Impacts of Urban Containment Policies on the Spatial Structure of US Metropolitan Areas
Author(s): Myungje Woo and Jean-Michel Guldmann
Source: *Urban Studies*, Vol. 48, No. 16 (December 2011), pp. 3511-3536
Published by: Sage Publications, Inc.
Stable URL: https://www.jstor.org/stable/43082055
Accessed: 04-02-2022 15:46 UTC

Urban Studies
48(16) 3511–3536, December 2011

Impacts of Urban Containment Policies on the Spatial Structure of US Metropolitan Areas

Myungje Woo and Jean-Michel Guldmann

[Paper first received, May 2009; in final form, December 2010]

Abstract

This paper examines the impacts of different types of urban containment policies (UCPs) on the spatial structure of US metropolitan areas, with a particular focus on UCP tightness. These UCPs include state-mandated urban growth boundaries (UGBs), locally adopted urban growth boundaries and urban service areas (USAs). Population and employment density gradients, taken as concentration measures, are estimated for 135 metropolitan areas and are then used in a simultaneous equation model to assess the impacts of different UCPs on metropolitan spatial structure. The results suggest that state-mandated 'strong' UGBs more effectively promote growth within the boundaries than locally adopted UGBs or USAs.

1. Introduction

Urban sprawl and suburbanisation in US metropolitan areas (MAs)[1] have caused central cities to lose large shares of population (20 per cent) and employment (25 per cent) to suburban communities during 1950–90 (Mieszkowki and Mills, 1993). In a recent study, Kneebone (2009) shows that over 45 per cent of the employees in the 98 largest MAs work 10 miles or more away from the city centre. Various growth management policies, such as development caps, development exactions, minimum density zoning, open space zoning and urban containment policies (UCPs), and smart growth strategies such as mixed land use, walkable neighbourhoods, diverse transport choices and compact development, have been implemented to prevent urban sprawl and the decline of central cities.

Myungje Woo is in the Center for Quality Growth and Regional Development, College of Architecture, Georgia Institute of Technology, 760 Spring St NW, Suite 213, Atlanta, Georgia, 30308, USA. E-mail: myungje.woo@coa.gatech.edu.

Jean-Michel Guldmann is in the City and Regional Planning Section, Austin E. Knowlton School of Architecture, The Ohio State University, 275 West Woodruff Avenue, Columbus, Ohio, 43210-1138, USA. E-mail: guldmann.1@osu.edu.

0042-0980 Print/1360-063X Online

DOI: 10.1177/0042098011399594

While UCPs may include diverse forms of growth management policies, only physical containment policies, such as urban growth boundaries (UGBs) and urban service areas (USAs), are here referred to as UCPs and are the focus of this paper. Several communities, including cities, counties (or regional councils) and state governments, have adopted some form of UCPs as a method to contain urban sprawl. Special attention is given to UCPs because they directly limit the physical size of communities, significantly affect the growth and location of population and economic activities, and influence the urban spatial structure at the regional level. For example, UCPs may reinforce a monocentric urban pattern, encourage a polycentric one or produce a dispersed one, failing to prevent urban sprawl. There has been much discussion on both the positive and negative impacts of UCPs (Carlson and Dierwechter, 2007; Wassmer, 2006; Nelson *et al.*, 2004; O'Toole, 2003; Carruthers, 2002; Pendall *et al.*, 2002; Richardson and Gordon, 2000; Levine, 1999; Ding *et al.*, 1999; Staley *et al.*, 1999). One of the controversial issues is the spatial impacts of UCPs, because their primary goals are to prevent urban sprawl and promote the central city. For example, although UCPs are known to encourage compact developments, slowing the increase of urbanised areas, and to promote concentrations of population and employment in UCP cities, critics argue that UCPs also generate a distorted land use pattern, such as leap-frog developments outside containment boundaries. Since UCPs vary in terms of adopted geographical area, from small town to region, they may have different effects on the urban spatial structure, which may significantly affect travel patterns, energy consumption and the environment. Moreover, it is important to distinguish among UCPs, because their tightness varies substantially. However, little is known regarding the differential impact of this tightness on the spatial distribution of population and economic activities at the metropolitan level. The purpose of this paper is to address this research gap by examining the impacts of different types of UCPs on the metropolitan spatial structure. This structure is measured by estimated population and employment density gradients, using a sample of 135 UCP and non-UCP metropolitan areas. A simultaneous equation estimation approach is used to analyse the determinants of these gradients and, in particular, the effects of UCP tightness. The empirical results show that state-mandated UGBs more effectively promote growth within the boundaries than locally adopted UGBs or USAs.

The remainder of the paper is organised as follows. Section 2 consists of a literature review. The methodology for measuring UCPs' impacts on density gradients is presented in section 3. Data sources and variables are described in section 4. Estimation results are presented and their implications are discussed in section 5. Section 6 concludes the paper.

2. Literature Review

While there is no agreed-upon universal definition of urban sprawl (Galster *et al.*, 2001; Brueckner, 2000; Burchell *et al.*, 1998; Weitz and Moore, 1998; Ewing, 1994), it is commonly accepted that sprawl has been promoted by political fragmentation and such policies as the tax treatment of mortgage interest and property taxes, zoning codes that favour low densities, low gasoline taxes, highway construction, large-lot residential zoning and local tax inducements to firms (Persky and Kurban, 2003; Carruthers, 2002; Nelson and Duncan, 1995). However, other policies have promoted central cities, including containment policies and smart growth programmes, such as downtown redevelopment programmes and transit-oriented development (TOD) projects. Nevertheless, large reinvestments in central-city revitalisation have not had much success in preventing urban sprawl (Nelson *et al.*, 2004). Under the theory that urban sprawl is the result of revealed preferences, urban containment policies (UCPs) that directly limit urban geographical growth, instead of guiding the behaviour of land market agents, are considered an efficient approach to prevent urban sprawl.

While policy-makers name UCPs differently (for example, urban growth boundary, growth management area, urban limit line, urban service area), Pendall *et al.* (2002) categorize them into urban growth boundaries, urban service areas and greenbelts.[2] An urban growth boundary (UGB) is defined as a line drawn around a municipality, with areas beyond the boundary not allowed or discouraged to have new developments (Pendall *et al.*, 2002; Staley *et al.*, 1999). Brueckner (2000) also defines a UGB as a zoning tool, with urban uses inside the boundary and rural uses, such as farmland, forest and low-density residential, outside. An urban service area (USA) is similar to a UGB in that it draws a line around an urban area, within which new developments are encouraged and public services are provided. However, USAs usually allow new developments beyond the boundary, but without provision of infrastructure and services, which then become the burden of developers, and are flexible in terms of boundary changes. Pendall *et al.* (2002) point out that USAs focus more on financial issues than on limiting geographical growth, while UGBs directly limit spatial growth by prohibiting new developments beyond the boundary. Local governments with USAs try to minimize the costs of public services by limiting the service boundary.

In terms of tightness, Nelson and Dawkins (2004) differentiate between 'strong' containment policies that promote rural and open space conservation and direct growth within the boundaries and 'weak' policies that emphasise infrastructure and land supply and have few tools to prevent the spread of development in outer areas. UGBs are here classified as 'strong' UCPs, that ensure no developments outside the boundaries, and USAs as 'weak' UCPs that do not. A state-mandated UGB is considered as the tightest UCP, because new development is allowed nowhere outside UGBs, at least within the state, and a locally adopted UGB is considered a moderately tight one, because spillover effects can occur in neighbouring jurisdictions that do not have UGBs. A USA is classified as the least tight UCP, because there is no restriction on developments outside USAs, although public services are not provided in those areas. The remainder of this section discusses the positive and negative impacts of UCPs as identified in the literature and reviews several density functions and gradients that have been used in studies measuring the urban spatial structure.

2.1 Impacts of UCPs

Empirical research confirms that many UCP goals have been achieved in contained communities. Carlson and Dierwechter (2007) show that UGBs accommodate new housing developments within the growth boundary, using a kernel density calculation on residential building permits from 1991 to 2002 for Pierce County, Washington. Wassmer (2006) uses regression analysis, with the square miles of land as the dependent variable and UCPs as one of the independent variables, to show that UCPs reduce the size of an urban area, reducing the use of land and promoting compact developments. Nelson *et al.* (2004) argue that UCPs contribute to the revitalisation of central cities, using regression analysis of the number of constructed residential units over 144 metropolitan areas. The positive impacts of UCPs can be summarised as follows. First, open space and farmland, which cannot compete on land value terms with urban land, have been preserved (Pendall *et al.*, 2002; Staley *et al.*, 1999). UCPs have also prevented urban sprawl, preserved agricultural land and encouraged higher-density development (Pendall *et al.*, 2002; Ding *et al.*, 1999). Secondly, UCPs have minimized the use of land, reducing lot sizes, encouraging infill and increasing residential densities, which has helped to achieve cost-efficient construction and reduce infrastructure and public operation costs (Pendall *et al.*, 2002; Staley *et al.*, 1999). Finally, UCPs have clearly separated urban and rural uses, ensuring an orderly transition from rural to urban land and accommodating new developments within the boundary (Carlson and Dierwechter, 2007; Wassmer, 2006; Nelson *et al.*, 2004).

