Intra-Urban Mobility and Changing Density Functions in Tel Aviv, 1995-2006

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This paper tests whether increasing metropolitanization impacts on the density functions of the metropolitan core area. Ostensibly, increasing the scale of the metro area should decrease core area densities unless other urban processes such as infilling and land incorporation are occurring simultaneously. In terms of dynamics, previous work indicates that this impact declines over time. We test these hypotheses with respect to the Tel Aviv metropolitan area over the last decade and in relation to densities of both population and economic activity. Using both census and model-simulated data and GIS-based and statistical tools, we observe a minimal shift in the center of gravity of the metropolitan core over time and identify the emergence of sub-centers. We extend current estimation approaches by estimating a density function with spatial effects where neighboring densities have a significant effect on current densities. Our results uphold the expected negative impact of distance on density for both population and economic activity and the hypothesized decrease in this effect over time. The mobility of economic activity seems more volatile than that of population suggesting that the simple model of employment dispersal following residential dispersal may not be universal.

1. Introduction

While the impact of the CBD in the modern metropolis is rather different to that posited in the classic Alonso-Mills-Muth (AMM) models of urban structure and polycentricity has become a fact of life in many large urban areas, the measurement of this dispersal is still predicated on a the existence of an urban focal point. The focal point is important because the estimation of change in house prices or urban densities with distance needs to be measured in relation to an existing condition which is invariably the CBD. Even in the presence of sub-centers, many studies have replicated the simple monocentric distance decay function of about 8 percent per mile for house prices (Glaeser and Kahn 2001), 12-16 percent for employment deconcentration (Macauley 1985, Glaeser and Kahn 2001) and a similar figure for population (McDonald and Bowman 1976). This surprising consistency illustrates the robustness of the density function as a tool for describing urban development.

Obviously the complex intra-mobility patterns of the modern metropolis serve to undermine some of the simplicities of the monocentric assumptions. While some authors extend the monocentric model to include secondary centers of employment or housing (Henderson and Mitra 1994), the distance decay relationship will necessarily be flatter. However the basic underlying utility function that implies a spatial equilibrium in the trade-off between central location and housing/transportation costs, will still hold irrespective of whether urban form is mono or polycentric. Metropolitan development is simply an extension in scale and scope, of polycentric development. This study tests whether increasing metropolitanization impacts on the density functions of the metropolitan core area. Ostensibly, increasing the scale of the metro area should decrease core area densities unless other urban processes such as infilling and land incorporation are occurring simultaneously. In terms of dynamics, previous work indicates that this impact declines over time. We test these hypotheses with respect to the Tel Aviv metropolitan area over the last decade and in relation to densities of both population and economic activity.

The objective of the paper is to take a fresh look at density functions for Tel Aviv using simulated data at a much finer level of analysis than has hitherto been used. In addition, we incorporate spatial estimation that takes direct account of the role of contagion effects in the estimation of density functions and the identification of incipient subcenters in the metropolitan area. While earlier studies have departed from the standard monocentric analysis by trying to identify clusters of emerging locations through examining significant positive residuals in the density functions, correlated or not across space (McDonald and Prather 1994, McMillen 2001), to our knowledge this has not been done in an explicitly spatial framework in the past. In section 2, we proceed to synthesize some of the findings relating to earlier work on the Tel Aviv metropolitan area. The third section then describes the method employed, both descriptive and analytical. We attempt to make the case for an estimation procedure that takes direct account of spatial spillover effects across neighboring measurement units and accounts for the bias that spatial dependence can cause. We argue that the spatial autoregressive (SAR) model offers an appropriate form of estimation. Due to the synthetic nature of the data used, the process behind its generation is described in Section 4. Empirical results are presented in section 5 and some insights relating to the on-going metropolitan processes fashioning the development of Tel Aviv, are discussed in the conclusions.

2. Literature Review

The use of the negative exponential density function to represent the urban structure for the monocentric city was pioneered by Clark (1951). This seminal contribution spawned considerable empirical work including Muth (1969) who tested this form on nearly 50 cities and McDonald and Bowman (1976) who went on to test the suitability of other functional forms such as the quadratic and higher order polynomials such as cubic spline (Mahamassi, Hadibaaj and Tong 1988). These forms were posited as more suitable for describing the realities of the monocentric city punctuated by discontinuities, emerging subcenters, peripheral housing estates and statutory land use controls such as growth boundaries or green belts. The argument was that all these complexities required more flexible functional forms for describing urban densities in population, employment and economic activity. However, whatever the form of estimation, the empirical results on the effect of polycentricity on population densities, are far from equivocal. Some studies find very little effect (Griffith 1981). Others find evidence in classic polycentric cities only such as Los Angeles (Gordon, Richardson and Wong 1986) while others still relate population density patterns to the influence of exogenously defined subcenters (Small and Song

1994). Other work looks at the effect of dual centers within a single city and their competing impacts on population densities (Alperovich and Deutsch 1996).

