do not change. Thus, the results under the fixed boundary case show that the tax on land rent is fully capitalized into land rents, and the capitalized land rents results in the lower housing service prices. Consistently, the elimination of the tax on capital increases the housing capital density (the ratio of 'capital to land'). Switching from the benchmark property tax to LVT lowers the overall price level including wage rate and the price of housing service. The tax on capital entails 'inflation effect', because the rental price of capital is fixed as numeraire and the user cost of capital increases by the tax amount. Hence, the elimination of the tax on capital lowers the overall price level. For example, in calculating the wage rate relative to capital cost, the LVT reform increases the wage rate relative to capital cost (and income relative to capital cost as well) due to the increase in economic efficiency. There are two countervailing forces regarding the price change such as wage rate relative to capital cost: replacement effect and efficiency effect. The replacement effect suggests that the reduced user cost of capital due to the tax reform would replace some labor with capital to the point that the elasticity of substitution allows. This decreases labor demand and wage rate accordingly. On the other hand, the efficiency effect suggests that the reduced cost of production due to the reduced user cost of capital increases the demand for labor and so wage rate. Depending on the relative sizes of the two forces, the wage rate relative to capital cost can either increase or decrease as a result of the tax reform. In our case, the efficiency effect dominated.

The imposition of LLZ increases the demand for land in all rings. For the rings with the LLZ, households consume housing services with a larger lot size, while for the rings without the LLZ, the immigrants from the rings with the LLZ add to the number of extant residents by increasing the total demand for residential lots. As a result, the land rents in all rings increase due to the LLZ. The positive income effect due to the increased land rent combined with the migration effect is directly related to the increase in prices as a result of the LLZ. Consistent with intuition and other results, the rings with the LLZ have lower household (population) densities while the rings without the LLZ have higher household (population) densities as compared to the case with the LLZ. Unlike the cases with fixed CBD and urban boundaries, the tax on land rent is not neutral in the case of endogenous CBD and urban boundaries. The tax on land rent lowers the land rents in all rings, and the areas near the urban boundary would shift to agricultural use. Brueckner (2003) found that there are two countervailing effects of the property tax regarding the urban size: improvement effect and dwelling size effect. In this case, the improvement effect of the capital property tax dominated, so that switching from the capital property tax to the LVT contracted the CBD and the urban area. The same qualitative results can be applied to the switching from the capital property tax to the graded property tax as well.

The model with three income groups as well generates the same qualitative results as in the basic model, but the following results. The rich live in the suburban areas, the poor live in the areas near the CBD, and the middle live in-between. This means that the income elasticity of housing consumption (or land consumption) is greater than the income elasticity of commuting costs. With respect to the wage rates and incomes relative to capital cost, the LVT reform and graded property taxes favor the poor and the middle more than do the rich, but the imposition of LLZ favors the rich more than does the middle and the poor. In the present model, the rich have the largest landholding.

The model with immobile housing capital and only partially mobile housing capital was considered with the recognition and assumption that in the short-term, the amount of housing capital, the boundary of CBD, and the boundary of urban area do not change. For any same tax policy, the more mobile the housing capital is, the lower the land rent is. It is because the more mobile housing capital allows firms to use more capital when the user cost of capital decreases due to the tax reform. Since the land area of each ring is fixed, the more use of capital means the more housing services. The longer time span (the more mobile housing capital) allows households to enjoy greater housing service at a lower housing service price. Consistently, the production decreases more as the housing capital becomes less mobile. Due to the immobility of housing capital, the user cost of factors increases, which causes the production to shrink.

When the government switched from the capital property tax to the LVT reform, the welfare increased by 1.7% (from $64,753 million to $65,857 million) for the fixed boundary case, and increased by 2.14% (from $64,753 million to $66,139 million) for the endogenous boundary case. The increase in welfare was larger for the case with the endogenous boundary than for the case with the fixed boundary. The percents (1.7% and 2.14%) appear to be small. However, the monetary values for the changes for the welfare ($1,104 million and $1,386 million) are not negligible but record 17.7% and 22.2% of the tax revenue, respectively in the economy. As the revenue preserving tax on capital increases (while the tax on land decreases accordingly), the welfare improvement from the benchmark weakens. When the tax on capital is 10% and the tax on land is 80%, the welfare is improved by 1.29% from the benchmark. When the tax on capital is 20% and the tax on land is 32%, the welfare improvement is as low as 0.3%. The existence of LLZ makes the welfare of households (as a landowner) further improved than the absence of the LLZ does, when the residents are landowners.

