# The Spatial Distribution of Population in 57 World Cities: The Role of Markets, Planning, and Topography

By

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**Abstract**

We calculate, on a consistent basis, population density gradients and other associated measures, for 57 large cities in 32 countries, across a wide range of regions and levels of development. We present brief discussions of the results in selected cities to illustrate some of the forces that affect density patterns, including but not limited to those implied by standard theoretical models of intraurban location. In second-stage analyses, we examine a number of determinants of urban form, including income, population, nature of the regulatory regime, natural constraint (physical geography), and transport costs.

Density gradients flatten with city population, and with falling transportation costs, as the standard urban model predicts. Results with respect to income are less robust, but these results are reconciled with a more robust version of the standard urban model. The standard urban model fits less well for cities with complex physical geography (large bodies of water, and other constraints). We also find that cities with extremely stringent urban regulations, as in South Africa, Korea and Russia, have flatter (sometimes inverted) population density gradients.

## Contents

## Introduction

In this paper we present a unique database of measures of urban form from 57 cities in 32 different countries, collected over more than two decades. After some discussion of selected cases, we use these data to test some predictions of the standard model of intraurban location, and to explain apparent departures from that model. Several key predictions of the so-called 'standard urban model' are confirmed; cities everywhere decentralize as their populations grow, their incomes rise, and transport costs fall, as the standard model predicts. But we also show that the way the market for land and real estate is organized and regulated has profound effects on urban form. This has potentially powerful implications for the value of the real estate capital stock, and for transportation systems.

Our analysis is mainly positive. We do not have a prior that most cities should be more dense, or less dense, as a general proposition. Thinking about optimal density is hard, especially once we step away from extremely simplified and stylized assumptions about the behavior of producers, consumers, and governments; and about (usually the lack of) externalities, information assymetries, and the like. Thinking about realistic optimal densities is an important line of research, and one we will discuss elsewhere. See, for example, Thurston and Yezer 1991, or Larson, Liu and Yezer 2012. We do, however, tackle some normative issues regarding better urban policies, rather than optimal density outcomes, below. We will argue that we can see large, if crudely measured, welfare losses from some very large departures from the model in cities like Moscow, Seoul, and Johannesburg.

## Population Density: Some Basic Facts

The simplest definition of urbanization is the existence of above-average density. Densities vary markedly across countries and within them. Divided evenly, every person in the world could have about 2 hectares of land. The United States has an above-average endowment of raw land, by world standards: about 3.1 hectares per person (or about 0.3 people per hectare [pph]). Some other countries, however, have even larger areas relative to their population: Canada has about 30 hectares of raw land per person, Australia has 40 per person, and Russia has 12 per person. At the other extreme of the density scale, examples of higher densities include China, which has only 0.75 hectare per person (or about 1.35 pph); India and Japan have about 3.5 pph; Korea and the Netherlands have about 4.75 pph; Bangladesh has about 10 pph; the city states Singapore and Hong Kong have about 65 pph.

The numbers presented in the previous paragraph, however, are extremely crude; densities vary even more within countries than across countries. To give some idea of the state density differences, if the entire United States, excluding Alaska, were settled at the densest state, New Jersey's, density, the country would contain more than 3 billion people. On the other hand, if the "lower 48" were settled at Wyoming's density, the country would contain about 14 million. Within the United States, most of the population lives within a few hundred miles of the major coasts (including the Great Lakes); with a few exceptions, such as Denver and Salt Lake City, most of the country is fairly empty between Minneapolis and the area 100 miles or so from the Pacific Ocean (Rappaport and Sachs, 2003). This pattern is not atypical; many countries have some fairly dense areas and some (often large) “empty quarters.” For example, almost 90 percent of Canada’s population lives within 200 miles of the U.S. border, most of China’s population lives within 100 miles of the coast, and very few Australians live very far from the coast.

Although country averages are often cited and are of some interest, densities across and within cities vary remarkably, whether in U.S. cities or in cities around the world. Table 1 presents the average population density, as we calculate it, for 57 large cities in 32 countries.[1] Enormous variation in the average density of cities is immediately apparent in table 1; these population densities range from 6 pph in Atlanta to 389 pph in Mumbai. According to these averages, the densest cities in our sample are mainly in Asia, but Africa has some fairly dense cities (Addis Ababa, Abidjan), and Europe has a few very dense cities in our sample (Barcelona and Moscow).

## Analytic Framework

Our analytic framework is the canonical "standard urban model" of Alonso (1964), Muth (1969) and Mills (1972) and its many extensions. The model is so well known that we will simply write

[1] Details of how we collect the data and calculate the built-up area and the average density of the built-up areas of the city are provided below. All results in this paper, and many additional results, will be made available at the time this draft is completed for journal submission at our respective websites. Our online database includes several observations, in addition to those in Table 1: additional calculations for Atlanta in 2000 and 2010; the South African province of Guateng, which contains Johannesburg and Praetoria; Jabotabek, which includes Jakarta, Bogor, Bekasi, and several other municipalities near Indonesia’s capital; and the municipality of Seoul in 2009. Houston is included in this table, but missing data led us to omit that city from most of the analysis below. Table 1 also includes the population of each city in our database, and a short code which we use to identify the cities in some of the charts below.

down a few familiar textbook results used in our empirical work below; see the original Alonso, Muth and Mills papers, or many later treatments such as Mills and Hamilton (1994), Fujita (1989), or Turnbull (1995) for derivations and other details.

The model postulates a representative consumer who maximizes utility, a function of some quantity of housing services consumed (H) and a unit priced non-housing good (X), subject to a budget constraint that explicitly includes commuting costs as well as the prices of housing (P) and non-housing (unit price). It is easy to show that equilibrium requires that change in commuting costs from a movement towards or away from a central business district (CBD) or other employment node equals the change in rent from such a movement. For such a representative consumer:

$$\Delta u \cdot t = -\Delta P(u) \cdot H(u)$$

where u is distance from the CBD and t is the cost of transport per unit distance. This equilibrium condition can be rearranged to show the shape of the housing price, or "bid rent" function:[2]

$$\frac{\Delta P(u)}{\Delta u} = -\frac{t}{H(u)}$$

Since bid rents (or such rents capitalized into asset prices) will tend to fall with distance from the CBD or other node, so will land rents (or values). If we add a simple supply side to the model that

[2] The model can be worked out for either homeowners or renters; in the latter case we can consider P as the rent per unit of housing services (flow price) rather than an asset price for each H.

permits the substitution of housing capital for land, in expensive (so far, central) locations, households will consume more structure per unit of land, and density will increase.[3]

Further, the literature has long shown that a simple but defensible version of the model, with Cobb Douglas utility and production functions, can yield a particular relationship between residential density and distance from the CBD:

$$D(u) = D_0 e^{-\beta u \varepsilon}$$

where D is population density at distance u from the center of a city; $D_0$ is the density at the center; e is the base of natural logarithms; β is "the gradient," or the rate at which density falls from the center. The final error term, ε, is included when the formulation is stochastic. Figure 1 illustrates a stylized example of density patterns, for a city with a central density of 100 persons per hectare, for different values of β.

This negative exponential measure of population density is the city form most often studied by urban economists; while often associated with the pioneering work of Alonso, Muth and Mills, it was actually first popularized among economists by Colin Clark.[4]

Among the other attractive properties of this measure, density is characterized by two parameters, with a particular emphasis on γ, which simplifies second stage analysis.[5] The function is easily estimable with OLS regression by taking logs:

[3] As is well known, the convexity of the land price surface will itself increase, as factor substitution is added to the model.

[4] McDonald, in his excellent (1989) review, points out that Stewart (1947) apparently first fit the negative exponential form described here, but notes that it was Clark (1951) that popularized the form among other urban scholars.

$\ln D(u) = \ln D_0 - \beta u + \varepsilon$

which can then be readily estimated with, say, density data from Census tracts, once distance of each tract from the central business district (CBD) is measured.[6]

Of course other functional forms have been used. Higher power terms in u have been added, splines fitted, Box-Cox and other flexible forms used. McDonald and Bowman (1976) provide a convenient review. This simple negative exponential is our benchmark and point of departure. It is emphatically ***not*** the form we claim best fits every city, as will become clear below.

Much of our focus will be on our estimates of α and β, especially β. But we also report and analyze three other city-specific measures. The first is δ, the average density of the built-up area of the city, our version of what is certainly the most commonly used density statistic.[7] The second is ρ, the R-squared from the log-linear regression above. Malpezzi and Guo (2003) develop the argument that this fit statistic is itself a useful measure of urban form. The third is ψ, the location of the annulus with the highest, or peak, density. We have already noted that many cities, especially large ones, have their peak residential density a few kilometers from the center; we will see that some cities have their peaks quite some distance from the usual definition of "center."

## Comparative Statics

[5] The simplicity of the form allowed early scholars hampered by limited data to crudely estimate density gradients without regression analysis, by assuming the form and fitting it to two observations, the average density of a central city, and the average density of a surrounding suburb, of known radii. See, for example, Mills (1972).
[6] To simplify notation, we will use α to represent the intercept, that is, $\alpha = \ln D_0$. Also, note that by convention β has a minus sign preceding it, so that a positive β means density is falling off with distance. When we say one city's β is larger than another's, we're saying that the gradient is steeper. A smaller gradient is a flatter city. But another, somewhat contradictory, convention is that when estimates of β are reported, we report the coefficients as estimated, which means we (typically) carry the minus sign with it.
[7] While average density seems simple enough, analysts using different definitions of the city will obtain different estimates, often substantially different.

It is often stated, perhaps too loosely, that the standard model implies that increases in the incomes of a city's residents will flatten price gradients, and hence density gradients. Consider equation 2, above, the slope of the bid rent or housing price function. Suppose there are now two consumers, one rich and one poor. Assume H is a normal good. If (for the moment), t is the same for both consumers but H is bigger for the rich (at every u), the rich bid rent function will be flatter. The rich will live in the suburbs and the poor in the center. Even if t also increases with income[8] (), as long as increases in H are "large" relative to increases in t, this result holds. By similar logic, as incomes rise generally as the city develops, as long as H increases faster than t with income, the envelope of all such bid rents will flatten.

While textbook treatments and some articles often assume that a positive income shock leads to larger increases in H than in t, implicitly or explicitly, it is obvious that the model itself does not *require* that increases in income flatten gradients *ceteris paribus*, since the relative income elasticities of t and y could be quite different than we just assumed. Wheaton (1977) and Glaeser and Kahn (2004) are among those who have cast doubt on this common story.

While the literature is somewhat complex and we reserve the right to modify our discussion here as we read more deeply, our first impression is that When one examines housing demand elasticities and transport cost elasticities in their respective literatures it is easy to question that the housing elasticity is much higher than the transport elasticity.[9] Several studies have argued that income elasticity of demand for automobile transportation is one probably one or greater.

[8] As is more realistic; an important element of travel cost is opportunity cost of time, which goes up as income rises.

