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The Spatial Distribution of Population in 48 World Cities: Implications for Economies in Transition

By

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December 17, 2003
Comments Welcome

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Executive Summary

This paper is one of the first attempts to examine urban form *systematically* around the world. While we have drawn a wide sample, comprising cities from all regions and all levels of development, in this paper we make special reference cities in "transition economies" (mainly in the World Bank's ECA Region, comprising Central and Eastern Europe, and some of the countries of the Former Soviet Union). By "systematically," we mean this is the first paper that examines a range of measures of urban form constructed in a largely consistent manner from largely consistent data. Urban economists have studied the spatial distribution of population intensively for the past 40 years, drawing on a longer literature in geography and other social sciences. We present data on selected measures of urban form for about 50, mostly large, metropolitan areas. While we discuss policy issues in light of the special concern of the ECA region, our cities are drawn from all major regions, from rich countries and poor, from market economies and economies in transition to market.

Empirical Findings

In this paper we have calculated, on a consistent basis, population density gradients for almost 50 large cities in some twenty countries. We have also constructed an alternative measure of city population dispersion. In a variety of 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 have 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 incomes rise and cities grow in population. However, we have evidence that many other things affect density, as Mills and Tan suggest; 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 very long period, change the form of the city.

The regulatory environment, and the existence of natural constraint, are the most consistent systematic determinant of our dispersion index. Income and population play a role, but much less than in density or in the gradient.

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? We first document that socialist cities are more likely to have stringent regulations, or "mixed cases," where a period of heavily regulated socialist development overlay an earlier period of market-oriented development. Moscow is the notable exception to this pattern, partly because of its longer history under socialism. Moscow is important on its own terms, but it is not necessarily an accurate representation of a "typical" socialist city. Furthermore, some of the most distorted urban forms are not socialist cities, but rather cities that developed under apartheid or that were built *de novo* from idealized plans, often as capitals, such as Brasilia. (Some Soviet cities developed for special purposes, such as Magnitogorsk or Novosibirsk were built *de novo*, but we have not as yet had the opportunity to analyze them.)

However, while it is good news that Moscow is probably an extreme case, not the prototype, of the socialist city, we can infer that the distortions in urban form caused by the mixed regulatory environment are still significant. Based on our own research, and on broadly related research such as that discussed in World Bank (1993 c), Renaud (1995 a, b) Buckley and Mini (2000) and Buckley, Ellis and Hamilton (2001), we discuss some of the more specific operational issues that arise from these distortions:

-- *The need to consider location in rent reforms*. In the past, rents for socialist units were rarely related to location. In many policy discussions of rent reform, the focus is often on raising rents, without necessarily focusing on locational differentials. With respect to countries still working through a stock of social housing, given the excess supply of units on the fringe of the city, it may not be easy or even fair to substantially raise rents for poorly located units, such as Moscow's large peripheral estates.

-- *Conversion of industrial land to other uses.* Another policy implication is that in cities like Moscow and Cracow, significant industrial parcels will have to be recycled for other uses, primarily residential. Some countries, including Russia, have mooted differential property tax rates for industrial uses. This would be a mistake, as it would retard this necessary redevelopment. However, redevelopment of large contiguous parcels of industrial land, as often found in ECA cities, can be difficult and expensive. Former industrial land is often heavily polluted and requires a cleaning of topsoil and other remediation before conversion. In addition, even in centrally located areas additional primary infrastructure has to be built to allow residential and commercial development.

-- *The rehabilitation or progressive elimination of poorly located "panel" housing.* First, in many socialist cities, though most spectacularly in Moscow, a great deal of past investment has been in housing that is worth very little, not only because of poor design and maintenance and incentives, but location. In many cities of Central and Eastern Europe market rents in "panel housing" is below maintenance cost. This creates a real conundrum for city managers. On the one hand, investing large sums of money to upgrade this existing stock would be risky, at best, given their location. On the other hand, at least in some cities these units are such a large proportion of the stock that it will take some years for markets to build sufficient replacement stock to house the population. The best policy is probably to undertake some "satisficing" maintenance, while accelerating the development of real estate markets that can fill the gap. This would include, but not be limited to, regulatory and planning environments conducive to market-driven infill as well as some greenfield development.

-- *Interaction with demographic trends.* Most ECA cities face falling populations over the next decades. In spite of the falling population there is still pressure on housing because household size is also falling, and many apartments in downtown areas have been transformed into offices or even torn down (as in Warsaw) to make room for office and commercial space. As incomes increase we can predict that the desire to consume more floor space per person will also fuel demand for more housing. Many small apartments (outside panel housing) are being consolidated into larger ones, thus diminishing the number of units. We have therefore a paradox of a concurrent falling population and a housing shortage.

-- *Using regulations to "reshape" socialist cities.* Transition economy planners should strive to avoid the twin problems discussed by Mills (2002 a, b): regulating to increase density, sometimes at the same time regulating to reduce density, without a clear idea of the costs and benefits of such regulation. Rather than micromanage density, whether by regulations preventing the development of single family housing in peripheral areas, or minimum plot size and unrealistic floor area ratios, planners should strive to broadly follow the market (Wallace 1988), regulating with a light touch when needed to deal with concrete and identifiable external costs.

-- *The need to monitor urban spatial structures, and the regulatory environment.* Mapping land uses, corresponding densities, housing prices and changes in prices

> are among the ways planners should monitor their cities. With this baseline data, planners would move on to studying whether permitted land uses, floor area ratios and the like are broadly appropriate. Too many planning exercises, like the development of many master plans, are static one-off exercises. Planners need to view plans and regulations as dynamic, just as the city is dynamic. In many ECA cities, planners consider that the monitoring of land prices and rents is not relevant to their job. In fact, because ECA cities lack interest group feed backs as mentioned above, monitoring the evolution of real estate prices and rents is the most useful tool to guide future land legislation and primary infrastructure investment.

In some ways, the most important prescription for planners in transition economies is, in a version of the Hippocratic oath, "to do no harm." As planning and regulatory systems continue to develop along with the market, policymakers in transition economies need to let the substantive requirements of their cities guide their design of regulations, rather than blindly copy forms and institutions from other countries. Otherwise-different experiences in cities as diverse as Brasilia and Seoul demonstrate that inappropriate planning and regulation can exist in otherwise market-oriented economies, but at great cost in suboptimal land use, increased commuting costs, and a weakened public fisc. As the Korea case points out (Kim 2001), it can be very difficult to unwind a distorted planning system once in place.

This paper highlights the centrality of regulation in determining city form and economic efficiency. However while the paper – and associated literature – has made some progress, further improvement is necessary. There is still some work to be done on measuring form, but it is even more apparent we still lack a completely satisfactory metric for municipal regulation. A completely satisfactory metric would have to be (1) conceptually well-founded, (2) empirically implementable at reasonable cost, and (3) eventually widely calculated for a range of cities to facilitate useful comparisons. Such a measure would provide a quick and cheap tool to assess when perverse regulatory behavior is damaging urban development. The World Bank Group is well placed to make such an effort, given the focus on institutions and "good governance" within the Bank.

Of course, the regulatory environment is a broad concept. One initial focus on measuring the urban policy environment should surely be land use regulations. Land use regulations can be a major problem in ECA cities, because they often contribute to the weakening of old urban centers and push "modern" development across municipal boundaries. The costs of "auditing" these regulations is low relative to potential benefits, especially now that most regulatory maps are in digital form. Such an analysis can be included as part of a City Development Strategy exercise. A debate on the issue of "urban shape" is often well-received in ECA countries, especially when clients are offered illuminating comparisons to other European cities.

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. There are of course potential gains simply from increasing the size of the database and the range of cities we study. 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 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.

Introduction

This paper is the first attempt to examine urban form *systematically* around the world, with special reference to "transition economies" (mainly in Central and Eastern Europe, and some of the countries of the Former Soviet Union). By "systematically," we mean that, while we draw on a large literature outlined below, this is the first paper that examines a range of measures of urban form constructed in a largely consistent manner from largely consistent data.

Urban economists have studied the spatial distribution of population intensively since the pioneering work of Alonso (1964), Muth (1969) and Mills (1972). Of course this work has a longer history, traceable at least back to von Thunen (1826), including studies by other social scientists such as Burgess (1925), Hoyt (1959) and Clark (1951). In addition to population distribution, there is a related empirical literature on the distribution of real estate prices (e.g. Follain and Malpezzi 1981) and the distribution of wages and incomes over space (Eberts 1981, Madden 1985). Much of this literature is ably surveyed by McDonald (1989). Broad reviews of the theoretical models behind this empirical work can be found in, for example, Wheaton (1979) Straszheim (1987) and Arnott *et al*. (1998).

Beginning with Colin Clark, there have been many hundreds of published studies of population density patterns for cities in developed countries. Despite the size of this literature, only a relative handful of studies have been published for developing and/or transition economies. Notable 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; several studies of Korea, such as Follain, Renaud and Lim (1979), Mills and Song (1979) and Son and Kim (1998); the path-breaking comparative study of Mills and Tan; and a series of studies by Alain Bertaud, mostly unpublished except for his study of Moscow and St. Petersburg with Bertrand Renaud (Bertaud and Renaud 1997).[1]

Thus the purpose of this paper is to extend the literature on urban form, with special reference to developing and transition economies. We present data on selected measures of urban form for about 50, mostly large, metropolitan areas. Our cities are drawn from all major regions, from rich countries and poor, from market economies and economies in transition to market.

An initial figure that will help motivate the study is Figure 1. Moscow and Paris are two cities[2] of roughly 10 million people. Paris is, like virtually all cities within a market system, subject to planning and regulation, but location decisions are driven primarily by markets (about which more below). Moscow, on the other hand, has for most of its post 1917 – pre-*Perestroika* history, developed without reference to land or real estate *markets*. Notice that Paris spreads out from a very dense center; while Moscow has a much smaller footprint. (In fact, Moscow's footprint is only 53 percent of Paris' footprint.) It is not easily seen in the figure, but can be confirmed by examining data in Appendix 1, that in Moscow the highest densities are in the periphery. Another fact that is not apparent, but that we develop below, is that despite its small footprint Moscow is not very compact. The average distance of a Moscow resident to the center is 56 percent greater than in Paris. Given that both cities exhibit a centralized pattern of employment location (by the standards of large cities), Paris is by this measure a more efficient city than Moscow.

In the paper, we demonstrate that measures based on simple models of urban form – and sometimes measures of departures from that model – are a useful way to characterize the cities. We show that several key predictions of the so-called 'standard urban model' are confirmed; cities

[1] See also Dale-Johnson and Brzeski (2000), although that paper focuses on the shape of the land price function in the socialist city, with additional discussion of the density of development by location.
[2] In this paper, unless we specify otherwise, we use the term "city" in its functional sense, as a synonym for metropolitan area, defined broadly as a labor market. Such a functional city may or may not correspond to the

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 powerful implications for the value of the real estate capital stock, and for transportation systems.

Why spatial structure matters

The spatial structure of a city is very complex. It is the physical outcome of the subtle interactions over centuries between land markets, and topography, infrastructure, regulations, and taxation. The complexity of urban spatial structures has often discouraged attempts to analyze them and *a fortiori* to try to relate urban policy to city shape.

Spatial aspects of urban development can have important impacts on economic efficiency and on the quality of the urban environment. However, the evolution of urban form, shaped by the complex interaction between market forces, public investment and regulations, is not often monitored. Consequently, the significant inefficiencies due to a poor spatial structure are often ignored until it is too late to do anything about it. On the other hand, progressive and well-functioning municipal urban planning departments will use spatial indicators to regularly monitor urban development and to propose regulatory or public investment action when necessary.

From an economic point of view, a city is a large labor and consumer market; the larger the size of the market and the lower the costs of transactions, the more prosperous is the economy. A deficient spatial structure fragments labor and consumer markets into smaller less efficient markets; it contributes also to higher transactions costs by unnecessarily increasing

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political jurisdiction of the same name.

distances between people and places. A deficient spatial structure increases the length of the city infrastructure network and therefore increases its capital and operating costs. A large literature now exists on the contributions of the development of cities to higher productivity; but a deficient spatial structure can reduce a city's productivity.

From an environmental point of view, a deficient spatial structure can decrease the quality of life by increasing the time spent on transport, by increasing air pollution, and contributing to the unnecessary expansion of urbanized areas in natural sites. Poor environmental quality can also lower a city's productivity.

A city's spatial structure is constantly evolving. Because of a lack of political consensus or a clear vision on spatial development, the combined effect of land use regulations and infrastructure investments may be inconsistent and contradict each other. It is therefore important that municipalities monitor the spatial trends of development and take regulatory remedial action if this trend contradicts municipal objectives.

In market economies, municipalities can influence the shape of urban development, not through direct design, but by implementing a coherent and consistent system of land use regulations, infrastructure investments, and land related taxes. However, in the long run, the shape of a city will depend on the way the real estate market reacts to the incentives and disincentives created by these regulations, infrastructure investments and taxes. Because external economic conditions are continuously changing and are unpredictable in the long term, the planning department of municipalities should constantly monitor the evolution the urban spatial structure, and adjust eventually the balance and nature of regulatory incentives and disincentives.

The Efficiency of Alternative Urban Forms

In one sense, the efficiency of the so-called standard model is axiomatic. That is, under certain simplifying assumptions about the functional forms of production and demand functions, an optimizing model of urban producers and consumers, a la Muth or Mills, yields a negative exponential function for population density, with a dense center falling off exponentially (steep at first, then flattening as one moves out).[3] While urban economists have quibbled with or relaxed many of the assumptions of the so-called standard model, probably the most central assumption – and the one extremely important for our current purpose – is the assumption that all employment is located at the center of the city. This is obviously an extreme abstraction, but many papers and models (again see Fujita) show that even when this assumption is relaxed, the

[3] We will present this "negative exponential" form mathematically (but still informally) below. See Appendix 2 for a somewhat formal review of such a model. See also Mills and Hamilton (1993) for an especially nice exposition of this model, and Fujita (1989) and Turnbull (1995) for some extensions. The classic references on this model are by Alonso, Muth and Mills.

general negative exponential shape can hold, *as long as there is a higher density of employment at the center than elsewhere*.

Many models have been developed that relax this strict monocentricity, including some that have two centers, some that have a center and a beltline of employment, others that have multiple nodes or a beltline.[4] Another strand of literature, seemingly different but analytically quite close, examines the effects of localized externalities, often one or more amenities somewhere away from the center. What these models generally have in common is (not surprisingly, once the assumption of strict monocentricity is relaxed, density gradients flatten and the efficient form of the city changes. However, it appears that at least in a rough sense, the monocentric form has been remarkably robust. Even in extremely decentralized labor markets such as Los Angeles or Atlanta, population density still largely follows the negative exponential in market economies (see Bertaud (2002 b) and Malpezzi and Guo (2001) as well as data cited in this paper).

While theory tells us that, under certain restrictive conditions, the negative exponential (or some relative, or approximation thereof) will be optimal, there is much to be done in future to test this notion empirically. Empirical tests to date have been limited by data availability (and of course this paper is partly a beginning at addressing this data problem). A related problem is that it is quite difficult to specify the model completely. From the simplest model, we know that urban form should affect transportation efficiency and housing costs.[5] In addition, many observers evince concern with externalities that are difficult to handle theoretically and even more so empirically. For example, commuting and other interurban travel can engender congestion; if energy is not appropriately priced, more commuting can increase external costs,

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[4] See, for example, White (1976), Yinger (1992).

[5] As will be seen below, the basis of the model is really a household's tradeoff between housing costs and

including air pollution as well as congestion. In addition, the existence in the real world of alternative travel modes and multiple, rather than single, employment nodes further complicates empirical work. Some planners or activists focus heavily on one or two of these outcomes, rather than examine them comprehensively as a package. Minimizing energy use, or maximizing transit use, is not the same as optimizing the welfare of a city's residents. That said, there is intense interest in the relationship between urban form and energy use and transportation; here we will briefly discuss some findings.

The relationship between urban form and energy efficiency – or at least gasoline use – has been highlighted by a much-cited paper by Newman and Kenworthy (1989), which shows that gasoline use per capita declines with urban density. Newman and Kenworthy's correlation weakens or largely disappears once GDP per capita is controlled for, and the relationship between urban form and (a particular and narrow definition of) energy efficiency is apparently much more difficult to disentangle than Newman and Kenworthy suggest (see Gordon and Richardson 1989, and Kirwan 1992).[6]

Whatever the difficulties, anyone interested in the welfare of inhabitants of cities in transition economies will be interested in energy use and pollution. For example, despite less gasoline use and a lower GDP, Soviet emissions – including those attributed to transport – are generally at comparable levels to the United States (see Faiz *et al*. 1996, Schipper, Marie-Lilliu and Gorham 2000, and Trumbull 1999). However, according to several studies cited in Trumbull, as Russian traffic has been increasing in recent decades, so has air pollution. But it appears that the big difference is not so much in automobile use or land use as in the technology

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transportation costs.

[6] We have estimated several models of the determinants of gasoline use with Newman and Kenworthy's original (1989) dataset, and found that adding (e.g.) income and the price of gasoline weakens N&K's results; the coefficient of density becomes insignificant in some models, and significant but with a smaller coefficient in others.

of automobiles in use. Russian fuels and automobiles are "dirty," at least in comparison to fuels and automobiles in the U.S. and most of Western Europe.

Thus it is probable that much larger improvements in air quality can come from improving automobiles and fuels, as was done in the U.S. and much of Western Europe over the past thirty years. These gains are likely to be large compared to possible modest gains from land use changes (see Faiz *et al*. 1996). Several papers, such as Solow's classic (1973) study and a more recent paper by Wheaton (1998) demonstrate that in cities with congestion, optimal density will be greater than in an unregulated market outcome. In fact, as Wheaton (1998) shows, correcting for the externality due to congestion actually increases the steepness of the gradient considerably.

While there is a strong theoretical literature some empirical support that the rough monocentric negative exponential model is an efficient form, we wish to caution that the relationship between urban form and efficiency is still under study and debate. Crane (2000) among others provides a nice review of some recent literature. In particular, many planners and advocates of so-called "new urbanism" maintain that redevelopment of neighborhoods and subdivisions to more transit oriented forms can change the forms of city and increase transit use. The evidence for this is weak and mixed, at best. In one of the best exercises to date, Bento *et al*. (2001) use U.S. National Public Transportation Survey data to estimate micro-level models of commute mode choice (bus, rail, car, walk or bike), and vehicle miles traveled. They find that in denser areas, commuters are more likely to use public transit, and households commute fewer miles, although they term the magnitudes involved "modest." However, it is important to note that densifying cities will tend to shorten trip lengths, but will also tend to increase the travel time for a given distance (Cheslow and Neels, 1975, Levinson and Kumar 1997). Unfortunately, Bento *et al*. do not address the time spent in transit, which as noted above almost certainly increases (per mile traveled) as density increases. Preliminary results from Malpezzi (1999 a) suggest that indeed (1) U.S. cities with steeper density gradients have shorter commute times, *ceteris paribus*; and (2) U.S. cities with higher densities in the center have shorter commute times, *ceteris paribus*.