A notable result is that switching to the LVT and graded property taxes reduces the welfare of the rich, but improves the welfares of the middle and the poor. Numerically, the welfare of the rich decrease by 2.79% for the pure LVT reform, decrease by 1.44% for 10% on capital, and decrease by 0.35% for 20% on capital. The welfare of the middle increase by 1.21% for the pure LVT reform, increase by 0.91% for the 10% on capital, and increase by 0.25% for the case with the 20% on capital. The welfare of the poor increase by 3.80% for the pure LVT reform, increase by 2.35% for the 10% on capital, and increase by 0.56% for the 20% on capital. In the current model, a household from the rich owns the largest land area, a household from the poor owns the smallest land area, and a household from the middle owns the level between them. Thus, the result suggests that the LVT discourages a large landholding. However, the imposition of LLZ suggests a reverse result pattern. The LLZ makes the rich gain, but the middle and the poor lose. In other words, even under the existence of LLZ, switching to the LVT and graded property taxes increases the welfare of the rich, but reduces the welfares of the middle and the poor.

The LVT reform improves the welfare of households even when the housing capital is immobile and only partially immobile. The more mobile the housing capital is, the greater the welfare is. Under the absence of LLZ, the welfare for the model with immobile housing capital version increases by 0.55%, that for the partially mobile housing capital version increases by 1.14%, and that for the perfectly mobile housing capital version increases by 1.70%. The same pattern holds true for the presence of LLZ as well. Given that the land area for each ring is fixed as a short-term feature, the higher mobility of the housing capital provides the more flexibility to use the amount of capital in establishing housing services, which causes the increase in economic efficiency. However, when considering the cases with immobile and only partially mobile housing capital, the presence of LLZ did not cause the welfare to increase for the same LVT reform policy. By this result, in the short-term period during which housing capital is immobile or only partially mobile, the positive income effect of the LLZ[90] is not great enough to offset the distortive effect of the LLZ.

The following are the summary of the sensitivity analyses. First, assuming that the urban residents are not landowners but there is only absentee landowner in the economy, the change (increase) of welfare for each tax reform is more significantly greater than before. For example, switching from the capital property tax to the LVT improved the welfare of households by 5.30%, which covers 45.3% of the tax revenue in the economy. Another finding is that the imposition of LLZ no longer improves the welfare of households. For example, for the LVT reform, the welfare improvement weakens by -0.08 percentage points (from 5.30% to 5.22%) with the LLZ on 6th and 7th rings, and weakens by -0.32 percentage points (from 5.30% to 4.98%) with the LLZ on 6th to 9th rings. Second, at a very low elasticity of substitution between factors ($\lambda = \delta$ =0.1), switching from the capital property tax to LVT or graded property tax expands the CBD and the urban area This result pattern is opposite to the result at the case of $\lambda = \delta$ =0.7.

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[90] LLZ increases land rents and as a result increases incomes.

Third, with the higher elasticity of substitution between housing and non-housing good, there were no changes in the qualitative results for switching from the capital property tax to the LVT and graded property tax.

Future Research

The current model can be extended for either policy application or pursuing academic issues. For the policy application, the current model can have more sectors, more tax options such as sales tax and income tax, more regions, diverse land use regulations, various types of housing markets, and the other. On the other hand, one can pursue the following academic issues by extending the current model.

First, the current model can be transformed into dynamic models. There are various ways to transform the current model to a dynamic model. Capital can be divided into the three factors of production (land, equipment capital, and structural capital) that are differentiated from each other with respect to durability and mobility, and model the characteristics in a dynamic setting. According to Plassmann and Tideman,

> Structures (immobile capital) are almost as immobile as land, but they are reproducible and depreciate over time. In the short-run a tax on structures will not affect the availability of structures in a region, while a policy that reduces the incentive to erect new structures will lead to a reduction in the number of available structures in the region over a longer span of time. Machines (mobile capital) are very mobile, reproducible, and depreciate faster than structures, partly because they become obsolete faster. A regional policy that reduces the incentive to use machines will lead to a rapid reduction in the number of available machines, because they will move to other regions. If a policy reduces the overall return to machines in all regions, it will lead, somewhat more slowly, to a decrease in the total number of machines by discouraging their production. A model that combines land and structures into a single inelastically supplied factor ignores the fact that structures need to be constructed, and it will therefore underestimate the negative long-run effect of taxing this hybrid factor--- (Plassmann and Tideman, 1999, 5).