In the context of the Tel Aviv metropolitan area, the earliest work grounded in the monocentric model is Shachar (1975). He fitted the standard negative exponential relationship for population density although his focus was really on assorted indices in the concentration of commercial activity. Subsequent work on density functions for both population and economic activity in Tel Aviv (Alperovich 1980, Stern 1994, Krakover and Adler 2009) reiterated this seemingly universal pattern. Much of this work has examined density functions for two or more periods. These dynamics show, as expected, an inter-temporal decline in the strength of the negative coefficient indicating that the effect of distance-decay decreases over time. This result is also replicated in other studies (Macauley 1985). In Table 1 we have calculated this inter-temporal change in the distance coefficients for Tel Aviv studies since Shachar (1975). To allow for comparison we have related to a uniform definition of the Tel Aviv metropolitan area that includes the 'metropolitan core' area defined here as encompassing the cities of Tel Aviv, Ramat Gan, Givatayim, Bnei Brak, Holon Bat Yam and Bnei Brak. This was the metropolitan area as defined in Shachar (1975) and serves at the centre of the contemporary metropolitan area. This is also the area of reference for the current study (Figure 1).

Figure 1 here

Despite the fact the distance decay effects relate to different time periods and that the studies all use different spatial units of analysis, a clear pattern emerges of a significant negative effect of distance that reduces over time. The size of this reduction varies by time period and form of estimation but their relative magnitudes remain comparable. The first comprehensive analysis of density functions (Shachar 1975) fitted two exponential functions and used 167 administrative units (statistical areas, SA's). In contrast, Alperovich's study (1980) that looked at the period 1961-76 and used only 25 SA's examined the factors impact distance decay (income, metropolitan size) and the temporal change in their effect. Stern's (1994) study attempted to estimate the differences in the intensity of the negative distance parameter when measured from different points within the metropolitan core (CBD, historic center etc) and by using various functions (standard Clark-Newling, root, lognormal etc). Recently, Krakover and Adler (2009) have used linear and exponential functions for testing the hypothesis that Tel Aviv's urban structure has evolved from monocentric to polycentricity, over the period 1972-2000. To support this, they use standard functional forms and a combination of census data for SA's and synthetic data for travel area zone (TAZ's) generated by a transportation model.

Table 1 here

3. Method

The method used for this study consists of two main parts. This first is descriptive and deals with mapping the dynamics of metropolitan population density and tracing the changing center of gravity of the metropolitan core over time. Despite the focus in this paper on the metropolitan core area, we are cognizant of the fact that metropolitan Tel Aviv in the 21st century is a polycentric system characterized by sub centers (Krakover and Adler 2009). Thus, using the 'neighborhood statistics' GIS function we endeavor to identify emergent metropolitan sub centers for the periods 1995-2006 both in terms of population and commercial activity. This procedure computes an output raster where the value at each location is a function of the input cells in some specified neighborhood of the location. For each cell in the input raster, the neighborhood function computes a statistic based on the value of the processing cells within a specified neighborhood and then sends this value to the corresponding cell location on the output raster. In the present case, the neighborhood comprises the seven cells adjacent to the target cell. The resultant maps depict the density nodes that emerge from the cumulative cell values.

An additional descriptive device relates to defining the center for gravity of the study area and locating the weighted center of the metropolitan core area. This exercise is important given the fact that this study estimates density functions over time. As such the measurement of the distance effect may need to change across time periods as the center of gravity of the area of observation may shift. We define the geometric center of the study area at each point in time as the weighted mean center of a cluster of points as follows:

$$\bar{x}_{wc} = \sum_j f_i x_i / \sum_j f_i \quad ; \quad \bar{y}_{wc} = \sum_j f_i y_i / \sum_j f_i$$

where *wc*= the weighted center and *f*= the frequency (or weighting) factor.

The analytic component of this analysis deals with estimating the density functions for the metropolitan core area for the years 1995, 2001 and 2006. This is done in two stages. In the first stage a simple estimate of the effect of distance on ln density is derived[1]. This is done both for population density and commercial activity density. However, given the nature of the data being used (continuous surfaces divided into grid cells), we suspect that spatial dependence inherent in the data is likely to result in biased estimation. On this basis, in the second stage we estimate the OLS model with spatial dependence. Two options are available for this. One is that spatial effects are expressed as serial correlation in the model's residuals (spatial autocorrelation, SAC). The other is that spatial dependence exists between the observations themselves (spatial lag or autoregression, SAR). Estimating a spatial regression calls for the use of a weight matrix (W) that gives more weight to closer observations. In this study we use inverse distance weighting i.e. $\omega_{ij}=1/d_{ij}$ to construct the weight matrix (Dubin 1998)[2], which seems suitable due to the grid-like structure of the data. We measure the inverse distance between the centroids of the grid cells as the data is point-oriented and not a continuous surface. First order neighbors are defined as all points within a 250m radius.