[9] The literature is complex, and at this point we know the housing literature better than the extensive transportation literature. We reserve the right to modify our discussion here as we read more deeply!

Research on housing demand generally presents evidence for income inelastic demand when looking within cities, and perhaps unitary demand when looking at long-run demand in aggregate time series, or across cities at different levels of development (Mayo 1981; Olsen 1987; Malpezzi and Mayo 1987; Davis and Ortalo-Magne 2005; Mills (date)).

Holding income constant, the effect of a fall in transport cost per se, e.g. from improved infrastructure, is less controversial; clearly, as transport costs fall, bid rents will flatten. Broadly, transport costs fall as cities develop and infrastructure is constructed and improved, and as commuting modes shift from costly time intensive walking through (say) bicycles to motorized transit to automobiles. Complications exist from mispricing of many, if not most, non-walking modes. Cost increases are also possible from congestion as a city at least temporarily outgrows its existing infrastructure. [More here, references]

Extensions to the model permit gradients to change with location-specific amenities as well. See Smith (1978), Follain and Malpezzi (1981), Wu (2002), Palmquist (1992), and especially relevant to this paper, Brueckner, Thisse and Zenrow (1999). Brueckner *et al.* point out that in Paris, there is a stronger tendency for richer households to live centrally, while poor households often live in the suburbs. This is in contrast to most North American cities, for instance. However, at least two other reasons may explain this observation. In Brueckner *et al.*'s model, high-income households value a centrally located amenity. Historic preservation and height restrictions prevent dense low-income housing from being developed in the center, while public housing projects have been located in the suburbs. But it is also conceivable that French tastes for housing and transport are different from, say, British or North American tastes. As previous paragraphs noted, the result that rich live in the suburbs and the poor centrally hinges on the income elasticity of demand for housing (and land) exceed the income elasticity of transport costs.[10] If the relative French elasticities are reversed, then so will the relative locations of rich and poor.[11] In any event, Paris' location of rich and poor could be explained by any or all of these possible explanations.

The standard urban model can also be modified to incorporate the effects of regulation. For example, consider a growth boundary or "greenbelt," as is found in many cities (London, Seoul, Portland, etc.). Figures 2 through 4 illustrate the effect of such a regulation on density. Of course there are many possible regulations, including zoning, subdivision rules, floor area ratios, height limitations, Many such regulations will, in general, be expected to increase central density and flatten the gradient; but others (e.g. large lot zoning) can have the opposite effects. In the end, regulations effect on the gradient can depend on their exact nature.[12]

To summarize: just as this model is canonical, it is also often criticized as simplistic. Real world cities are far from monocentric. The world is divided up into two kinds of people: those who find the simple form informative and useful, despite its shortcomings (e.g. Muth 1985), and those who believe these shortcomings too serious to set aside (e.g. Richardson 1988). In fact, given the predicted flattening of population density gradients as cities grow and economies develop, it can be argued that the monocentric model on which it rests contains the seeds of its own destruction;

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[10] In the next draft we'll present more explicit evidence on these elasticities.

[11] It should also be noted that subsidized housing for the poor is located partly by administrative fiat rather than driven entirely by market forces. Differing political pressures have arguably made it easier for French governments to locate *Habitation à Loyer Modéré* (HLM, subsidized housing) in the *banlieues* on the periphery of French cities, while a different political constraint pushed U.S. public housing into central city locations.

[12] In a pair of recent papers, Mills (2002 a, b) draws interesting parallels, and some contrasts, between common regulations that increase density, and common regulations that lower density. See Malpezzi (1999 b) for a more detailed discussion of the various kinds of urban regulations.

and that a gradual deterioration of the fit of the model is itself consistent with the underlying model.

Table 2 summarizes the qualitative comparative static results from our discussion above.

## A Selection of Previous Empirical Literature

Clark (1951) presented data for 19 cities in 9 countries, with a limited number of repeat observations in time for 9 of the cities. Following Clark's paper, there have been hundreds of studies of population density patterns for cities in developed countries. However, most studies examine only one or a few cities, and with very few exceptions, there is little in the way of cross-country comparison. In particular, despite the size of this literature, only a relative handful of studies have been published for developing and/or emerging economies. Notable early exceptions include the World Bank's City Study of Bogota and Cali (Ingram and Carroll 1981; Mohan 1994; Ingram 1998); Asabere's studies of Accra; Cummings and DiPasquale (1994) have studied Chile; Parr et al. (1988) the United Kingdom, and Glickman (1979) Japan. Several studies have examined Korea, such as Follain, Renaud and Lim (1979), Mills and Song (1979) and Son and Kim (1998). More recent studies of individual countries include Sridhar (2007, India), Terzi and Bolen (2009, Turkey) and Garcia-López (2010, Barcelona). One of the authors of this paper, Alain Bertaud, has prepared a series of country case studies, mostly unpublished except for his study of Moscow and

St. Petersburg with Bertrand Renaud (Bertaud and Renaud 1997) and his case study comparing Atlanta and Barcelona (Bertaud 2003).[13]

Mills and Tan's survey of international studies of population density is, in many respects, the previous study closest in spirit to this paper. Those authors make a number of careful comparisons among a wide range of studies, most using the negative exponential model, e.g. Brush (1968), Ingram and Carroll (1980), Mills and Ohta (1976), and Mills and Song (1979). Mills and Tan relate flattening gradients to rising incomes and growing cities, but in a somewhat qualitative, informal way. That is, Mills and Tan generally presented tabular evidence, e.g. of average density gradients by city size and by country (and hence by GDP per capita). They presented evidence that population density gradients fall over time, worldwide; and that this is further related to growth in incomes and the size of cities. Given the wide range of data sources and estimation procedures followed by the studies that form the base of their comparison, Mills and Tan were careful to make mainly qualitative comparisons. In our study, we have the advantage of comparable data collected and analyzed for over 50 large metropolitan areas around the world.

## Data

### Density Measures

[13] Many of these unpublished papers are available at http://alainbertaud.com .

The first contribution of this study is to estimate a series of population density measures for 57 major metropolitan areas around the world, as consistently as possible. These cities span 32 countries, and contain roughly 240 million people, or 8 percent of the world's urban population. We then model their determinants. The cities for which we have developed data are listed in Table 1, above.

The data have been collected, city-by-city, over two decades, by Alain Bertaud. Bertaud's method is to analyze the built-up area of the city, i.e. to begin with population density in census tracts (or their nearest local equivalents). The data are scanned into a GIS system for further processing. The average density is then measured net of areas that are not built up, such as large parks, lakes, rivers, greenbelts, mountains and other rugged terrain, and the like. For example, we omit New York's Central Park (which, unusually, is its own Census tract); we subtract other parks over 4 hectares, and some areas of the Harlem and Hudson Rivers from other Census tracts that are contained within otherwise inhabited tracts. Streets and roads, and commercial development, are all considered part of the built up fabric of the city, and included.

The sample of cities is opportunistic; they comprise cities Bertaud has been invited to study over the time period, and a few cities for which he was able to gather data through personal contacts (e.g. Marseille). The sample is therefore not representative in the sense of a scientifically drawn sample, but there is wide variation, incorporating rich countries (e.g. France, Germany, the United States), poor countries (e.g. Vietnam, Afghanistan, Ethiopia), and emerging markets (e.g. China, Brazil, Mexico). All continents are represented: 21 in Asia, 17 in Europe, 10 in North America (including Mexico), 5 in Africa, and 4 in Latin America. The data collected and processed span the years 1990 to 2009. It should be emphasized that ***data from 1990 or even 2000 do not perfectly represent current population distributions, especially in fast growing cities, and also especially in cities in transition from environments like Soviet-era central planning, or apartheid.*** We present very limited evidence below on the recent evolution of cities from Atlanta, Seoul, and Tianjin that further motivates future data collection and research.[14]

The basic data processing proceeds as follows. We start with census tract data, or the closest local equivalent. The data are processed in CAD and/or GIS. We assign the population from each tract by mapping them over 1 kilometer annuli. If a tract lies entirely within an annulus, it's assigned that distance from the CBD. But of course many tracts spill over two, three, or sometimes more annuli. Consider a tract that spills across three annuli (Figure 5). The tract is divided into 3 polygons, of equal density set equal to the tract average. That is, the tract's population is assumed to be proportional to the area of each polygon. Each polygon is then assigned the distance of that annulus to the CBD. We group all polygons and then take weighted average of the density of the polygons by annulus, weights equal to assumed population of the polygon.

Figure 6 presents a plot of our polygon data for Chicago; Figure 7 presents the smoothed 1-km annuli data for the same city.

This paper focuses on the 1-km annuli data (average weighted by population of each polygon within an annulus). "Tracts" vary in size and construction from one city/country to the next; so do the polygons we construct from them. Averaging by 1-km ring provides more comparable estimates than using different kinds of tracts and polygons. In addition to our preferred measures,

[14] Small area data (e.g. U.S. Census tracts) are only easily publicly available in a few countries; in addition careful processing of the data in a GIS environment is resource intensive.

presented here, both the weighted average densities by annuli, and the processed polygon data are available in our larger online database. So are some alternative summary measures (e.g. weighted quartiles of density within annuli). Most results are surprisingly robust to choice of method, as we will note below. Of course, many variations of these measures are possible. In our online database, available on request (and posted online after we've finalized the current paper), we provide interested users with both the polygon and annuli data as well as some constructed summary measures we do not analyze in this paper.

To focus on the measures we will use, we start with the annuli data for each city. We then estimate the simple model $\ln D(u) = \alpha - \beta u$. For each city we now have the following variables:[15]

ALPHA: The estimated constant;

BETA: Estimated population density gradient;

SEALPHA: Standard error of the constant;

SEBETA: Standard error of the population density gradient;

DENS_R2: R Squared from this model.

Other density measures include:

BLTAREA: Built up area of the city, in hectares;

DENSITY: Persons per hectare built up area;

[15] Names are as assigned in the AGGREGATE worksheet of the database, and in our SAS programs for data analysis, available on request when this draft is completed.

APDTCBD: The average person's distance to the CBD;

PEAK: The location of densest annulus, in KM from the CBD;

NANNULI: Number of annuli in the city.

So far we have often discussed distance to the center/distance to the CBD without discussing how we measure the center. This is a non-trivial issue. In the simplest urban models, all employment is on the head of a pin at the center. Of course taken literally no such city exists. More realistic versions postulate a central node of high employment density with its own distribution, often its own negative exponential form. Mills 1972 is the classic reference; see also Kemper and Schmenner 1974. Later studies examine multiple centers, beltlines, and other nodes; see Redfearn (2007). Even the largest cities with the most dispersed employment have some location with the highest employment density. The CBD is usually the location with the highest rents in the market, even if these are commercial rather than residential, as well as the highest density of employment.

In the end, for each city, Bertaud chose the center, usually in line with traditional local views. For example Seoul City Hall was chosen as the central point of Seoul, not the alternate center south of the Han, Gangnam.