However, several negative characteristics of UCPs have emerged. While some studies find that UCPs direct new growth to central areas, other studies suggest that UCPs produce new developments outside the controlled areas without achieving the desired densities inside these areas because of the rise of housing prices[3] within the boundaries (Richardson and Gordon, 2000; Levine, 1999). Brueckner (2001) concludes that UCPs restrict the spatial size of cities, with increased housing prices and reduced housing consumption, while maintaining absentee landowners' revenues. Also, while UCPs contribute to higher population density, they generate more vehicle miles travelled (VMT) (Rodriguez *et al.*, 2006). Table 1 summarises these recent discussions on the positive and negative impacts of UCPs. The different results and apparent contradictions may be due to differences in the geographical levels and characteristics of UCPs, calling for a broader examination of the effects of UCPs on the urban spatial structure at the metropolitan level.

2.2 Density Functions and Gradients

Because UCPs affect housing, land markets and, more generally, the urban spatial structure, and because employment and population density functions have often been used to analyse the spatial structure of MAs, a short overview of these functions is presented here. Population or employment densities generally decline with distance from the MA centre and the density gradients derived from these functions have been used to measure the extent of spatial concentration. While alternative functional specifications have been used (McDonald, 1989), the negative exponential function, first proposed by Clark (1951), has been most often used, with

$$D(x) = D_0 e^{-\gamma x} \qquad (1)$$

where, $D(x)$ is the density at distance x from the central business district (CBD); D_0 the density at the CBD; and γ the constant density gradient.

The monocentric model has been extended to fit a polycentric development pattern, with multiple identified employment centres. This model assumes that every centre has an influence and requires non-linear estimation (Anas *et al.*, 1998). Alternative approaches include cubic spline density functions, where the relationship between density and distance is modelled with piecewise and continuous polynomials (Anderson, 1985) and non-parametric estimation procedures, such as locally (or geographically) weighted regression, to allow for local variations in the estimated parameters (McMillen and McDonald, 1997; Fotheringham *et al.*, 1998).

The estimated density gradients have been used as variables for further analyses. For example, Cooke (1978) and Thurston and Yezer (1994) use population and employment density gradients to examine causality relationships between population and employment. Alperovich (1983) investigates the main factors that influence the population density gradients of Israeli cities, regressing the estimated gradients on transport costs, income, city age and the tightness of the land market (land area per resident). While the relationships between population and employment densities and the factors that influence density gradients are well addressed in these studies, they fail to consider the policies that may affect population and employment.

Table 1. Positive and negative impacts of UCPs

	Positive	*Negative*
Open space and farmland	Preservation of open space and farmland (Pendall *et al.*, 2002; Staley *et al.*, 1999)	Unintended social disparity: new winners are wealthier households who own non-commercial farms as a hobby and are subsidised by lower land values outside the growth boundary (O'Toole, 2003)
		Threat to open spaces: the scarcity of available land[a] within the boundary may be a threat to open and recreational spaces, as these spaces can be converted into urban uses (Richardson and Gordon, 2000)
Housing development	Revitalisation of central cities increasing residential constructions (Nelson *et al.*, 2004)	Displacement of rental housing: one-third of the rental housing constructed in California during the 1980s was displaced from controlled to non-controlled communities (Levine, 1999)
	Accommodation of new housing developments within the boundary (Carlson and Dierwechter, 2007)	Negative welfare impacts on the land and housing markets by raising housing prices (O'Toole, 2007; Richardson and Gordon, 2000)
		Restriction on choices of residence: UCPs do not allow for the spacious housing lots that most people prefer to own in suburban areas (O'Toole, 2003)
Spatial structure	Orderly transition from rural to urban land use	Spillover effects: the edge of cities has become a low-density residential ring outside UCP boundaries (Nelson, 1994)
	Reduction of land consumption promoting compact developments (Wassmer, 2006; Pendall *et al.*, 2002; Staley *et al.*, 1999; Ding *et al.*, 1999)	Increase of vehicle miles travelled (Rodriguez et al., 2006)
Economy		Unintended economic result: the above negative impacts of UCPs may also negatively affect the regional economy by restricting the location of new industries and their employees, who would move in from other regions

[a] In Portland, Oregon, the urban growth boundary was established in 1979 and vacant land within the boundary has decreased by almost 20 per cent between 1980 and 1997 (Staley *et al.*, 1999).

3. Methodology

To measure the influence of the central city, the central focus of this paper, the density gradients for both population and employment are estimated with the monocentric negative exponential model and used as the endogenous variables in regression models. The choice of the monocentric model, instead of a polycentric one, can be justified as follows.

First, most (if not all) MAs have a dominant centre, generally identified as the historical CBD. Historically, both population and employment densities have been observed to decrease away from this centre. The relatively recent emergence of secondary centres generates kinks in this declining pattern, but does not eliminate it altogether. Thus, flatter density curves are likely to emerge in MAs with multiple secondary centres and the monocentric model will capture this flatter pattern, as desired. Secondly, it is not clear how a unique, integrated measure characterising the spatial structure of all the sample MAs could be derived from a polycentric density model, because MAs vary considerably in terms of number, size and composition of secondary centres. This, certainly, could be the subject of further research, but is clearly beyond the scope of this study.

The interrelationships between population and employment density gradients and other determinants, including urban containment policies, are then assessed using a simultaneous equation modelling (SEM) approach. Similar SEM applications can be found in Steinnes (1977), who uses shares of residents and employees in the centre city and the suburban ring; Carlino and Mills (1987), who use population and employment densities to analyse population and employment growth; and Boarnet (1994), who uses changes in population and employment as the endogenous variables.

The negative exponential model assumes that the decrease in density from the CBD results from utility maximisation of residents and profit maximisation of firms. An urban resident prefers a short commute, while a suburban resident trades off accessibility to employment for more living space (Chen *et al.*, 2008). When household income rises, the following situations are possible: an increase in the opportunity cost of commuting because time is more valuable; and, an increase in housing consumption because housing is a normal good. If the income elasticity of demand for housing space is larger than the income elasticity of commuting costs, wealthier people will live in suburban areas with larger houses (Alperovich, 1983). As a result, as income increases, people tend to move further out for more housing space, because their bids for housing shift from the centre to outer areas. Such trade-off may also be affected by socio-demographic and neighbourhood attributes, including population density, crime rate and school quality. Many studies suggest that population density positively affects household's residential location choice, and crime rate does so negatively, while the effect of school quality on residential location choice varies by race (Bhat and Guo, 2004; Srour *et al.*, 2002; Barrow, 2002).

The size of a MA must also be considered. In larger MAs with high population density, transport costs are higher due to long commuting times, traffic congestion and sometimes congestion fees. However, even small MAs in terms of land area can induce significant traffic congestion due to high population density, constrained infrastructure network (such as bridges) and insufficient transit systems. People may consider moving to the central city if transport costs are very high and if differences in neighbourhood attributes, such as school quality and crime rate, between suburban areas and the central city are negligible. The choice of residential location in suburban areas is also restricted when urban containment policies are adopted due to their limitation on spatial growth. This is why urban policies must be incorporated into the analysis. The general simultaneous equation model proposed to explain population and employment density gradients is

$$PDG = \mathrm{F}(EDG, POPD_0, \mathbf{SE}, \mathbf{HOUS}, \mathbf{TRANS}, \mathbf{FIN}, \mathbf{GOV}, \mathbf{UCP}) \tag{2}$$

$$EDG = \mathrm{G}(PDG, EMPD_0, \mathbf{SE}, \mathbf{HOUS}, \mathbf{TRANS}, \mathbf{FIN}, \mathbf{GOV}, \mathbf{UCP}) \tag{3}$$

where, *PDG* and *EDG* are the population and employment density gradients of the MA; $POPD_0$ and $EMPD_0$ are its CBD population and employment densities; **SE** is a vector of socioeconomic characteristics (rural population, income and employment by sector); **HOUS** is a vector of housing characteristics (tenure, vacancy rate, and central city age); **TRANS** is a vector of a transport variable (workers owning one or more cars); **FIN** is a vector of financial characteristics (federal expenditures and property tax); **GOV** is a vector of institutional characteristics (fragmentation and land use regulation); and **UCP** is a vector representing the numbers of years of UCP enforcement, indicating how long ago stringent (UGBs) and less stringent (USAs) containment policies have been adopted.

Stringent containment policies are subdivided into state-mandated UGBs (hereafter State UGB) and locally adopted UGBs (hereafter Local UGB). This distinction is important because, in MAs with State UGB, urban growth may take place in several cities where UGBs are adopted, promoting polycentric patterns, as illustrated in Figure 1. Thus, most urban development and growth can only occur within UGBs in states where state-wide UGBs are adopted. However, under Local UGB, while urban growth takes place in cities with UGBs, spillover effects may affect surrounding jurisdictions that are not subject to UGBs. An example of Local UGB is illustrated in Figure 2. Similarly, locally adopted USAs (hereafter Local USA), which are least stringent, may generate spillover effects in surrounding areas because there is no restriction beyond the USAs, as illustrated in Figure 3. While there are state-mandated USAs, only locally adopted USAs are included in the analysis because most state-mandated USAs were adopted in 1999 or after.