Central Planning vs. Market Oriented Development

One proposition that has been demonstrated innumerable times, in many different contexts, is this: If a good is unpriced, it will be fundamentally misallocated. Much attention has been paid to the so-called "tragedy of the commons," where a good is unpriced and entry to the market is essentially free (e.g. fisheries). The market for land and real estate in a prototypical socialist economy is slightly different. The good, here land, is indeed unpriced; but entry is strictly controlled by a central planning authority.

It was demonstrated many years ago that in theory the central planning problem is the dual of a competitive market allocation. Given enough information and a proper objective function, *in theory* planners should be able to allocate a good or set of goods every bit as efficiently as the market.[7]

One of the fundamental lessons of the socialist experiment, at least in its purer forms, is that this theoretical duality breaks down in practice. One reason it breaks down is that planners often have objectives other than efficiency and equitable distribution (see Daniel 1989, Kornai 1992, and Buckley, Daniel and Thalwitz 1993 for example). But there is an even more fundamental problem. Even if planners were to have the "correct" objective function, Lange–like demonstrations of the potential efficiency of central planning require perfect information.

One of the central characteristics of market allocation processes is that they are highly decentralized. Any given actor – producer, consumer, or regulator – needs only limited information about market conditions in their own small patch of the economy. In effect, even with the best-trained, equipped and intentioned planners, central planning as a way to run an economy breaks down because of information failures. Markets are robust with respect to such failures because they are so informationally decentralized.

When one considers an aspatial economy, we think of a central planner struggling to allocate hundreds or perhaps thousands of goods. How do the markets for steel, plastic, automobiles, electronic parts, etc. all fit together and interact? Furthermore, how are these interactions updated over continuous time, as technology changes, new sources of supply are discovered or manufactured, and demand patterns change? The genius of the information decentralization imbedded in markets is that while real-world markets are imperfect, with many fits and starts, they manage to make these thousands of allocation decisions in a reasonably efficient manner.[8]

The problem becomes even more difficult when we consider real estate markets. Land and real estate is the majority of the tangible capital stock in every country, market or socialist. Not only is the market for real estate large, it is an essential input into every productive process, and an essential part of every individual's consumption bundle. Further complicating matters, unlike fairly homogeneous goods like wheat or oil, virtually every parcel of land, and every piece of real property built upon this land, is unique. Land, housing, and other forms of real estate are characterized by extraordinary heterogeneity. If central planning can't handle the

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[7] The point was demonstrated technically as early as 1936 by Oskar Lange.

[8] In cases of market failure, it may be the case that with some public intervention – taxation, subsidy, regulation, or the like – the government may be able to marginally improve over market allocations (although there are many examples where interventions that would be efficient in theory have not worked out so in practice. See Malpezzi

informational content of a market comprised of a few thousand more-or-less homogenous commodities, it certainly can be expected to have little success in allocating literally millions of parcels, each with their own location- and property-specific characteristics.

What are some other characteristics of market-oriented real estate systems? First, note that market-oriented does not mean *laissez faire*. Land and real estate markets are characterized by strong interdependencies and external costs and benefits. Furthermore, an important characteristic of land is its access to infrastructure; and infrastructure often exhibits extraordinary economies of scale and elements of natural monopoly. Thus it should be no surprise that in every market oriented economy, land and real estate are and should be appropriately regulated and planned.

Another characteristic of market oriented real estate systems is that development decisions are made primarily by private actors, working under regulatory and property rights frameworks set by governments and society. Within this framework, their objective function is to maximize profits, or revenue minus cost. This explains why they consider both the supply and demand sides of the market. Thus a low-income housing developer, for example, might find herself using extremely expensive land; once they make a judgment that they will be able to produce units of sufficient density, and that given access to jobs and schools and amenities, even moderate-income households would pay sufficiently to earn normal profits.

In the prototypical socialist system, real estate development is undertaken by state kombinats or other entities whose objective function is typically to minimize costs,[9] subject to a budget allocation from the government. However, a further difficulty is that in a socialist system

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(2000) and Malpezzi and Mayo (1997 a)).

[9] One can find examples in market economies of outposts of cost minimization in real estate. For example, in a number of mixed economies such as India or the United States, one can find public housing units which are built in inappropriate locations, largely because public housing authorities are out to minimize costs subject to a budget

under central planning, inputs may be significantly mispriced, or even unpriced. For example, in pre-Peristroika Moscow, land was unpriced, and allocated purely based on planning decisions. Once land had been allocated to a particular user, for example to an industrial enterprise or as a housing estate, they had usufruct rights but no rights to alienate (sell or sub-lease).[10] Thus no market for land or real estate developed, and little redevelopment or densification takes place over time. Another way to think about this in terms of economists' shorthand. Economists characterize real estate development in the short run as "putty-clay," where capital (improvements) are initially formless and can take on any required form; but once development takes place, the 'putty' hardens into 'clay' and structures cannot be changed, at least at reasonable cost. However, in the long run – over several decades or more – economists characterize real estate markets as putty-putty; they are initially formless, and costlessly formed; eventually, once improvements depreciate sufficiently, cities can again be reformed at low cost. However, in the prototypical socialist city, such re-formulation or redevelopment does not generally take place, because of deficiencies in property rights and the lack of a functioning real estate market. The socialist city is putty-clay in the long run as well as the short run.

In market economies, different potential users bid for land which is then allocated to the highest and best use. But suppose the highest and best use generates large external costs for neighbors. It is incumbent upon government to tax or regulate specific uses in a way that at least approximately modifies the revenue-cost calculation to guide development appropriately. In a metaphor favored by our colleague, Steve Mayo, well-regulated regulatory markets use a sort of *ju jitsu* approach that guides development to appropriately adjust for externalities. A prototypical

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allocation, rather than maximize the difference between revenues and cost.

[10] Russia only passed a basic urban land ownership law in 2002, 13 years into the transition process.

central planner favors a *sumo* approach of simply blocking or pushing development by *force majeure*.

Another characteristic of market-oriented development is that because individuals and firms have property rights in land, and these rights can be alienated, there is an incentive to *redevelop* land as a city grows and highest and best use changes. In a prototypical socialist city, such redevelopment rarely takes place. Since there is no market for land or real estate, firms and households have no markets in which to capture gains from permitting redevelopment of their land; and in fact without such a market, no one quite knows what the gains to redevelopment are.

Another important difference is in the way planners and regulators work in market versus oriented economies. As Bertaud and Renaud (1997) demonstrate, cities like Paris are organized along market principles. It is clear from both theory and practice that French planners – planners in all market-oriented economies – take account of market forces in their decisions.[11] Without market reference, central planners in socialist economies are at a loss for benchmarks for the efficient allocation of land, even if that was their main objective.

In most pre-*Perestroika* socialist economies, the legal and property rights foundation for real estate was undeveloped or nonexistent. Land, housing and real estate were not even considered economic goods; the socialist analog of national income accounting, Net Material Product, did not even count the output of land or real estate in the national income accounts; nor was land or real estate considered part of the national capital stock.

[11] France's economy is generally heavily regulated, by the standards of OECD countries, as recent discussions of labor regulations highlight. But from the point of view of land use, Paris is not an extraordinarily heavily regulated city, in spite of the height restriction in downtown Paris. Mixed used development is allowed in most areas of Paris and suburbs, so that the market establishes how much floor space is devoted to retail or office space and where this space is provided, not the zoning plan. Although heights are limited, floor area ratios are very high. It is also permissible to rent rooms within houses and to subdivide apartments if the market requires smaller units. Rental one room apartment of 15 sq. meters are common (chambre de bonne), and have allowed many a poor student to live

The Relationship Between Price Gradients and Density Gradients

In market-driven cities and market-oriented economies, density patterns occur because of price differentials. More to the point, even in the simplest Alonso-style model of an agriculturally based city, with a central market, initial land prices are higher at and near the center, and decline with distance from it. Once initial simplifying assumptions of constant returns per unit of land are relaxed (that is, once substitution between land and other factors of production are permitted), real estate developers (and indirectly consumers) economize on the use of land at more expensive locations. They do this by adding more capital per unit of land, e.g. by building multi-family units instead of single family, and by building the tallest units with the highest floor area ratios at the closest in locations. In market-oriented cities, it is the price gradient that gives rise to the density gradient. These prices are willingness to pay for central locations, and are driven by savings in transportation costs.

Thus the paradox of a socialist city is as follows. In the prototypical socialist city, especially a city like Moscow with highly centralized employment (for a city of its size) consumers value close-in locations. Because socialist planners in such a market made location decisions without market benchmarks, planners have built more densely on the periphery, i.e. have invested the highest proportion of the capital stock where it is worth the least. As Eckert (cited in Bertaud and Renaud), as well as Mozalin (1995), have shown in previous work, following *Perestroika*, in the early 1990s Moscow underwent a period of "price discovery."[12] Initially consumers were uncertain as to the value of alternative locations. Prices were initially

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close to the Eiffel tower or Notre Dame if they so choose.

[12] See also analysis of recent land price gradients in Cracow in Dale-Johnson and Brzeski (2001). While they find some decline in the fit of their land price model over time, point estimates of the gradient were also becoming steeper over time, consistent with a price discovery process. Dale-Johnson and Brzeski also note that the real cost of transport was increasing over their study period, which would also imply a steepening of their land price gradient (especially given that the price gradient can adjust faster than the density gradient).

largely random across locations, and in particular there was little apparent premium for accessibility. However, over time consumers began to figure out the value of location. Thus a price gradient began to appear that took on the values familiar from market economies. In broadly similar terms, Bertaud has shown the same process at work in Crakow, Poland.

The upshot is that in the prototypical socialist city, *density gradients and price gradients are not in line with each other*. This is fundamentally different from market cities, where "form follows price." In extreme cases, such as Moscow, price and density gradients go in opposite directions. This has extraordinary implications for the valuation of the capital stock. Furthermore, many socialist cities have allocated far too much land to industrial uses, particularly in close-in locations. This is because of the aforementioned lack of incentives for redevelopment. We can predict that over the next several decades, if market forces are permitted to operate, while some large single-family units will be built on the periphery for higher income households, we can expect increasing infill and densification in available locations in or close to the central city. But until property rights are sorted out and transactions facilitated, this redevelopment will probably be further delayed. An obvious implication for tax policy is that property taxes should be based on highest and best use, not current use. Examples such as the movement in Russia to tax industrial urban properties at (lower) current use value will delay, rather than enhance, the redevelopment of the city.

It should be noted that socialist cities are not the only cities that can or do develop in contradiction to market principles. Older colonial cities sometimes had strict segregation of land uses, e.g. when colonial residents monopolized certain sections of the city; in more modern times, the form of several South African cities remains heavily influenced by apartheid (World

Bank 1993 b). Some "new towns" have been built *de novo*, from a theoretical plan, rather than with reference to market forces; examples include Brasilia and Curitiba.[13]

The Measurement of Urban Form

Population Density Gradients

The measure of city form that has been most often studied by urban economists is the population density gradient from a negative exponential function, often associated with the pioneering work of Alonso, Muth and Mills, but actually first popularized among urban scholars by Colin Clark.[14] More specifically, the population density of a city is hypothesized to follow:

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

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; γ 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 2 illustrates a stylized example of density patterns, for a city with a central density of 100 persons per hectare, for different values of γ.

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. The function is easily estimable with OLS regression by taking logs:

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

[13] To be more specific, Brasilia was built *de novo*, but Curitiba's form is a planning overlay on an existing city. Under the guidance of long-time mayor Jaime Lerner, the city's master plan was implemented featuring a dense transport corridor, with most low income households at the end of the corridor. Thus Curitiba is a designed city, in the sense that the design was the objective, rather than a response to market forces. What Brasilia and Curitiba have in common is that the shape of the city was itself the planner's objective, while in (say) Moscow the final shape was an unintended consequence of a process.

[14] 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.

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.[15]

The exponential density function also has the virtue of being derivable from a simple model of a city, albeit one with several restrictive assumptions, e.g. a monocentric city, constant returns Cobb-Douglas production functions for housing, consumers with identical tastes and incomes, and unit price elasticity of demand for housing.

As is well known, the standard urban model of Alonso, Muth and Mills predicts that population density gradients will fall in absolute value as incomes rise, the city grows, and transport costs fall. 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. Also, it is conceivable that French tastes for housing and transport are different from, say, British or North American tastes. Recall from our discussion of the standard model, that 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. If the relative French elasticities are reversed, then so will the relative locations of rich and poor. In any event, Paris' location of rich and poor could be explained by any or all of these possible explanations.

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[15] To simplify notation, we will use α to represent the intercept, that is, $\alpha = \ln D_0$.

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 3 through 5 illustrate the effect of such a regulation on density. Such regulations will, in general, be expected to increase central density but flatten the gradient.[16]

The negative exponential function often fits the data rather well, for such a simple function in a world of complex cities. Sometimes it does not fit well, as we will confirm. Many authors have experimented with more flexible forms, such as power terms in distance on the right hand side.

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

An Alternate Measure of Dispersion

In addition to the traditional gradient measure, many other measures of urban form have been put forward and studied. The simplest, of course, is the average density of the city or metropolitan area. Others include measures such as the weighted average of straight line or rectangular distances from one set of points in a city to another, or functions based on densities other than the negative exponential, such as the normal density (Ingram 1971; Pirie 1979; Allen *et*

[16] 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.

al. 1993). However we would like to consider an alternative measure of urban form, which we term a dispersion measure.[17]

Dispersion

From experience we know that cities come in many different shapes. Cities' shape can be defined by three variables: the surface of the built-up area, the shape of the built-up area and the way the population density is distributed within this same built-up area.

We can thus represent a city as a 3-dimensional object. The shape of the built up area will be represented in the x-y plane, and density will be represented in the z plane. We thus obtain a solid whose geometric properties can be analyzed. Such a solid has a center of gravity, which is the point to which the sum of distance from all other points of the shape is the shortest.

All else equal, a city shape which decreases the distance between people's residences and the main place of work and consumption will be more favorable to the functioning of labor and consumer markets. For a given built-up area, the shorter the average distance per person to the main place of work or to the main commercial areas, the better would be the performance of the city shape.

Traditionally, planners and urban economists consider that a city is either monocentric or polycentric, depending on the location of the main employment and retail centers. In reality no city is purely monocentric or purely polycentric. Cities have only degrees of monocentrism and polycentrism. In a realistic classification of cities there would be a continuum between very monocentric toward very polycentric cities, with most cities located in between.

[17] In Bertaud (2000) and earlier versions of this paper, we termed this a "compactness" index. However, the larger the index, the *less* compact the city; so we have renamed this as our "dispersion" index.

In general, polycentric cities do not contain two or three centers, but a large number of small centers. These centers do not act as CBD for the surrounding areas, they are not the center of mini-cities. Because their accessibility from the rest of the metropolitan area, they are points of condensation of employment and commerce. Their catchment area is in fact the entire metropolitan area. If it was not, large polycentric cities would have the productivity linked to the scale of their component elements. In a very polycentric city, employment and commerce are widely distributed among many small centers, and that the trips they generate are widely distributed across the metropolitan area. By contrast a theoretically pure monocentric city generates only trips along its radius.

The challenge is to develop a dispersion index which would be applicable to a monocentric and to a polycentric city. In a monocentric city the main place of work and commerce would be the CBD. In a polycentric city the center of gravity of the shape would be the closest point to all centers of employment and commerce. The measure of the average distance per person to the CBD – in the case of a monocentric city – or to the center of gravity of the population – in the case of a polycentric city – provides a simple but defensible measure of the performance of city shape.

Our dispersion index, ρ, is the ratio between the average distance per person to the CBD, and the average distance to the center of gravity of a cylindrical city whose circular base would be equal to the built-up area, and whose height will be the average population density:

$$\rho = \frac{\sum_i d_i w_i}{C}$$

where ρ is the dispersion index, d is the distance of the ith tract from the CBD, weighted by the tract's share of the city's population, w; and C is the similar, hypothetical calculation for a cylindrical city of equivalent population and built up area. A city of area X for which the average distance per person to the CBD is equal to the average distance to the central axis of a cylinder which base is equal to X would have a dispersion index of 1. See Figure 6.

Of course the denominator, C, is merely a baseline against which to compare the actual dispersion of the city. We are not arguing that cylindrical cities are in some sense optimal, merely that some cities will be more compact than this baseline (have a lower value of ρ),and some will be less compact (have a higher value of ρ).

In the majority of cities the CBD and the center of gravity of the population coincide. This is the case for Beijing, London, Moscow, New York, Paris, Shanghai, and many other cities. In others the CBD is quite distant from the center of gravity. We would expect that cities in which the CBD is eccentric (far away from the center of gravity) would be mostly polycentric. In a polycentric city the location of CBD is not very important as more trips are generated to and from many other sub-centers. A number of the cities that have an eccentric CBD are predictably dominantly polycentric (Houston, San Francisco, Los Angeles, Rio de Janeiro) but others are dominantly monocentric (Bombay, Curitiba, Cracow). The dispersion index we propose here – based on distance to the CBD – is a potentially a good indicator of sprawl for dominantly monocentric cities, and for polycentric cities in which the center of gravity and the CBD coincide. The dispersion index – as calculated in this paper – might have less significance for polycentric cities where the CBD is eccentric.

The Determinants of Urban Form

Many papers are devoted to measurement and specification issues, e.g. what form the so-called density gradient should take. But perhaps the most interesting literature is that which explains *variation* in patterns of population density among cities.

The well-known "standard urban model" of Alonso (1964), Muth (1969) and Mills (1972) postulates a representative consumer who maximizes utility, a function of housing (H) and a unit priced numeraire nonhousing good, subject to a budget constraint that explicitly includes commuting costs as well as the prices of housing (P) and nonhousing (1). It is easy to show that equilibrium requires that change in commuting costs from a movement towards or away from a 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. This equilibrium condition can be rearranged to show the shape of the housing price function:

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

Now consider 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 (as is more realistic), as long as increases in H are "large" relative to increases in t, this result holds. Also, as incomes rise generally, the envelope of all such bid rents will flatten. Also, clearly, as transport costs fall, bid rents will flatten.

The standard urban model can also be extended to include location-specific amenities. These amenities can be "goods" like high quality schools, or views; alternatively they can be "bads" like localized crime or pollution. See, for example, Li and Brown (1980), Follain and Malpezzi (1981), Diamond and Tolley (1982), Chesire and Sheppard (1995), among many applications.