## Collateral Data

Collateral data come from several sources; more details are available in the data dictionary of our spreadsheet database. We summarize the data here. Our independent variables include:

CITYPOP: City population, from our original local data sources.

LCITYPOP: Log of the city population.

ADPOPLAST40: Annual growth rate of city population, last 40 years prior to data collection. From United Nations *World Urbanization Prospects*.

CITYURBANPOP: City population as a share of country urban population. The numerator is CITYPOP from local data sources; national population is from the World Bank's World Development Indicators.

MEDHHY: Estimated city median household income. See text below for our estimation procedure.

LMEDHHY: Log estimated city median household income.

CAPITAL: Capital city dummy.

GEOCON: Strong geographic constraint dummy. Based on our own interpretation of the city's physical geography.

DISTOCEAN2000: Distance to ocean. UN data.

VEHPERTH: Country motor vehicles per 1000, average of available data circa 2000s. World Development Indicators.

GASPRICE2010: Country gasoline, pump price per liter, average of available data circa 2000s. World Development Indicators.

It is worth providing some detail about how we estimate MEDHHY, city median household income. We begin with a source that has collected such data: UN Habitat Housing and Urban Development Indicators data on city median household income for a sample of 122 cities in 62 countries. We regress the ratio of this city median household income to World Bank GDP per capita on (1) the log of gross national income per capita; (2) the ratio of purchasing power parity GDP per capita to GDP per capita at market exchange rates; and (3) the log of city population. This regression captures about half the variation in the *ratio*, and a good deal more of the variation in median household city income. We then use these coefficients to estimate the ratio for our cities, our years; and we multiply this ratio times the GDP PC, readily available, to yield MEDHHY. Note that this estimated median household income varies by city, and by year.

Finding appropriate transport variables is difficult. In this draft we rely on the country level data on vehicles per thousand population, and on gasoline prices. We use averages of available World Bank world development indicators data from the 2000. We are in the process of obtaining earlier data to better match some of our early cities.

## Categorizing Regulatory Environments

A theme of much of our previous work, separately and together, is the role regulation plays in housing and real estate markets, urban form, and consumer welfare. Regulation *per se* is, of course, neither good nor bad. What matters is the cost and benefit of specific regulations under specific market conditions.

That said, in work such as Angel and Mayo (1996), Bertaud (1989, 1992 a, b, 1997), Fu and Somerville (2001), Malpezzi (1990), Malpezzi and Ball (1993) and World Bank (1993) we and others find evidence that many cities in many countries systematically over-regulate housing and real estate markets, leading to higher prices and volatility (Malpezzi and Wachter 2002).[16] In several of those papers various indices of regulation have been developed. Unfortunately, the overlap between cities with independent regulatory measures and our set of cities is insufficient for estimation. We therefore create a categorical variable for markets that, in our opinion, are excessively regulated. In this context, we don't merely mean planning, zoning or building codes that are a little restrictive, as in say New York or London or San Francisco. Rather, we mean a regulatory regime that ignores or violently contradicts market forces, such as found in Moscow or Seoul or Johannesburg. If anything, many of the "moderately" regulated cities with values of zero, such as London or New York, can be argued to be restrictive in their own right. The difference is a matter of degree.

Initially we categorized cities using a simple 0-1 dummy variable; cities like Moscow, Brasilia, and Johannesburg were graded 1, and market-oriented cities like Paris, Rio and London were graded zero. But it quickly became apparent that this simply bifurcation was insufficient.

We then constructed a three-part categorization of cities by their regulatory environment (REGCAT): 0 for market oriented (though still planned) cities like Paris, Bangkok or most U.S. cities; 1 for cities which have overlaid stringent planning on a market-oriented base, like Warsaw or Sofia; and 2 for the cities most stringently planned in violation of market principles, like Moscow, Brasilia, Seoul or Johannesburg.

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[16] As pointed out in Fischel (1990) and Malpezzi (1996), surprisingly few empirical studies of land use and development regulations have examined both costs *and* benefits.

An alterative, more flexible for estimation purposes, uses the same catories to compute two separate 0-1 dummy variables. REG1=1 if REGCAT=1, and 0 if REGCAT=0 or 2. REG2=1 if REGCAT=2, and 0 if REGCAT=0 or 1.

Another major categorization is by Socialist/Nonsocialist. Note that most of our countries categorized as Socialist are no longer so; we use this label to denote that most of their postwar urban evolution came under socialism. Also, for reasons explained below, we include Chinese cities in the non-socialist category, with market economies like Paris.

Our categorization of the regulatory environment, REGCAT, is partly subjective, and constructed by the same authors that collected the data for and constructed the dependent variables. The possibility of bias, or if you prefer, endogeneity in the regulatory categorization, is real. We've attempted to construct this qualitative regulatory dummy by focusing on the nature of the market system and planning regime without reference to the density patterns, but of course we can't be sure how successful we are at blocking out this knowledge.

In this paper we investigate several alternatives to our previous categorization schemes. We consider several alternative measures of housing or real estate related regulations and institutions, specifically the housing enabling index of Angel and Mayo; an index we construct based on elements of the World Bank's *Doing Business* survey; and Jones Lang LaSalle's Real Estate Transparency Index. Several other candidate indexes were considered, including data from Kenworthy and Haube (1999), and the Kim Mapezzi and Kim 2005 regulatory index, but were dropped because of insufficient overlap with our sample of cities. We also make use of indicator variables of conditions that are directly observable and hence less subject to endogeneity concerns. These include indicator variables for whether a city has a large and constraining Greenbelt or growth boundary; whether a city has a recent history of apartheid; whether a city is effect country with a history of central economic planning; and interaction of central planning with the per capita income; whether a city has been purpose built as a national capital city, within the last century.

Angel and Mayo's index, and the JLL index, are used as-is. We construct our own simple index from Doing Business responses. The World Bank's Doing Business has four data elements related to real estate development:

Time required to register a property in days.

Number of procedures to register a property.

Time required to build a warehouse in days

Number of procedures to build a warehouse.

These elements are reported as national data, but are actually collected for the largest city in each country. Data are obtained from local experts, and refer to the rules de jure. Actual experience/enforcement may vary de facto.

We standardize each of the four elements separately, for all countries in the DB database. Then we sum the standardized indexes. We call this BMINDEX. Larger values of the index => greater ease of real estate development. BMINDEX varies by country. It does not vary by city within country. It does not vary by year.

To summarize, our policy variables include:

REGULAT: original simple regulation dummy

REG1: Regulation dummy, strong but mixed

REG2: Regulation dummy, uniformly strong

REGCAT: Regulation category, 1=strong mixed, 2=uniformly strong

ENABLE1: Angel & Mayo Enabling Index

JLL_COMP: JLL Composite Real Estate Investment Index

BMINDEX: B&M Real Estate Development Index

SOCIALIST=Dummy for a socialist economy.

APARTHEID: Dummy for apartheid.

NEWCAP: Dummy for a newly planned capital.

GREENBELT: Dummy for a large greenbelt.

## Results I: The Measures of Urban Form

## Discussion of Selected Cities

The best way to begin to get a feel for urban form is to start by browsing charts of selected cities. In the online spreadsheet appendix we present a chart for each city, where the average density is presented for each 1-kilometer annulus, starting at the center. In this paper we present a selection: four cities that, broadly speaking, follow the "standard urban model" density pattern; and four that depart substantially from that pattern. The former category is represented by London, New York, Paris and Shanghai (Figures 8 to 11). The latter category's representatives are Brasilia, Johannesburg, Moscow and Seoul (Figures 12 through 15).

Note the scales of figures 8 through 15 differ for each city. Shanghai is the city with the densest center in our sample of 57 cities, at about 1000 persons per hectare. New York City, while by far the densest central city in our US data set, is less than 200 persons per hectare in its densest annulus. Note, by the way, that London is *not* very dense, with a peak central density that's about half of New York's and a third of Paris's. This has potentially strong implications for the possibility of increasing London Metropolitan housing supply by building up, and infill development, as well as oft-mooted additional greenfield development (Barker 2005).

Paris fits the standard model rather well, other than having peak density 2 km out rather than in the first annulus. This is especially notable given that Paris has height restrictions at the center, and new town/HLM developments on the periphery, that we might expect to push the density down at the center and pull it up farther out. It's instructive that while central Paris does not have any high rise residential, many older neighborhoods of six story buildings are quite dense.

Brasilia is a good (?) example of a new town, carved out of the Brazilian jungle as a new capital, and designed by Oscar Niemeyer (architect) and Lúcio Costa (urban planner). They were taken by then-popular theories of "the optimal city." They designed the city for a population of 400,000, which they viewed as the fixed optimum; once the city filled up to that number, done. Of course by 1991 our city contained over 1.5 million. Most of the population, including virtually all the poor, live in satellite towns outside the original planned areas.

Johannesburg is an example of a serious perversion of land use regulation, apartheid. One of the problems engendered by this development "model" is the extreme commuting burden it puts on many residents; two hour one-way commutes are surprisingly common, and traffic deaths and injury rates are among the highest in the world.

Moscow, analyzed more deeply by Bertaud and Renaud (1997), shows the outcome when there is no real land market, but rather housing development by Soviet kombinats operating with no market information to guide them. Each vintage of Soviet housing in Moscow was simply put up at the then-edge of the city; more to the point, old housing, obsolete factories from the twenties, and so on, were never taken down, so land was never recycled as the city grew. Enormous daily commuting flows required the Soviet government to spend substantial sums on subway and other transport infrastructure; current governments labor under the fiscal burden of maintaining and operating the system.

Seoul is a very interesting case. Compared to the Soviet or apartheid-era South African economies, the Korean economy has been more market driven, albeit with much greater public intervention in economic matters than many other countries. Housing and land development, however, have been some of the most heavily regulated and distorted markets in that country, as documented in Hannah Kim and Mills, and Kim Malpezzi and Kim, among others. Seoul is constrained by a large greenbelt, land development is heavily influenced by a large public developer with substantial market power (and eminent domain!), and the system of financing and subsidies approaches the Byzantine.

Why is Shanghai, representing another socialist country, so different than Moscow? At least part of the story is that as a much poorer city (prior to the 1990 date of our data!), Shanghai could not manage the distortions Moscow did. Up until that time, most Shanghainese walked or bicycled to work; it has only been since our data collection that the city's growth has exploded, floorspace per capita has doubled, and commuting and other travel has moved to bus, metro and automobile. Furthermore, prior to 1990 much of Shanghai's housing was provided by state owned enterprises as part of the "iron rice bowl," and these were often likely to develop dense low quality apartments near the workplace.

Of our 57 cities, most broadly follow the "standard" pattern broadly like Figures 8 to 11, more or less. Unsurprisingly, many larger cities have their peak densities one or two kilometers from the center, after which we observe the negative exponential pattern, more or less. This is simply because such cities use up substantial land in their CBD for offices and other nonresidential uses. Also, note that while many cities roughly follow a form that roughly approximates the negative exponential, many different densities are exhibited; richer cities tend to be less dense than poor cities (though some older European cities like Marseille are very dense, and U.S. cities are in a league of their own for lack of density). Also, larger cities tend to be denser, and to have somewhat flatter distributions.