Another way of transforming the current model to a dynamic model is that as some authors such as Alex Anas did, we incorporate durable housing features such as construction costs and demolition costs in a perfect foresight framework to address LVT and other local tax issues.

Second, the urban literature has changed its focus on from mono-centric city to polycentric city. So, the modeled urban structure can have suburban business districts and internal residential districts additionally, which would be a more realistic urban structure.

Third, the basic model assumes the exogenous transportation cost function. But according to Brueckner (1987), the fact that urban traffic congestion (and hence the cost of travel) is endogenous has been stressed in a number of studies. The existence of the transportation cost is critical in the developed model. So, varying the assumption about it would change the quantitative results and may change some qualitative results.

APPENDICES

APPENDIX 1

SOLUTION METHODOLOGY

Complementary Problem[91]

To introduce the solution methodology, consider a very simple economy as an example. Assume that there are two sectors (or products) (X and Y), two factors (L and K), and one representative consumer with utility function (U). L and K have inelastic (fixed) supply, but can move freely between sectors. Let p_x, p_y, p_l, and p_k be the prices of X, Y, L, and K, respectively. And let I be consumer's income. We specify the model as follows.

(1) Production function for X, $X = X(L_X, K_X)$

(2) Production function for Y, $Y = Y(L_Y, K_Y)$

(3) Labor market equilibrium, $L = L_X + L_Y$

(4) Capital market equilibrium, $K = K_X + K_Y$

(5) Utility function, $U = U(X, Y)$

(6) Budget constraint, $I = p_l \cdot L + p_k \cdot K = p_x \cdot X + p_y \cdot Y$

There are two general ways to formulate the problem above.

The first is to model the economy as an optimization problem. From this approach, a general equilibrium would be the solution to a big linear or non-linear programming

[91] For this and next subsections, I mostly followed the materials from the GAMS/MPSGE workshop held in the University of Colorado during Oct. 18-22, 2004 (Instructors: Dr. James R. Markusen, Dr. Thomas F. Rutherford)

problem in which some objective function is maximized or minimized subject to a set of constraints. In other words, an objective function must be chosen for the entire model, and each agent's problem such as the household's utility maximization problem and firm's profit maximization problem becomes one of the constraints to be met (or optimized) for the chosen objective function. However, in many cases, formulating a model as an optimization problem makes us face the difficulty of choosing an objective function for the entire model. Especially, for example, when there are multiple household types with different preferences and different factor endowments in a model, the difficulty of choosing a representative objective function becomes clearer.

The second way of formulating and solving the problem is the following. The present dissertation also takes the approach. In this approach, there is no need to choose an objective function to formulate and solve the problem. Instead, individual optimizing behavior and decisions of consumers and firms are embedded in functions describing the agents' choices in response to the values of variables facing them. Individual optimization is used to derive demand and supply functions that describe how consumers and firms will react to prices and other variables. And then finding general equilibrium becomes a matter of finding the solution to a square system of 'n' equations in 'n' unknowns. Instead of thinking about how to optimize, finding the values of the 'n' unknown variables in 'n' equations is a lot easier and simpler concept.

Furthermore, the general equilibrium is formulated as a system of weak inequalities, with each inequality associated with a particular non-negative variable such as price or quantity. If a particular weak inequality holds as an equation, then the associated variable is strictly positive. If it holds as a strict inequality, then the value of the associated variable is zero. This approach is referred to as a complementarity problem in mathematics, and the associated variables are referred to as complementary variables.

Now, turn to the specific example above. Assuming that all markets are perfectly competitive, a minimum average cost is taken to be unit price. The procedure to derive the equilibrium system is as follows. First, solve the underlying cost and expenditure minimization problems for producers and consumers respectively, so that individual firm's (or household's) optimizing behavior is embedded in the derived functions of the model. In the present example, we want to solve for the cost function for each sector where the cost functions embody cost minimizing behavior. Regarding the welfare (U), from the point of the household, the same optimization as the firm's cost minimization problem confronts him/her. In other words, the household satisfies a given level of utility by minimizing expenditure on goods (X and Y). The minimum average expenditure is considered as unit price of welfare, assuming that the expenditure function is the function with the characteristics of the first degree of homogeneity. Thus, although the welfare is actually not a production sector, we can treat the welfare as a sector in solving the problem, using the analogy. More specifically expressing,

'unit' cost functions for X and Y are $cx = C_x(p_l, p_k)$, $cy = C_y(p_l, p_k)$,

'unit' expenditure function for U is $e = e(p_x, p_y)$.