Of course a number of studies have examined the distribution of population in one or a few markets outside the U.S. For example, Bertaud and Renaud (1997) have examined Russia (see Mozolin (1994) for a related study of housing prices); Asabere et al. (1982, 1983), for analysis of Ghanaian cities; Cummings and DiPasquale (1994) have studied Chile; Parr et al. (1988) the United Kingdom, Glickman (1979) Japan, and Mills and Song (1979) Korea. But except for Mills and Tan (1980), careful comparisons of such outcomes across countries are hard to find.

Mills and Tan's survey of international studies of population density is, in many respects, the closest to this paper we've found in the literature so far. 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 about 50 large metropolitan areas around the world.

Data

The first contribution of this study, then, is to consistently estimate a series of population density measures (the traditional gradient, and dispersion) for 48 major metropolitan areas around the world. These 48 cities span 27 countries, and contain roughly 230 million people, or 8 percent of the world's urban population. We then model their determinants. The cities for which we have developed data include: [18]

Abidjan	Ahmedabad	Atlanta
Bangkok	Barcelona	Beijing
Berlin	Buenos Aires	Bombay
Capetown	Chicago	Cracow
Curitiba	Guangzhou	Hong Kong
Houston	Hyderabad	Jakarta
Johannesburg	Ljubljana	London
Los Angeles	Marseille	Mexico City
Moscow	New York	Paris
Portland	Prague	Riga
Rio de Janeiro	San Francisco	Seoul
Shanghai	Singapore	Sofia
St Petersburg	Stockholm	Tianjin
Toulouse	Tunis	Warsaw
Washington	Yerivan	

The data have been collected, city-by-city, over about a decade, by Alain Bertaud. Bertaud's method is to analyze the built-up area of the city, i.e. to measure population density in census tracts (or their nearest local equivalents). The measure is net of areas that are not built up such as large parks, lakes, greenbelts, mountains and other rugged terrain, and the like. The sample of cities is opportunistic; they comprise cities Bertaud has been invited to study over the time

[18] The "we" in this sentence is editorial. Credit for the painstaking data collection - by far the bulk of the work undertaken for this paper - is due the first author, Alain Bertaud. Analytic duties were shared. (S.M.)

period, and a few cities for which he was able to gather data through personal contacts (e.g. Marseille).

Collateral data come from several sources. Our classification of cities and countries by regulatory environment is our own, and discussed below. Data on GDP and automobile ownership per capita are from the World Bank's World Development Indicators. We also make use of Angel and Mayo's (1996) index of enabling housing markets.[19]

One obvious shortcoming is that our GDP numbers are national. There are, unfortunately, no systematic comparable data on output or income at the metropolitan level, across countries. On the other hand, it is well known that output and income increase with city size, even after controlling for cost-of-living increases (Mera 1973, Carlino 1987, Henderson 1988, Sveikauskas 1975, World Bank 1991). As higher incomes and larger city sizes both flatten density gradients, if we find the expected positive sign for both variables in our regressions, we can infer that the estimated effect of income will be somewhat understated, and the estimated effect of city population somewhat overstated, because national GDP will capture most of the cross-city variation in our data, but not all; city size will mostly capture its own effect, but will also proxy for within-country city size effects on income.

In the event, the best way to begin the analysis of differences among cities is to examine city-specific charts of density by distance. These are contained in the Data Appendix. Dots on the charts indicate average density of built-up areas at each 1 km annulus from the center of the city. The solid line indicates the exponential density gradient. Note in particular the inversion of the classic declining population density in cities with heavy-handed planning legacies (Moscow, Seoul), and (the ultimate perversion of planning) apartheid cities (Johannesburg and Capetown).

[19] We also had hoped to make use of data from Kenworthy and Haube (1999), especially data on the geographic concentration of employment. In the event, only about 15 cities overlapped our two samples, and in particular those

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). 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 were graded zero. But it quickly became apparent that this simply bifurcation was insufficient.

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authors collect little data from (current or former) socialist cities.

Cities develop over many decades, and many cities in our sample have a history of market-oriented development, with an overlay of super-stringent planning over several recent decades. Examples would include many of the cities from Eastern and Central Europe, which typically were under socialist planning for about 40 years, often with at least some part of the housing market privately provided. For example, see the 3-D representation of Crakow in Figure 7, which is closer to the urban form of a market city – closer to Paris – than to Moscow. Moscow, recall, has been planned with a particularly heavy hand for much of the 70 years or so after the 1917 revolution. Other cities which are included in this most fundamental group are cities that were planned and built "from scratch," such as Brasilia and Curitiba; and the South African cities, which grew substantially under apartheid era under some of the most draconian land use regulations ever known.

An especially interesting case is that of Seoul, Korea is, of course, a spectacularly successful economy in many respects over the past four decades. But as Hannah, Kim and Mills (1993), Green, Malpezzi and Vandell (1996) and others discuss in detail, Korea's land and housing policies, and corresponding market performance, have lagged policies and performance in other areas. Among other problems, Seoul (and other major cities) has large and stringently enforced greenbelts, and very stringent restrictions on the conversion of land from rural to urban uses. Land development is dominated by a public agent, the Korea Land Corporation, that wields significant market power. The housing finance system is poorly developed, for a country of Korea's GDP. While there have been recent reforms, they have been modest.

It is also worth noting that our Chinese cities have density patterns that closely confirm to market. See Shanghai's 3-D profile in Figure 8, and see the Appendix entries for Beijing and Shanghai. Why did Chinese cities conform so closely to the market model? One word: transportation. Until very recently, most workers in Chinese cities commuted by foot or bicycle.

The cost of walking or bicycling, primarily physical effort and the opportunity cost of time, reveals willingness to pay for transportation; the time saved to travel a given distance in a more capital intensive mode is a good proxy for a market fare. The only way Moscow has been able to sustain its strange form is by enormous subsidization of public transit, including the subway system.[20] However, it is important to note that our Chinese cities represent larger, older, cities – Beijing, Shanghai and Tianjin. The urban form of other kinds of cities – for example, very fast developing, medium sized cities – will probably be quite different.[21]

With these considerations in mind, we have 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.

Our other 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 above, we include Chinese cities in the non-socialist category, with market economies like Paris.

We point out that our categorization of the regulatory environment, REGCAT, is partly subjective, and constructed by the same authors that collected the data for and constructed the

[20] Moscow's subway carries more passengers than any other in the world, for 5 rubles (about 15 cents) per ride.

[21] For example, Zhu (1999) examines the very different experience of rapidly growing Shenzen. Even here, there will probably be differences. Shenzhen is unique in its function as a special purpose, transition-to-market, city. It is likely that Chinese cities where the historical core was originally small compared to what has been built latter might show a different pattern. For instance, Changsha or Loyang might show a different more "socialist" pattern. Wenzhou, also, for different reasons might show a different pattern (absorption of clusters of dense towns where towns enterprises were located). But in general there was very little building going on in Chinese cities between the end of World War II and 1979, and even less during the Cultural Revolution. So the socialist ideology did not have much chance to leave an imprint on city shape. The large housing estates which were built around Shanghai and Tianjin in the early eighties were built at a uniform residential density of about 350 persons/hectare, resulting in a built-up density of about 160 p/ha. Given the very high density of the core, this gave the impression of a "normal" suburban density and contributed to the steep gradient.

dependent variables. The possibility of bias, or if you prefer, endogeneity in the regulatory categorization, is real. We've attempted to construct the regulatory dummy without reference to the density patterns, but of course we can't be sure how successful we are at blocking out this knowledge. In the future it would be desirable to construct completely independent measures of real estate regulation. Preliminary attempts have been made, such as those undertaken by the UN Housing and Urban Development Indicators Programme.[22] However, the Indicators project as currently organized seems to be collecting less information on the kinds of policy variables required.

Results I: The Measures of Urban Form

The best way to begin to get a feel for urban form is to start by browsing Appendix 1. In the appendix we present a chart for each city, where the average density is presented for each 1-kilometer annulus, starting at the center. Notice that most cities broadly follow the "standard" pattern, more or less. Actually, many larger cities have their highest 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.

[22] Angel (2000) and Angel and Mayo (1996) are the best reviews of the Housing and Urban Development Indicators efforts. See also Murray (2001). Discussion of indicators applied to ECA countries can be found in Buckley and Tsenkova (2001) and Hegedus, Mayo and Tosics (1997). In recent years the World Bank has disengaged from the effort, and remaining efforts by the United Nations Centre for Human Settlements (Habitat) have focused more on

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 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 where developed *de novo* as planned "new towns" (Curitiba, Brasilia).[23]

Table 1 presents our gradient estimates, dispersion indexes, and several other key variables, for each city. Cities are listed by country, which in turn are listed first by socialist-nonsocialist, then alphabetically.[24] For New York, San Francisco and Seoul, separate estimates were undertaken for the city (corresponding roughly to a metropolitan area, or PMSA in U.S. Census jargon), and to a broader region (roughly corresponding to a U.S. CMSA). In this paper we've dropped the broader CMSA-like regions from subsequent analysis.

In the event, most cities have negative population density gradients, as predicted by the standard urban model. Brazilia, Capetown, Moscow, and Seoul have inverted gradients, i.e. population density increases with distance from the center, at least over some relevant range.

Exploratory Data Analysis by Income and Population

Figures 9 and 10 plot the gradient and dispersion measures by GDP per capita. Overall, it is not clear that the gradient falls with GDP, as the standard urban model predicts (Figure 9). On the one hand, several heavily planned cities (Moscow, Capetown, Seoul, but especially Brasilia) have

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measuring housing market outcomes but have downplayed regulatory and policy variables..

[23] Houston's density pattern is frankly somewhat puzzling. In a separate study by Malpezzi and Guo (2001), Houston largely follows the negative exponential model.

positive gradients that are largely unrelated to GDP. Bombay, though one of the lower income cities in the sample, has a practically flat gradient. On the other hand, among market cities, Toulouse and Marseille have very steep gradients, more like Chinese cities than the other richer OECD cities in ours sample. Singapore also has a steep gradient for such a high-income city. Heteroskedasticity is also apparent in Figure 1.

Dispersion varies less systematically across income (Figure 10). Bombay and Brasilia are clear and very influential outliers, the least compact cities in our sample. Shanghai, on the other hand, is the "champ" for dispersion.

If one removes a few non-market outliers (especially Brasilia, but also Moscow, Seoul, Capetown, and Curitiba), the gradient also flattens as cities grow in population, although again there is significant variation around trend, and changing variance (Figure 11). There is some apparent heteroskedesticity in city size for the dispersion measure as well (Figure 12).

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.

Exploratory Data Analysis by Type of Market

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[24] For this paper, we characterize Berlin as socialist. Frick (1995) briefly reviews planning issues stemming from the 40 year separation, and recent integration, of East and West Berlin.

We begin by exploring two key measures of urban form by two categories. The two key measures are the dispersion index described above; and the traditional density gradient beloved of urban economists. Our two categorizations are the tripartite regulatory categorization discussed above; and whether or not a city is in a (formerly) socialist country. Table 2 presents these summary statistics.

The broad patterns from Table 2 are evident. As measured, the larger the gradient *in absolute value*, the steeper the drop-off of population density. Thus, very heavily regulated cities – the nonmarket category, REGCAT=2 – have much flatter gradients, whether means or medians are compared. In fact, the mean and median gradients within this category are nearly flat (-.01 and -.02, respectively). In the market category (REGCAT=0), and the mixed case (REGCAT=1), means and medians are an order of magnitude larger, around 0-.10. Interestingly, the differences between market cities – REGCAT=0 – and mixed cases – REGCAT=1 – are more modest. The means for the two regulatory categories are -.127 and -.112, respectively. The corresponding medians are -.09 and -.12.

The second section of Table 2 presents the predicted value of density (persons per square km) at the center of each city.[25] Table 2 shows clearly that more heavily regulated metro areas are less dense at the center than market oriented cities. Of course, as with other exploratory data analysis in this section, we have not controlled for size of city or income, so we will see if this pattern holds up in multivariate results to be presented below.

The larger the dispersion index, the less compact the city. Once again, Table 2 shows that heavily regulated cities (REGCAT=2) are less compact, on average or "on median," than moderately regulated cities, whether REGCAT=0 or REGCAT=1. For REGCAT = 0, 1 and 2 the

[25] The estimated constant term from each city's density regression, alpha, is the estimate of the log of the density. In Table 1 we presented this coefficient. In this table, we exponentiate each alpha to present the more natural

mean dispersion index is 1.09, 1.29 and 1.72 respectively; the corresponding medians are 1.01, 1.16 and 1.39.

Interestingly, whether means or medians are compared, socialist (transition) cities and non-socialist (including Chinese) cities look similar. The real story is in the very high variances of gradients and dispersion indices in the non-socialist cities; remember that this group includes such pathological cases as Brasilia and Capetown.

While our paper is based on what is, as far as we know, the most extensive international data of this type ever assembled, unfortunately the data do not permit reliable analysis by a two–way breakdown (REGCAT by Socialist/Nonsocialist). Our two categorizations are related, but not extremely strongly. Table 3 presents a very simple ordered probit model, predicting REGCAT by the socialist/nonsocialist city distinction, and the log of GDP per capita. Socialist cities are more likely to be in one of the two higher regulatory categories. Other variables (in this model variant GDP per capita) were insignificant. Socialist cities are, on average, more regulated cities.

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

In the preceding paragraphs we have presented our estimates of γ and ρ, 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:

$$\gamma, \alpha, R^2, \rho = f(Y, P, t, G)$$

population density measure.

where in addition to the endogenous variables defined above Y is income (proxied here by GDP Per Capita); P is city population; t is a vector representing transport infrastructure; and G are measures of geographical constraint. Locational subscripts (i) are omitted.

Table 4 presents the results of OLS regression estimates of the determinants of density gradients. The most important independent variables -- GDP per capita, population, and our regulatory/economic structure variables -- have been discussed above. We considered two simple transportation variables, the log of automobiles per capita, and the price of gasoline per liter. In preliminary regressions, we found that neither variable performed consistently; since degrees of freedom are a problem, we omit those variables in the final tables.

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.[26] 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.

In the event, our preliminary gradient regressions perform quite well. First, consider the first three columns, which present a simple model estimated on samples sorted by REGCAT. For the market-oriented cities, gradients increase (flatten) with the log of income, and the log of city population, as predicted by the standard urban model. However, the effect of population is considerably larger than that of income. A ten percent increase in income flattens the gradient by

[26] 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.

about 0.004; a ten percent increase in population by about 0.01. But recall the important point from above: given the fact that our GDP data are national, and output and incomes vary systematically with size of city, we believe our estimates underestimate the true effect of income, and overestimate the true effect of population.

Other regressions, not shown, demonstrate that the higher the proportion of motor vehicles to a country's population, *ceteris paribus*, the flatter the gradient. In the mixed case (REGCAT=1), while the qualitative effects of income and population on gradients is the same, the magnitude of the effect is roughly halved. On the other hand, for the heavily planned REGCAT=2 cities, income and population have virtually no explanatory power (as we'd expect, if these cities were truly planned without reference to the operation of land markets, at least in shadow prices as in China).

Of course we wish to be careful when basing some regressions on as few as 9 observations, even when examining simple and (we would hope) robust relationships. A statistically insignificant result could signal a lack of effect, but it could also be due to a low-power test, due to small sample size. Thus the fourth column of Table 4 presents regression results pooling all cities, but including dummy variables for our regulatory categories (as well as the price of gasoline). In that column we see (1) income and population work as the standard model predicts; gradients flatten when incomes rise or populations increase. The average gradient in a "mixed case" (REGCAT=1) city, conditional on income and population, will be about .11 flatter than in a market city. Since the mean gradient over the sample is about –0.095, that's a considerable flattening. The effect is even more remarkable for the very stringent (REGCAT=2) case: the gradient would flatten, on average, by about 0.17.

While regulation affects the gradient profoundly, it is harder to find a pattern with respect to the socialist (or transition) cities, vis a vis others. Consider columns 5 and 6. Socialist cities have density gradients that are strongly influenced by population; but not (apparently) by income. Perhaps the real story is that, once we stop controlling for regulation, we cannot explain much of the variance in gradients among non-socialist cities, once we permit contamination of the sample by apartheid cities and the like.

The models of determinants of the fit of the log predicted density at the center (predicted alpha) in Table 5 can be similarly characterized: densities at the center are lower for heavily regulated cities, and mixed cases, even after controlling for income and city size. Socialist densities at the center are also lower, according to the point estimate; but the effect is not statistically significant.

The models of determinants of the fit of the simple gradient estimate (Table 6) are less successful. Only in the pooled model do we find much in the way of interpretable results. Richer cities, and larger cities, have smaller R^2 statistics, as expected, but the variables are not significantly different from zero. The strongest results are that more stringent regulation (REGCAT=1 and, even stronger, REGCAT=2) reduces fit.

The dispersion regression results are readily characterized (Table 7). Dispersion *per se*, at least as we've measured it, is related to income and population in market economies, but not in heavily regulated or mixed-cases. In market economies, the strongest result is that dispersion declines (the index rises) whenever a city faces an extraordinary geographic constraint. It is related to regulation, at least as measured, in the pooled regression (column 4). Stringently regulated (REGCAT=2) cities have much higher levels of the index, i.e. are less compact. In fact, setting the index equal to two more than doubles the value of the dispersion index (more than halves the compactness).

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 a variety of 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 incomes rise and 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.

The regulatory environment, and the existence of natural constraint, are the most consistent systematic determinant of our dispersion index. Income and population play a role, but much less than in density or in the gradient.

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? First, note our probit model confirms that socialist cities are more likely to have stringent regulations, or mixed cases. Second, note that most socialist cities (with the exception of Chinese cities)[27] fall into the "mixed category" (REGCAT=1), not the most stringent category. The mixed nature is due to the overlay of several decades of central planning over an originally mature market-oriented city. Moscow is the notable

[27] As we discuss elsewhere, our Chinese cities over-represent large, old cities, and may be poor guides to developing urban form in fast-growing medium size cities.

exception to this pattern, partly because of its longer history under socialism. Students of transition economies should note that Moscow is important on its own terms, but it is not necessarily an accurate representation of a "typical" socialist city. Furthermore, some of the most distorted urban forms are not socialist cities, but rather cities that developed under apartheid, or that were built *de novo* from idealized plans, often as capitals, such as Brasilia. (Of course some Soviet cities developed for special purposes, such as Magnitogorsk or Novosibirsk were built *de novo*, but we have not as yet had the opportunity to analyze them.)

However, while it is good news that Moscow is probably an extreme case, not the prototype, of the socialist city, we can infer that the distortions in urban form caused by the mixed regulatory environment are still significant. What are some of the more specific operational issues that will arise from these distortions?