But a number of cities depart from these standard patterns. We've already noted Moscow's departure from such norms; St. Petersburg also departs from the standard model, but much less so than Moscow. Actually, visual inspection of the spreadsheet appendix will confirm that (with the exception of Seoul) the greatest departures from market-oriented forms come from two other kinds of cities: those which developed under apartheid (Capetown, Johannesburg), and those which were developed *de novo* as planned "new towns" (notably Brasilia).

Obviously we cannot discuss each of almost 60 cities in any depth in a single short article. Bertaud and Renaud (1997) compare Paris and Moscow in some detail, focusing on the contrast between a market based (but hardly unregulated!) city, and a city largely developed under an especially rigid form of central planning. Bertaud (2003) compares Atlanta and Barcelona, focusing on the interactions between density and transportation. A larger selection of case studies and related material are available at Bertaud's website.

## Simple Density Gradients and Related Statistics by City

Table 3 presents our gradient estimates, from simple log-linear regressions described above, and several other key variables, for each city.

The results in Table 3 are sorted by the size of the density gradient estimate. Cities like Guanghzou, Toulouse, Shanghai and Singapore generally have the largest (most negative) or steepest gradients, but also among the best fits of the first stage models. Cities like Moscow, Johannesburg and Mumbai have positive gradients, and  often poor fits.  In the event, most cities have negative population density gradients, as predicted by the standard urban model.

## Exploratory Data Analysis by Income and Population

Figures 16 and 17 plot the gradients (coefficients BETA)  by city population, and city median household income, respectively.  We further categorize the data in these two plots by our simple binary categorization of the regulatory environment.  These simple plots suggest that, unconditionally, larger cities have flatter gradients, and richer cities have somewhat flatter gradients. Notice that in both charts the regression line through the more stringently regulated cities lies well above the moderately regulated cities; that is, these are flatter gradients, on average, after controlling very simply for population and income, in turn.

[More on this para., measures presented, next draft] Cities with steeper gradients are generally more compact. That can be true even when they have a larger overall "footprint," as we saw from our analysis of Paris and Moscow. Paris very broadly exhibits the classic gradient from the standard urban model, despite strong planning controls, height limitations in the center, and the promotion of new town development on the periphery. Moscow has developed with a much smaller footprint, and very dense housing on the periphery of the city. But despite the *apparent* dispersion from a smaller footprint, Moscow is actually much less compact than Paris. The dense developments of Moscow's periphery put enormous demands on commuting and on transport infrastructure.

## Results II: Multivariate Models of the Determinants of Gradients, and Dispersion

In the preceding paragraphs we have presented our estimates of $\alpha$, $\beta$, $\psi$ and $\rho$, and undertaken exploratory data analysis. In this section we examine the determinants of each in turn, using a simple multivariate model, or rather series of models.

In the second stage, the city or metropolitan area is again the unit of observation. Using the notation introduced above, we model the determinants of population gradients and dispersion:

$\alpha, \beta, \psi, \rho = f(Y, N, T, R, G)$

where in addition to the endogenous variables defined above Y is income; N is city population; T is a vector representing transport variables; R specifies the regulatory regime; and G are measures of geographical constraint. Locational subscripts (i) are omitted.

Among possibly important omitted variables, one we'd most want is a measure of the centrality of employment. A city with dispersed population can still be somewhat efficient, to the extent employment is also dispersed and significant agglomeration economies are not foregone by this dispersal.[17] However, we note that the cities with the inverted gradients (most decentralized population) are Capetown, Moscow and Seoul, and all three have high proportions of their employment in the central city (see World Bank 1993 b, and Bertaud and Renaud 1997). In the future, we would also like to add better measures of geography (natural constraint) and, if possible, variables capturing fiscal and localized amenity differences.

Table 4 presents simple ordinary least squares second stage regressions for our five key variables: city average density, location of peak annulus, intercept of the negative exponential model, than the density gradient from the simple negative exponential. We also present the R-squared of the negative exponential model.

We use OLS for our first estimates without apology. While these five variables are surely related, identification of a more arts-and-craftsy set of regressions requires restrictions we have some difficulty in developing and defending. For example, what variables might exist that

[17] We qualify this with ‘somewhat’ efficient, because if employment nodes are greatly dispersed, the city’s role as a unified labor market and generator of agglomeration economies can start to break down.

appear in the equation for one of these measures and not the other? What, for example, would affect average density, but not the gradient? Or vice versa? We believe given the nature of our data and the difficulty of identification that least-squares, despite its potential lack of efficiency, is our best alternative.

Parsimony is also important. With more than 50 cities we could, putting our minds to it, estimate a model with 40 right-hand side variables that would yield very good fits but tell us nothing interesting. In table 4 we imposed a restriction that each of the five equations incorporates the first four variables: population, income, a regulatory variable and a transport proxy. We then use forward stepwise to allow the data to tell us what else mattered.

In tables 4 and five we highlight in blue shading any coefficients which are close to any commonly used level of significance.

In the regression for the density gradients bigger cities have flatter gradients as expected, but the coefficient of the log of median household income is not significantly different from zero. The coefficient estimate is negative with the t statistic of -1.67, which is close to the 10% significance level. If we interpret this coefficient as zero, we could argue that globally, as incomes rise, changes in transport costs roughly balance changes in housing demand in the fundamental equation of the standard urban model. If we take the negative coefficient at face value then it could be argued that globally the effective transport cost is only slightly larger than the effective housing demand.  In the next draft we'll use individual coefficient regression diagnostics developed by Belseley, Kuh and Welsch to see if we can shed light on differences in country preferences. We'll also examine the multicollinearity among income, population and transportation costs in greater detail.

## Conclusions

### *Empirical Findings*

In this paper we have calculated, on a consistent basis, population density gradients for almost 50 large cities in some 27 countries. We have also constructed an alternative measure of city population dispersion. In second-stage analyses, we have examined several potential determinants of urban form. Our focus has been on income, population, and the nature of the regulatory regime. To a lesser extent, we have examined the role of natural constraint (physical geography), and transport mode.

The first important finding is that in many cities – perhaps a surprisingly large number, to some – the negative exponential density gradient implied by the standard urban model fits the data quite well. On the other hand, in a number of cities, population density departs a *lot* from the standard model. A few cities that depart substantially are cities, like Seoul, that are usually characterized as market economies but extraordinary regulatory environments for land use; some are centrally planned cities, like Moscow or Brasilia; and others are cities that developed under apartheid, like Capetown.

In a second stage model we find that density gradients flatten with income, with city population, and with falling transportation costs, as the standard urban model predicts. We also find that cities with extremely repressive urban regulations, as in South Africa, Korea and Russia, have flatter (sometimes inverted) population density gradients. However, improving our measurement of the urban policy environment remains an important subject for future research.

In several respects, our results confirm the findings from the two-decade earlier study of Mills and Tan (1980). The negative exponential function is a useful framework for studying urban form (although we have also analyzed a competing measure of dispersion). Like Mills and Tan, but based on more data, we find persistent and strong patterns of decentralization as cities grow in population. However, we have evidence that many other things affect density, as Mills and Tan suggest (p. 321); in this paper, we have shown that the effect of the regulatory regime of the city is profound. We have also demonstrated that natural constraint matters, but so far to a lesser extent than man-made constraints.

Socialist (transition) cities are more likely to be stringently regulated, or most often to be in the 'mixed case' where a stringently planned, non-market urban form has overlaid an existing market-driven city. However, once mode of regulation is controlled for, there is no identifiable residual effect of socialism. *Regulation is the transmission mechanism*. Changing regulations will, over a long period, change the form of the city.

## Policy Implications

What are the implications of these preliminary results for those concerned with urban form, or more directly, with city efficiency in transition economies?

## Future Research

We have found that our most basic results are very robust to changes in model and sample; the numbers may change slightly, but qualitative results will almost surely remain robust. Still, we have some thoughts on a longer run research agenda.

All models are simplifications. As a very well-known physicist has put it, "everything should be as simple as possible – but not more so." We believe our initial analysis of simple gradients and our dispersion measure has yielded a number of important insights. But returns from studying this data are not exhausted. It can be fruitful to study urban form using measures that vary more flexibly, and that include tools developed by geographers and regional scientists, such as models of spatial autocorrelation.[18] These measures are harder to characterize with a parameter or two, and hence harder to do comparisons; but such research can lead to improved analysis of "Type 2" cities, where regulation is a mixed case, and within an annulus one might find a mix of Moscow-style planned housing, and the remnants of earlier (as well as more recent) market developments.

There are of course potential gains simply from increasing the size of the database and the range of cities we study. In addition to general improvements from added degrees of freedom, with more data we can analyze additional interesting taxonomies. For example, is there such a

[18] See Follain and Gross (1983), Cheshire and Sheppard (1995), and Malpezzi and Guo (2001), and references therein.

thing as a "European city?" This question could be better answered if we have enough European cities, both qualitatively and more quantitatively (permitting sufficiently powerful hypotheses tests). With sufficient data we could do more to go beyond simple generalizations. Are apparent differences between (say) European and U.S. cities related to differences public expenditure in core amenities? Are U.S. cities really mainly pure localized labor markets with a very low level of amenities in the center? What effect, if any, does a change in the transportation network have on form?

Other large gains could come from continued efforts to systematize and coordinate data collection on cities, including but not limited to the kinds of data we examine here. The Housing and Urban Development Indicators Project, initiated at the World Bank and UNCHS (Habitat), and now mainly carried out under UN auspices, could be one possible avenue for such an effort. Many individual efforts, like the Indicators Project, Bank-sponsored data collection on urban form by Newman and colleagues, and our own effort, could make a greater contribution with stronger design, including but not limited to (a) more overlap among sampled cities, (b) wider geographic and country profile scope (including more ECA countries), and (c) less of a laundry-list approach and more focus on improving and collecting key indicators of economic and environmental outputs, and measures of the policy environment.

To quote McDonald and Bowman:

> *In a sense there is no real conclusion to this research because the directions in which further research could proceed are almost endless. Data for more urban areas of different sizes advantages can be used. More functions can be proposed. More sophisticated estimation procedures and criteria can be used. The authors of the [M&B] study stand ready to supply other researchers with the tools developed especially for the study, but no guarantee of the payoff for using the tools is implied.*

We agree completely!