And, according to Shepard's lemma,

X producer's demand for labor to produce unit of output X is $\frac{\partial C_x}{\partial p_l} = cx_{pl}$,

X producer's demand for capital to produce unit of output Y is $\frac{\partial C_x}{\partial p_k} = cx_{pk}$, consumer's compensated demand for X to provide unit of utility is $\frac{\partial e}{\partial p_x} = e_{px}$.

Now, specify the general equilibrium as the solution to a square system of nine weak inequalities in nine unknowns (*X, Y, U,* p_x, p_y, p_l, and p_k, p_u and *I)*. Here, define p_u as income needed for satisfying unit utility, and call it 'utility price'.

The derived or defined equations to solve the problem are as follows:

(1) Non-positive profits for X	$C_x(p_l, p_k) \geq p_x$
(2) Non-positive profits for Y	$C_y(p_l, p_k) \geq p_y$
(3) Non-positive surplus for U	$e(p_x, p_y) \geq p_u$
(4) Supply - Demand for X	$X \geq e_{px}(p_x, p_y) \cdot U$
(5) Supply - Demand for Y	$Y \geq e_{py}(p_x, p_y) \cdot U$
(6) Supply - Demand for U	$U \geq \frac{I}{p_u}$
(7) Supply - Demand for L	$L^* \geq cx_{pl} \cdot X + cy_{pl} \cdot Y$
(8) Supply - Demand for K	$K^* \geq cx_{pk} \cdot X + cy_{pk} \cdot Y$
(9) Income balance	$I = p_l L^* + p_k K^*$

Here, since welfare or utility (U) is not a product, do not necessarily name the inequality (6) as supply-demand inequality. However, the inequality condition (6) plays a role to solve the system. These weak inequalities can be solved for the nine unknowns*: X,* *Y, U,* p_x, p_y, p_l, and p_k, p_u and *I.* Note that these inequalities are of three types: 1) zero-profit inequalities (1)-(3), 2) market clearing inequalities (4)-(8), and 3) income balance equation (9).

If zero profit condition holds as a strict inequality, profits for that activity are negative, that activity will not be used, while if zero profit condition holds as an equality, that activity will be determined with a positive number and used. Here, the complementary variable to a zero-profit condition is mathematically defined as a quantity, the activity level. The activity level (quantity) is determined according to how the zero profit condition holds. Regarding the inequality (3) above, we consider that if unit expenditure is greater than p_u (utility price), no utility is provided to households, while expenditure is equal to p_u, a certain level of utility is provided to households.

If market-clearing condition holds as strict inequality, supply exceeds demand for that good or factor, so its price must be zero, while if the market-clearing condition holds as equality, so its price must be a positive number. Here, the complementary variable to the market clearing inequality is mathematically defined as the price of the goods or the factor. The price of the goods is determined according to how the market clearing condition holds. Regarding the inequality (6) above, we consider that if unit utility level provided to households is greater than households' demand for utility, p_u (utility price) is zero, while if unit utility level provided to households is equal to households' demand for utility, p_u is a positive number. The complementary variable to income balance equation is just defined as the income of the agent. The correct association of inequalities and unknowns in the square system is thus as follows:

Inequality	Complementary Variable
(1) Non-positive profits for X	X
(2) Non-positive profits for Y	Y
(3) Non-positive profits for U	U
(4) Supply - Demand for X	p_x
(5) Supply - Demand for Y	p_y
(6) Supply - Demand for U	p_u
(7) Supply - Demand for L	p_l
(8) Supply - Demand for K	p_k
(9) Income balance	I

Constructing Micro-Consistent Data and SAM (Social Accounting Matrix)

To calibrate parameters for specified functions and to get a solution for an economy, not only do we need data but also the data should be micro-consistent. Constructing Social Accounting Matrix (SAM) helps us to develop micro-consistent data.