An obvious first indication of spatial dependence in the data is provided by the Moran's I (MI) statistic for spatial autocorrelation[3] . Given the presence of a significant MI, it can be shown that the choice of spatial regression estimation in the univariate case results in nearly identical estimators. The reason for this is that the SAR model is formally a restricted version of the SAC model. The unrestricted SAC model can be expressed as follows:

$$Y_i = \alpha_i + \beta X_i + \rho W Y_i + u_i$$
$$u_i = \phi W u_i + v_i \qquad (1)$$

[1] Krakover and Adler (2009) show that when estimating density functions for a monocentric city, no real difference arises from linear or geometric estimation

[2] Alternative weighting schemes of course exist. Common border weighting where element $\omega_{ij}=1$, units i and j share a common border and $\omega_{ij}=0$ is otherwise (Cliff and Ord 1981) was not considered appropriate due to the grid structure of the data. Exponential distance decay weighting, i.e.$\omega_{ij}=\exp(-d_{ij})$ (Fik et al 2003) did not yield very different outcomes .

[3] Morans I (MI) is defined as:

$$MI = N / S_0 \sum_i \sum_j W_{ij} * (x_i - \mu) * (x_j - \mu) / \sum_i (x_i - \mu)^2$$

where $S_0 = \sum_i \sum_j w_{ij}$ (constant weight); N =- Number of observations, w_{ij} = spatial weights based on aerial distances between centroids of the cells, x_i and x_j are observations i,j with average value μ .

where;

$u_i = Bv_i$

$B = (I - \phi W)^{-1}$

Substituting for u_i:

$$Y_i = \alpha_i + \beta X_i + (I - \phi W)^{-1} v_i$$

$$(I - \phi W)Y = \alpha (I - \phi W) X + v \qquad (2)$$

Equation (2) can reduce to:

$$Y_i = \alpha_i + \phi WY_i + \beta X_i + \phi WX_i + v_i \qquad (3)$$

Equation (3) is the mixed SAR model also called the 'spatial Durbin' model in the literature (Anselin et al 1996). In this model spatial effects are expressed both in the spatial autoregressive parameter and in the spatial lag on the independent variable ϕWX_i. We can therefore see overlap between the SAC and SAR models where the only difference is the spatial lag on the independent variable in the SAC model. Therefore the SAR model is a restricted version of the SAC model and our SAR estimates are presented below. [4]

4. Data and Variables

4.1 Data preparation

In contrast to previous work on intra-urban density patters in Israel, the data preparation for the present study was not straightforward. Two primary data sources have been used. We use observed (real) data on population and commercial activity densities from the National Census 1995 and Travel Survey 1996, conducted by the Israel Central Bureau of Statistics (CBS). These data are used at the statistical areas (SA) level for Tel Aviv and its 5 satellite cities, i.e. the metropolitan core as defined by Shachar (1976). In the absence of census data post 1995, density data for 2001 and 2006 is 'synthetic', i.e. derived from the UrbanSim land use microsimulation model that has been calibrated for the Tel Aviv metropolitan area (Felsenstein, Ashbel and Be-nun 2007). In similar fashion, Krakover and Adler (2009) used estimated data

[4] Equation (3) was also estimated empirically in this study but since the ϕWX_i parameter did not yield significant results, the results presented relate to the SAR model only.

from a transportation model to estimate density functions for Tel Aviv for the year 2000.

The derived data is generated by letting the UrbanSim model run from its base year of 1995 till the target years of 2001 and 2006. The model simulates the activities of the principle agents affecting land use such as firms, households, developers and governments and their resultant impacts on land use via density, land prices and mobility patterns. Data is organized on a 250m grid and each grid cell is allocated a SA to which it corresponds (Figure 2). Data from each census tract is transferred to the grid using GIS and where a SA covers more than one grid, data is divided equally between the grid cells. Tabular data is incorporated in a two-stage process. In the first stage, data is allocated to a GIS vector layer of SA's. In the second stage this is converted to raster using zonal statistics. Wherever there is more than one grid cell per SA, the data is allocated proportionally to the cells. This is based on the assumption that SA's are homogenous units

Figure 2 here

4.2 Variables

This study relates to two density variables. The first relates to population density that is measured as the number of people residing in a given grid cell (Res) when all cells are of equal size[5].The second variable relates to density of economic activity. This is measured by the share of the grid cell occupied by commercial activity (Com). The first variable therefore uses volume of people while the second relates to land area coverage.

Distance is measured as the aerial distance from the center of each cell to the CBD of the city of Tel Aviv. This is defined above (Section 3) in respect to the geometric center of the metropolitan core area. Using the same definition for the city , we combine the geometric centers for population and commercial activity as follows, $(\sqrt{Res^{0.5}} + \sqrt{Com^{0.5}})$. Over the three periods, this center is empirically found to be close to the Ichilov Hospital in central Tel Aviv with slight deviations across the years. To arrive at a point estimator, we delimited a polygon around the three weighted centers and used the centroid of the resultant polygon to represent the CBD

[5] Since population density relates to the density of people at place of residence, population density and residential density are synonymous.

for the city. The other variables in this study (weight matrix, lags etc) are generated in the estimation process using the GeoDa software package (Anselin 2003).