ADD:

Malpezzi and Guo

Mayo hsg demand

Olsen hsg demand

Davis and FOM

M&M housing demand

Malpezzi and Wachter hsg demand

Mills housing demand

Fischel

Belseley Kuh and Welsch

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| Table 1: Average Population Density of Selected World Cities | | | | | | |
|---|---|---|---|---|---|---|
| City | Country | City Code | Year | City Population | Built-up Area, Hectares | Average Persons per Hectare, Built-up Area of the City |
| Mumbai | India | MUM | 1991 | 9,825,137 | 252 | 389 |
| Hong Kong | Hong Kong | HK | 1990 | 5,400,000 | 147 | 367 |
| Guangzhou | China | GZU | 1990 | 2,021,545 | 55 | 365 |
| Seoul Municipality | Korea, Rep. of | SEO1 | 1990 | 10,287,403 | 319 | 322 |
| Shanghai | China | SHA | 1990 | 7,396,783 | 258 | 286 |
| Seoul + New Towns | Korea, Rep. of | SEO3 | 1990 | 13,804,242 | 489 | 282 |
| Lahore | Pakistan | LAH | 1998 | 6,310,000 | 240 | 246 |
| Tianjin | China | TNJ1 | 1988 | 3,499,718 | 154 | 228 |
| Hyderabad | India | HYD | 1991 | 3,043,896 | 137 | 223 |
| Kabul | Afghanistan | KBL | 2005 | 3,025,718 | 141 | 215 |
| Hanoi | Vietnam | HOI | 2009 | 3,055,180 | 146 | 209 |
| Bangalore | India | BLR | 1991 | 3,948,129 | 191 | 207 |
| Moscow | Russia | MOS | 1990 | 8,543,867 | 470 | 182 |
| Addis Ababa | Ethiopia | ADD | 2002 | 3,933,313 | 222 | 177 |
| Barcelona | Spain | BRC | 1990 | 2,775,000 | 163 | 171 |
| Tianjin | China | TNJ2 | 2000 | 4,264,577 | 251 | 170 |
| Yerivan | Armenia | YER | 1990 | 1,249,406 | 74 | 168 |
| Ho Chi Minh City | Vietnam | HCM | 2009 | 6,711,969 | 449 | 150 |
| Tehran | Iran | THE | 1996 | 6,751,290 | 464 | 146 |
| Beijing | China | BJG | 1990 | 5,333,291 | 367 | 145 |
| Abidjan | Cote d'Ivoire | ABJ | 1990 | 1,826,981 | 127 | 143 |
| Ahmedabad | India | AHM | 1991 | 2,865,386 | 214 | 134 |
| Surabaya* | Indonesia | SUR | 2010 | 5,622,259 | 335 | 133 |
| Jakarta | Indonesia | JAK | 1990 | 8,222,000 | 649 | 127 |
| St Petersburg | Russia | STP | 1990 | 4,241,341 | 351 | 121 |
| Singapore | Singapore | SNG | 1990 | 2,034,814 | 189 | 107 |
| Tunis | Tunisia | TUN | 1990 | 1,232,508 | 121 | 102 |
| Rio de Janeiro | Brazil | RIO | 1991 | 5,569,898 | 554 | 101 |
| Mexico City | Mexico | MEX | 2000 | 15,566,109 | 1,624 | 96 |
| Sofia | Bulgaria | SOF | 1999 | 1,137,000 | 120 | 94 |
| Paris | France | PAR | 1990 | 7,877,729 | 893 | 88 |
| Danang | Vietnam | DNG | 2009 | 842,523 | 96 | 88 |
| New York City MSA | United States | NYC1 | 1990 | 7,198,101 | 904 | 80 |
| Prague | Czech Republic | PRG | 1990 | 1,210,000 | 171 | 71 |
| Warsaw | Poland | WAR | 1993 | 1,639,675 | 235 | 70 |
| Buenos Aires | Argentina | BAR | 2000 | 10,924,711 | 1,647 | 66 |
| Cracow | Poland | CRA | 1988 | 730,600 | 112 | 65 |
| Riga | Latvia | RIG | 2000 | 759,255 | 119 | 64 |
| Budapest | Hungary | BPT | 1990 | 1,937,162 | 309 | 63 |
| London | United Kingdom | LDN | 1990 | 6,626,272 | 1,062 | 62 |
| Bangkok | Thailand | BGK | 1990 | 7,788,042 | 1,351 | 58 |
| Brasilia | Brazil | BRS | 1991 | 1,508,725 | 272 | 55 |
| Curitiba | Brazil | CTA | 1991 | 1,497,049 | 276 | 54 |
| Marseille | France | MSL | 1990 | 800,447 | 151 | 53 |
| Johannesburg | South Africa | JB1 | 1991 | 5,415,060 | 1,027 | 53 |
| Ljubjana | Slovenia | LJU | 1990 | 247,969 | 54 | 46 |
| New York CMSA | United States | NYC2 | 1990 | 10,752,915 | 2,674 | 40 |
| Toulouse | France | TOU | 1990 | 343,952 | 95 | 36 |
| Berlin | Germany | BLN | 1990 | 4,212,381 | 1,176 | 36 |
| Stockholm | Sweden | STK | 2000 | 1,426,922 | 400 | 36 |
| Capetown | South Africa | CAP | 1990 | 2,264,000 | 701 | 32 |
| Los Angeles | United States | LA | 1990 | 9,317,412 | 4,162 | 22 |
| Washington, DC | United States | DC | 1990 | 2,835,771 | 1,362 | 21 |
| San Francisco MSA | United States | SF1 | 1990 | 3,018,540 | 1,622 | 19 |
| Chicago | United States | CHI | 1990 | 7,294,248 | 4,694 | 16 |
| San Francisco Bay CMSA | United States | SF2 | 1990 | 5,098,724 | 3,234 | 16 |
| Portland | United States | PRT | 2000 | 1,230,013 | 888 | 14 |
| Houston | United States | HOU | 1990 | 3,796,847 | 3,515 | 11 |
| Atlanta | United States | ATL90 | 1990 | 2,514,199 | 4,279 | 6 |

**Table 2: Expected Signs in Second Stage Regressions**

| | Average Density | Density Intercept | Density Gradient | Density R2 | Location of Peak Annulus (KM) |
|---|---|---|---|---|---|
| Income | – | – | + (??) | ? | ? |
| Population | + | + | + | -- | + |
| Pop Growth | – | – | + | -- | ? |
| Transport Cost | + | + | – | +? | ? |
| Geographic Constraint | + | +? | ? | -- | ? |
| Development Regulation | ? | + | ? | ? | +? |

Expect more noise, fewer significant relationships in second-stage regressions in the group of cities that are severely regulated (central planning, apartheid, etc.)