The rehabilitation or progressive elimination of "panel" housing. First, in many socialist cities, though most spectacularly in Moscow, a great deal of past investment has been in housing that is worth very little, not only because of poor design and maintenance and incentives, but location. In many cities of Central and Eastern Europe market rents in "panel housing" is below maintenance cost. "Panel housing" apartment units are trading much below replacement costs. This creates a real conundrum for city managers. On the one hand, investing large sums of money to upgrade this existing stock would be risky, at best, given their location. On the other hand, at least in some cities these units are such a large proportion of the stock that it will take some years for markets to build sufficient replacement stock to house the population. The best policy is probably to undertake some "satisficing" maintenance, while accelerating the development of real estate markets that can fill the gap. This would include, but not be limited to, regulatory and planning environments conducive to market-driven infill as well as some greenfield development.

Interaction with demographic trends. Most ECA cities face falling populations over the next decades. Will this lead to a reduced demand for housing, possibly easing the solution to the "panel housing" problem? How will this decline affect urban form? In spite of the falling population there is still pressure on housing because household size is also falling, and many apartments in downtown areas have been transformed into offices or even torn down (as in Warsaw) to make room for office and commercial space. As incomes increase we can predict that the desire to consume more floor space per person will also fuel demand for more housing. Many small apartments (outside panel housing) are being consolidated into larger ones, thus diminishing the number of units. We have therefore a paradox of a concurrent falling population and a housing shortage.

The need to consider location in rent reforms. In the past, rents for socialist units were rarely related to location. In many policy discussions of rent reform, the focus is often on raising rents, without necessarily focusing on locational differentials. With respect to countries still working through a stock of social housing, given the excess supply of units on the fringe of the city, it won't be easy or even fair to raise rents for poorly located units, such as Moscow's large peripheral estates.

Conversion of industrial land to other uses. Another policy implication is that in cities like Moscow and Cracow, significant industrial parcels will have to be recycled for other uses, primarily residential. Some countries, including Russia, have mooted differential property tax rates for industrial uses. This would be a mistake, as it would retard this necessary redevelopment. However, redevelopment of large contiguous parcels of industrial land, as often found in ECA cities, can be difficult and expensive. Former industrial land is often heavily polluted and requires a cleaning of topsoil and other remediation before conversion.[28] In addition, even in centrally located areas additional primary infrastructure has to be built to allow residential and commercial development.

Not converting underused industrial land may have serious consequences for the future of a city. New development will have to occur farther away from the CBD, requiring further extension of essential infrastructure - water, electricity, telecommunications and sometimes heating, as well as transportation, lengthening daily trips. The public transport system may not be expanded in the new areas while servicing the nearly empty industrial zone. A substantial portion of existing infrastructure may be underutilized while the incremental cost of infrastructure at the periphery might be rising, especially if previous socialist real estate investments have yielded negative value.

This mismatch between location of infrastructure and demand for it can encourage an increase in motorization and probably a further deterioration of the public transport system. In turn, the newly created suburbs will tend to develop new modern retail and employment centers contributing to a weakening of the CBD. Without the resources to link these suburbs by an efficient road and transit network, such a metropolitan area will end up with a fragmented built-up area and a fragmented labor and consumer market, further weakening the city's economy.

This scenario is not farfetched. Budapest, for instance, is already facing this problem. The very attractive and dense center is cut out from its suburbs by a large, polluted, nearly deserted industrial belt. Suburban centers developing outside the municipal area are developing fast. The transport links between these suburban centers and the city center are deficient and already

[28] Of course, recycling former industrial land close to city centers can raise numerous environmental issues. Comparing the social cost-benefit of redeveloping brownfields, compared to greenfield development, becomes difficult and subtle. See Russ (1999) for discussion of engineering and development issues involved.

contribute to congestions. Because the city center cannot expand into the adjacent industrial belt, its economic potential is limited. By contrast suburban centers have no problems expanding in greenfield areas outside the reach of the existing transit network. In the long run, the historical center will become less accessible and most new investments will be made in the suburbs. By necessity, cars will then become the dominant mode of transport. The city center will loose its dominant role as a job center, and possibly also the quality of its cultural amenities will deteriorate. The lack of contiguity in development will be reflected by an increased value for the dispersion index.

Using regulations to "reshape" socialist cities. Transition economy planners should strive to avoid the twin problems discussed by Mills (2002 a, b): regulating to increase density, sometimes at the same time regulating to reduce density, without a clear idea of the costs and benefits of such regulation. Rather than micromanage density, whether by regulations preventing the development of single family housing in peripheral areas, or minimum plot size and unrealistic floor area ratios, planners should strive to broadly follow the market (Wallace 1988), regulating with a light touch when needed to deal with concrete and identifiable external costs.

Designing regulations which are consistent with markets is relatively easy in market economies, because zoning changes are usually preceded by public hearings where suppliers and consumers have a chance to express a well informed opinion. It is more difficult in former socialist economies because (1) existing land use does not provide much indication of what the market "want", (2) public participation in local government issues is still embryonic, and (3) interest groups are much less organized and informed about technical issues such as zoning. In ECA cities the best approach to regulations could be the one used in Warsaw (see Bertaud 2000).

In Warsaw zoning areas are divided into 3 broad categories*, market driven areas* covering about 48% of the municipal area, *segregated areas for noxious uses* (14%) containing heavy industries and utilities, and *protected areas* (37%) including historical areas, university areas, and green areas to be protected. Within these categories are of course subcategories adapted to more specific uses. The original feature of Warsaw proposed zoning is of course the market driven area category. In this zoning category, regulations allow almost any mix of non-noxious use and establishes a limit on density far above the current density, providing developers with an incentive to redevelop existing structures in a more intensive way wherever there is demand for it. At the same time, the historical monuments and the natural features, such as the bluff dominating the Vistula River, are fully protected. Prague zoning, by contrast, contains more than 68 zoning categories. Practically each plot is zoned individually and reflects existing land use. This does not provide much incentive for developers.

City structures and public transport in ECA cities. Based on data collected to date, the structure of ECA cities appears characteristically European much more than it is socialist, i.e. most of the ECA cities we have studied[29] have a dominant high density mixed use urban core defined by a large number of jobs and a high level of cultural amenities (operas, museums, concert halls, theaters, restaurants, luxury retail, etc). ECA cities' cores are typically served by an extensive network of public transport (metro, tramways, buses) and the trip mode split between transit and car is always more than 50 percent. This is an advantage as the high density core would be incompatible with commuting patterns dominated by automobiles, as in most U.S. cities. However, because of the liability created by obsolete industrial areas and by the suburban

[29] As noted above, despite the effort expended in collecting our data, most of our ECA cities represent Central European cities, and a few Western Russian cities (Moscow, St. Petersburg). It would be fruitful to study other cities in the future, including, among others, single-use cities like Novosibirsk, Asian cities (including Siberian), and the like.

belts of panel housing, new modern areas have a tendency to be developed in distant suburbs, outside the reach of the main transport network. In addition, because many ECA cities have municipal borders close to their built-up boundaries, new development at higher densities in distant suburbs are often encouraged by much more lenient zoning regulations and less red tape in suburban municipalities than the one prevalent in the core city. This 'border effect' is visually detectable in Budapest and Cracow, for instance. The border effect caused by the disparities of land use and tax regulations at the fringe of urbanization might accelerate the weakening of the city core, and an increase in motorization compared to what it would have been if the regulatory and tax environment had been homogenous inside and around large cities.

The need to monitor urban spatial structures, and the regulatory environment. Planners in transition economies should monitor their cities. Mapping land uses, corresponding densities, housing prices and changes in prices is a start. With this baseline data, planners would move on to studying whether permitted land uses, floor area ratios and the like are broadly appropriate. Too many planning exercises, like the development of many master plans, are static one-off exercises. Planners need to view plans and regulations as dynamic, just as the city is dynamic. In many ECA cities, planners consider that the monitoring of land prices and rents is not relevant to their job. In fact, because ECA cities lack interest group feed backs as mentioned above, monitoring the evolution of real estate prices and rents is the most useful tool to guide future land legislation and primary infrastructure investment.

In some ways, the most important prescription for planners in transition economies is, in a version of the Hippocratic oath, "to do no harm." As planning and regulatory systems continue to develop along with the market, policymakers in transition economies need to let the substantive requirements of their cities guide their design of regulations, rather than blindly copy forms and institutions from other countries. Otherwise-different experiences in cities as diverse as Brasilia and Seoul demonstrate that inappropriate planning and regulation can exist in otherwise market-oriented economies, but at great cost in suboptimal land use, increased commuting costs, and a weakened public fisc. As the Korea case points out (Kim 2002), it can be very difficult to unwind a distorted planning system once in place.

This paper highlights the centrality of regulation in determining city form and economic efficiency. However while the paper – and associated literature – has made some progress, further improvement is necessary. There is still some work to be done on measuring form, but it is even more apparent we still lack a completely satisfactory metric for municipal regulation. A completely satisfactory metric would have to be (1) conceptually well-founded, (2) empirically implementable at reasonable cost, and (3) eventually widely calculated for a range of cities to facilitate useful comparisons. Such a measure would provide a quick and cheap tool to assess when perverse regulatory behavior is damaging urban development. The World Bank Group is well placed to make such an effort, given the focus on institutions and "good governance" within the Bank.

Of course, the regulatory environment is a broad concept. One initial focus on measuring the urban policy environment should surely be land use regulations. Land use regulations can be a major problem in ECA cities, because they often contribute to the weakening of old urban centers and push "modern" development across municipal boundaries (Budapest). The costs of "auditing" these regulations is low relative to potential benefits (as the Bank's study of Cracow demonstrated), especially now that most regulatory maps are in digital form. Such an analysis can be included as part of a City Development Strategy exercise. Such exercises must be undertaken with the knowledge that they can be sensitive; some officials will not welcome evaluation and criticism of the outcomes of their past efforts at regulation and planning. Often support for regulatory framework reform will come from those who are affected most directly: developers, property owners and possibly managers of public transport companies. In quite a few countries environmentalists are beginning to focus on issues related to urban form, albeit often without much hard evidence behind their positions. A debate on the issue of "urban shape" is often well-received in ECA countries, especially when clients are offered illuminating comparisons to other European cities.

Of course this paper is a first assessment. It is not the last word on the effects 40 years of socialist policies have had on the structure of cities in Central Europe, Russia and Central Asia. Yet, from this research, and previous work such as Buckley and Mini (2000) and Renaud (1995 a, b), it is clear the distortions created in Central Europe have legacies: empty and seriously misallocated land parcels within cities, environmental costs, and underutilized central areas. These costs are paid by business and households in the form of higher rents and living costs. The large peripheral housing estates with low or even negative values are physically durable, and some of this worthless stock will likely be in place for years to come. Cities need a strategy to address these distortions so as to modernize at a cost that remains affordable. Development of effective strategies requires careful data collection and analysis, and further development of very concrete policy options. The estimated value of housing privatization in ECA far exceeds all other privatizations[30] - a questionable transfer of wealth to many, if urban policies in ECA don't change. East Germany is an example of how following badly designed socialist urban policies with equally misguided post-socialist policies can fail: banks are hard hit by the burden of non-performing real estate loans, renovated apartments have been oversupplied by perhaps 30 percent, new construction is proceeding apace beyond the "socialist housing belt" but redevelopment of inner cities is neglected, and the costs of maintaining the old stock is contributing substantially to the indebtedness of the Laender.

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.[31] 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 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

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[30] Buckley and Mini (2000) estimated Russia's housing privatization amounts to 3 - 4 times ECA GDP.
[31] See Follain and Gross (1983), Cheshire and Sheppard (1995), and Malpezzi and Guo (2001), and references

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.

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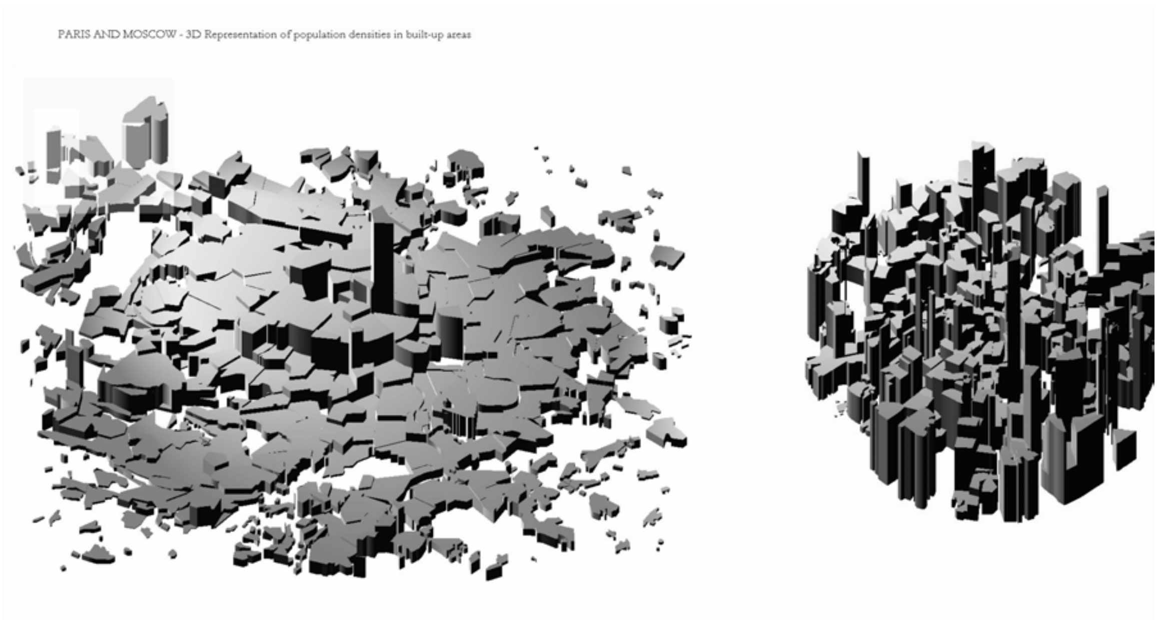
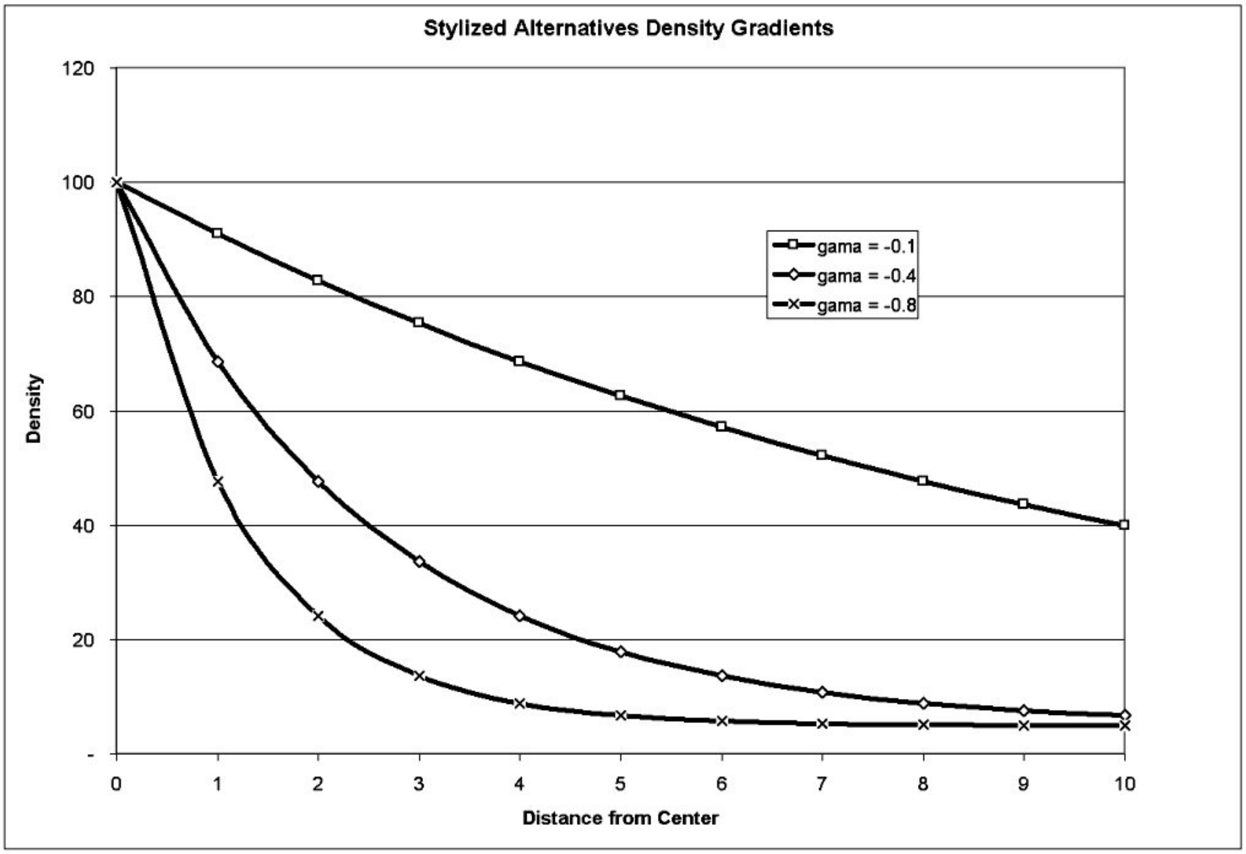

PARIS AND MOSCOW - 3D Representation of population densities in built-up areas

Figure 1



Stylized Alternatives Density Gradients
120
100
80
60
40
20
-
Density
0
1
2
3
4
5
6
7
8
9
10
Distance from Center
gama = -0.1
gama = -0.4
gama = -0.8