4. Data

4.1 Selection of Metropolitan Areas

The impacts of UCPs on the urban spatial structure are analysed by examining population and employment density gradients in both contained and uncontained areas. The density gradients of US MAs are used as the endogenous variables and, therefore, the

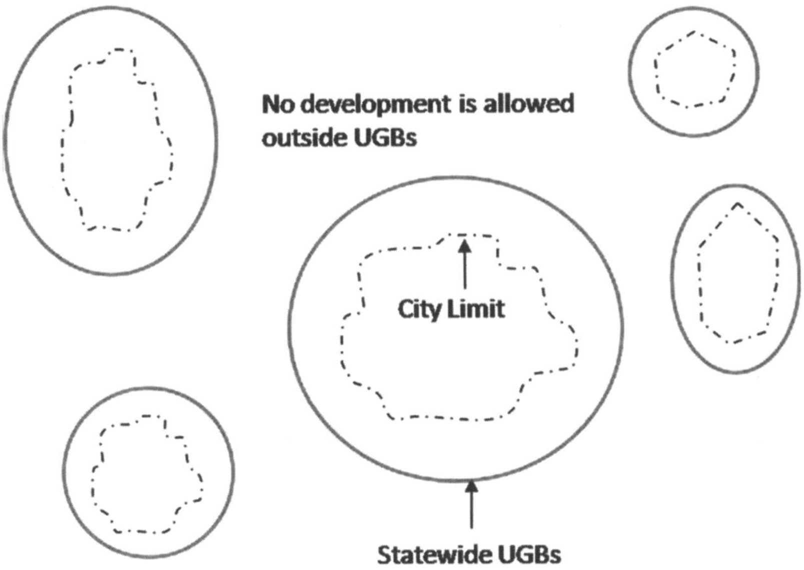

Figure 1. State-mandated UGBs.

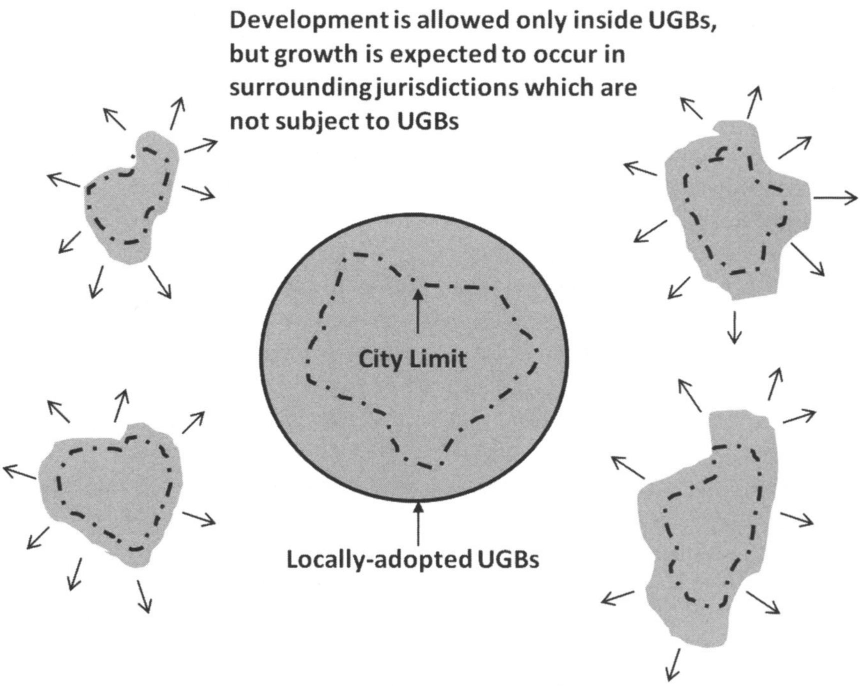

Figure 2. Locally adopted UGBs.

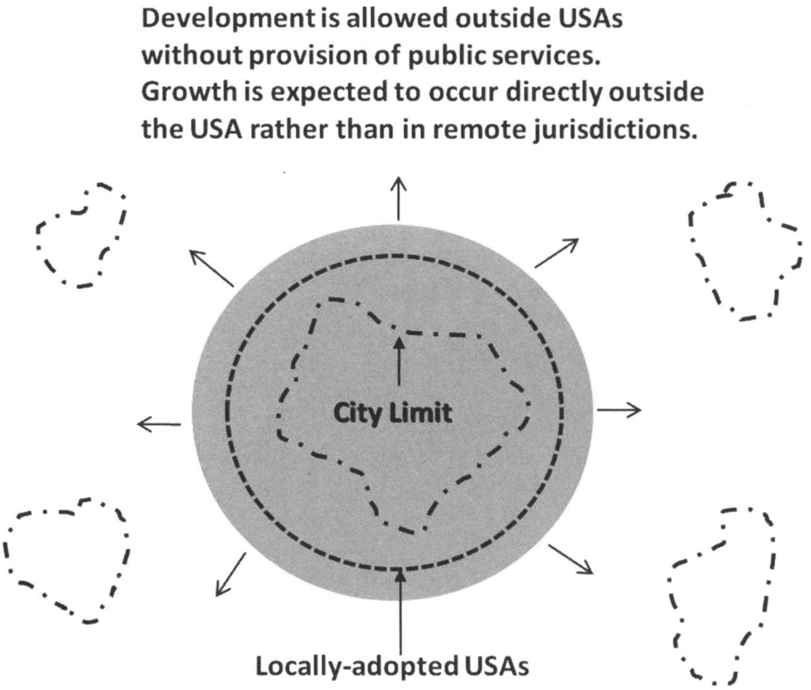

Figure 3. Locally adopted USAs.

primary spatial unit of this analysis is a MA. To estimate these gradients, population and employment data for the year 2000 at the traffic-analysis-zone (TAZ) level are used.

Based on Census 2000 data, 135 metropolitan statistical areas (MSAs), out of 368 census-defined MSAs, are selected as the sample for the following reasons. Consolidated metropolitan statistical areas (CMSAs) have been discarded because they are too large to capture the influence of a unique CBD. CMSAs sometimes extend across more than one state. On the other hand, MSAs are MAs surrounded by non-metropolitan areas. Since MSAs do not closely interact with other MAs, the impacts of UCPs can be measured effectively within MSAs. Also, some MSAs without consistent TAZ-level data on population and employment across their counties were removed from the sample (for example, Columbus, Ohio).

The sample of the 135 MSAs is compared with the whole population of MSAs in Table 2. The total population and employment in 1990 and 2000 for all the 368 MSAs have been extracted from the Woods and Poole database (Woods and Poole Economics, Inc., 2004). The Woods and Poole database covers both historical data and projections for selected years from 1969 through 2030, containing regional demographic and economic data, such as population by age and ethnicity, employment, earnings and income, at the combined statistical areas, metropolitan statistical areas and county levels. Table 2 shows that the sample is not significantly different from the 368 MSAs in terms of total population and employment in 1990 and 2000, population and employment changes over 1990–2000 and growth rates during the same period, suggesting that the sample is representative of all US MSAs.

4.2 Variables

4.2.1 Density gradients. The basic spatial unit for estimating an MSA density gradient is the traffic analysis zone (TAZ), as used in the 2000 Census Transportation Planning Package (CTPP). Geographical information system (GIS) coverage and attribute files have been obtained from the US Bureau of Transportation Statistics (BTS) and

Table 2. Comparisons of the sample MSAs with the MSA population

				T-test		
Variable	*Sample*	*Number*	*Mean (thousands)*	*Method/variances*	*t*	*Pr>|t|*
Population (1990)	Sample MSAs Population MAs	135 368	556.88 562.32	Satterthwaite/ unequal	−0.06	0.95
Population (2000)	Sample MSAs Population MAs	135 368	648.46 641.57	Satterthwaite/ unequal	0.07	0.94
Employment (1990)	Sample MSAs Population MAs	135 368	317.55 322.69	Satterthwaite/ unequal	−0.10	0.92
Employment (2000)	Sample MSAs Population MAs	135 368	397.04 387.54	Satterthwaite/ unequal	0.16	0.87
Population change	Sample MSAs Population MAs	135 368	91.59 79.26	Pooled/equal	0.70	0.49
Employment change	Sample MSAs Population MAs	135 368	79.48 64.85	Pooled/equal	1.18	0.24
Population growth rate	Sample MSAs Population MAs	135 368	15.86 per cent 14.65 per cent	Pooled/equal	0.91	0.36
Employment growth rate	Sample MSAs Population MAs	135 368	24.37 per cent 22.88 per cent	Pooled/equal	1.02	0.31

the Environmental Systems Research Institute (ESRI).[4] The population and employment density gradients for 2000 have been estimated for each MSA using the negative exponential model and OLS regression. The CBD population and employment densities ($POPD_0$ and $EMPD_0$ in equations 2–3) are the densities of the TAZ with the highest employment density. This TAZ was identified as the CBD for the estimation of the density functions. These are the only variables derived from detailed geographical data. All the other data described in the following sections pertain either to the whole MSA or its central city.