5 .Empirical Results

5.1 Description of Trends over Time

Ostensibly, the shift in the center of gravity over time in the study area, should reflect the deconcentration of population and economic activity. Remarkably, the movement of the geometric center has been minimal. Across all three time periods the weighted center of the metropolitan core has remained on the east side of the Ayalon freeway in the area of Yad Eliyahu (Figure 3). This area is nearer to the new CBD of Tel Aviv clustered around the office towers of Ramat Gan than it is to the old CBD centered on the banking district around Allenby and Yehuda Halevi streets. It lies just east of the projected (planned) CBD that is expected to develop in the future along the Ayalon freeway. The estimated center of gravity therefore reflects the equilibrium created by the centripetal forces pulling the population to the popular residential locations north and east of the metropolitan area and the centrifugal forces that entrench existing economic activity in the current CBD areas.

Figure 3 here

From a metropolitan-wide perspective, two important questions arise. First can we identify the emergence of incipient centers of either population or economic activity that are likely to compete with current centers? Second, do these centers develop on the basis of spatial spillover from existing centers? If so, contagion may be an issue in understanding density patterns.

We investigate the first question using neighborhood statistics. Figure 4 shows the analysis is relation to population density for the metropolitan core area (outlined) and wider region. Each cell value incorporates the individual cell value and the density level of the neighboring cells. Thus the data surface for the entire metro area gives an interpolative effect of emerging concentrations. As can be seen by comparing 1995 and 2006, within the confines of the metropolitan core there is a population entrenchment in existing centers (Tel Aviv, Bat Yam, Holon and Bnei Brak) while seemingly emergent concentrations in 1995 such as Herzliya do not to materialize by 2006. In the wider metropolitan area, Petach Tikva develops as a sub center while the incipient growth of Or Yehuda and Kiryat Ono in 1995 does not seem to take root by 2006. The overall picture for population growth is one of self-sustaining growth of the centers within the metropolitan core and only selective sub-center development outside this area.

Figure 4 here

Commercial development over this same period displays a more diffuse picture (Fig 5). At the beginning of the period, initial sub-centers exist in Bnei Brak in the north and Holon/Bat Yam in the south. By 2006, these have grown and have been supplemented by other centers in the city of Tel Aviv and on the perimeter of the metropolitan core in Rishon Letzion and Givat Shmuel. In the wider metropolitan area, we can identify a pattern of further non-continuous diffusion, which could be either leading or following residential movement. This situation could be indicative of disequilibrium in the metropolitan system with unsynchronized development of population and commercial sub centers.

Figure 5 here

5.2 Density Functions for the 2000's: Spatial Estimation

Table 2 presents the results of the estimated density functions for 1995, 2001 and 2006. The estimations relate to population and commercial activity and relate to the metropolitan core area. Each function is estimated twice: once using OLS and once using the SAR model (see section 3 above). The unit of observation is the 250m sq grid cell and 1832 such units are generated for the study area.

Table 2 here

The first consistent finding is the (expected) significant inverse relationship between density and distance. This relationship is more accentuated for population density but nevertheless still characterizes the density pattern of commercial activity. The magnitudes of the OLS coefficients are slightly larger than those found in similar studies (Shachar 1975, Krakover and Adler 2009) but without noticeable bias. Coefficients for population density are roughly double those for employment density indicating a faster distance decay pattern. In all cases however, distance itself contributes a small fraction of the variance in density as evidenced by the low R^2 values and this contribution is smaller for commercial activity than it is for population.

The spatial correlation coefficient (MI) is positive and significant for all periods and indicates spatial dependence in the data. As a result we run a series of SAR regressions that all produce positive and significant autoregressive coefficients for all activity in all time periods. This seems to indicate the potency of contagion effects in the creation of subcenters and in the emergence of clusters of residential and commercial activity (McMillen 2001).

Despite these general patterns we can discern some differences across the models. First, as noted earlier, population density functions become flatter over time. The impact of distance becomes attenuated over the period 1995-2006, a finding that is replicated other studies (section 2 above). This effect occurs in both the OLS and SAR estimations. The neighborhood or contagion effect also becomes more moderate over time. In the case of commercial activity this finding is less equivocal. Over the period 1995-2001 density patters in commercial activity seem to strengthen and the effect of distance increases, all pointing to growing concentration in commercial activity. However, these trends are reversed over the period 2001-2006. The effect of neighbors is also inconsistent over this period.

In sum, the analytic findings point to a clear pattern of continuing concentration in metropolitan Tel Aviv although the impact of this trend seems to decline over time. The density patterns discovered would seem to include no small measure of the spatial spillover and reciprocal effects between neighboring spatial units. These findings seem to show that spatial entrenchment and spatial spillover can occur simultaneously.

6. Conclusions

What new insights can we derive from the above results with respect to the continuing metropolinization of Tel Aviv? While many of the processes of deconcentration, both continuous and leap-frogging, are similar to those occurring elsewhere (Benguigi, Czamaski and Marinov 2001), in Tel Aviv this has not resulted in a weakened central city. The estimated density functions above hint at the continued dominance of the metropolitan center, even if not to the same extent as a decade ago. In this respect, the metropolitan processes fashioning Tel Aviv's development are closer to the European form of decentralization than that of the US (Dijst and Vazquez 2007). In contrast to the latter, they do not result in a hollow metropolitan center or population density craters so often identified elsewhere (Newling 1969). This testifies to Tel Aviv's power in reinventing itself. Despite a population downturn in the 1980's and early 1990's, an unfavorable demographic balance and attempts to capture CBD activities by neighboring jurisdictions, the estimated weighted center of gravity for the city has remained remarkably stable over the decade 1995-2006 .