Figure 2

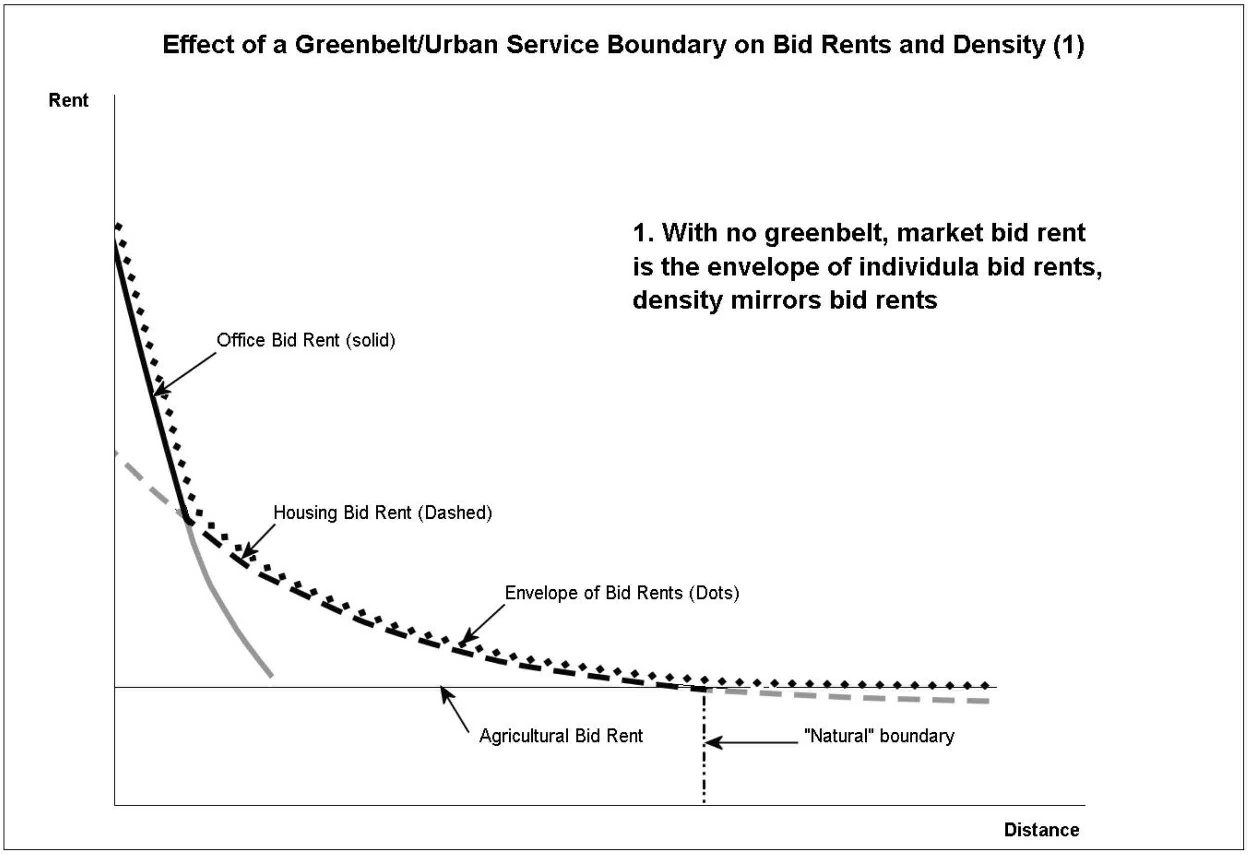

Effect of a Greenbelt/Urban Service Boundary on Bid Rents and Density (1)
Rent
1. With no greenbelt, market bid rent is the envelope of individula bid rents, density mirrors bid rents
Office Bid Rent (solid)
Housing Bid Rent (Dashed)
Envelope of Bid Rents (Dots)
Agricultural Bid Rent
"Natural" boundary
Distance

Figure 3

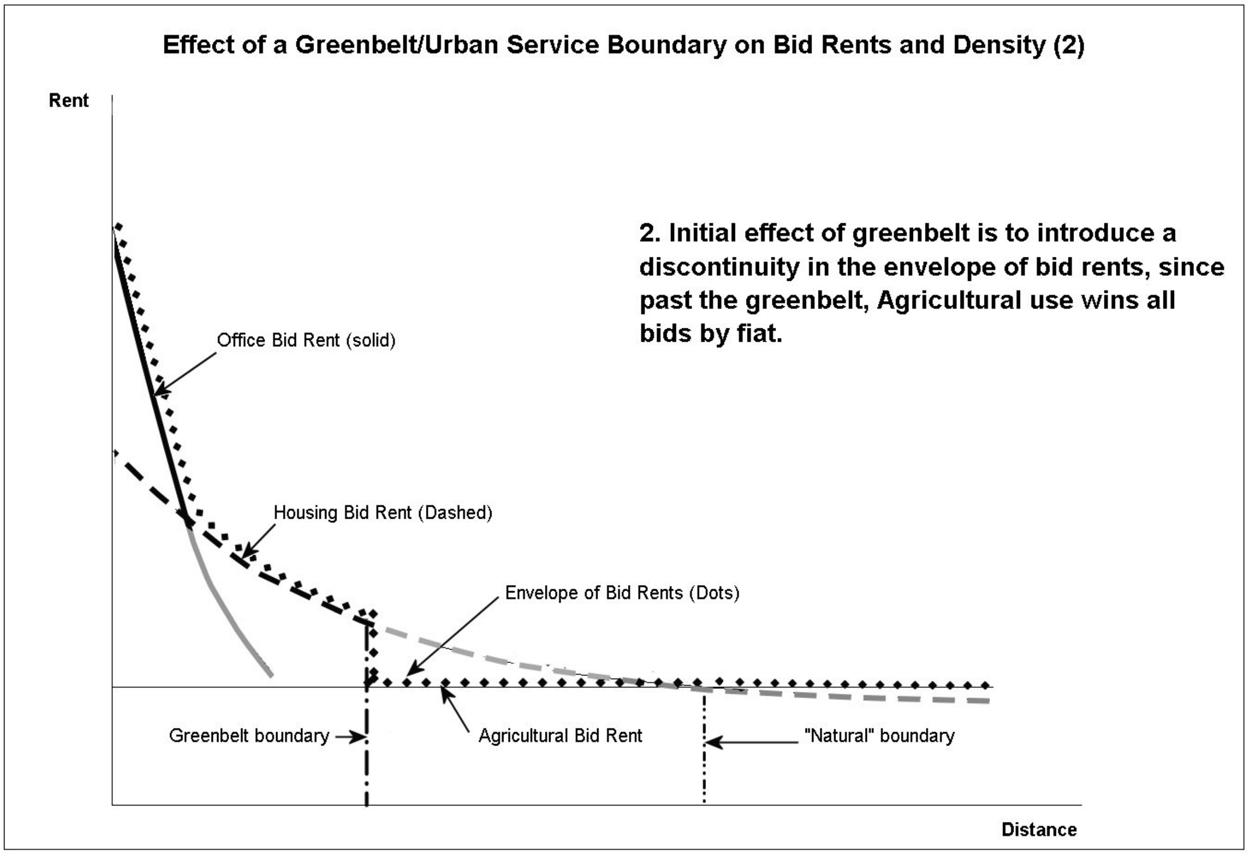

Effect of a Greenbelt/Urban Service Boundary on Bid Rents and Density (2)
Rent
2. Initial effect of greenbelt is to introduce a discontinuity in the envelope of bid rents, since past the greenbelt, Agricultural use wins all bids by fiat.
Office Bid Rent (solid)
Housing Bid Rent (Dashed)
Envelope of Bid Rents (Dots)
Greenbelt boundary
Agricultural Bid Rent
"Natural" boundary
Distance

Figure 4

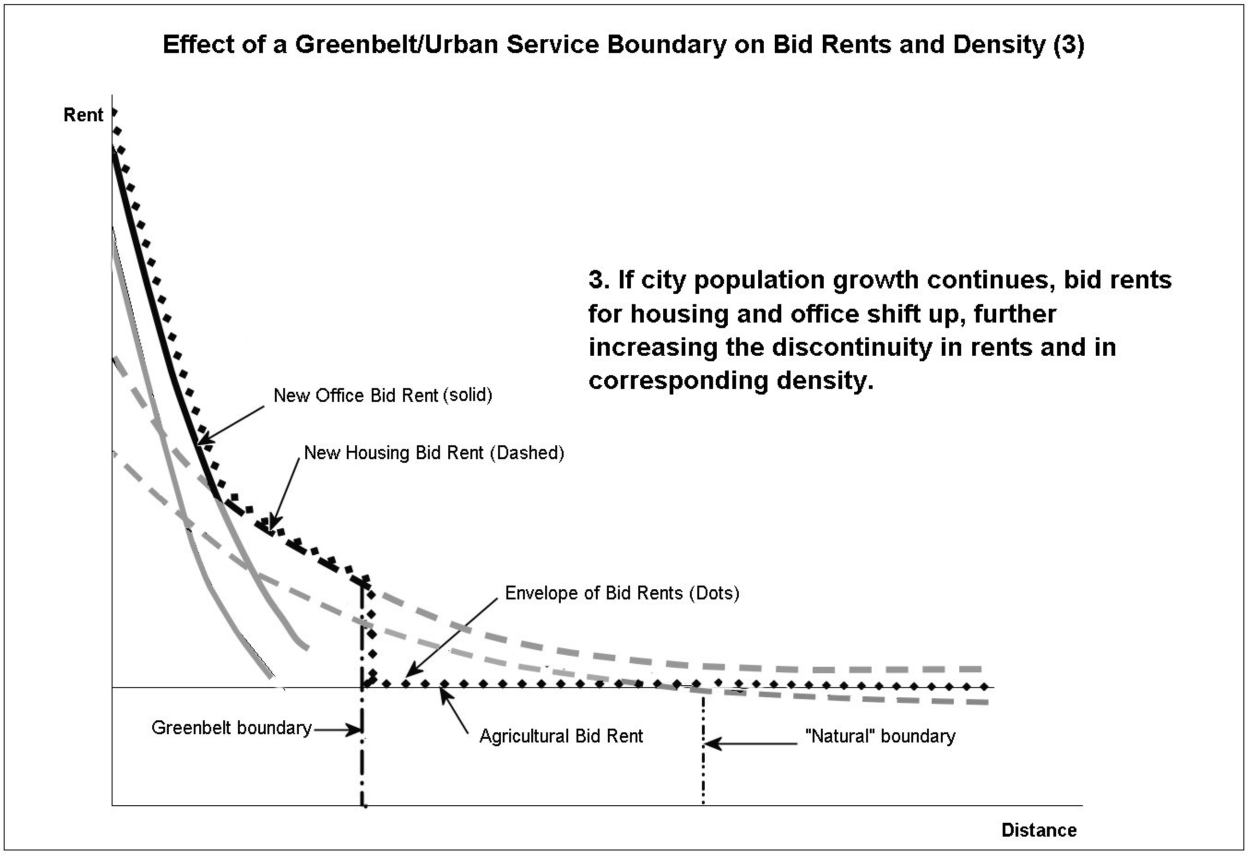

Effect of a Greenbelt/Urban Service Boundary on Bid Rents and Density (3)
Rent
3. If city population growth continues, bid rents for housing and office shift up, further increasing the discontinuity in rents and in corresponding density.
New Office Bid Rent (solid)
New Housing Bid Rent (Dashed)
Envelope of Bid Rents (Dots)
Greenbelt boundary
Agricultural Bid Rent
"Natural" boundary
Distance

Figure 5

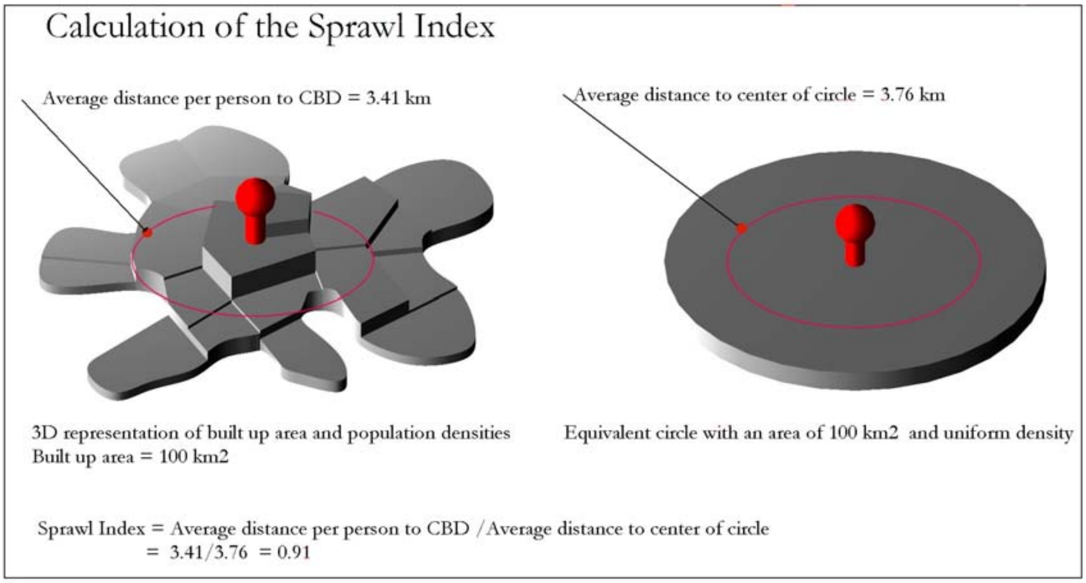
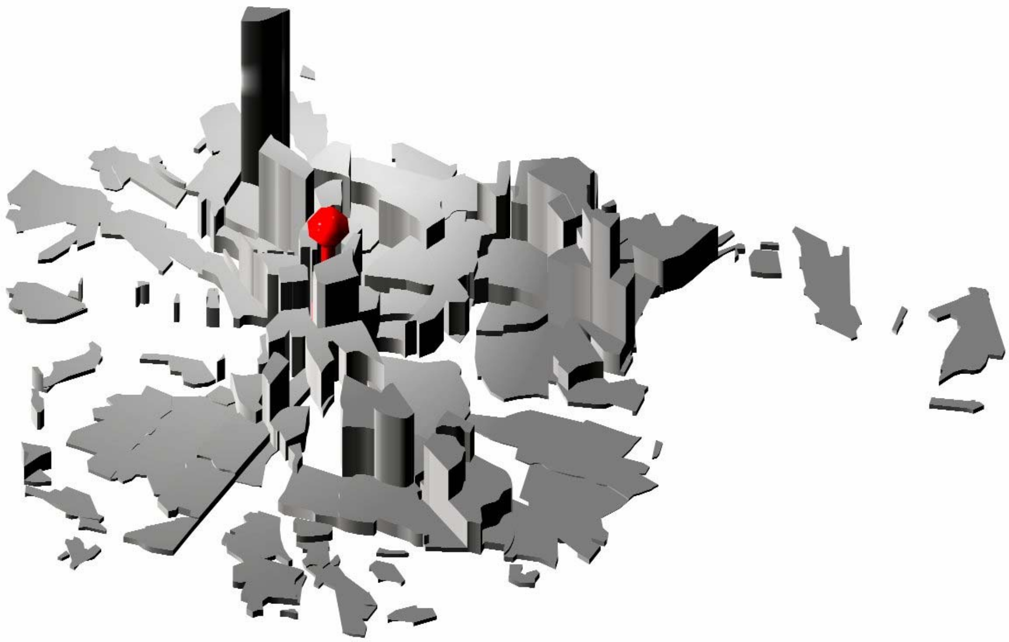

Calculation of the Sprawl Index
Average distance per person to CBD = 3.41 km
Average distance to center of circle = 3.76 km
3D representation of built up area and population densities
Built up area = 100 km2
Equivalent circle with an area of 100 km2 and uniform density
Sprawl Index = Average distance per person to CBD /Average distance to center of circle
= 3.41/3.76 = 0.91

Figure 6



Cracow - 3D representation of population densities

Figure 7

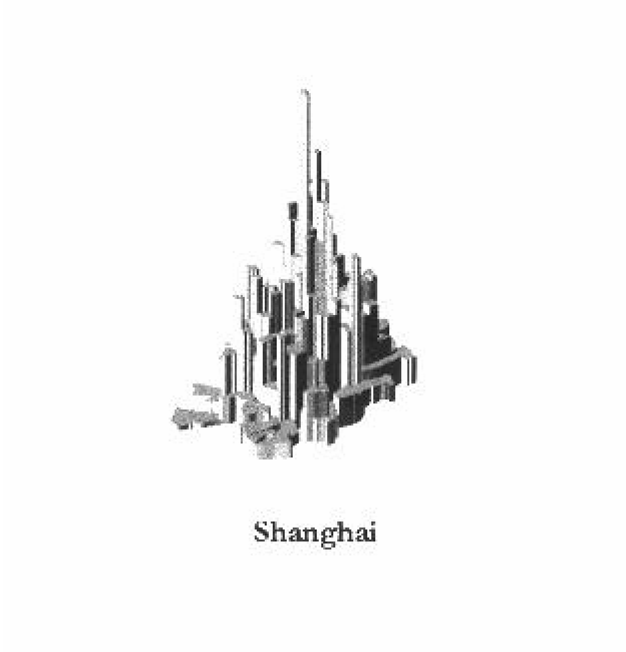
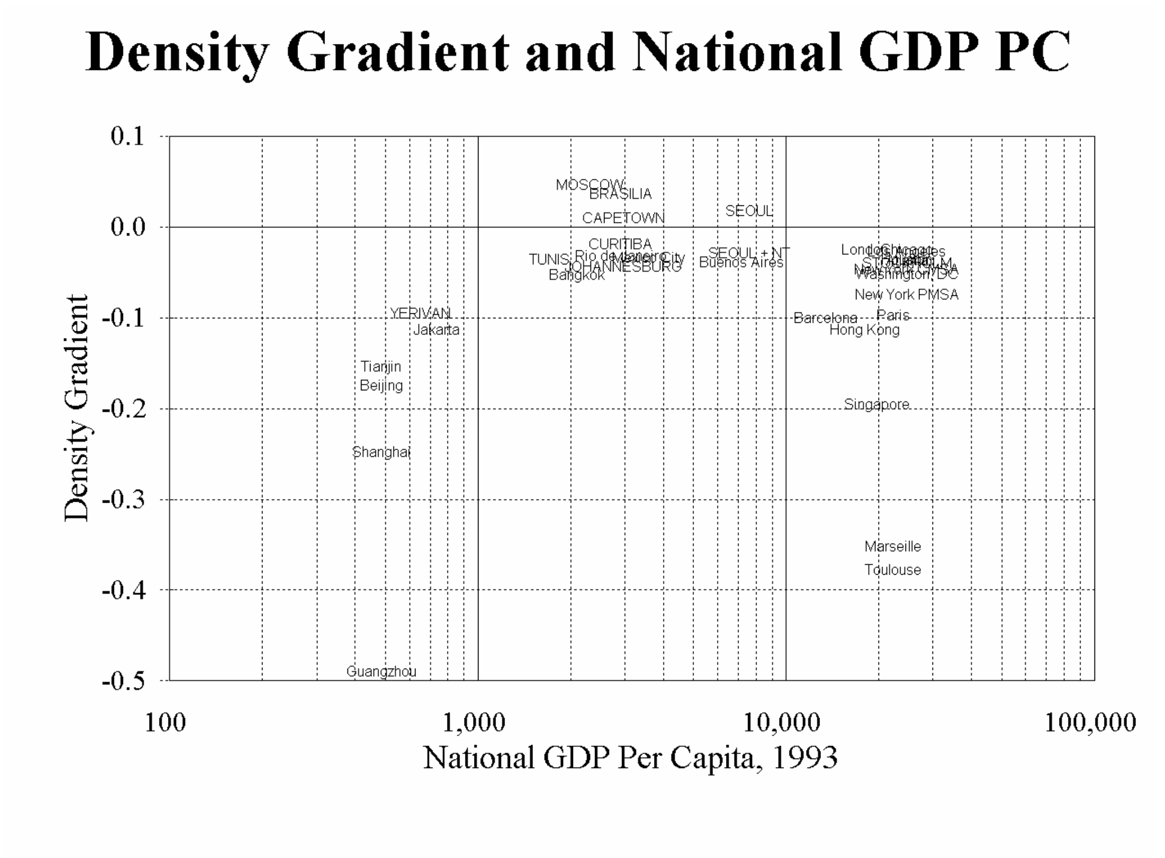