Socioeconomic characteristics. There are two models regarding the effects of income on suburbanisation: 'natural evolution' and 'flight from blight'. According to the natural evolution model, an increase in household income leads to an increase in housing consumption. The flight from blight model assumes that households, as their income increases, move to the suburbs in response to the fiscal and social problems associated with the central city. On the other hand, Wassmer (2008) argues that the percentage of households with higher income (for example, greater than $100 000) is positively related to compact urban areas. Also, as an MA becomes more fully suburbanised, the density gradient for the MA is likely to become smaller, indicating a population dispersed across the MA. To account for these factors, data on per capita income, share of households with income greater than $100 000 and rural population share have been collected from American FactFinder.[5] These variables characterise the whole MSA, except the share of households with higher income, which characterises the central city, and is used to assess the influence of the central city on the MSA.

Because different industry sectors have different agglomeration economies and bid rents, the shares of employment may contribute differently to the shaping of the density gradients and the urban spatial structure (Burchfield *et al.*, 2006; Wassmer, 2008). The shares of employment in manufacturing, wholesale, retail, and finance/insurance/real estate are used, as derived from the 2000 CTPP.

Housing characteristics. Increasing housing values[6] induce people to move farther out, as long as the demand for high-density residential developments in the central city does not increase. Homeownership is closely related to suburbanisation. For example, the homeownership boom in the 1990s fuelled the growth of the White population in the outer suburbs (Harris and McArdle, 2004). Also, a higher vacancy rate for housing units and an old central city correspond to more suburbanisation with smaller density gradients (Alperovich, 1983). The central-city variables include the housing vacancy rate, the central-city age, based on its incorporation year (representing the extent of the deterioration of the central city) and the homeownership rate, all drawn from American FactFinder.

Transport characteristics. Improvements in transport systems, in particular highways, and low fuel prices have reduced transport costs and promoted the use of cars rather than transit systems, leading to more spread-out urban areas. Muth (1969) uses car registration and Alperovich (1983) uses the percentage of car-owning families to represent transport costs. However, their results differ: negative for Muth and positive for Alperovich, who interprets this difference as related to differences in car-purchasing habits. If the costs of purchasing and operating a car are high, transport costs are high, resulting in steeper density gradients. Wassmer (2008) uses the percentage of households owning one or more cars as a proxy for transport cost and finds that this variable negatively affects population density and increases the size of urbanised areas. In this research, the share of workers owning one or more cars, drawn from the 2000 CTPP, is used to control for transport cost. While this share is likely to be correlated with transport costs, it may be a weak proxy, but alternative integrated measures of these costs are not available at the MA level.

Government financial characteristics. Persky and Kurban (2003) show that federal spending in central cities does not prevent urban sprawl, because its effect is outweighed by federal subsidies to housing, which reduce development costs in outer areas. To account for this, three variables of federal expenditures over 1993–99 are drawn from the Consolidated Federal Funds Report (CFFR) (US Bureau of the Census). Specifically, federal expenditures per capita in central cities are used to examine whether federal spending in central cities contributes to the vitality of the cities. Also, the variables of federal expenditures per capita on housing and transport at the MA level are used to control for the contribution to suburbanisation of MA-wide federal spending on housing and transport.

Brueckner and Kim (2003) discuss the impact of the property tax on urban sprawl with two countervailing theoretical models: the 'dwelling size effect' and 'depressing improvement effect' models. In the dwelling size effect model, the property tax increases population density because consumers tend to reduce their dwelling sizes to avoid higher taxes, while, in the depressing improvement effect model, it contributes to urban sprawl by reducing the intensity of land development in urban areas because taxing capital (for example, improvement) discourages developers from developing vacant lands. Such opposite effects are also found in empirical analyses. For example, Song and Zenou (2006) show that higher property tax rates tend to reduce the size of urbanised areas, while Wassmer (2008) argues that the reliance of state-wide own-source revenue on the property tax negatively affects population density, resulting in the expansion of urbanised areas. To account for possible property taxation effects, the shares of property taxes in county and municipal government revenues by state were obtained from the 1997 Census of Governments.

UCPs and land use regulations. The UCP variables represent the number of years during which the UCPs (State UGB, Local UGB and Local USA) have been adopted in the central cities. Among the 135 sample MSAs, there are 5 State UGB MSAs, 19 Local UGB MSAs, 19 Local USA MSAs and 92 uncontained MSAs. The contained areas were identified through diverse sources, including Wassmer (2006), Nelson *et al.* (2004), Nelson and Dawkins (2004), Gerber and Philips (2004), Kolakowski *et al.* (2000) and Aytur *et al.* (2007), local comprehensive plans and relevant websites. In addition, the contained areas were confirmed by an email survey of planners in public agencies implemented by the authors over 2005–07. They used a list of possible sample cities identified from the published literature and web information, to gather information on the UCPs, including the existence and characteristics of such policies, their adoption year and their geographical scale (state-mandated or locally adopted). The 135 sample MSAs are listed in the Appendix.

Other land use policies and the political fragmentation of regions contribute to urban sprawl and the shape of the urban spatial structure. To account for differences in state-wide urban policies, two dummy variables, indicating the existence of state planning legislation with guidelines for land use elements and the formal adoption of local comprehensive plans, are derived from the

Summary of State Land Use Planning Laws, prepared by the Institute for Business and Home Safety (1998) in collaboration with the American Planning Association. In addition, the number of municipalities in each MA is calculated to measure the degree of fragmentation in the planning system of a region and possible development competitions in fringe areas, promoting low-density suburbanisation (Wassmer, 2008).

5. Results

5.1 Overview

Table 3 shows that central-city housing characteristics differed significantly between contained and uncontained areas in 2000. As expected, median housing values are higher in contained central cities than in uncontained ones. Contained central cities have a lower housing vacancy rate than uncontained ones, implying that the limited supply of land due to UCP adoption may reduce existing housing stock abandonment and may encourage new growth within growth boundaries. In addition, the median housing age in central cities with UGBs (both State UGB and Local UGB) is significantly lower than that in uncontained central cities. This is consistent with Nelson *et al.* (2004), who suggest that new developments are likely to take place in contained central cities through infill development and redevelopment. However, there is no statistical evidence that the median housing age of Local USA central cities is different from that of uncontained central cities. These differential housing characteristics under containment policies may affect the spatial structure of both suburban areas and central cities.

Table 4 shows that central cities with statewide UGBs have had population growth over 1990–2000 that is about twice as high as uncontained ones. However, during the same period, the suburban areas of contained central cities with all forms of UCPs have experienced a population growth similar to that of uncontained central cities: 20.83 per cent with State UGB, 22.71 per cent with Local UGB, 16.23 per cent with Local USA and 18.82 per cent for uncontained central cities. Since suburban cities are bounded by growth boundaries under State UGB, it is likely that their growth is accommodated within their own growth boundaries. However, in uncontained suburban areas of Local UGB and Local USA MSAs, the suburban growth of 22.71 per cent and 16.23 per cent beyond the growth boundaries may take place in both incorporated and unincorporated areas, thus allowing for growth dispersion since there are no restrictions on development in such suburban cities.

Central cities with State UGB have also a much higher employment growth rate (27.87 per cent) than uncontained cities (11.06 per cent), while their suburban areas have an average growth rate of 22.38 per cent, significantly lower than the growth rate for the suburban

Table 3. Housing value, vacancy rate and age in central cities for different types of MSA in 2000

Variable	*State UGB*	*Local UGB*	*Local USA*	*Uncontained*
Median housing value ($)	137 240***	126 436***	104 673***	86 053
Vacancy rate (percentage)	5.74***	6.25***	7.29*	8.77
Median house age (years)	29.4**	29.1***	36.3	37.3

Notes: *** significant at the 1 per cent level; ** significant at the 5 per cent level; and * significant at the 10 per cent level. The statistical significance (t-test) is related to the difference between contained MSAs and uncontained MSAs.

Table 4. Comparison of population and employment growth across different urban areas

Type of Area	*State UGB*	*Local UGB*	*Local USA*	*Uncontained*
Population growth, 1990–2000, (percentage)				
Central city	25.39**	13.55	12.42	13.02
Suburban area	20.83	22.71	16.23	18.82
Metropolitan area	22.61	19.30	15.20	15.55
Employment growth, 1990–2000, (percentage)				
Central city	27.87**	11.15	5.63	11.06
Suburban area	22.38*	31.82	34.53	43.13
Metropolitan area	26.68	17.76	14.96*	23.83

Notes: ** significant at the 5 per cent level; and * significant at the 10 per cent level. The statistical significance (t-test) is related to the difference between contained MSAs and uncontained MSAs.

areas of uncontained central cities (43.13 per cent). However, Local UGB and Local USA do not seem to prevent the suburbanisation of employment, allowing for growth rates in suburban areas approximately three times or more larger than those in central areas. These data suggest that State UGB promotes population and employment growth in both central cities and suburban areas, while the slow employment growth in the central cities of Local UGB, Local USA and uncontained MSAs is compensated by the high employment growth of their suburban areas, thus inducing non-residential sprawl.