Our use of spatial estimation also points to the existence of incipient subcenters at the metropolitan level. While the window of examination here is only a decade and not enough time to really observe the germination and growth of a subcenter, the empirical results are indicative of what can be done using tests of proximity to identify new clusters. It is true that these new concentrations do not display the sharp breaks in continuity often associated with subcenters (McMillen and Lester 2003) and that their form of graphic representation through neighborhood statistics serves to wash out some of the mini-peaks that can exist in the data. However, it cannot be denied that if density functions have spatially correlated residuals or are spatially autoregressive, then something to do with contagion must be affecting the observed patterns. Our data show this to be the case for Tel Aviv. Subcenter development is one of the identifying characteristics of US metropolitan areas (McMillen and Lester 2003). Tel Aviv thus shows a dualism in its metropolitan development that positions it in some respects close to European model and in other, closer to the North American pattern.

Bibliography

Alperovich G. (1980) Determinants of Population Density Gradient in the Tel Aviv Metropolitan Area, *Urban Studies*, 17, 185-192.

Alperovich G. and Deutsch Y (1996) (1980) Urban Structure with Two Co-existing and Almost Completely Separate Populations, *Regional Science and urban Economics*, 26, 171-187.

Anselin, L., A, Bera, R. Florax and M. Yoon (1996) Simple Diagnostic Tests for Spatial Dependence. *Regional Science and Urban Economics,* 26, 77-104.

Anselin L. (2003) *GeoDa™ 0.9 User's Guide*, Spatial Analysis Laboratory Department of Agricultural and Consumer Economics, University of Illinois, Urbana-Champaign,IL, http://sal.agecon.uiuc.edu/

Benguigui L, Czamanski D and Marinov M (2001) City Growth as a Leap-frogging Process: An Application to the Tel-Aviv Metropolis, *Urban Studies*, 38 (10); 1819-1839

Clark C (1951) Urban Population Densities, *Journal of the Royal Statistical Society, Series A*, 114, 490–496.

Cliff A.D and Ord J.K. (1981) *Spatial Processes: Models and Applications*, Pion, London.

Dijst M and Vazquez C (2007) Employment Deconcentration in European Metropolitan Areas: A Comprehensive Comparison and Policy Implications, pp 265-292 in Razin E, Dijst and Vazquez (eds.) *Employment Deconcentration in European Metropolitan Areas: Market Forces and Planning Regulations*, Springer, Berlin

Dubin R, A. (1998) Spatial Autocorrelation: A Primer, *Journal of Housing Economics*, 7, 304-327.

Felsenstein, D. Ashbel E. and Ben-Nun A. (2007) Microsimulation of Metropolitan Employment Deconcentration, pp199-218 in Koomen E., Stillwell J., Bakema A. and Schloten H. (eds) *Modelling Land Use Change: Progress and Applications*, Springer, Dordrecht, The Netherlands.

Fik, T.J., Ling D.C. and Mulligan G.F (2003) Modeling Spatial Variation in Housing Prices: A Variable Interaction Approach, *Real Estate Economics*, 31 (4), 623-646.

Glaeser E.L and Kahn M (2001) Decentralized Employment and the Transformation of the American City, Brookings-Wharton Papers on Urban Affairs 2, 2-63.

Gordon P., Richardson H. and Wong H. (1986) The Distribution of Population and Employment in a Polycentric City; The Case of Los Angeles, *Environment and Planning A*, 18, 161-173.

Griffith D. (1981) Modeling Urban Population Density in a Multi-Centered City, *Journal of Urban Economics*, 9, 298-310.

Henderson V.and Mitra A (1998). The New Urban Landscape: Developers and Edge Cities, *Regional Science and Urban Economics,* 26 (6), 613–43.

Krakover S. (1985) Spatio-Temporal Structure of Population Growth in Urban Regions: the cases of Tel-Aviv and Haifa, Israel, *Urban Studies*, 22, 317–328.

Krakover S and Adler E (2009) Metropolitan Tel Aviv; From Monocentric to Dispersed Structure, pp. 315-337 in Kipnis B (ed.) *Tel Aviv-Yafo: From a Garden Suburb to a World City,* Pardess Publications, Haifa.

Macauley M. (1985), Estimation and Recent Behavior of Urban Population and Employment Density Gradients, *Journal of Urban Economics* 18, 251–60.

Mahamassani H, Hadibaaj M and Tong C.C (1988) Characterization and Evolution of Spatial Density Patterns, *Transportation*, 15, 232-1256.

McDonald J.F and Bowman H.W (1976) Some Tests of Alternative Population Density Functions, *Journal of Urban Economics*, 3,242-252

McDonald J.F and Prather P.J. (1994) Suburban Employment Centres: the Case of Chicago, *Urban Studies,* 31, 201-218.