Figure 8



Density Gradient and National GDP PC
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
Density Gradient
100
1,000
10,000
100,000
National GDP Per Capita, 1993
MOSCOW
BRASILIA
CAPETOWN
SEOUL
CURITIBA
TUNIS
Bangkok
SEOUL + NT
Buenos Aires
YERIVAN
Jakarta
Tianjin
Beijing
Shanghai
Guangzhou
Barcelona
Hong Kong
Paris
New York PMSA
Washington, DC
Singapore
Marseille
Toulouse

Figure 9

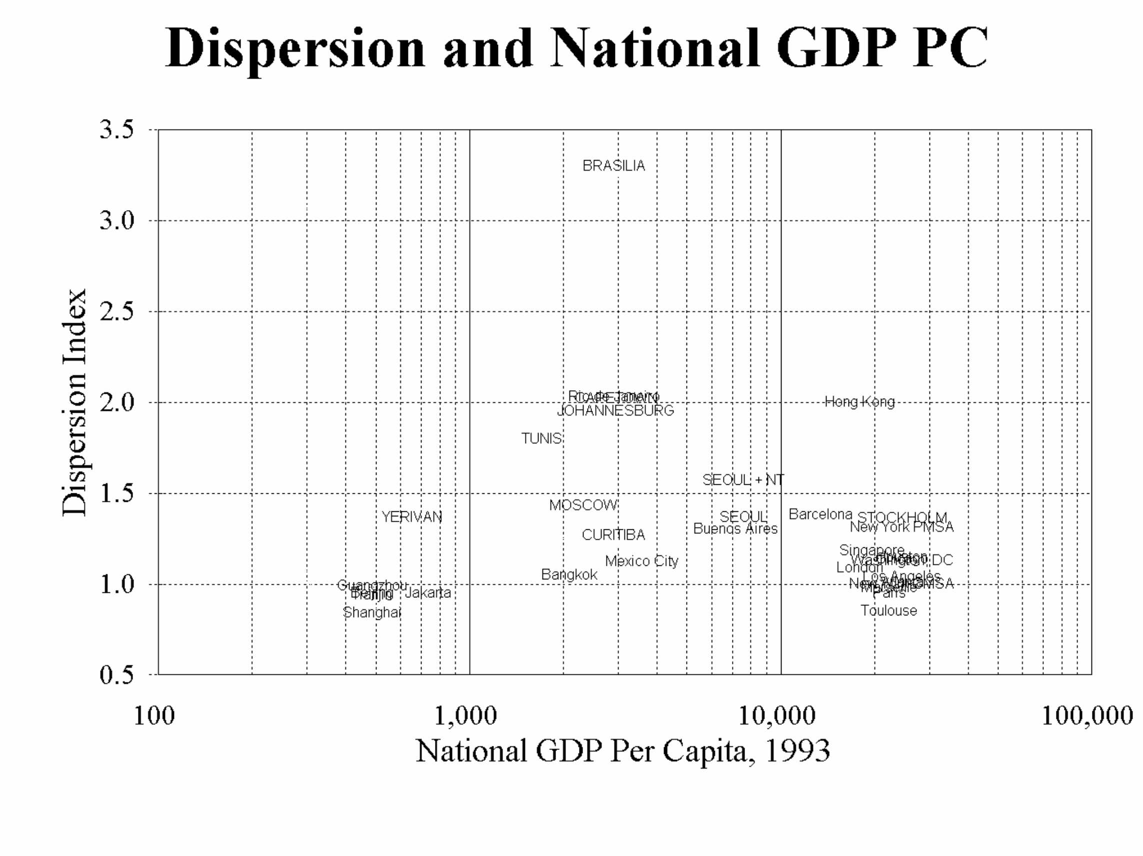

Dispersion and National GDP PC
Dispersion Index
3.5
3.0
2.5
2.0
1.5
1.0
0.5
100
1,000
10,000
100,000
National GDP Per Capita, 1993
BRASILIA
JOHANNESBURG
Hong Kong
TUNIS
SEOUL + NT
MOSCOW
YERIVAN
SEOUL
Buenos Aires
Barcelona
STOCKHOLM
New York PMSA
CURITIBA
Singapore
Mexico City
London
Bangkok
Los Angeles
Guangzhou
Jakarta
Paris
Shanghai
Toulouse

Figure 10

Density Gradient and City Population

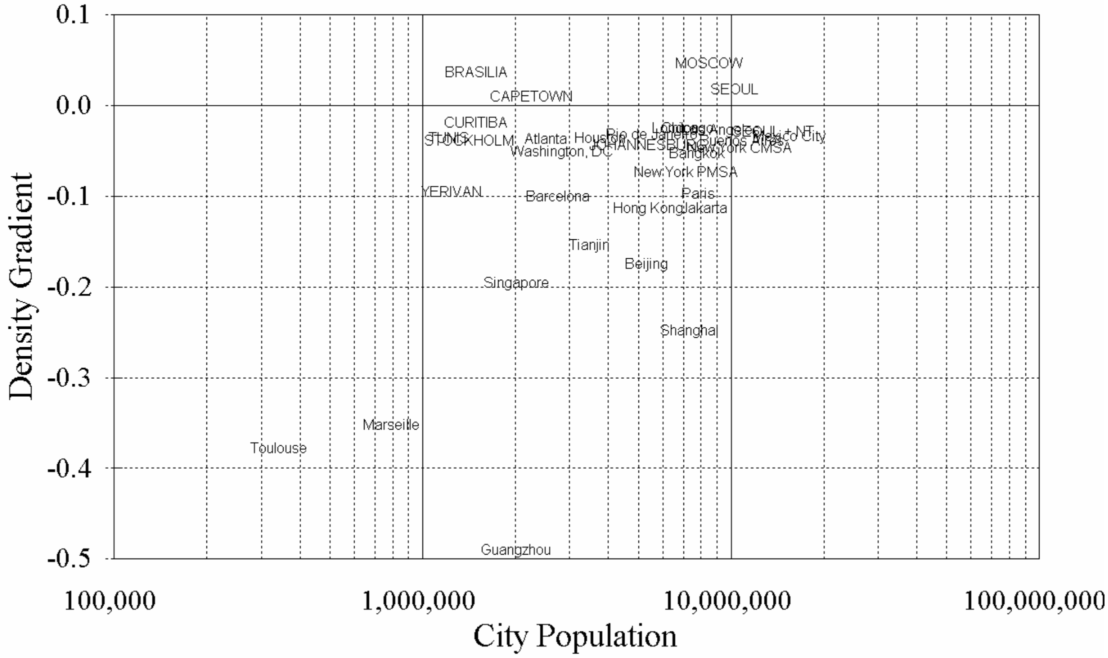


Figure 11

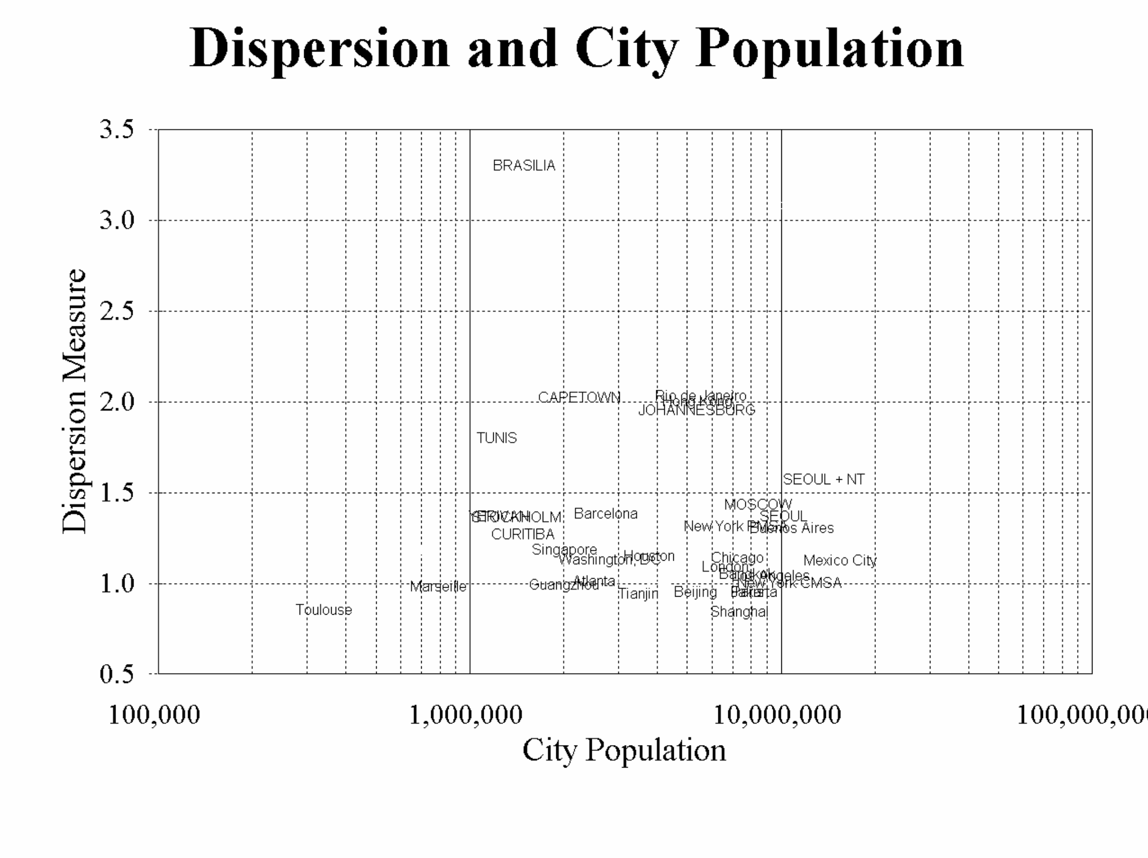
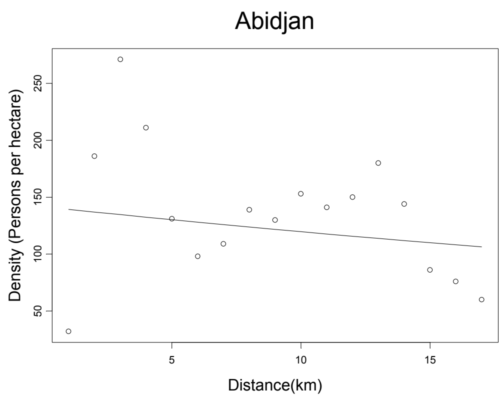
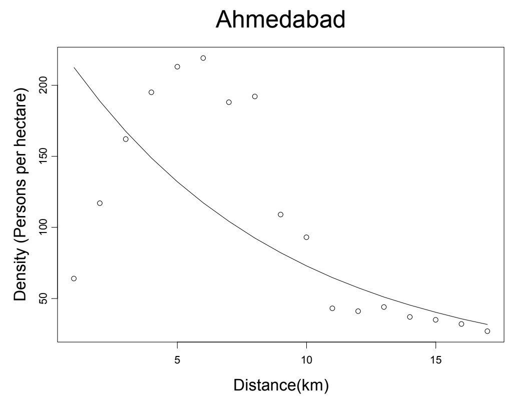
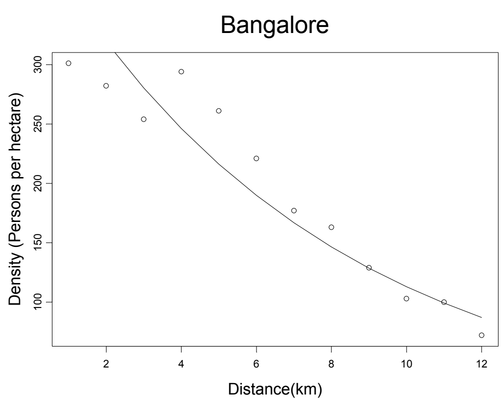
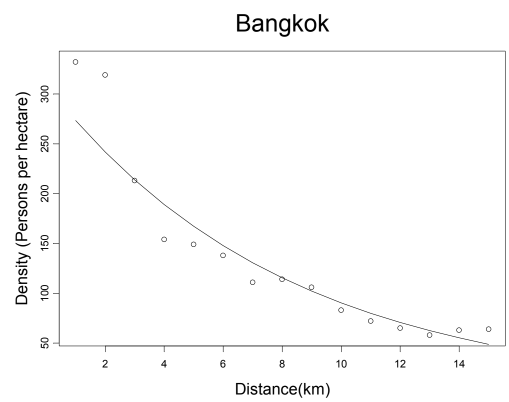

Dispersion and City Population
Dispersion Measure
3.5
3.0
2.5
2.0
1.5
1.0
0.5
BRASILIA
CAPETOWN
Rio de Janeiro
JOHANNESBURG
TUNIS
SEOUL + NT
MOSCOW
SEOUL
Buenos Aires
Barcelona
CURITIBA
Singapore
Houston
Chicago
London
Mexico City
New York CMSA
Atlanta
Tianjin
Beijing
Shanghai
Marseille
Toulouse
100,000
1,000,000
10,000,000
City Population

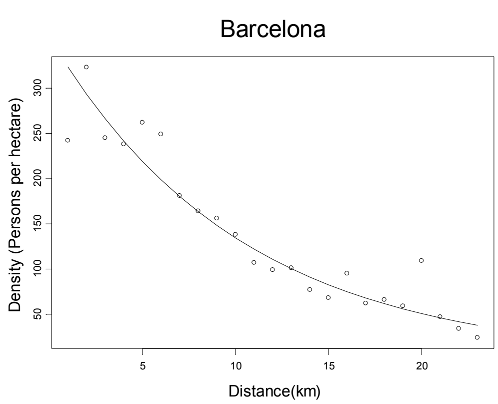
Figure 12

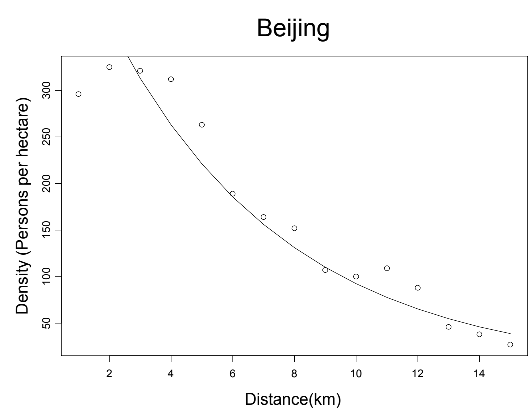

Abidjan
Density (Persons per hectare)
50
100
150
200
250
5
10
15
Distance(km)

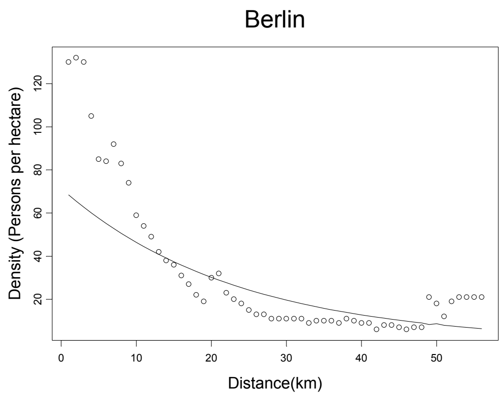

Ahmedabad
Density (Persons per hectare)
50
100
150
200
5
10
15
Distance(km)

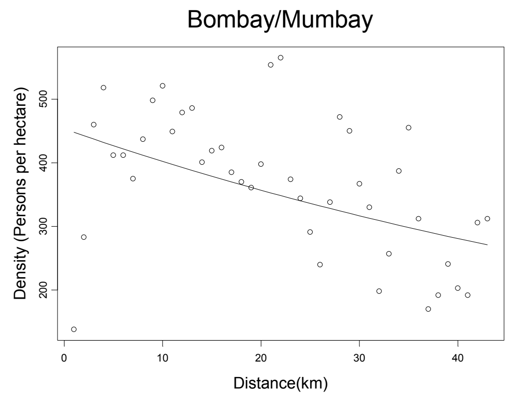

Bangalore
Density (Persons per hectare)
100
150
200
250
300
2
4
6
8
10
12
Distance(km)

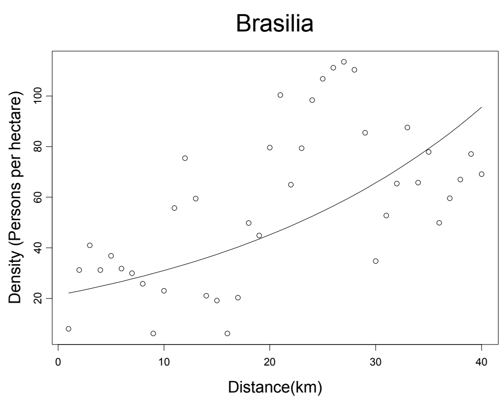

Bangkok
Density (Persons per hectare)
50
100
150
200
250
300
2
4
6
8
10
12
14
Distance(km)

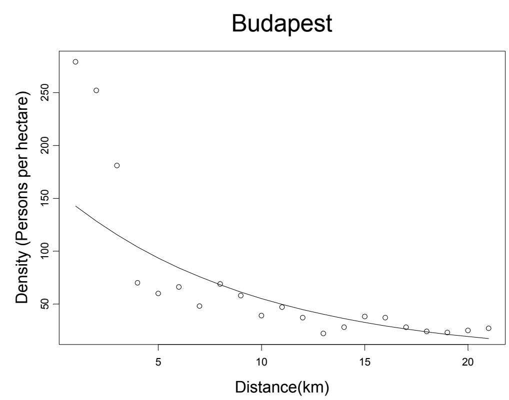

Barcelona
Density (Persons per hectare)
50
100
150
200
250
300
5
10
15
20
Distance(km)

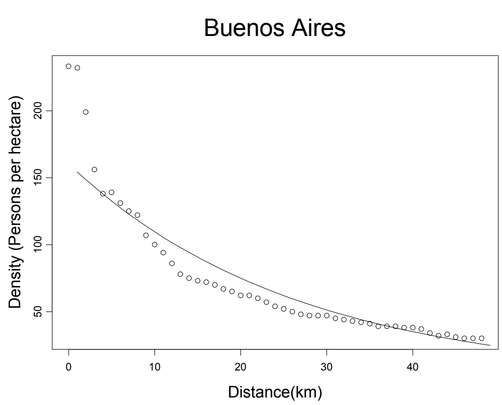

Beijing
Density (Persons per hectare)
50
100
150
200
250
300
2
4
6
8
10
12
14
Distance(km)