In summary, it appears that MAs with statewide UGBs attracted both population and employment in both their central cities and suburban areas over 1990–2000, while locally contained and uncontained MAs experienced much higher population and employment increases in suburban areas than in central cities.

The population and employment density gradients of the 135 selected MSAs (43 contained and 92 uncontained central cities) are estimated using the negative exponential model with TAZ-level data. The centroid of the TAZ with the highest employment density is taken as the location of the CBD. In addition, street maps have been used to verify further that this centroid is indeed located within the downtown area.

Table 5 shows that, as expected, the employment density gradients are steeper than the population ones, implying that residents are located further out from the CBD than economic activities. However, the difference between population and employment density gradients is relatively small in State UGB MSAs (0.014), but larger for Local UGB (0.041) and Local USA MSAs (0.069). Residential and economic activities are thus more likely to co-locate in UGB MSAs than in Local USA MSAs, possibly because of higher land values in UGB MSAs.

A monocentric pattern is efficient if the size of the MA is relatively small. However, as the MA grows, this monocentric structure may become inefficient, generating negative externalities such as pollution and congestion. A polycentric development pattern, where population and economic activities are concentrated in several sub-centres as well as in the CBD, is known as the most efficient spatial structure in terms of energy savings and environmental quality (for example, air pollution), by reducing commuting and travel time (Haines, 1986; cited by Heim, 2001, p. 273). Both the population and employment density gradients are lowest in State UGB MSAs, because most of the land in the central cities and the other MSA municipalities is densely developed, implying that State UGB

Table 5. Average population and employment density gradients in contained and uncontained MSAs in 2000

	Metropolitan areas			
Measures	*State UGB (n = 5)*	*Local UGB (n = 19)*	*Local USA (n = 19)*	*Uncontained (n = 92)*
Population density gradient	0.063**	0.117**	0.198	0.165
Employment density gradient	0.077***	0.158**	0.267	0.230
R^2 of population density function	0.115***	0.213***	0.345	0.316
R^2 of employment density function	0.123***	0.255**	0.387	0.350

Notes: *** significant at the 1 per cent level; ** significant at the 5 per cent level. The statistical significance (t-test) is related to the difference between contained MSAs and uncontained MSAs.

MAs may have a polycentric structure. This is supported by the lower R^2 for the population and employment density functions in State UGB MAs (around 0.12), in contrast to 0.35 and 0.39 in Local USA MSAs. Hence, for the contained MSAs, the tighter the containment policies, the closer to the polycentric structure. However, it should be noted that the density gradient alone does not make it clear whether these MAs are moving towards urban sprawl with a dispersed development pattern or towards a polycentric pattern.

5.2 Effects of UCPs on Density Gradients

Estimation results. Equations (2) and (3) are estimated with three-stage least squares (3SLS),[7] while taking the logarithm of the endogenous variables (population and employment density gradients) and of all the exogenous variables. The error terms of the two equations may include the effects of the same unobserved variables, hence are likely to be correlated. The 3SLS procedure takes this contemporaneous correlation of errors into account to improve the efficiency of the parameter estimates (Kennedy, 2003). Table 6 presents descriptive statistics for all the selected variables. Possible multicollinearity was assessed with the variance inflation factor (VIF) and correlation analysis for the explanatory variables.[8] Table 7 presents the estimation results. Both the order and the rank identification conditions are verified. The reduced forms of the simultaneous equations are presented in Table 8.

Impacts of non-UCP variables. Both the employment density gradient and the population density in the CBD have positive effects on the population density gradient (0.438 and 0.513), while the impact of the population density gradient on the employment density gradient is not significant. However, the employment density in the CBD has a significant and positive effect on the employment density gradient. The share of the rural population in the metropolitan area has a positive effect on both gradients, pointing to higher population and employment concentrations in the central cities.

Table 7 shows an interesting result regarding the impacts of homeownership rates on the population density gradient. For example, the homeownership rate in the central city positively affects the population density gradient (0.460), whereas the homeownership rate at the metropolitan level has a negative effect (–1.109). It also negatively affects the employment density gradient (–1.034). An increase in owner-occupied housing in the central city positively affects the population of the central city, possibly contributing to its revitalisation. On the other hand, more

Table 6. Descriptive statistics

Variable	*Unit*	*Mean*	*Minimum*	*Maximum*
Population density gradient, MSA	(estimated)	0.160	0.016	0.496
Employment density gradient, MSA	(estimated)	0.220	0.017	0.652
Population density, CBD	Person/acre	6.82	0.00	71.13
Employment density, CBD	Employee/acre	181.3	13.7	1,290.7
Rural population share, MSA	Percentage	19.8	1.7	43.2
Housing vacancy rate-central city	Percentage	8.1	3.1	16.6
Central-city age	Year	158	81	314
Share of households with income greater than $100 000, central city	Percentage	12.8	3.4	31.8
Homeownership rate, MSA	Percentage	67.1	45.6	79.8
Homeownership rate, central city	Percentage	54.1	37.6	70.9
Per capita income, MSA	$	19 919	9 899	26 219
Share of employment in manufacturing, MSA	Percentage	13.5	2.2	40.6
Share of employment in wholesale, MSA	Percentage	3.6	1.7	7.4
Share of employment in retail, MSA	Percentage	12.2	9.7	17.6
Share of employment in finance/insurance/real estate (FIRE), MSA	Percentage	6.3	2.7	15.3
Share of workers owning one or more cars, MSA	Percentage	96.5	92.4	98.1
Federal expenditure per capita, central city	$	4 135	49	41 730
Federal expenditure per capita on housing, MSA	$	370	34	966
Federal expenditure per capita on transport, MSA	$	172	50	553
Share of state's county own-source revenue from property tax, state	Percentage	26.7	11.4	87.1
Share of state's municipal own-source revenue from property tax, state	Percentage	14.4	2.5	50.4
Number of cities within MSA	Number	41	6	317
State planning legislation with guidelines for land use elements, state	1 or 0	0.26	0	1
Formal adoption of local comprehensive plans, state	1 or 0	0.57	0	1

Table 7. Structural equations for population and employment density gradients

Variable	*Population density gradient*	*Employment density gradient*
Intercept	−1.570	−0.135
	(−0.69)	(−0.05)
Population density gradient	–	0.221
		(1.47)
Employment density gradient	0.438***	–
	(4.53)	
Population density, CBD	0.513***	–
	(5.34)	
Employment density, CBD	–	0.607***
		(5.75)
Housing vacancy rate-central city	−0.319***	−0.072
	(−3.78)	(−0.62)
Central-city age	−0.095	−0.184
	(−1.01)	(−1.59)
Share of households with income greater than $100 000, central city	−0.122*	−0.043
	(−1.82)	(−0.51)
Homeownership rate, MSA	−1.109***	−1.034**
	(−2.94)	(−2.08)
Homeownership rate, central city	0.460**	0.348
	(2.43)	(1.5)
Rural population share	0.337***	0.361***
	(4.22)	(4.9)
Per capita income	0.074	0.082
	(0.36)	(0.35)
Share of employment in manufacturing	−0.078	−0.109
	(−1.2)	(−1.51)
Share of employment in wholesale	0.083	0.124
	(0.85)	(1.11)
Share of employment in retail	0.540**	0.875**
	(2.12)	(2.59)
Share of employment in finance, insurance and real estate	0.026	−0.183
	(0.26)	(−1.55)
Share of workers owning one or more cars	−0.804	5.274^
	(−0.27)	(1.62)
Federal expenditure per capita, central city	0.023	−0.006
	(0.93)	(−0.22)
Federal expenditure per capita on housing, MSA	−0.018	–
	(−0.57)	
Federal expenditure per capita on transport, MSA	–	0.109*
		(1.73)
Share of state's county own-source revenue from property tax	0.130*	0.108
	(1.74)	(1.26)
Share of state's municipal own-source revenue from property tax	−0.078^	−0.025
	(−1.66)	(−0.45)
Number of cities within MSA	−0.148***	−0.183***
	(−3.56)	(−3.27)

Table 7. Continued

Variable	*Population density gradient*	*Employment density gradient*
State planning legislation with guidelines for land use elements	−0.035 (−0.72)	−0.097 (−1.6)
Formal adoption of local comprehensive plans	−0.151*** (−2.86)	−0.157** (−2.35)
State UGB (years)	−0.008** (−2.13)	−0.010** (−2.14)
Local UGB (years)	−0.003^ (−1.62)	−0.003 (−1.4)
Local USA (years)	0.002 (1.09)	0.003* (1.71)
System weighted R^2	0.796	

Notes: *** significant at the 1 per cent level; ** significant at the 5 per cent level; * significant at the 10 per cent level; and ^ significant at the 11 per cent level.