McMillen D.P (2001) Polycentric Urban Structure: The Case of Milwaukee, *Economic Perspectives*, Federal Reserve Bank of Chicago, 2Q, 5-26

McMillen, D.P, and Lester, T.W. (2003). Evolving Subcenters: Employment and Population Densities in Chicago, 1970-2020. *Journal of Housing Economics,* 12 (1), 60-81.

Muth C (1969), *Cities and Housing,* University of Chicago Press Chicago, IL

Newling B.E. (1969). The Spatial Variation of Urban Population Densities, G*eographical Review*,59, 242–252.

Shachar A (1975) Patterns of Population Density in the Tel Aviv Metropolitan Area, *Environment and Planning*, *A*, 7 (3), 279-291.

Small, K.A., and Song, S. (1994). Population and Employment Densities: Structure and Change. *Journal of Urban Economics*, 36 (3), 292-313.

Stern D. (1994) Historical Path-Dependence of the Urban Population Density Gradient, *Annals of Regional Science,* 28 (2), 197-222.

Table 1: Review of Previous Studies

	Study				
	(1)	(2)	(3)	(4)	(5)
	Shachar (1975)	Alperovich (1980)	Stern (1994)	Krakover and Adler (2009)	Current Paper
% Change					
Period I	-14%	-33%	-38%	-39%	-25%
Period II	-27%	-28%	–	-30%	-10%
Function	Geometric	Geometric	Geometric	OLS	OLS
Units	167 Stat. Areas	24 Stat. Areas	219 Stat. Areas	232-325 Stat. Areas	1832 Grid Cells

Notes

Study (1)	I	1961-1967	;	II	1967-1972
Study (2)	I	1961-1972	;	II	1972-1978
Study (3)	I	1972-1983	;	II	–
Study (4)	I	1972-1983	;	II	1983-1995
Study (5)	I	1995-2001	;	II	2001-2006

Table 2: Results of OLS and Spatial Regression

		Density Functions							
		Population				Economic Activity			
Period	Form of Estimation	LnDist	ρWY	R^2	MI	LnDist	ρWY	R^2	MI
1995	OLS	-0.0959**		0.06	0.682**	-0.0504**		0.01	0.211**
	SAR	-0.0178**	0.0822**	0.68		-0.0315**	0.0374**	0.12	
2001	OLS	-0.0716**		0.04	0.641**	-0.0539**		0.01	0.184**
	SAR	-0.0157**	0.0798**	0.63		-0.0372**	0.0309**	0.09	
2006	OLS	-0.0644**		0.03	0.625**	-0.0383**		0.007	0.309**
	SAR	-0.0150**	0.0786**	0.61		-0.0205*	0.0468**	0.20	

n = 1832; SAR = Spatial Autoregressive Model; MI = Spatial Correlation Coefficient (Moran's I);
ρWY = Spatially weighted autoregressive parameter
= $p < 0.05$**; $p < 0.001$