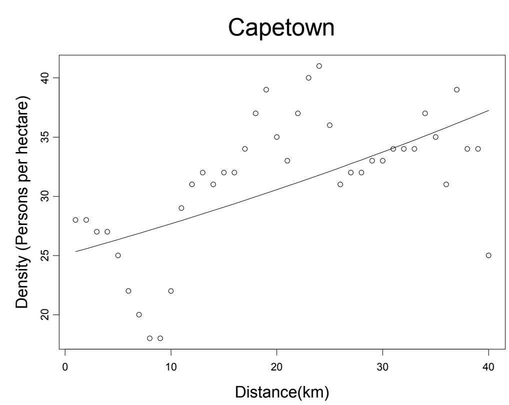

Berlin
Density (Persons per hectare)
Distance(km)

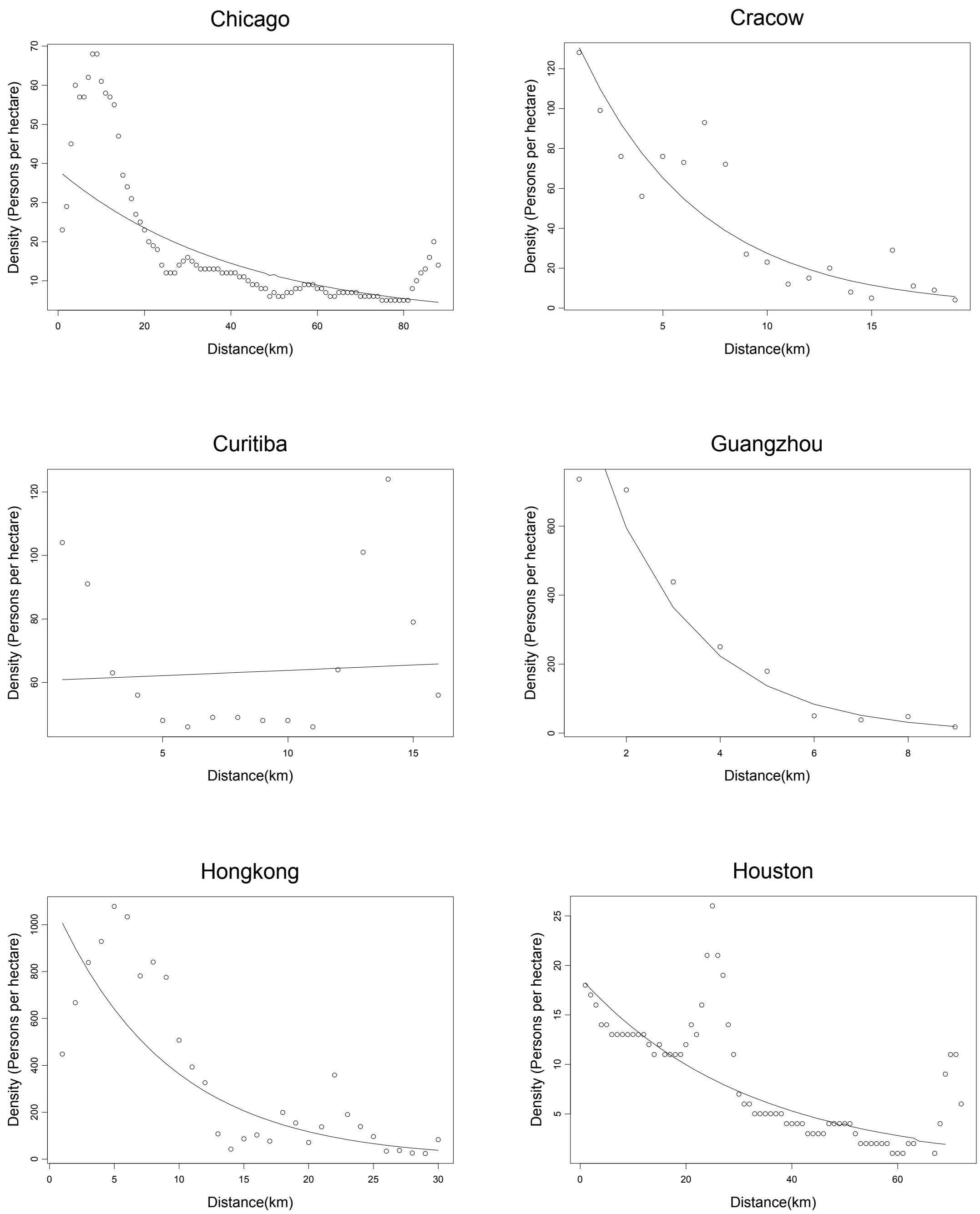

Bombay/Mumbay
Density (Persons per hectare)
Distance(km)

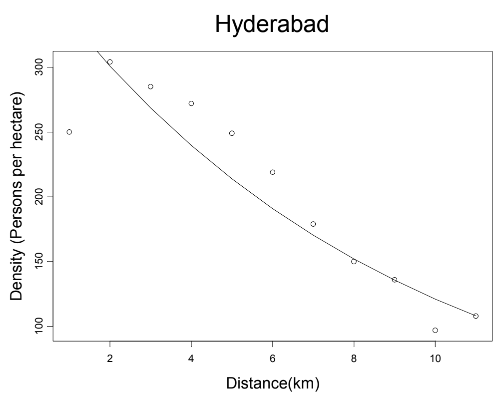

Brasilia
Density (Persons per hectare)
Distance(km)

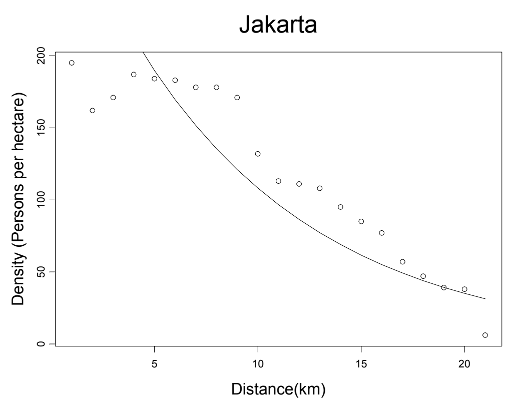

Budapest
Density (Persons per hectare)
Distance(km)

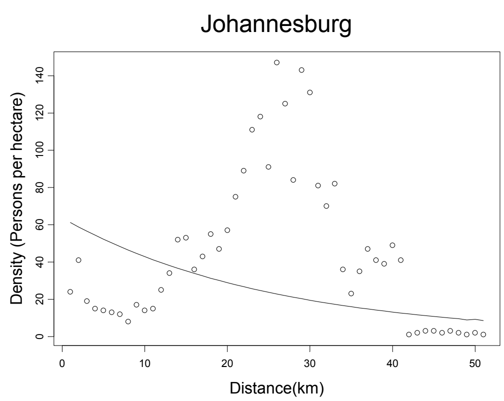

Buenos Aires
Density (Persons per hectare)
Distance(km)

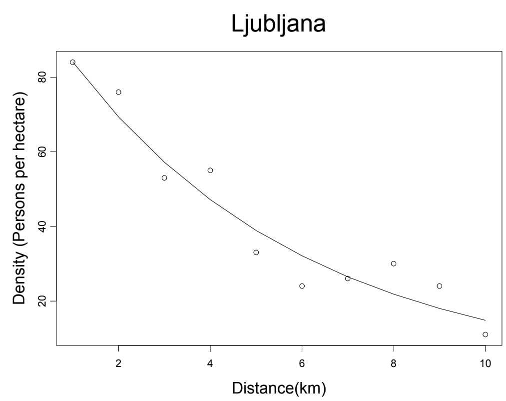

Capetown
Density (Persons per hectare)
Distance(km)

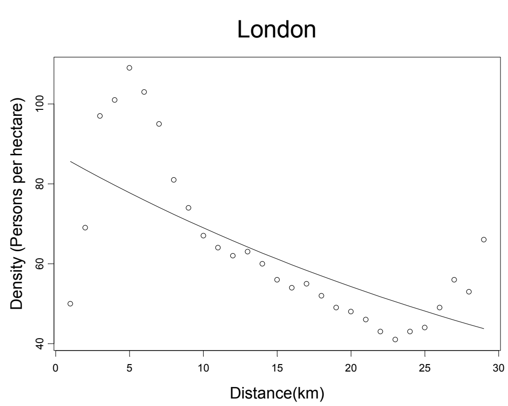

Chicago
Density (Persons per hectare)
Distance(km)
Cracow
Density (Persons per hectare)
Distance(km)
Curitiba
Density (Persons per hectare)
Distance(km)
Guangzhou
Density (Persons per hectare)
Distance(km)
Hongkong
Density (Persons per hectare)
Distance(km)
Houston
Density (Persons per hectare)
Distance(km)

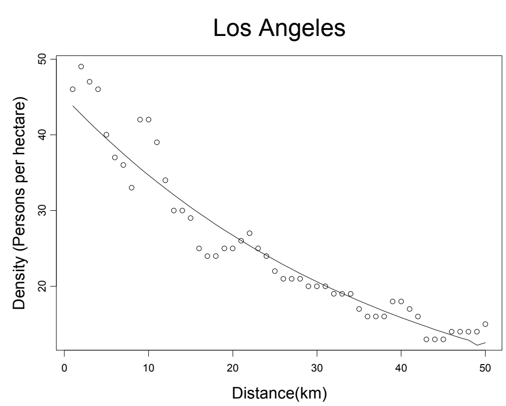

Hyderabad
Density (Persons per hectare)
100 150 200 250 300
2 4 6 8 10
Distance(km)

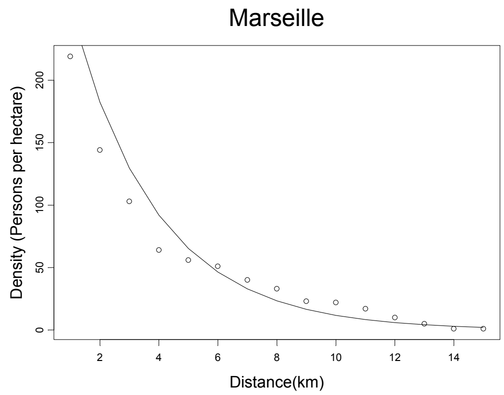

Jakarta
Density (Persons per hectare)
0 50 100 150 200
5 10 15 20
Distance(km)

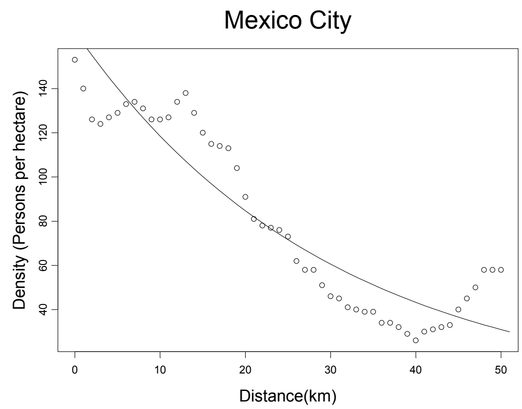

Johannesburg
Density (Persons per hectare)
0 20 40 60 80 100 120 140
0 10 20 30 40 50
Distance(km)

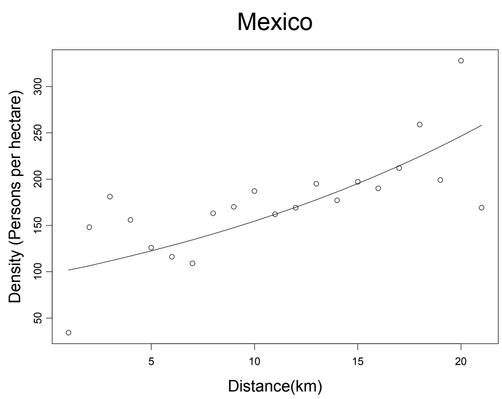

Ljubljana
Density (Persons per hectare)
20 40 60 80
2 4 6 8 10
Distance(km)

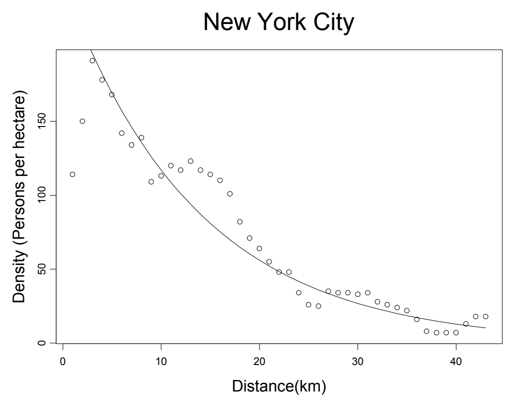

London
Density (Persons per hectare)
40 60 80 100
0 5 10 15 20 25 30
Distance(km)

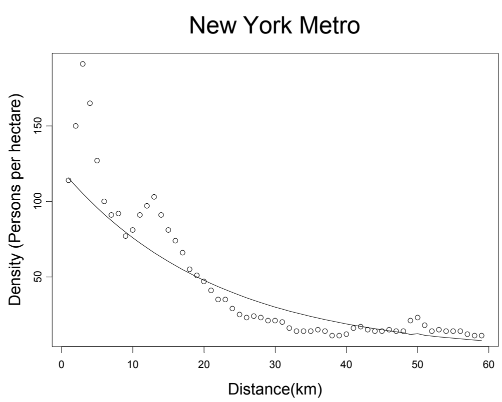

Los Angeles
Density (Persons per hectare)
20 30 40 50
0 10 20 30 40 50
Distance(km)

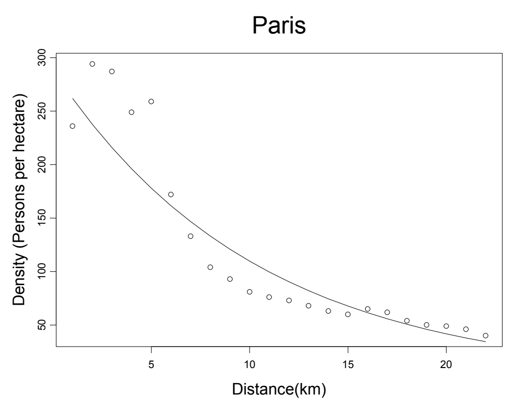

Marseille
Density (Persons per hectare)
Distance(km)

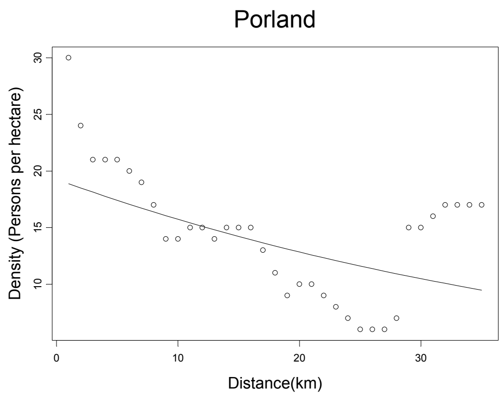

Mexico City
Density (Persons per hectare)
Distance(km)

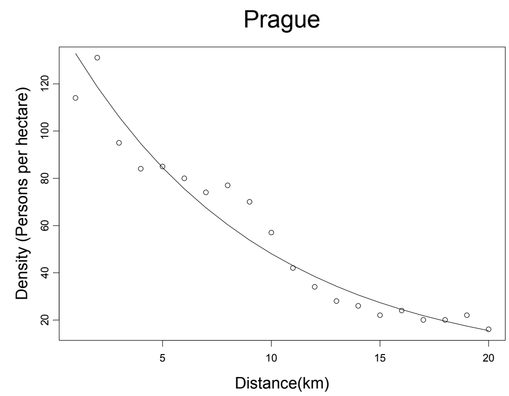

Mexico
Density (Persons per hectare)
Distance(km)

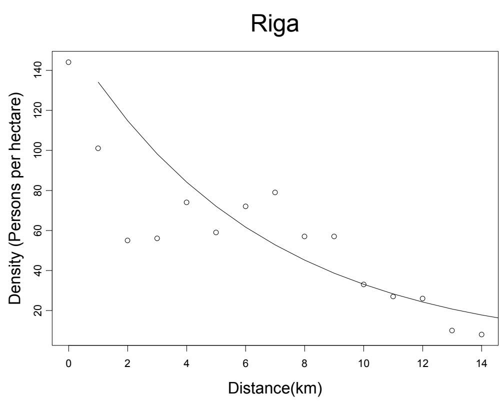

New York City
Density (Persons per hectare)
Distance(km)

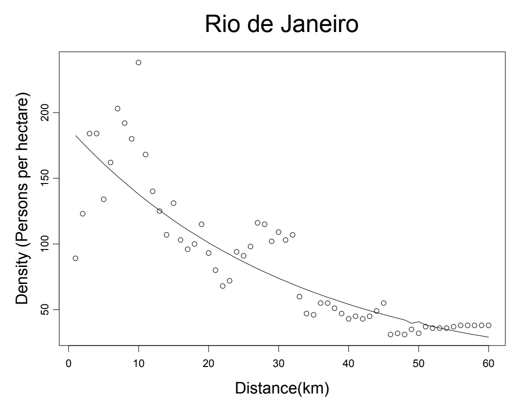

New York Metro
Density (Persons per hectare)
Distance(km)

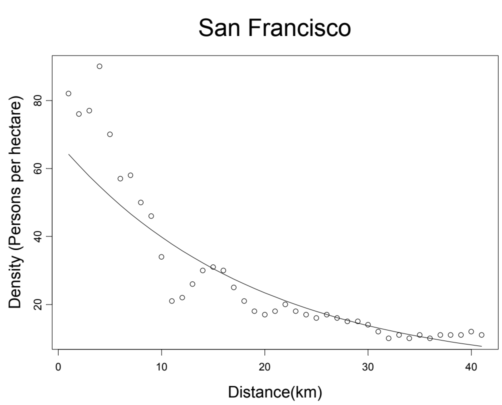

Paris
Density (Persons per hectare)
Distance(km)

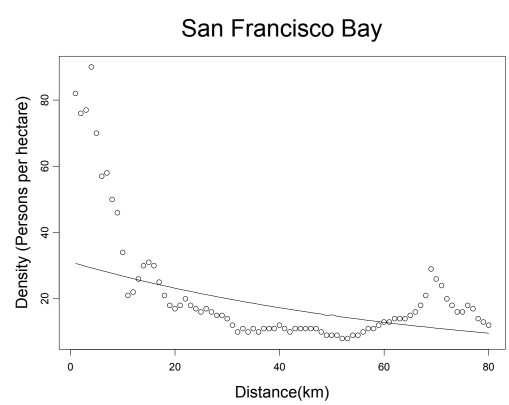

Porland
Density (Persons per hectare)
Distance(km)