Table 8. Reduced-form equations for population and employment density gradients

Variable	*Population density gradient*	*Employment density gradient*
Intercept	−1.804 (−0.521)	−0.534 (−0.163)
Population density, CBD	0.568*** (4.566)	0.126 (1.155)
Employment density, CBD	0.294*** (3.097)	0.672*** (6.061)
Housing vacancy rate, central city	−0.388*** (−3.043)	−0.158 (−1.31)
Central city age	−0.195 (−1.345)	−0.227 (−1.637)
Share of households with income greater than $100 000, central city	−0.156 (−1.509)	−0.077 (−0.783)
Homeownership rate, MSA	−1.729*** (−3.156)	−1.416** (−2.688)
Homeownership rate, central city	0.678** (2.447)	0.498* (1.894)
Rural population share	0.548*** (7.339)	0.482*** (6.966)
Per capita income	0.122 (0.389)	0.109 (0.369)
Share of employment in manufacturing	−0.139 (−1.48)	−0.140 (−1.551)
Share of employment in wholesale	0.152 (1.039)	0.158 (1.131)
Share of employment in retail	1.022** (2.751)	1.101*** (3.096)
Share of employment in finance, insurance and real estate	−0.06 (−0.392)	−0.196 (−1.339)

(Continued)

Table 8. (Continued)

Variable	*Population density gradient*	*Employment density gradient*
Share of workers owning one or more cars	1.666	5.643
	(0.383)	(1.365)
Federal expenditure per capita, central city	0.022	−0.002
	(0.586)	(−0.042)
Federal expenditure per capita on housing, MSA	−0.02	−0.004
	(−0.573)	(−0.061)
Federal expenditure per capita on transport, MSA	0.053	0.121***
	(1.449)	(15.644)
Share of state's county own-source revenue from property tax	0.196*	0.152
	(1.792)	(1.451)
Share of state's municipal own-source revenue from property tax	−0.099	−0.047
	(−1.376)	(−0.691)
Number of cities within MSA	−0.253***	−0.239***
	(−4.915)	(−4.794)
State planning legislation with guidelines for land use elements	−0.086	−0.116
	(−1.132)	(−1.601)
Formal adoption of local comprehensive plans	−0.243***	−0.211***
	(−3.324)	(−3.023)
State UGB (years)	−0.014**	−0.013**
	(−2.647)	(−2.568)
Local UGB (years)	−0.005^	−0.004
	(−1.656)	(−1.567)
Local USA (years)	0.003	0.004*
	(1.365)	(1.81)

Notes: *** significant at the 1 per cent level; ** significant at the 5 per cent level; * significant at the 10 per cent level; and ^ significant at the 11 per cent level.

owner-occupied (rather than rental) housing at the metropolitan level encourages population dispersion, implying that more owner-occupied houses were developed in outer areas than in central cities.

The coefficients of the structural equations measure the direct effects of the exogenous variables on the endogenous variables, without capturing the indirect effects embodied in the other equations. The reduced-form coefficients incorporate both the direct and indirect effects of the exogenous variables (Carlino and Mills, 1987). The results for the reduced-form equations in Table 8 are consistent with those for the structural equations. Also, as all variables are in logarithmic form, the coefficients represent the elasticities of the endogenous variables with respect to the exogenous variables. For example, according to Table 8 (the coefficients of the reduced form), a 1 per cent increase in the homeownership rate in central cities results in 0.68 per cent and 0.50 per cent increases in the population and employment density gradients respectively. A 1 per cent increase in the housing vacancy rate in central cities reduces by 0.39 per cent the population density gradient. Unexpectedly, the share of households with income greater than $100 000 in central cities, which represents the vitality of central cities, contributes to the flattening of the population density gradient as well, although it is not significant in the reduced-form equations. This suggests that attracting higher-income people to reside in the central city does not prevent urban sprawl, although it may contribute to the revitalisation of the central cities. The share of retail employment positively affects the density gradients, with a 1 per cent increase in the share of retail employment resulting in 0.54 and 0.88 per cent increases in the population and employment density gradients respectively, perhaps due to the location advantages of central cities with higher density.

While the share of workers owning one or more cars (a proxy for transport cost) has no statistical significance for the population density gradient, its negative sign is consistent with Muth's result. A 1 per cent increase in per capita federal expenditures on transport at the MSA level results in a 0.12 per cent increase in the employment density gradient. This may be because an improved accessibility due to such improvements helps to keep central cities attractive to businesses. The impact of the property taxes on the population density gradient is ambiguous, as the effects of state-wide own-source revenue from the property tax vary across geographical locations. For example, the share of the state-wide county own-source revenue from the property tax positively affects the population density gradient, supporting the dwelling size effect model and Song and Zenou's (2006) results, while the share of the state-wide municipal own-source revenue from the property tax decreases the density gradient, supporting the improvement effect and Wassmer's finding (2008).

Finally, the number of cities within the MSA and the state-wide mandate for formal adoption of local comprehensive plans negatively affect both the population and employment density gradients, implying that fragmentation is associated with a sprawled development pattern (Wassmer, 2008). However, central-city age, per capita income, the employment shares in manufacturing, wholesale and finance/insurance/real estate, federal expenditures per capita in central cities, and the existence of state planning legislation with guidelines for land use elements, all turned out to be insignificant for both the population and employment density gradients.

Effects of UCP variables. The expectations of UCP effects are as follows. First, under State UGB, urban growth is likely to be concentrated within all cities, both central and suburban, where UGBs are mandated by the state, and development does not occur in surrounding areas beyond UGBs. Secondly, under Local UGB, urban growth may be restricted only in central cities where UGBs are adopted and spillover effects may take place in surrounding suburban or exurban counties and cities where no containment policies are adopted. Thirdly, USAs may also have spillover effects in all surrounding areas. These expectations were supported by the results of the descriptive analyses in Table 4. The SEM measures the statistical significance of these effects.

The results for both the structural and reduced-form equations in Tables 7 and 8 indicate that: the State UGB variable has significant effects on both the population and employment density gradients;[9] the Local UGB variable only impacts the population density gradient (11 per cent level); and, the Local USA variable only impacts the employment density gradient, implying that communities with weak containment policies do not generate significant spatial effects at the regional level in terms of population density.

State UGB and Local UGB have both negative and significant effects on the population density gradient, while State UGB has only a negative effect on the employment density gradient. As indicated in Table 5, the negative impacts of UGBs on density gradients confirm that these communities are moving away from monocentricity, where most of the urban functions of the metropolitan area are concentrated in the CBD. This is because the central city is already densely developed and other suburban communities within growth boundaries are also densely developed. Although population and employment are concentrated in the central cities, other suburban centres also attract population and employment within their UGBs. Table 4 supports this conclusion, showing that population and employment increased between 1990 and 2000 across State UGB MAs with similar growth rates for central cities and suburban areas.

While both State UGB and Local UGB have negative effects on the population density gradient, the coefficient of State UGB (–0.014) in the reduced-form equations is almost three times as large as that of Local UGB (–0.005), implying that State UGB MAs are more dispersed than Local UGB MAs within the growth boundary. In other words, a 1 per cent increase in the number of years a state-mandated UGB is in force decreases the population density gradient by 0.014 per cent, but the same increase leads to a 0.005 per cent decrease in the case of a locally adopted UGB, implying that State UGB MAs tend to infill three times faster than Local UGB ones.

In summary, strong containment policies, such as state-mandated UGBs, contribute to both central-city revitalisation and suburban population expansion, which is accommodated within the UGBs of those suburban areas. Thus, state-mandated UGBs encourage infill development within MAs and increase population density. Locally adopted UGBs also promote infill developments within MAs. However, the rate of infill is smaller than in the case of state-mandated UGBs. Thus, the results suggest that locally adopted UGBs, which do not address growth at the state level, are less effective than state-mandated UGBs, supporting the need for planning at the state or beyond.

6. Conclusions

Urban sprawl has been criticised as an undesirable development pattern, not only because it increases infrastructure and public service costs but also because it has negative effects on the environment, consuming fragile lands and producing longer trips and air pollution. Urban containment policies (UCPs) have been increasingly adopted by communities to curb urban sprawl. This paper has examined how different UCPs, such as state-mandated urban growth boundaries (UGBs), locally adopted UGBs and urban service areas (USAs), affect the urban spatial structure of MAs, in order to assess whether UCPs produce a desirable spatial structure and successfully prevent urban sprawl. A simultaneous equation model, with employment and population density gradients as endogenous variables, has been used to examine the impacts of UCPs. The results show that more owner-occupied housing in outer areas, a higher housing vacancy rate in the central city and a fragmented regional planning system promote population dispersion, whereas an increase in the homeownership rate in the central city encourages a larger population concentration in the CBD. The effects of UCPs on the urban spatial structure appear to vary, depending on the geographical and tightness scope of the containment policies. In particular, the results suggest that state-mandated 'strong' containment policies accommodate growth within the growth boundaries more effectively than locally adopted UGBs and USAs. These impacts of UCPs on the urban spatial structure provide insights to policy-makers who consider adopting growth management policies and suggest that UCPs at the state level, rather than at the local level, generate more efficient spatial structures in metropolitan areas.