Figure 1: Tel Aviv Metropolitan Core Area and Wider Region

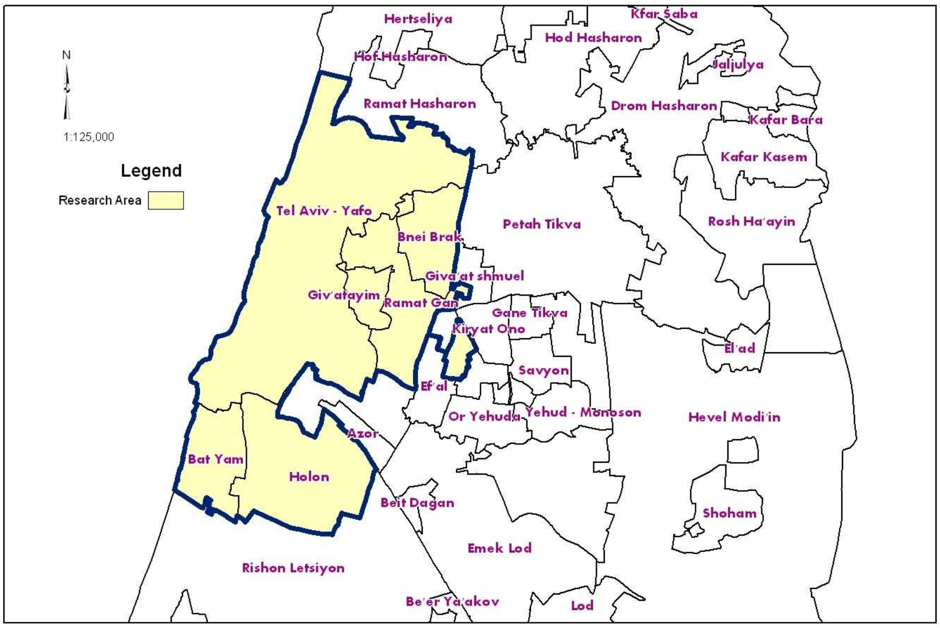


Figure 2: Grid Cell Data Preparation in UrbanSim

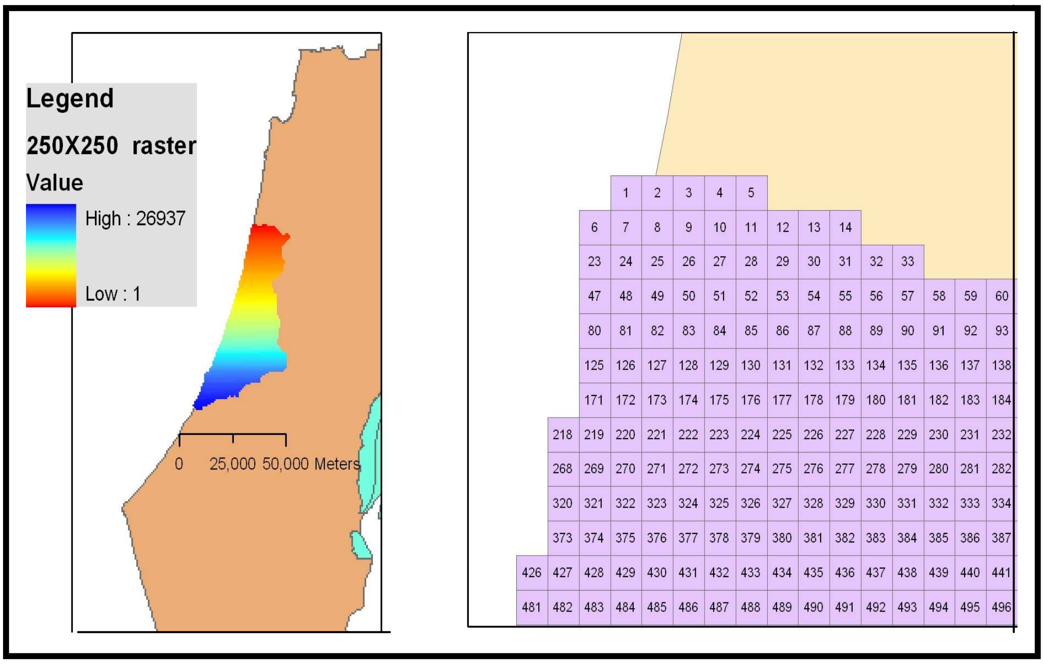


Figure 3: Estimated Weighted Center of Gravity for Tel Aviv Metropolitan Core in relation to Old, New and Planned CBD Areas.

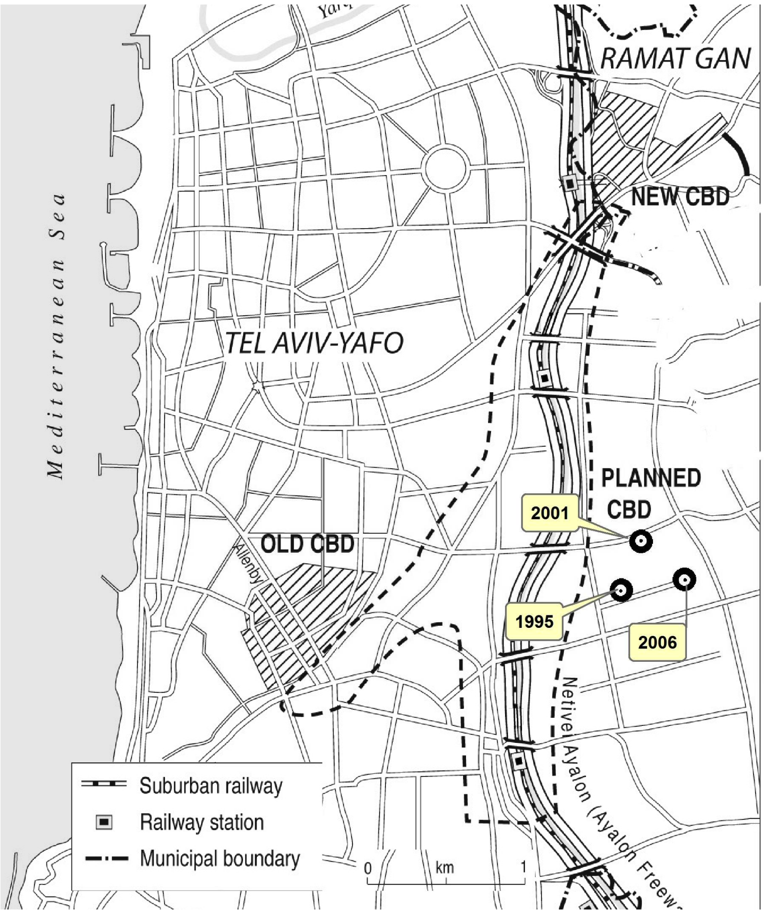
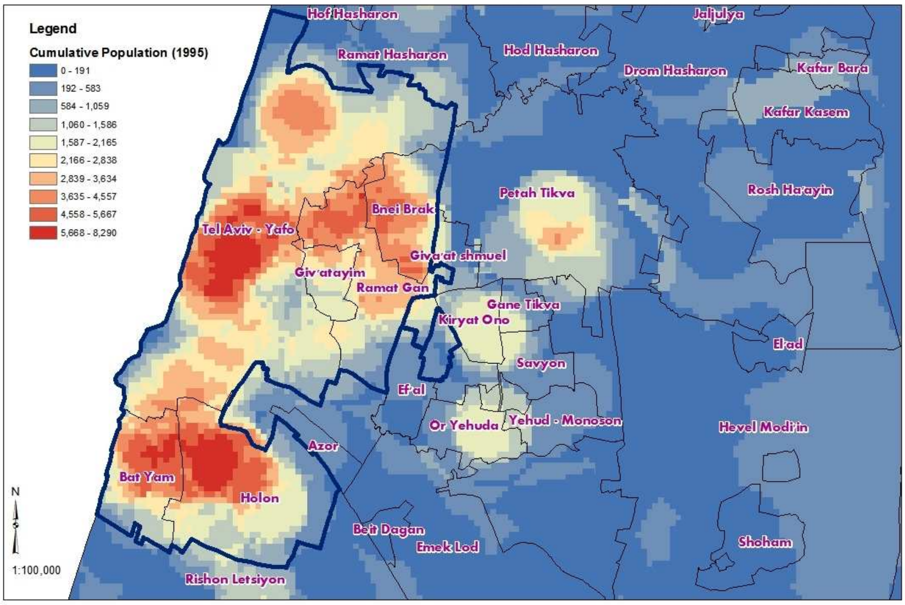