## Table 3: Parameters from Log-Linear Density Gradient Regressions on 1-km Annuli Data

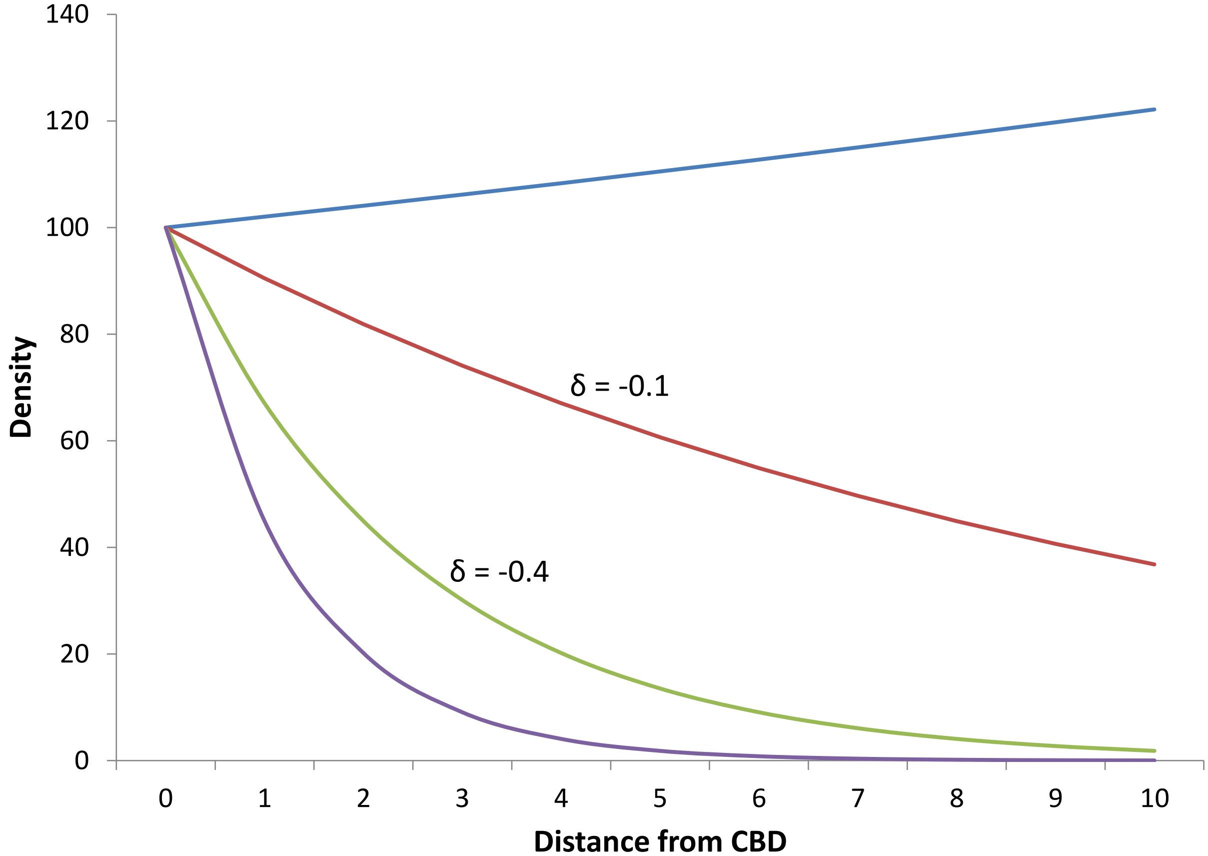
| | | Location of Densest Annulus | Number of Annuli | Constant from Density Gradient Regression | Estimated Pop Gradient from Density Gradient Regression | Standard Error Constant from Density Gradient Regression | Standard Error Estimated Pop Gradient from Density Gradient Regression | Absolute Value of t-Statistic Estimated Pop Gradient from Density Gradient Regression | R2 from Density Gradient Regression |
|---|---|---|---|---|---|---|---|---|---|
| BERTCITY | YEAR | **PEAK** | **NANNULI** | **ALPHA** | **BETA** | **SEALPHA** | **SEBETA** | **ABSTBETA** | **DENS_R2** |
| Guangzhou | 1990 | 1 | 9 | 7.36 | -0.489 | 0.243 | 0.043 | 11.3 | 94.8 |
| Toulouse | 1990 | 1 | 9 | 5.21 | -0.377 | 0.160 | 0.028 | 13.2 | 96.2 |
| Marseille | 1990 | 1 | 15 | 5.95 | -0.352 | 0.317 | 0.035 | 10.1 | 88.7 |
| Da Nang | 2009 | 1 | 19 | 6.08 | -0.248 | 0.454 | 0.040 | 6.2 | 70.0 |
| Shanghai | 1990 | 1 | 14 | 7.21 | -0.247 | 0.048 | 0.006 | 43.8 | 99.4 |
| Singapore | 1990 | 3 | 21 | 6.06 | -0.195 | 0.105 | 0.008 | 23.4 | 96.7 |
| Ljubjana | 1990 | 1 | 10 | 4.63 | -0.194 | 0.163 | 0.026 | 7.4 | 87.0 |
| Beijing | 1990 | 2 | 15 | 6.27 | -0.174 | 0.125 | 0.014 | 12.7 | 92.6 |
| Krakow | 1988 | 1 | 19 | 5.05 | -0.174 | 0.231 | 0.020 | 8.6 | 81.3 |
| Abidjan | 1990 | 3 | 17 | 4.95 | -0.169 | 0.263 | 0.026 | 6.6 | 2.8 |
| Warsaw | 1993 | 1 | 18 | 5.32 | -0.168 | 0.179 | 0.016 | 89.4 | 87.0 |
| Riga | 2000 | 1 | 15 | 4.89 | -0.154 | 0.199 | 0.024 | 6.3 | 75.6 |
| Tianjin 88 | 1988 | 1 | 13 | 6.34 | -0.153 | 0.159 | 0.020 | 7.6 | 84.0 |
| Tianjin 00 | 2000 | 1 | 15 | 6.12 | -0.148 | 0.086 | 0.010 | 15.6 | 94.5 |
| Sofia | 1999 | 1 | 12 | 5.25 | -0.138 | 0.103 | 0.014 | 9.9 | 91.0 |
| Bangalore | 1991 | 1 | 12 | 6.02 | -0.130 | 0.089 | 0.012 | 10.7 | 92.0 |
| Ahmedabad | 1991 | 6 | 17 | 5.48 | -0.119 | 0.254 | 0.025 | 4.8 | 60.6 |
| Hyderabad | 1991 | 2 | 11 | 5.93 | -0.114 | 0.097 | 0.014 | 8.0 | 87.5 |
| Hong Kong | 1990 | 5 | 30 | 7.03 | -0.113 | 0.255 | 0.014 | 7.9 | 69.0 |
| Jakarta | 1990 | 1 | 21 | 5.81 | -0.113 | 0.216 | 0.017 | 6.6 | 69.5 |
| Prague | 1990 | 2 | 20 | 5.00 | -0.113 | 0.070 | 0.006 | 19.3 | 95.0 |
| Tehran | 1996 | 6 | 29 | 5.81 | -0.112 | 0.145 | 0.008 | 13.2 | 87.0 |
| Jabotabek | 1990 | 5 | 40 | 5.61 | -0.107 | 0.077 | 0.003 | 32.7 | 96.6 |
| Budapest | 1990 | 1 | 21 | 5.06 | -0.105 | 0.170 | 0.014 | 7.8 | 76.2 |
| Barcelona | 1990 | 2 | 23 | 5.88 | -0.098 | 0.102 | 0.007 | 65.6 | 89.0 |
| Paris | 1990 | 2 | 22 | 5.67 | -0.097 | 0.093 | 0.007 | 13.7 | 90.4 |
| Yerevan | 1990 | 1 | 11 | 5.48 | -0.094 | 0.142 | 0.021 | 4.5 | 69.1 |
| St Petersburg | 1990 | 3 | 24 | 5.44 | -0.084 | 0.246 | 0.022 | 3.9 | 47.0 |
| New York City | 1990 | 3 | 43 | 5.50 | -0.073 | 0.099 | 0.004 | 18.7 | 89.5 |
| Hanoi | 2009 | 1 | 15 | 5.85 | -0.066 | 0.078 | 0.009 | 7.8 | 82.0 |
| Ho Chi Minh City | 2009 | 3 | 27 | 5.63 | -0.063 | 0.124 | 0.008 | 8.1 | 72.0 |
| San Francisco | 1990 | 4 | 41 | 4.21 | -0.053 | 0.074 | 0.003 | 17.2 | 88.3 |
| Bangkok | 1990 | 1 | 50 | 5.05 | -0.052 | 0.084 | 0.003 | 18.2 | 87.3 |
| Washington, DC | 1990 | 3 | 30 | 3.92 | -0.051 | 0.085 | 0.005 | 10.6 | 80.0 |
| New York CMSA | 1990 | 3 | 59 | 4.79 | -0.046 | 0.095 | 0.003 | 16.9 | 83.4 |
| Berlin | 1990 | 2 | 56 | 4.26 | -0.043 | 0.151 | 0.005 | 9.3 | 61.7 |
| Johannesburg | 1991 | 26 | 54 | 4.21 | -0.043 | 0.395 | 0.013 | 3.2 | 17.7 |
| Addis Ababa | 2002 | 1 | 22 | 5.52 | -0.039 | 0.242 | 0.018 | 2.1 | 18.0 |
| Surabaya | 2010 | 3 | 18 | 5.24 | -0.039 | 0.215 | 0.020 | 2.0 | 19.3 |
| Stockholm | 2000 | 2 | 33 | 4.06 | -0.039 | 0.145 | 0.008 | 5.0 | 44.3 |
| Buenos Aires | 2000 | 1 | 49 | 5.04 | -0.038 | 0.042 | 0.002 | 25.2 | 93.1 |
| Atlanta 90 | 1990 | 2 | 72 | 2.77 | -0.036 | 0.032 | 0.001 | 47.5 | 97.0 |
| Tunis | 1990 | 1 | 20 | 4.97 | -0.036 | 0.130 | 0.011 | 3.3 | 37.6 |
| Houston | 1990 | 30 | 77 | 3.15 | -0.035 | 0.138 | 0.003 | 11.3 | 63.1 |
| Mexico City | 2000 | 1 | 51 | 5.08 | -0.034 | 0.072 | 0.002 | 13.5 | 78.7 |
| Rio de Janeiro | 1991 | 10 | 60 | 5.24 | -0.031 | 0.064 | 0.002 | 17.1 | 83.4 |
| Atlanta 00 | 2000 | 2 | 72 | 2.85 | -0.029 | 0.032 | 0.001 | 37.9 | 95.4 |
| Seoul + New Towns 90 | 1990 | 4 | 38 | 5.84 | -0.028 | 0.251 | 0.011 | 2.5 | 15.1 |
| Los Angeles | 1990 | 2 | 50 | 3.80 | -0.026 | 0.027 | 0.001 | 28.1 | 94.3 |
| Chicago | 1990 | 9 | 88 | 3.65 | -0.024 | 0.098 | 0.002 | 12.8 | 65.6 |
| London | 1990 | 5 | 29 | 4.47 | -0.024 | 0.078 | 0.005 | 5.3 | 50.9 |
| Atlanta 10 | 2010 | 3 | 72 | 2.89 | -0.023 | 0.047 | 0.001 | 20.5 | 85.7 |
| Portland | 2000 | 1 | 35 | 2.96 | -0.020 | 0.124 | 0.006 | 3.3 | 24.4 |
| Curitiba | 1991 | 14 | 16 | 4.22 | -0.018 | 0.164 | 0.017 | 1.1 | 7.7 |
| San Francisco Bay CMSA | 1990 | 4 | 80 | 3.44 | -0.015 | 0.110 | 0.002 | 6.2 | 33.2 |
| Mumbai | 1991 | 22 | 43 | 6.12 | -0.012 | 0.097 | 0.004 | 3.1 | 19.2 |
| Kabul | 2005 | 17 | 17 | 5.22 | -0.006 | 0.244 | 0.024 | 0.2 | 0.4 |
| Gauteng (Jburg and Praeto | 2002 | 2 | 100 | 3.32 | 0.003 | 0.106 | 0.002 | 1.9 | 4.0 |
| Cape Town | 1990 | 24 | 40 | 3.22 | 0.010 | 0.056 | 0.002 | 4.3 | 32.4 |
| Lahore | 1998 | 14 | 15 | 5.46 | 0.011 | 0.121 | 0.013 | 0.8 | 4.7 |
| Seoul Municipality 90 | 1990 | 4 | 17 | 5.49 | 0.018 | 0.197 | 0.019 | 0.9 | 5.5 |
| Seoul Municipality 09 | 2009 | 19 | 19 | 5.18 | 0.036 | 0.070 | 0.006 | 5.9 | 67.2 |
| Brasilia | 1991 | 27 | 40 | 3.06 | 0.037 | 0.200 | 0.009 | 4.4 | 32.5 |
| Moscow | 1990 | 20 | 21 | 4.57 | 0.047 | 0.151 | 0.012 | 3.9 | 44.4 |