Potential measurement errors, including weak proxies and measurement in different years, and omitted variable bias, should be explored in future research to improve the singling-out of the effects of UCPs in the model. In addition, the measurement of the urban spatial structure in this paper is based on the simple monocentric model. This approach could be extended along the following lines. In addition to a better characterisation of polycentricity for all sample MAs, as discussed earlier, natural geographical barriers to urban growth, such as mountains, oceans and large lakes, could be quantified into the model because natural geography may play an important role in shaping the urban spatial structure in many US metropolitan areas.

Notes

1. A metropolitan area (MA) is defined by the US Census Bureau as an area that contains either a place with a minimum population of 50 000 or a Census-Bureau-defined urbanised area and a total MA population of at least 100 000 (75 000 in New England). Each MA is classified either as a metropolitan statistical area (MSA) or as a consolidated metropolitan statistical area (CMSA) divided into primary metropolitan statistical areas (PMSAs).
2. Greenbelts were excluded from this study because of too few cases in the US.
3. However, Landis *et al.* (2002) argue that growth control programmes are not primarily responsible for California's high housing prices and rents, and the effect of UGBs on housing prices is relatively small in magnitude (Phillips and Goodstein, 2000).
4. For BTS, see: http://www.transtats.bts.gov; for ESRI, see: http://arcdata.esri.com/data/tiger2000/tiger_download.cfm.
5. See: http://factfinder.census.gov.
6. The median house value was dropped from the list of exogenous variables due to its correlation with other variables, such as the central-city vacancy rate (0.50), the per capita income (0.58) and the federal expenditure on housing (0.50).
7. Three-stage least squares (3SLS) is a more efficient technique than two-stage least squares (2SLS) because it accounts for cross-equation error correlations. It extends 2SLS (Kennedy, 2003), by calculating the 2SLS estimates of the identified equations (population and employment density gradient equations in this paper) and by using these estimates to estimate the structural equations' errors and the contemporaneous variance–covariance matrix of these errors. The cross-model correlation computed from the 2SLS residuals is approximately 65 per cent.
8. There is the challenge of possible endogeneity of explanatory variables especially when they are correlated with unobserved factors. To overcome this problem, an instrumental variable estimation has been used (Song and Zenou, 2006; Wassmer, 2008). Some pairs of independent variables used in this paper appear to be correlated (the correlation matrix is not shown here but is available from the authors upon request). However, the degree of correlation is not severe (0.36 at most) and therefore the endogeneity bias is expected to be minimal.
9. Since the state-mandated UGBs in the sample are concentrated in the north-west of the country (for example, four in Washington and one in Oregon), the results associated with population and employment density gradients may reflect some characteristics of these states.

References

Alperovich, G. (1983) An empirical study of population density gradients and their determinants, *Journal of Regional Science*, 23(4), pp. 529–540.

Anas, A., Small, K. A. and Arnott, R. J. (1998) Urban spatial structure, *Journal of Economic Literature*, 36(3), pp. 1426–1464.

Anderson, J. E. (1985) The changing structure of a city: temporal changes in cubic spline urban density patterns, *Journal of Regional Science*, 25(3), pp. 413–425.

Aytur, S., Rodriguez, D., Evenson, K. and Catellier, D. (2007) *Relationships of urban containment policies to physical activity: a longitudinal analysis of large U.S. metropolitan areas.* The University of North Carolina, Chapel Hill (www.activelivingresearch.org/alr/files/Aytur_Plenary_2007.pdf).

Barrow, L. (2002) School choice through relocation: evidence from the Washington, D.C. area, *Journal of Public Economics*, 86(2), pp. 155–189.

Bhat, C. and Guo, J. (2004) A mixed spatially correlated logit model: formulation and application to residential choice modeling, *Transportation Research B*, 38, pp. 147–168.

Boarnet, M. G. (1994) The monocentric model and employment location, *Journal of Urban Economics*, 36, pp. 79–97.

Brueckner, J. K. (2000) Urban sprawl: diagnosis and remedies, *International Regional Science Review*, 23(2), pp. 160–171.

Brueckner, J. K. (2001) Urban sprawl: lessons from urban economics, in: W. G. Gale and J. R. Pack (Eds) *Brookings-Wharton Papers on Urban Affairs*, pp. 65–89. Washington, DC: Brookings Institution.

Brueckner, J. K. and Kim, H. (2003) Urban sprawl and the property tax, *International Tax and Public Finance*, 10, pp. 5–23.

Burchell, R. W., Shad, N. A., Listokin, D. *et al.* (1998) *Costs of Sprawl-revisited.* Transit Cooperative Research Program Report No. 39, Washington, DC: National Academy Press.

Burchfield, M., Overman, H. G., Puga, D. and Turner, M. A. (2006) Causes of sprawl: a portrait from space, *Quarterly Journal of Economics*, 121(2), pp. 587–633.

Carlino, G. A. and Mills, E. S. (1987) The determinants of county growth, *Journal of Regional Science*, 27(1), pp. 39–54.

Carlson, T. and Dierwechter, Y. (2007) Effects of urban growth boundaries on residential development in Pierce County, Washington, *The Professional Geographer*, 59(2), pp. 209–220.

Carruthers, J. I. (2002) The impacts of state growth management programmes: a comparative analysis, *Urban Studies*, 39(11), pp. 1959–1982.

Chen, J., Chen, C. and Timmermans, H. J. P. (2008) Accessibility trade-offs in household residential location decisions, *Transportation Research Record*, 2007/2008, pp. 71–79.

Clark, C. (1951) Urban population densities, *Journal of the Royal Statistical Society*, 114, pp. 490–494.

Cooke, T. W. (1978) Causality reconsidered: a note, *Journal of Urban Economics*, 5, pp. 538–542.

Ding, C., Knaap, G. J. and Hopkins, L. D. (1999) Managing urban growth with urban growth boundaries: a theoretical analysis, *Journal of Urban Economics*, 46, pp. 53–68.

Ewing, R. H. (1994) Characteristics, causes, and effects of sprawl: a literature review, *Environmental and Urban Issues*, 21(2), pp. 1–15.

Fotheringham, A. S., Brunsdon, C. and Charlton, M. (1998) Geographically weighted regression: a natural evolution of the expansion method for spatial data analysis, *Environment and Planning A*, 30, pp. 1905–1927.

Galster, G., Hanson, R., Ratcliffe, M. R. *et al.* (2001) Wrestling sprawl to the ground: defining and measuring an elusive concept, *Housing Policy Debate*, 12(4), pp. 681–717.

Gerber, E. R. and Phillips, J. H. (2004) *Growth management policy in California communities.* Policy Report No. 2, Center for Local, State, and Urban Policy, University of Michigan.

Haines, V. A. (1986) Energy and urban form: a human ecological critique, *Urban Affairs Quarterly*, 21(3), pp. 337–353.

Harris, D. J. and McArdle, N. (2004) *More than money: the spatial mismatch between where homeowners of color in metro Boston can afford to live and where they actually reside.* The Metro Boston Equity Initiative of The Harvard Civil Rights Project.

Heim, C. E. (2001) Leapfrogging, urban sprawl, and growth management: Phoenix, 1950–2000, *American Journal of Economics and Sociology*, 60(1), pp. 245–283.

Institute for Business and Home Safety (1998) *Summary of state land use planning laws.* Tampa, FL.

Kennedy, P. E. (2003) *A Guide to Econometrics*, 5th edn. Cambridge, MA: The MIT Press.

Kneebone, E. (2009) *Job sprawl revisited: the changing geography of metropolitan employment.* Metro Economy Series, The Metropolitan Policy Program, Brookings Institution, Washington, DC.

Kolakowski, K., Machemer, P., Thomas, J. and Hamlin, R. (2000) *Urban growth boundaries: a policy brief for the Michigan legislature.* Urban and Regional Planning Program, Department of Geography, Michigan State University.

Landis, J. D., Deng, L. and Reilly, M. (2002) *Growth management revisited: a reassessment of its efficacy, price effects, and impacts on metropolitan growth patterns.* Working paper, Institute of Urban and Regional Development, University of California at Berkeley.

Levine, N. (1999) The effects of local growth controls on regional housing production and population redistribution in California, *Urban Studies*, 36(12), pp. 2047–2068.

McDonald, J. F. (1989) Econometric studies of urban population density: a survey, *Journal of Urban Economics*, 26, pp. 361–385.

McMillen, D. P. and McDonald, J. F. (1997) A nonparametric analysis of employment density in a polycentric city, *Journal of Regional Science*, 37(4), pp. 591–612.

Mieszkowski, P. and Mills, E. S. (1993) The causes of metropolitan suburbanization, *Journal of Economic Perspectives*, 7, pp. 135–147.

Muth, R. (1969) *Cities and Housing*. Chicago, IL: The University of Chicago Press.

Nelson, A. C. (1994) Oregon's urban growth boundary policy as a landmark planning tool, in: C. Abbott, D. Howe and S. Adler (Eds) *Planning the Oregon Way: A Twenty Year Evaluation*, pp. 25–47. Corvallis, OR: Oregon State University Press.

Nelson, A. C. and Dawkins, C. J. (2004) Urban *containment in the United States: history, models, and techniques for regional and metropolitan growth management*. PAS Report No. 520, American Planning Association.

Nelson, A. C. and Duncan, J. B. (1995) *Growth Management Principles and Practices*. Chicago, IL: American Planning Association Planners Press.