SAM is a comprehensive, and economy-wide data framework, which typically represents the economy of a country, elaborating the linkages between the supply and use table (commonly known as the Input-Output table) and institutional sector accounts. Here, the Input-Output table shows inter-industrial linkages of the various industries in an economy, and provides a detailed analysis of the process of production and the use of goods and services (products) and the income generated from the production process. More technically, SAM is a square matrix in which each account is represented by a row and a column. Each cell shows the payment from the account of its column to the account of its row – the incomes of an account appear along its row, its expenditures along its column. SAM consists of ‘double-entry’ accounting, which requires that, for each account in the SAM, total revenue (row total) equals total expenditure (column total).

Table A1 is a small SAM that is constructed for the example economy of the previous section. The system of equations can be thought of as consisting of three activities (or commodities), X and Y, and U, and four markets, X, Y, L, and K. Here, although U is not a production sector, we treat it as an activity, using the analogy between U and production sector. The analogy is that as X and Y are produced using factors L and K, U is also generated using X and Y. The U can be considered as the commodity that households consume, as U is satisfied by consuming on X and Y. Note that all the numbers in SAM are dollar values, quantities times prices.

Reading rows as receipts, we see from the first row of the SAM in Table A1 that 100 is spent on good X in sector U. Likewise, reading across row we see that 40 units of labor enter sector X and 60 units enter sector Y. And we also see that household’s income is 200, which consist of his/her endowments of L (100) plus K (100). SAM can be quite detailed in their representation of an economy, and they are also quite flexible.

Table A1. Traditional SAM (social accounting matrix)

	PX	PY	PU	PL	PK	X	Y	U	HOUSE-HOLDS
PX								100	
PY								100	
PU									200
PL						40	60		
PK						60	40		
X	100								
Y		100							
U			200						
HOUSEHOLDS				100	100				

It is often convenient to use a rectangular[92] SAM format (Table A2). In the rectangular SAM, we have one row for every market. There are two types of columns in the rectangular SAM, corresponding to production sectors and consumers. A rectangular SAM is balanced or micro-consistent when row and column sums are zeros. Positive numbers represent the value of commodity flows into the economy (sales or factor supplies), while negative numbers represent the value of commodity flows out of the economy (factor demands or final demands). A row sum is zero if the total amount of commodity flowing into the economy equals the total amount of commodity flowing out of the economy. This is market clearance, and one such condition applies for each commodity in the model. Columns in this matrix correspond to production sectors or consumers. A production sector column sum is zero if the value of outputs equals the cost of inputs. A consumer column is balanced if the sum of primary factor sales equals the value of final demands. Zero column sums indicate zero profits or product exhaustion in

[92] Both types of SAM Table are rectangular. However, as can be seen from Tables 3 and 4, the reason why the new SAM is called as a 'rectangular SAM' may be that the new SAM is not a square.

an alternative terminology. Prices can be chosen as one, and representative quantities for activities can be chosen such that activity levels are also equal to one (e.g., activity X at level one produces 100 units of good X).

The numbers in the SAM are used as a benchmark. Using the benchmark numbers, we can generate values for most parameters of the specific forms of utility and production functions. Substituting the parameter values into the functions, we can conduct counterfactual analyses by running the program and comparing new results with the benchmark.

Table A2. Transformed ‘Rectangular’ SAM

Markets	X	Y	U	HOUSEHOLDS
PX	100		-100	
PY		100	-100	
PU			200	-200
PL	-40	-60		100
PK	-60	-40		100

APPENDIX 2

DERIVATION OF THE EQUATION (3.15)

The budget and time constraints of a household in ring j is follows.

$$P_N \cdot x_N^j + P_H^j \cdot x_H^j + P_W \cdot l^j$$
$$= P_W \cdot T + \left(\sum_j r_L^j \cdot L^j \Big/ N \right) + \overline{r_K} \cdot \frac{\overline{K}}{N} - \mathrm{c} \cdot D^j - P_W \cdot \Gamma \cdot D^j \quad (1)$$

$$l^j + W^j + \Gamma \cdot J^j = T \quad (2)$$

The above budget constraint can be summed for the whole population and all rings and expressed as follows.