Figure 4: Identifying Population Subcenters Using Neighborhood Statistics (a)1995 and (b) 2006

(a)



(b)

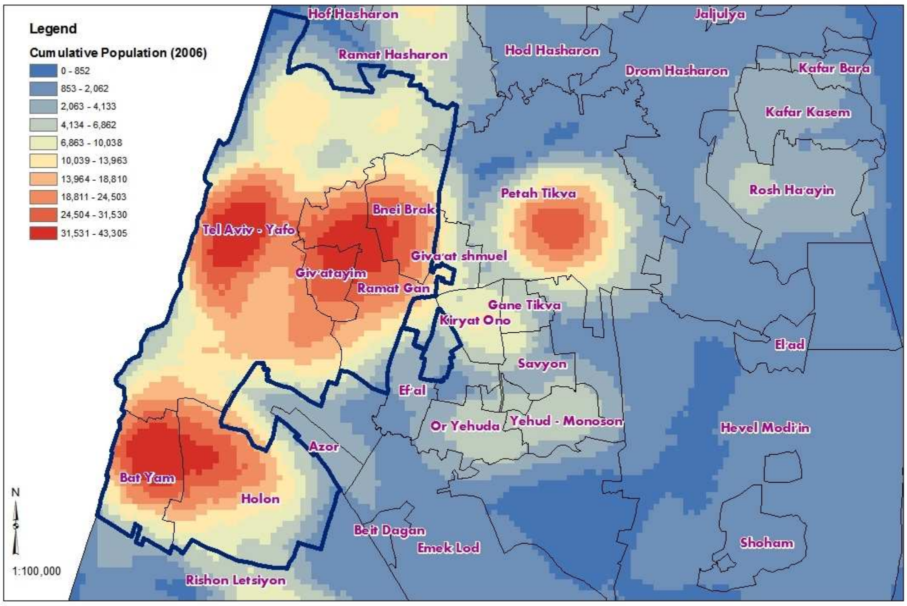
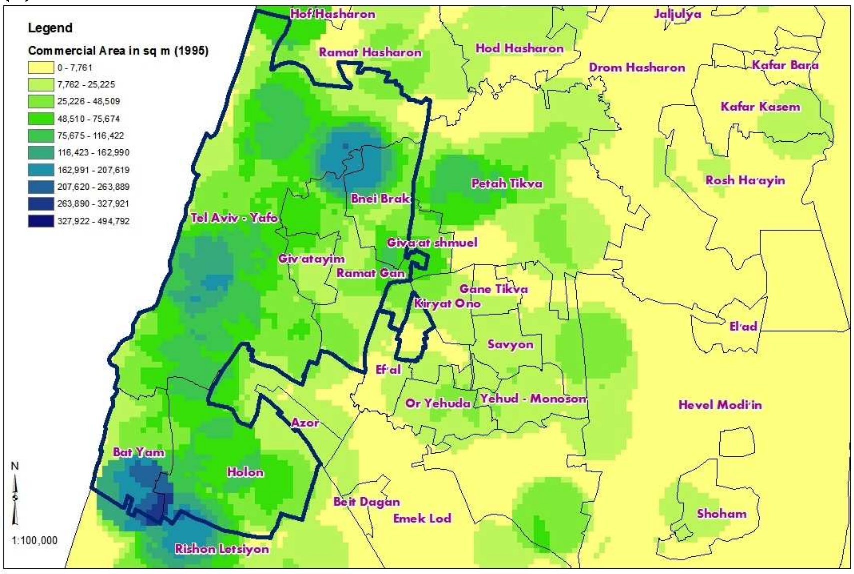


Figure 5: Identifying Commercial Activity Subcenters Using Neighborhood Statistics
(a) 1995 and (b) 2006

(a)



(b)