## Table 4: Simple OLS Models of Five Outcomes; Modified Stepwise

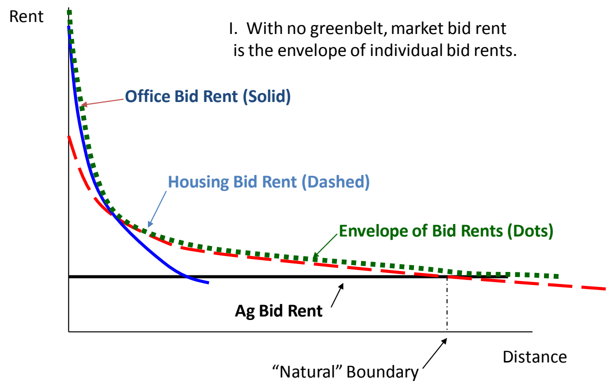
| _TYPE_ | Intercept | Log of City Population | Log of City Median Household Income | B&M Continuous Regulatory Index | Vehicles per 1000 National Population | Annual City Population Growth, Past 40 Years | National Capital Dummy | Strong Geographic Constraint Dummy | Dummy for Apartheid | Dummy for a Large Greenbelt | Dummy for a Newly Planned Capital | Degrees of Freedom | R-Squared | Adjusted R-Squared |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *CITY AVERAGE DENSITY* | | | | | | | | | | | | | | |
| Coefficient | -141.453 | 18.943 | 6.717 | 1.309 | -0.257 | | -32.111 | 43.359 | -128.176 | 30.211 | -87.256 | 43 | 0.603 | 0.520 |
| Standard Error | 162.618 | 10.774 | 11.486 | 12.833 | 0.064 | | 19.273 | 19.897 | 49.725 | 33.214 | 74.804 | | | |
| t-Statistic | -0.870 | 1.758 | 0.585 | 0.102 | -4.000 | | -1.666 | 2.179 | -2.578 | 0.910 | -1.166 | | | |
| P>\|t\| | 0.389 | 0.086 | 0.562 | 0.919 | 0.000 | | 0.103 | 0.035 | 0.013 | 0.368 | 0.250 | | | |
| *LOCATION OF PEAK ANNULUS* | | | | | | | | | | | | | | |
| Coefficient | -17.218 | 1.483 | -0.362 | 2.320 | 0.002 | | -0.916 | 2.147 | 22.825 | 5.736 | 18.620 | 43 | 0.716 | 0.657 |
| Standard Error | 10.082 | 0.668 | 0.712 | 0.796 | 0.004 | | 1.195 | 1.234 | 3.083 | 2.059 | 4.637 | | | |
| t-Statistic | -1.708 | 2.221 | -0.509 | 2.916 | 0.450 | | -0.767 | 1.740 | 7.404 | 2.786 | 4.015 | | | |
| P>\|t\| | 0.095 | 0.032 | 0.614 | 0.006 | 0.655 | | 0.448 | 0.089 | 0.000 | 0.008 | 0.000 | | | |
| *INTERCEPT OF NEGATIVE EXPONENTIAL FIT TO CITY ANNULI* | | | | | | | | | | | | | | |
| Coefficient | 5.046 | 0.031 | 0.157 | -0.024 | -0.003 | -13.171 | -0.245 | | -2.230 | -0.720 | -0.862 | 43 | 0.682 | 0.616 |
| Standard Error | 1.579 | 0.103 | 0.109 | 0.122 | 0.001 | 6.089 | 0.181 | | 0.476 | 0.319 | 0.819 | | | |
| t-Statistic | 3.195 | 0.303 | 1.444 | -0.196 | -5.447 | -2.163 | -1.355 | | -4.681 | -2.258 | -1.052 | | | |
| P>\|t\| | 0.003 | 0.763 | 0.156 | 0.845 | 0.000 | 0.036 | 0.183 | | 0.000 | 0.029 | 0.299 | | | |
| *DENSITY GRADIENT, SIMPLE NEGATIVE EXPONENTIAL* | | | | | | | | | | | | | | |
| Coefficient | -0.852 | 0.056 | -0.023 | -0.002 | 0.000 | | 0.043 | 0.031 | 0.127 | 0.113 | 0.109 | 43 | 0.514 | 0.412 |
| Standard Error | 0.193 | 0.013 | 0.014 | 0.015 | 0.000 | | 0.023 | 0.024 | 0.059 | 0.039 | 0.089 | | | |
| t-Statistic | -4.414 | 4.383 | -1.668 | -0.132 | 2.379 | | 1.871 | 1.325 | 2.157 | 2.870 | 1.231 | | | |
| P>\|t\| | 0.000 | 0.000 | 0.103 | 0.896 | 0.022 | | 0.068 | 0.192 | 0.037 | 0.006 | 0.225 | | | |
| *R2 of NEGATIVE EXPONENTIAL FIT TO CITY ANNULI* | | | | | | | | | | | | | | |
| Coefficient | 57.101 | 0.834 | 2.973 | -2.174 | -0.004 | -481.056 | | -13.645 | -51.875 | -51.802 | 41.930 | 43 | 0.552 | 0.458 |
| Standard Error | 54.522 | 3.538 | 3.768 | 4.176 | 0.022 | 219.365 | | 6.730 | 16.310 | 11.234 | 28.564 | | | |
| t-Statistic | 1.047 | 0.236 | 0.789 | -0.521 | -0.179 | -2.193 | | -2.028 | -3.181 | -4.611 | 1.468 | | | |
| P>\|t\| | 0.301 | 0.815 | 0.434 | 0.605 | 0.858 | 0.034 | | 0.049 | 0.003 | 0.000 | 0.149 | | | |

| Simple OLS Models of Five Outcomes, By Regulatory Stringency | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **Intercept** | **Log of City Population** | **Log of City Median Household Income** | **B&M Continuous Regulatory Index** | **Degrees of Freedom** | **R-Squared** | **Adjusted R-Squared** |
| **MODERATE REGULATORY ENVIRONMENT** | | | | | | | | |
| | *CITY AVERAGE DENSITY* | | | | | | | |
| | Coefficient | -25.253 | 23.909 | -24.152 | 28.803 | 30 | 0.308 | 0.239 |
| | Standard Error | 244.857 | 15.426 | 9.155 | 21.943 | | | |
| | t-Statistic | -0.103 | 1.550 | -2.638 | 1.313 | | | |
| | P>\|t\| | 0.919 | 0.132 | 0.013 | 0.199 | | | |
| | *LOCATION OF PEAK ANNULUS* | | | | | | | |
| | Coefficient | -12.055 | 0.909 | 0.135 | 1.320 | 30 | 0.109 | 0.020 |
| | Standard Error | 9.913 | 0.625 | 0.371 | 0.888 | | | |
| | t-Statistic | -1.216 | 1.456 | 0.365 | 1.486 | | | |
| | P>\|t\| | 0.233 | 0.156 | 0.718 | 0.148 | | | |
| | *INTERCEPT OF NEGATIVE EXPONENTIAL FIT TO CITY ANNULI* | | | | | | | |
| | Coefficient | 5.614 | 0.120 | -0.234 | 0.286 | 30 | 0.236 | 0.159 |
| | Standard Error | 2.726 | 0.172 | 0.102 | 0.244 | | | |
| | t-Statistic | 2.060 | 0.698 | -2.293 | 1.170 | | | |
| | P>\|t\| | 0.048 | 0.491 | 0.029 | 0.251 | | | |
| | *DENSITY GRADIENT, SIMPLE NEGATIVE EXPONENTIAL* | | | | | | | |
| | Coefficient | -1.026 | 0.059 | 0.001 | -0.030 | 30 | 0.329 | 0.262 |
| | Standard Error | 0.284 | 0.018 | 0.011 | 0.025 | | | |
| | t-Statistic | -3.619 | 3.330 | 0.087 | -1.194 | | | |
| | P>\|t\| | 0.001 | 0.002 | 0.931 | 0.242 | | | |
| | *R2 of NEGATIVE EXPONENTIAL FIT TO CITY ANNULI* | | | | | | | |
| | Coefficient | 16.135 | 1.238 | 5.010 | -2.065 | 30 | 0.120 | 0.032 |
| | Standard Error | 75.510 | 4.757 | 2.823 | 6.767 | | | |
| | t-Statistic | 0.214 | 0.260 | 1.774 | -0.305 | | | |
| | P>\|t\| | 0.832 | 0.796 | 0.086 | 0.762 | | | |
| **STRINGENT REGULATORY ENVIRONMENT** | | | | | | | | |
| | *CITY AVERAGE DENSITY* | | | | | | | |
| | Coefficient | -441.028 | 67.148 | -50.748 | -11.169 | 15 | 0.551 | 0.461 |
| | Standard Error | 309.670 | 19.164 | 18.546 | 19.346 | | | |
| | t-Statistic | -1.424 | 3.504 | -2.736 | -0.577 | | | |
| | P>\|t\| | 0.175 | 0.003 | 0.015 | 0.572 | | | |
| | *LOCATION OF PEAK ANNULUS* | | | | | | | |
| | Coefficient | -28.078 | 2.754 | -0.530 | 2.554 | 15 | 0.153 | -0.016 |
| | Standard Error | 41.978 | 2.598 | 2.514 | 2.623 | | | |
| | t-Statistic | -0.669 | 1.060 | -0.211 | 0.974 | | | |
| | P>\|t\| | 0.514 | 0.306 | 0.836 | 0.346 | | | |
| | *INTERCEPT OF NEGATIVE EXPONENTIAL FIT TO CITY ANNULI* | | | | | | | |
| | Coefficient | 4.131 | 0.391 | -0.596 | -0.162 | 15 | 0.518 | 0.422 |
| | Standard Error | 2.863 | 0.177 | 0.171 | 0.179 | | | |
| | t-Statistic | 1.443 | 2.209 | -3.478 | -0.908 | | | |
| | P>\|t\| | 0.170 | 0.043 | 0.003 | 0.378 | | | |
| | *DENSITY GRADIENT, SIMPLE NEGATIVE EXPONENTIAL* | | | | | | | |
| | Coefficient | -0.752 | 0.031 | 0.027 | 0.013 | 15 | 0.432 | 0.319 |
| | Standard Error | 0.214 | 0.013 | 0.013 | 0.013 | | | |
| | t-Statistic | -3.513 | 2.355 | 2.083 | 1.003 | | | |
| | P>\|t\| | 0.003 | 0.033 | 0.055 | 0.332 | | | |
| | *R2 of NEGATIVE EXPONENTIAL FIT TO CITY ANNULI* | | | | | | | |
| | Coefficient | 241.805 | -9.077 | -6.255 | -4.618 | 15 | 0.139 | -0.033 |
| | Standard Error | 125.052 | 7.739 | 7.489 | 7.813 | | | |
| | t-Statistic | 1.934 | -1.173 | -0.835 | -0.591 | | | |
| | P>\|t\| | 0.072 | 0.259 | 0.417 | 0.563 | | | |

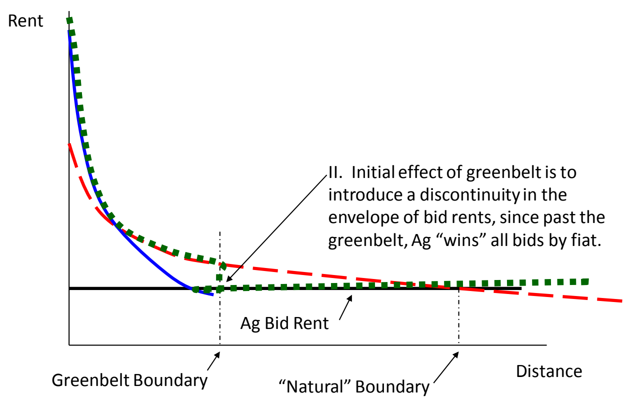
# Fig. 1: Stylized Density Gradients



## Fig. 2: Closed City Effect of A Greenbelt/Urban Service Boundary on Bid Rents (I)




## Fig. 3: Closed City Effect of A Greenbelt/Urban Service Boundary on Bid Rents (II)




## Fig. 4: Closed City Effect of A Greenbelt/Urban Service Boundary on Bid Rents (III)

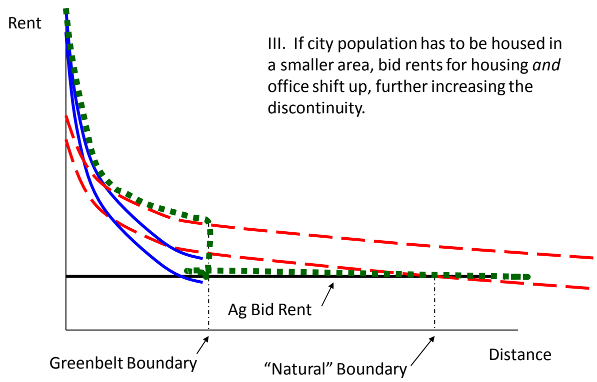
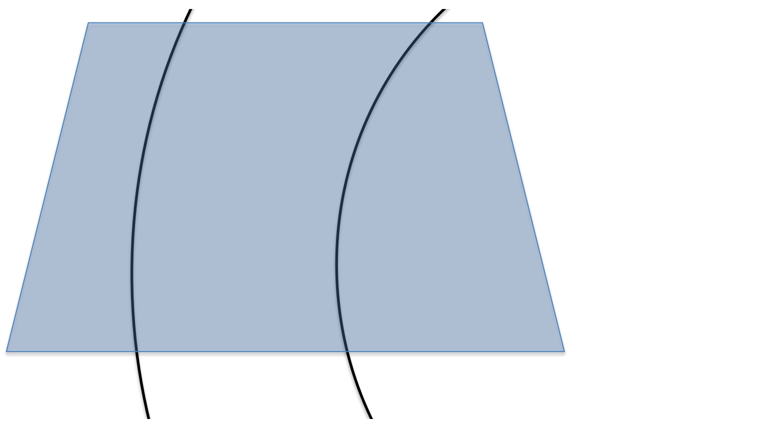


Fig. 5: Consider a tract that spills
across three annuli. The
tract is divided into 3 polygons,
of equal density set equal to the tract average.
That is, the tract's population is assumed to
be proportional to the area of each polygon.