$$\sum_i n^j \cdot P_N \cdot x_N^j + \sum_i n^j \cdot P_H^j \cdot x_H^j + \sum_i n^j \cdot P_W \cdot l^j$$
$$= N \cdot P_W \cdot T + N \cdot \left(\sum_j r_L^j \cdot L^j \Big/ N \right) + \overline{r_K} \cdot \overline{K} - \sum_j n^j \cdot \mathrm{c} \cdot D^j - \sum_i n^j \cdot P_W \cdot \Gamma \cdot D^j$$
$$= \sum_j n^j \cdot P_W \cdot W^j + \sum_j n^j \cdot P_W \cdot l^j + N \cdot \left(\sum_j r_L^j \cdot L^j \Big/ N \right) + \overline{r_K} \cdot \overline{K} - \sum_j n^j \cdot \mathrm{c} \cdot D^j \quad (3)$$

Since the $\sum_i n^j \cdot P_W \cdot l^j$ is cancelled out on both sides,

$$\sum_i n^j \cdot P_N \cdot x_N^j + \sum_i n^j \cdot P_H^j \cdot x_H^j$$
$$= \sum_j n^j \cdot P_W \cdot W^j + N \cdot \left(\sum_j r_L^j \cdot L^j \Big/ N \right) + \overline{r_K} \cdot \overline{K} - \sum_j n^j \cdot \mathrm{c} \cdot D^j$$

(4)

On the other hand, the zero profit conditions are given below,

$$\Pi_H = \sum_J n^j \cdot P_H^j \cdot S_H^j - \overline{r_K} \cdot \sum_j n^j \cdot k_H^j - \sum_j n^j \cdot r_L^j \cdot L^j = 0 \tag{5}$$

$$\Pi_N = P_N \cdot S_N - \overline{r_K} \cdot K_N - r_L^1 \cdot L^1 - P_W \cdot \sum_j n^j \cdot W^j = 0 \tag{6}$$

In equilibrium, supply for each good is equal to demand for each good, and so

$$\begin{aligned}&\sum_i n^j \cdot P_N \cdot x_N^j + \sum_i n^j \cdot P_H^j \cdot x_H^j = P_N \cdot S_N + \sum_i n^j \cdot P_H^j \cdot S_H^j \\ &= \sum_j n^j \cdot P_W \cdot W^j + N \cdot \left(\overline{\sum_j r_L^j \cdot L^j / N} \right) + \overline{r_K} \cdot \overline{K} - \sum_j \mathrm{n}^{\mathrm{j}} \cdot \mathrm{c} \cdot D^j\end{aligned} \tag{7}$$

Substituting (5) and (6) into (7),

$$\begin{aligned}&P_N \cdot S_N + \sum_i P_H^j \cdot S_H^j = \overline{r_K} \cdot K_N + r_L^1 \cdot L_N^1 + \sum_j n^j \cdot P_W \cdot W^j + \sum_j (n^j \cdot \overline{r_K} \cdot k_H^j + n^j \cdot r_L^j \cdot L_H^j) \\ &= \sum_j n^j \cdot P_W \cdot W^j + N \cdot \left(\overline{\sum_j r_L^j \cdot L^j / N} \right) + \overline{r_K} \cdot \overline{K} - \sum_j n^j \cdot \mathrm{c} \cdot D^j\end{aligned} \tag{8}$$

Rearranging (8),

$$\begin{aligned}&(\overline{r_K} \cdot K_N + \sum_j n^j \cdot \overline{r_K} \cdot k_H^j) + (r_L^1 \cdot L_N^1 + \sum_j n^j \cdot r_L^j \cdot L_H^j) \\ &= N \cdot \left(\overline{\sum_j r_L^j \cdot L^j / N} \right) + \overline{r_K} \cdot \overline{K} - \sum_j \mathrm{n}^{\mathrm{j}} \cdot \mathrm{c} \cdot D^j\end{aligned} \tag{9}$$

From (9), if there is no monetary commuting cost ($\sum_j \mathrm{n}^{\mathrm{j}} \cdot \mathrm{c} \cdot D^j$), then,

$$\begin{aligned}&Demand = \overline{r_K} \cdot K_N + \overline{r_K} \cdot \sum_j n^j \cdot k_H^j + r_L^1 \cdot L_N^1 + \sum_j n^j \cdot r_L^j \cdot L_H^j = \\ &N \cdot \sum_j \left(\overline{L^j / N} \right) + \overline{r_K} \cdot \overline{K} = Supply(endowment)\end{aligned} \tag{10}$$