Nelson, A. C., Burdy, R. J., Feser, E. *et al.* (2004) Urban containment and central-city revitalization, *Journal of the American Planning Association*, 70(4), pp. 411–425.

O'Sullivan, A. (2003) *Urban Economics*, 5th edn. New York: McGraw-Hill/Irwin.

O'Toole, R. (2003) *San Jose demonstrates the limits of urban growth boundaries and urban rail*. Policy Study No. 309, Reason Foundation.

O'Toole, R. (2007) *The planning tax: the case against regional growth-management planning*. Policy Analysis No. 606, Cato Institute, Washington, DC.

Pallagst, K. M. (2007) *Growth Management in the US: Between Theory and Practice*. Aldershot: Ashgate.

Pendall, R., Martin, J. and Fulton, W. (2002) *Holding the line: urban containment in the United States*. A discussion paper prepared for The Brookings Institution Center on Urban and Metropolitan Policy.

Persky, J. and Kurban, H. (2003) Do federal spending and tax policies build cities or promote sprawl?, *Regional Science and Urban Economics*, 33(3), pp. 361–378.

Phillips, J. and Goodstein, E. (2000) Growth management and housing prices: the case of Portland, Oregon, *Contemporary Economic Policy*, 18(3), pp. 334–344.

Richardson, H. W. and Gordon, P. (2000) *Compactness or sprawl: America's future vs. the present*. Paper presented at the *Association of Collegiate Schools of Planning Conference*, Atlanta, November.

Rodriguez, D. A., Targa, F. and Aytur, S. A. (2006) Transport implications of urban containment policies: a study of the largest twenty-five US metropolitan areas, *Urban Studies*, 43(10), pp. 1879–1897.

Song, Y. and Zenou, Y. (2006) Property tax and urban sprawl: theory and implications for US cities, *Journal of Urban Economics*, 60, pp. 519–534.

Srour, M., Kockelman, K. and Dunn, T. (2002) Accessibility indices: connection to residential land prices and location choices, *Transportation Research Record*, 805, pp. 25–34.

Staley, S. R., Edgens, J. G. and Milder, G. C. S. (1999) *A line in the land: urban-growth boundaries, smart growth, and housing affordability*. Policy Study No. 263, Reason Public Policy Institute, November.

Steinnes, D. N. (1977) Causality and intraurban location, *Journal of Urban Economics*, 4, pp. 69–79.

Thurston, L. and Yezer, A. M. J. (1994) Causality in the suburbanization of population and employment, *Journal of Urban Economics*, 35, pp. 105–118.

Wassmer, R. W. (2006) The influence of local urban containment policies and statewide growth management on the size of United States urban areas, *Journal of Regional Science*, 46(1), pp. 25–65.

Wassmer, R. W. (2008) Causes of urban sprawl in the United States: auto reliance as compared to natural evolution, flight from blight, and local revenue reliance, *Journal of Policy Analysis and Management*, 27(3), pp. 536–555.

Weitz, J. and Moore, T. (1998) Development inside urban growth boundaries, *Journal of the American Planning Association*, 64(4), pp. 424–441.

Woods and Poole Economics, Inc. (2004) *Complete economic and demographic data source*. Washington, DC.

Appendix

Table A1. List of metropolitan areas used in the analysis

Number	*Metropolitan area*	*State*	*UCP*
1	Birmingham	AL	—
2	Huntsville	AL	—
3	Tuscaloosa	AL	—
4	Little Rock–North Little Rock	AR	Local USA
5	Fayetteville–Springdale–Rogers	AR	—
6	Fort Smith	AR	—
7	Tucson	AZ	Local UGB
8	Phoenix–Mesa	AZ	—
9	Santa Barbara–Santa Maria–Lompoc	CA	Local UGB
10	San Diego	CA	Local UGB
11	Merced	CA	Local UGB
12	Fresno	CA	Local UGB
13	Stockton–Lodi	CA	Local UGB
14	Modesto	CA	Local UGB
15	Sacramento–Yolo	CA	Local UGB
16	Bakersfield	CA	—
17	Fort Collins–Loveland	CO	Local UGB
18	Colorado Springs	CO	—
19	Gainesville	FL	Local UGB
20	Melbourne–Titusville–Palm Bay	FL	Local UGB
21	Tallahassee	FL	Local UGB
22	Jacksonville	FL	Local UGB
23	Tampa–St Petersburg–Clearwater	FL	Local UGB
24	Ocala	FL	Local UGB
25	Daytona Beach	FL	—
26	Fort Myers–Cape Coral	FL	—
27	Lakeland–Winter Haven	FL	—
28	Pensacola	FL	—
29	Athens	GA	—
30	Atlanta	GA	—
31	Augusta–Aiken	GA	—
32	Columbus	GA	—
33	Macon	GA	—
34	Savannah	GA	—
35	Cedar Rapids	IA	—
36	Davenport–Moline–Rock Island	IA	—
37	Des Moines	IA	—
38	Boise City	ID	—
39	Springfield	IL	Local USA
40	Champaign–Urbana	IL	—
41	Rockford	IL	—
42	Evansville–Henderson	IN	—
43	Fort Wayne	IN	—
44	Indianapolis	IN	—
45	Lafayette	IN	—
46	South Bend	IN	—
47	Kansas City	KS	—
48	Lexington	KY	Local USA
49	Louisville	KY	—
50	Baton Rouge	LA	—

Table A1. Continued

Number	*Metropolitan area*	*State*	*UCP*
51	Lafayette	LA	—
52	Lake Charles	LA	—
53	New Orleans	LA	—
54	Shreveport–Bossier City	LA	—
55	Portland	ME	—
56	Saginaw–Bay City–Midland	MI	Local UGB
57	Kalamazoo–Battle Creek	MI	Local USA
58	Benton Harbor	MI	—
59	Grand Rapids–Muskegon–Holland	MI	—
60	Jackson	MI	—
61	Lansing–East Lansing	MI	—
62	Rochester	MN	Local USA
63	Minneapolis–St Paul	MN	Local USA
64	Duluth–Superior	MN	—
65	Springfield	MO	—
66	St Louis	MO	—
67	Biloxi–Gulfport–Pascagoula	MS	—
68	Raleigh–Durham–Chapel Hill	NC	Local USA
69	Charlotte–Gastonia–Rock Hill	NC	Local USA
70	Fayetteville	NC	Local USA
71	Hickory–Morganton–Lenoir	NC	—
72	Fargo–Moorhead	ND	—
73	Lincoln	NE	Local USA
74	Omaha	NE	—
75	Albuquerque	NM	Local USA
76	Las Cruces	NM	—
77	Las Vegas	NV	—
78	Reno	NV	—
79	Albany–Schenectady–Troy	NY	—
80	Binghamton	NY	—
81	Buffalo–Niagara Falls	NY	—
82	Rochester	NY	—
83	Syracuse	NY	—
84	Utica–Rome	NY	—
85	Dayton–Springfield	OH	Local USA
86	Canton–Massillon	OH	—
87	Lima	OH	—
88	Toledo	OH	—
89	Youngstown–Warren	OH	—
90	Oklahoma City	OK	—
91	Tulsa	OK	—
92	Eugene–Springfield	OR	State UGB
93	Lancaster	PA	Local USA
94	York	PA	Local USA
95	Allentown–Bethlehem–Easton	PA	—
96	Harrisburg–Lebanon–Carlisle	PA	—
97	Pittsburgh	PA	—
98	Charleston–North Charleston	SC	Local USA
99	Columbia	SC	—
100	Sioux Falls	SD	Local UGB
101	Knoxville	TN	Local UGB

(Continued)

Table A1. Continued

Number	*Metropolitan area*	*State*	*UCP*
102	Johnson City–Kingsport–Bristol	TN	—
103	Memphis	TN	—
104	Nashville	TN	—
105	Amarillo	TX	—
106	Austin–San Marcos	TX	—
107	Beaumont–Port Arthur	TX	—
108	Brownsville–Harlingen–San Benito	TX	—
109	Bryan–College Station	TX	—
110	Corpus Christi	TX	—
111	El Paso	TX	—
112	Laredo	TX	—
113	Longview–Marshall	TX	—
114	Lubbock	TX	—
115	McAllen–Edinburg–Mission	TX	—
116	San Antonio	TX	—
117	Tyler	TX	—
118	Waco	TX	—
119	Provo–Orem	UT	—
120	Salt Lake City–Ogden	UT	—
121	Charlottesville	VA	Local USA
122	Norfolk–Virginia Beach–Newport News	VA	Local USA
123	Richmond–Petersburg	VA	—
124	Roanoke	VA	—
125	Burlington	VT	—
126	Olympia	WA	State UGB
127	Bellingham	WA	State UGB
128	Richland–Kennewick–Pasco	WA	State UGB
129	Yakima	WA	State UGB
130	Appleton–Oshkosh–Neenah	WI	Local UGB
131	Green Bay	WI	Local USA
132	Madison	WI	Local USA
133	Charleston	WV	—
134	Huntington–Ashland	WV	—
135	Wheeling	WV	—