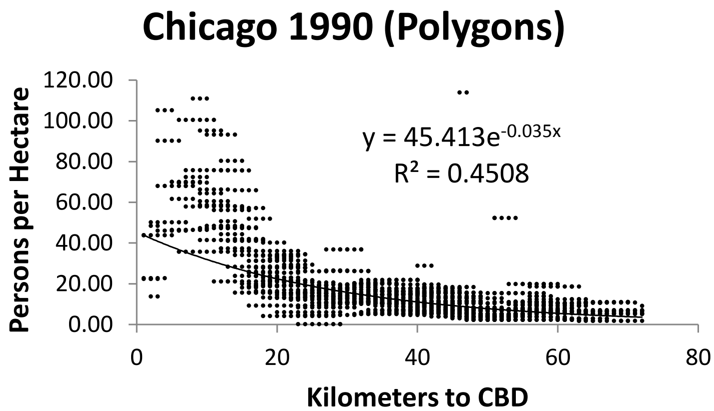

Chicago 1990 (Polygons)
y = 45.413e^-0.035x
R² = 0.4508
Persons per Hectare
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
20
40
60
80
Kilometers to CBD

Fig. 6

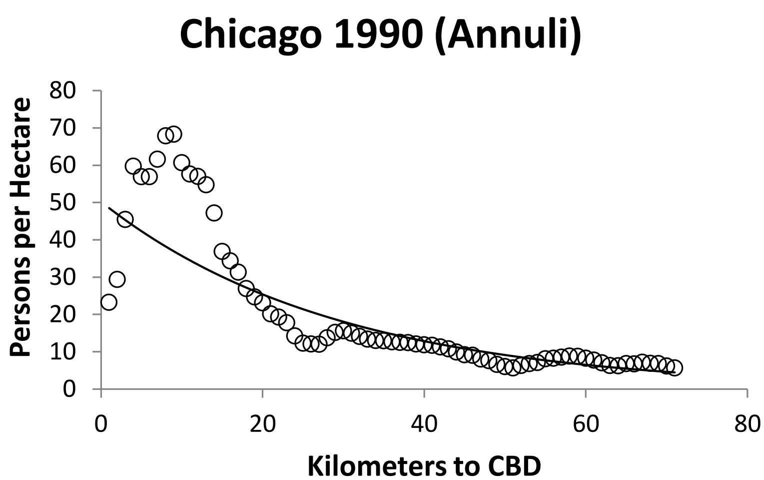
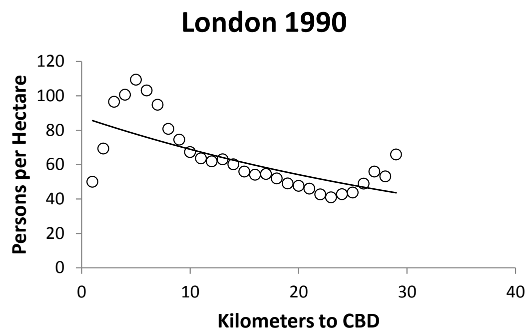
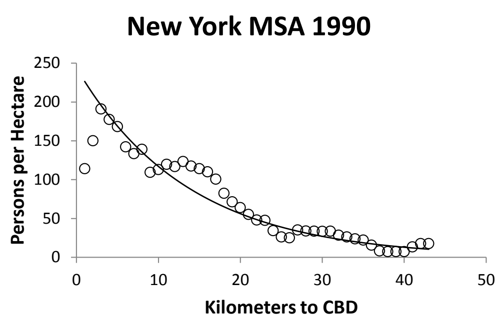
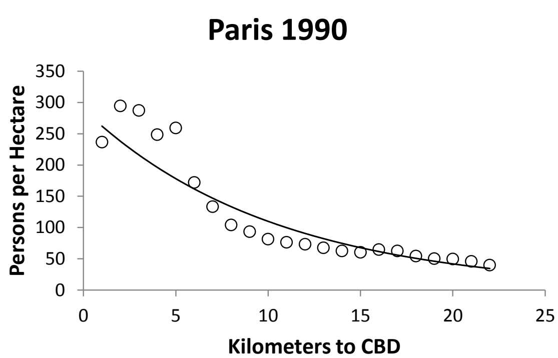

Chicago 1990 (Annuli)
Persons per Hectare
80
70
60
50
40
30
20
10
0
0
20
40
60
80
Kilometers to CBD

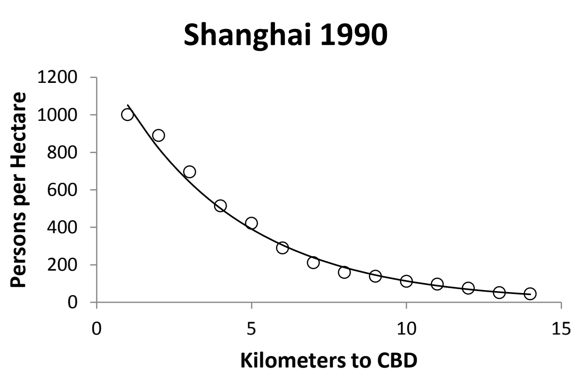
Fig. 7

Figures 8 through 11

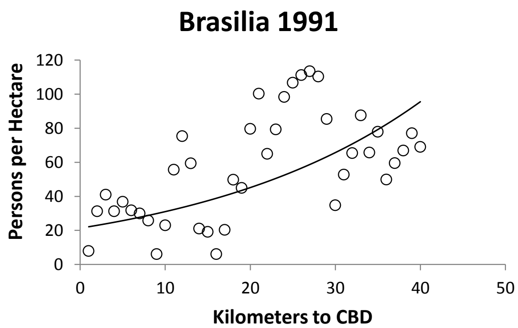


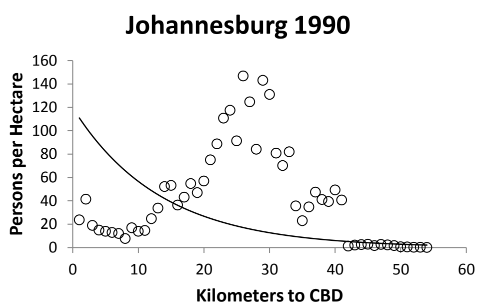



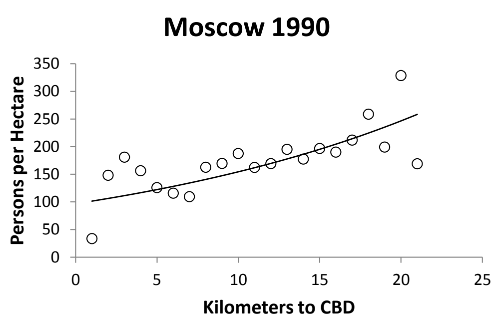



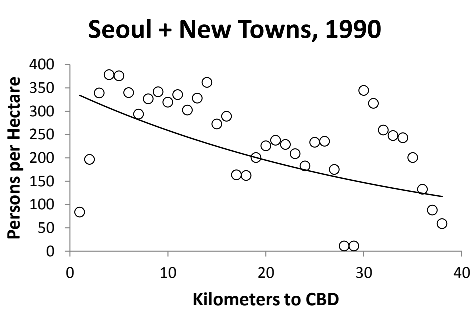



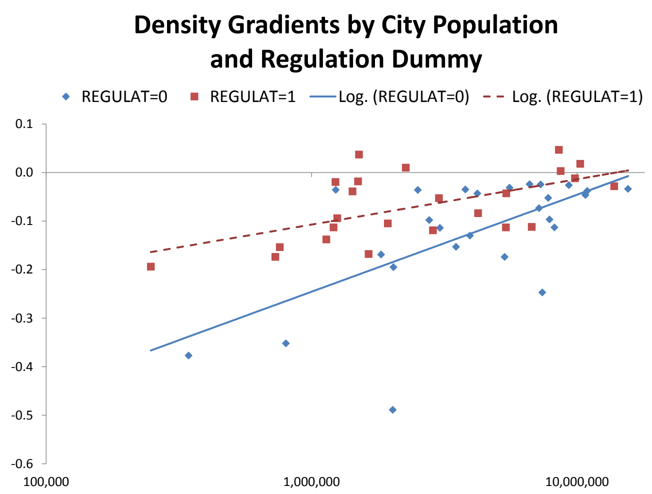
Figures 12 through 15

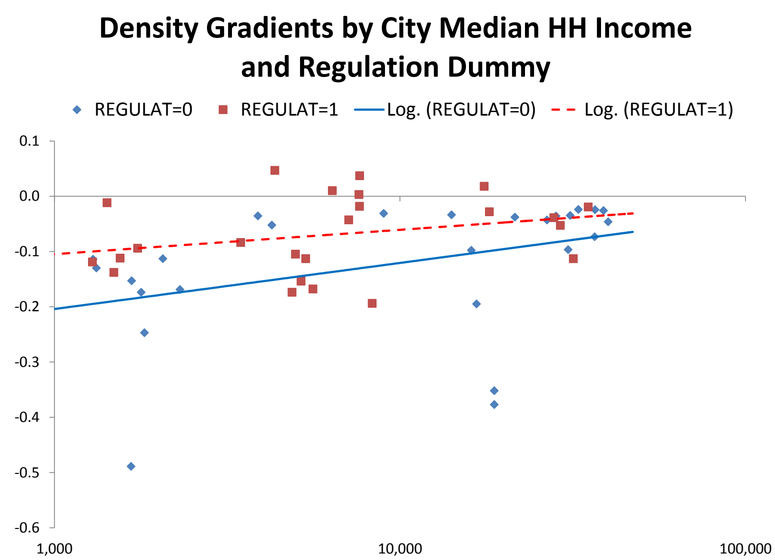



Density Gradients by City Population
and Regulation Dummy
REGULAT=0
REGULAT=1
Log. (REGULAT=0)
Log. (REGULAT=1)
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
100,000
1,000,000
10,000,000


Density Gradients by City Median HH Income
and Regulation Dummy
REGULAT=0
REGULAT=1
Log. (REGULAT=0)
Log. (REGULAT=1)
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
1,000
10,000
100,000