The above condition means that when there is no monetary commuting cost, the sum of values of land demand and capital demand must equal the sum of values of land endowment and capital endowment. If the value of land demand ($r_L^1 \cdot L_N^1 + \sum_j n^j \cdot r_L^j \cdot L_H^j$) is greater than the value of land endowment ($N \cdot \sum_j (\overline{L^j / N})$), the value of capital demand ($\overline{r_K} \cdot K_N + \overline{r_K} \cdot \sum_j n^j \cdot k_H^j$) must be smaller than the value of capital endowment ($\overline{r_K} \cdot \overline{K}$), by the difference ($r_L^1 \cdot L_N^1 + \sum_j n^j \cdot r_L^j \cdot L_H^j - N \cdot \sum_j (\overline{L^j / N})$). On the other hand, if the value of land demand is smaller than the value of land endowment, the value of capital demand must be greater than the value of capital endowment by the difference. Otherwise, the budget constraint can't be met and the model is not closed and not solved.[93]

However, under the situation that there is the monetary commuting cost,

$$
\begin{aligned}
&(\overline{r_K} \cdot K_N + \sum_j n^j \cdot \overline{r_K} \cdot k_H^j) + (r_L^1 \cdot L_N^1 + \sum_j n^j \cdot r_L^j \cdot L_H^j) \\
&= N \cdot (\overline{\sum_j r_L^j \cdot L^j / N}) + \overline{r_K} \cdot \overline{K} - \sum_j \mathrm{n}^{\mathrm{j}} \cdot \mathrm{c} \cdot D^j
\end{aligned}
\tag{11}
$$

must hold.

We here assume that there is the export of non-housing good (Ex). Further assume that the export of non-housing good (Ex) is greater than the monetary commuting cost ($\sum_j \mathrm{n}^{\mathrm{j}} \cdot \mathrm{c} \cdot D^j$) and call the difference ($Ex - \sum_j \mathrm{n}^{\mathrm{j}} \cdot \mathrm{c} \cdot D^j$) 'net export

---

[93] Note here, the condition that money inflow into the economy equals money outflow from the economy has been derived from the budget constraint.

value'. Here, because of the existence of the net export value, trade balance is not required to meet the budget constraint and close the model.

$$
\begin{aligned}
&(\overline{r_K} \cdot K_N + \sum_j n^j \cdot \overline{r_K} \cdot k_H^j) + (r_L^1 \cdot L_N^1 + \sum_j n^j \cdot r_L^j \cdot L_H^j) \\
&= N \cdot (\overline{\sum_j r_L^j \cdot L^j \big/ N}) + \overline{r_K} \cdot \overline{K} + Ex - \sum_j \mathrm{n}^{\mathrm{j}} \cdot \mathrm{c} \cdot D^j
\end{aligned} \tag{12}
$$

See notations below: note that ring 1 is CBD.

x_N^j Per capita consumption of non-housing good in ring j = 2,3,4, ---, 11

x_H^j Per capita consumption of housing services in ring j = 2, 3,4, ---, 11

l^j Per capita consumption of leisure in ring j = 2, 3,4, ---, 11

P_N Price of a unit of the non-housing good

P_H^j Price of a unit of housing services per year in ring j = 2, 3,4, ---, 11

P_W Hourly wage rate

r_L^j Rental rate of land for ring j = 1,2,3,4, ---, 11

$\overline{r_K}$ Fixed rental rate of capital

W^j Hours supplied by a worker in ring j = 2, 3,4, ---, 11

c The fixed roundtrip money cost per mile and per capita

$\dfrac{\overline{\sum_j L^j}}{N}$ Per capita land endowment (fixed and averaged for all locations)

$\overline{K}$ Total capital endowment (fixed) summed for all uses and for all population

$\boldsymbol{\Gamma}$ Per capita round trip time for work per mile

D^j Distance in miles from the midpoint of ring j to the city center

T	Per capita time endowment for leisure, work, and commuting
Ex	Export value for all population
N	Total number of households
n^j	Number of households in ring j = 2, 3,4, ---, 11
L_H^j	Per capita land demand in ring j = 2, 3,4, ---, 11
k_H^j	Per capita capital demand in ring j = 2, 3,4, ---, 11
S_H^j	Per capita supply of housing in ring j = 2, 3,4, ---, 11
S_N^j	Per capita supply of non-housing in ring j = 2, 3,4, ---, 11
π_H	Profit in housing sector
π_N	Profit in non-housing good sector

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