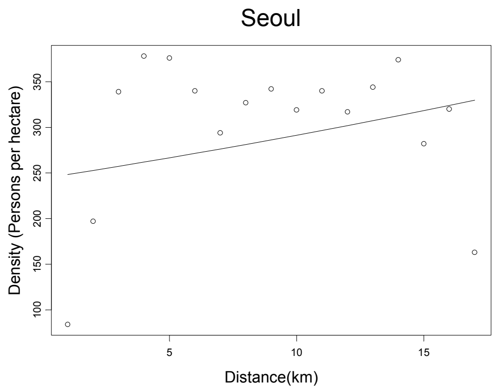

Prague
Density (Persons per hectare)
Distance(km)

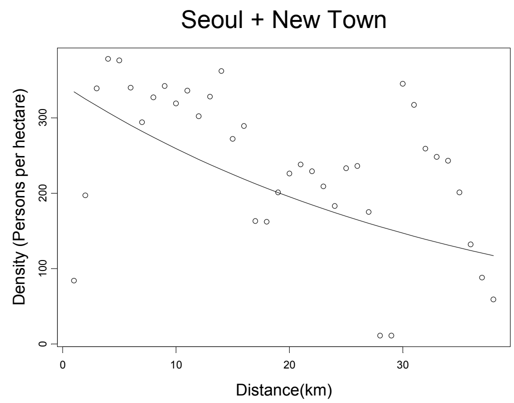

Riga
Density (Persons per hectare)
Distance(km)

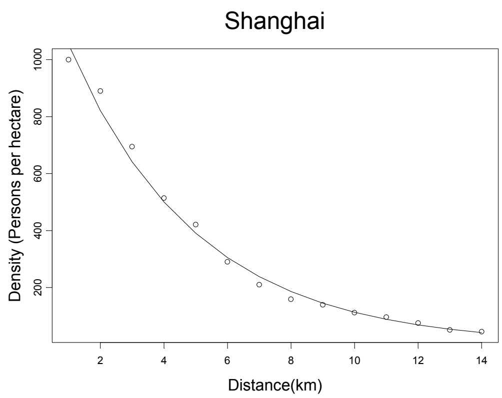

Rio de Janeiro
Density (Persons per hectare)
Distance(km)

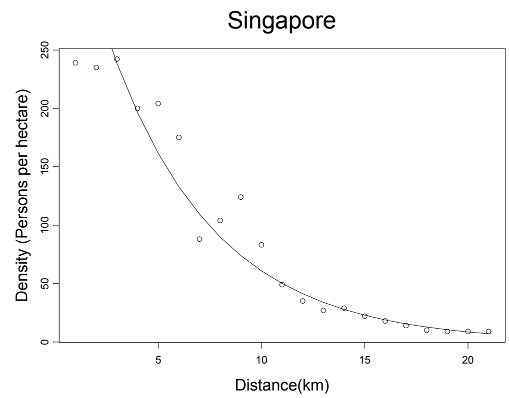

San Francisco
Density (Persons per hectare)
Distance(km)

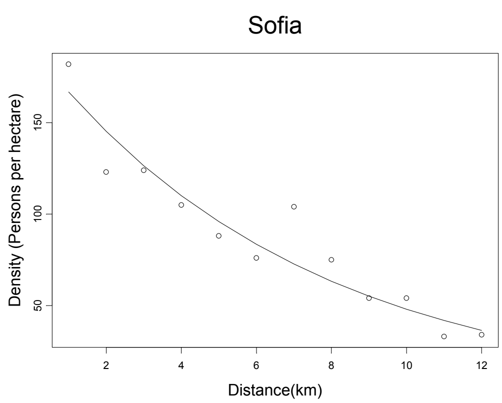

San Francisco Bay
Density (Persons per hectare)
Distance(km)

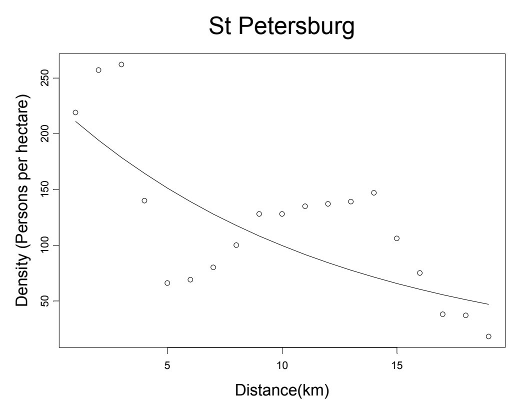

Seoul
Density (Persons per hectare)
100
150
200
250
300
350
5
10
15
Distance(km)

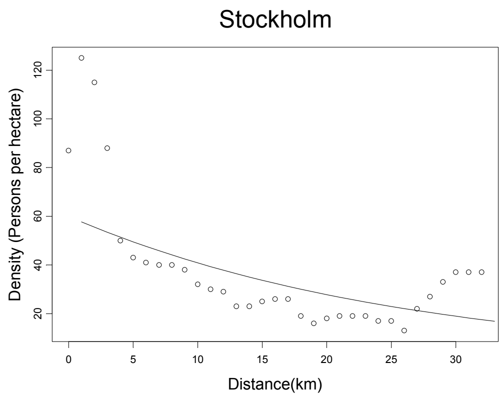

Seoul + New Town
Density (Persons per hectare)
0
100
200
300
0
10
20
30
Distance(km)

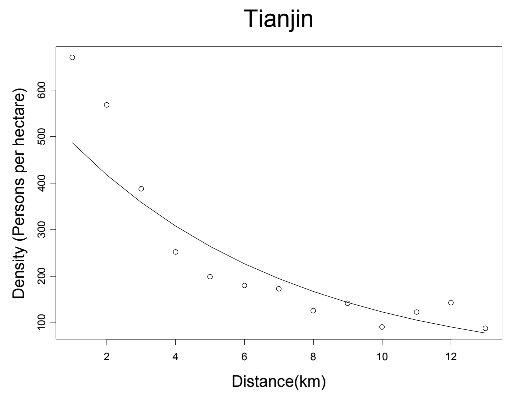

Shanghai
Density (Persons per hectare)
200
400
600
800
1000
2
4
6
8
10
12
14
Distance(km)

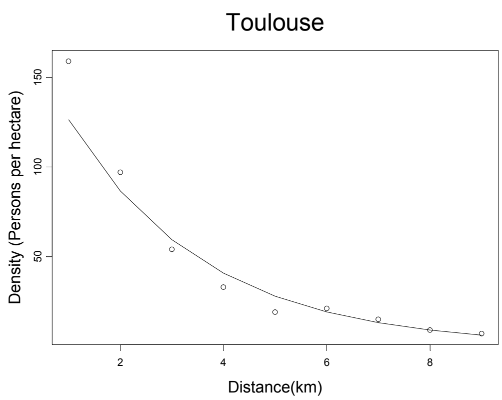

Singapore
Density (Persons per hectare)
0
50
100
150
200
250
5
10
15
20
Distance(km)

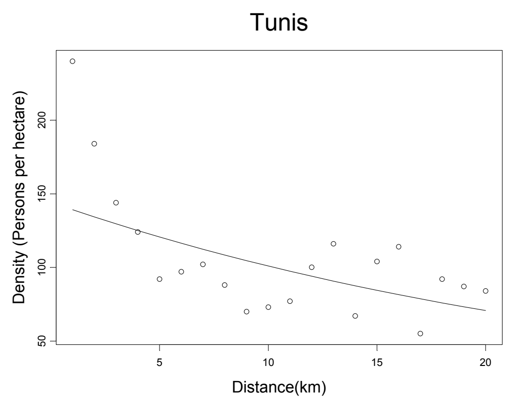

Sofia
Density (Persons per hectare)
50
100
150
2
4
6
8
10
12
Distance(km)

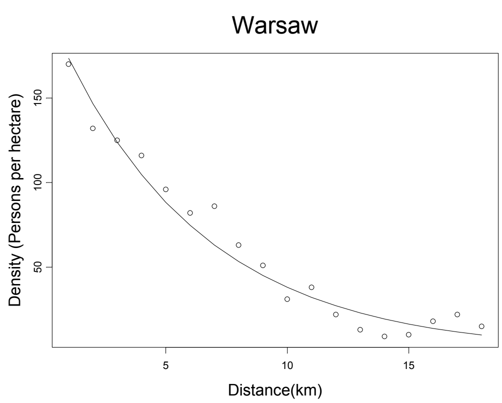

St Petersburg
Density (Persons per hectare)
50
100
150
200
250
5
10
15
Distance(km)

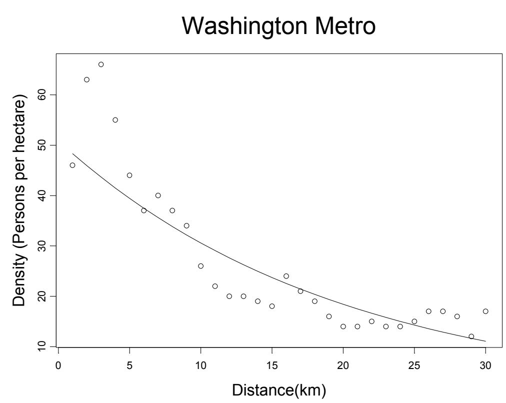

Stockholm
Density (Persons per hectare)
20 40 60 80 100 120
0 5 10 15 20 25 30
Distance(km)

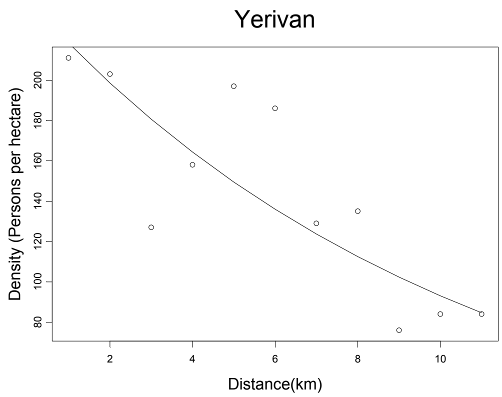

Tianjin
Density (Persons per hectare)
100 200 300 400 500 600
2 4 6 8 10 12
Distance(km)


Toulouse
Density (Persons per hectare)
50 100 150
2 4 6 8
Distance(km)


Tunis
Density (Persons per hectare)
50 100 150 200
5 10 15 20
Distance(km)


Warsaw
Density (Persons per hectare)
50 100 150
5 10 15
Distance(km)


Washington Metro
Density (Persons per hectare)
10 20 30 40 50 60
0 5 10 15 20 25 30
Distance(km)


Yerivan
Density (Persons per hectare)
80
100
120
140
160
180
200
2
4
6
8
10
Distance(km)

Appendix 2: Derivation of a Negative Exponential Population Density Function From the 'Standard Urban Model'[32]

In this appendix, we derive the negative exponential density model discussed in the text. Basic references on this model include Alonso (1964), Muth (1969) and Mills (19). In this appendix we closely follow the exposition of this model in Appendix A of Edwin S. Mills and Bruce W. Hamilton's *Urban Economics* (1984, 4th edition). Mills and Hamilton in turn draw on Mills' classic "Aggregative Model of Resource Allocation in a Metropolitan Area" (*American Economic Review*, 57(2), May 1967, pp. 197-210).

Assumptions and notation:

1. The urban area has a single predetermined center, called the CBD (Central Business District). Land is a featureless plain, which among other things implies that transportation cost is proportional to distance. Generally this will imply a circular city, except that we will assume that $2\pi-\phi$ radians of the circle are not available, say due to perhaps topographical characteristics, such as an ocean or large lake). So ϕ radians are available for urban use.

2. There are N households, each consisting of one worker. All the urban area's employment is located in our semicircular CBD with a radius of $\underline{u}$ miles. Thus the area of the CBD is $(\phi/2)\underline{u}^2$ square miles.

3. In this first simple model, all available land outside the CBD is used for housing as far away from the center as is necessary to house all N workers. Land required for transportation is, for the moment, assumed proportional to land required for housing, and not considered separately. The total amount of land available for housing within u miles of the city center is $(\phi/2)u^2 - (\phi/2)\underline{u}^2$.

4. ϕ, $\underline{u}$, and N are exogenous.

5. Commuting cost depends only on the straight-line distance between the residence and the city center. It follows that land rent and the intensity of land use also depend on straight-line distance from city center, i.e. u.

6. Housing services are produced with land and capital inputs. The production function is assumed to be of Cobb-Douglas form. Let $X_s(u)$ denote the aggregate output of housing service at u, then:

$$X_S(u) = AL(u)^{\alpha} K(u)^{1-\alpha} \qquad \text{(A.1)}$$

where A and α are constants. A is a scale parameter, and α is distribution parameter, $0< \alpha<1$. As is well known, because the exponents sum to 1, this production function exhibits constant return to scale. K(u) and L(u) represent inputs of capital and land in the production of housing services u miles from the center. A typical house may be worth four times the land it occupies, which suggests that α might be about 0.2.

7. Input and output markets are perfectly competitive. Assume that the market for housing capital is national, so that its rental rate, r, is independent of u and the amount used in urban housing. Land rent, R(u), and the rental rate for housing services, p(u), are endogenous.

8. Assume all households have 'identical' incomes and preferences. Assume households consume the housing services at a cost that includes both rent, and the cost of commuting. Households also consume a unit-priced numeraire good, representing nonhousing goods and services. The household's utility function can be represented by $U(x_1, x_D)$, where x_D is consumption of housing and x_1 is dollars of expenditure on the numeraire good. So the household's budget constraint can be written as:

[32] This appendix was drafted by Yongping Liang. We are also indebted to Kyung-Hwan Kim for comments.

$$p_1 x_1(u) + p(u)x_D(u) + tu = w \quad \text{(A.2)}$$

where p_1 is the price of nonhousing goods (not dependent on u), and p(u) is the price of housing services. t is the cost per 2 miles of commuting. A worker who lives u miles from work must make one round trip commute each day, i.e. travel 2u miles per day, and w is the exogenous income of a households.

9. The demand for housing services per worker living at u, $x_D(u)$, is

$$x_D(u) = Bw^{\theta_1} p(u)^{\theta_2} \quad \text{(A.3)}$$

where B is a scale parameter. θ_1 and θ_2 are income and price elasticities of demand for housing respectively. Aggregate demand for housing at u can then be represented as:

$$X_D(u) = x_D(u)N(u) \quad \text{(A.4)}$$

10. Assume nonurban uses of land command a fixed rent, $\overline{R}$.

Equilibrium conditions:

(1). Households maximize utility, subject to the budget constraint. That is,

$$\begin{aligned} &\max U(x_1, x_D) \\ &s.t. p_1 x_1 + p(u)x_D = m \end{aligned} \quad \text{(A.5)}$$

The first order conditions for maximzing the household's utility imply:

$$\begin{aligned} MU_1 - \lambda p_1 &= 0 \\ MU_2 - \lambda p(u) &= 0 \end{aligned} \quad \text{(A.6)}$$

where MU_1 is the marginal utility of consuming one unit of nonhousing, MU_2 is the marginal utility of consuming one unit of housing service, and λ is the Lagrangian multiplier.

Given a utility level, we have the following equation:

$$MU_1.dx_1 + MU_2.dx_D = 0 \quad \text{(A.7)}$$

Then let Δx_1, Δx_D to be approximation of dx_1 and dx_D. From (A.6) and (A.7) we obtain the marginal rates of substitution between housing and non-housing goods. The optimality condition requires:

$$\frac{\Delta x_D}{\Delta x_1} = -\frac{p_1}{p(u)} \quad \text{(A.8)}$$

(2). Next we consider locational equilibrium. Consider the effect of a small change in u (Δu) on p, x_1 and x_D. From the budget constraint (A.2) we can write

$$p_1 \Delta x_1(u) + \Delta p(u)x_D(u) + p(u)\Delta x_D(u) + t\Delta u = 0 \quad \text{(A.9)}$$

Here Δx_1, Δx_D and Δp are the resulting small changes in x_1 x_D and p. Since the cross product of (Δx_D Δp) is nearly zero, it has been ignored in equation (A.7).
Substituting (A.5) into (A.6) yields

$$\frac{\Delta p(u)}{\Delta u} = -\frac{t}{x_D(u)} \qquad \text{(A.10)}$$

Equation (A.10) is the **locational equilibrium condition**. It is sometimes referred to as "the fundamental equation of urban economics". The intuition behind this equation is important but straightforward: in equilibrium, the benefits of moving towards the suburbs, a reduction in housing rent will be offset by the increase of commuting cost. This equation plays a central role in our discussion within the body of the paper.

The housing demand of a household $x_D(u)$ will satisfy (A.10), which yields

$$p'(u).x_D(u) + t = 0 \qquad \text{(A.11)}$$

where $p'(u)$ is the slope of p(u).

(3) The goal of housing producers is to maximize profit. In equilibrium, firms equate the marginal product of each factor to input rental rates at each u. Differentiating equation (A.1) yields the marginal products of land and capital:

$$MP_{L(U)} = \alpha A L(u)^{\alpha-1} K(u)^{1-\alpha} = \alpha X_S(u)/L(u) \qquad \text{(A.12)}$$

and

$$MP_{K(u)} = (1-\alpha) A L(u)^{\alpha} k(u)^{-\alpha} = (1-\alpha) X_s(u)/K(u) \qquad \text{(A.13)}$$

Therefore, the equations relating factors' marginal products to their rental rates are

$$\frac{\alpha p(u) X_S(u)}{L(u)} = R(u) \qquad \text{(A.14)}$$

and

$$\frac{(1-\alpha) p(u) X_S(u)}{K(u)} = r \qquad \text{(A.15)}$$

(4) Other Equilibrium Conditions

This particular model abstracts from "leapfrog" development, which is not possible in this model's because in equilibrium, no available land can be left unused out to the edge of the urban area. Thus,

$$L(u) = \phi u \qquad \text{(A.16)}$$

In equilibrium, the urban area can extend only as far as households can bid land away from non-urban uses. Thus the distance from the center to the edge of the edge of the urban area is $\bar{u}$, where R($\bar{u}$)= $\bar{R}$.
(A.17)

The land available for housing must house all N workers in the urban area. If N(u) workers live u miles from the center, the total number of workers in the urban area is :

$$\int_{\underline{u}}^{\bar{u}} N(u)du = N \qquad \text{(A.18)}$$

Finally, for housing market to be clear, the aggregate demand for housing service should equal to the aggregate supply of housing service.

$$X_D(u) = X_S(u) \qquad \text{(A.19)}$$

Now the setup of the model is complete.

Solution of the Model

The land rent function is the key to this model. Solving (A.12) and (A.13), we obtain:

$$L(u) = \frac{\alpha p(u) X_S(u)}{R(u)} \quad \text{and} \quad K(u) = \frac{(1-\alpha) p(u) X_S(u)}{r}$$

Substituting these two equations for L(u) and R(u) in equation (A.1) yields

$$p(u) = [A\alpha^{\alpha}(1-\alpha)^{(1-\alpha)}]^{-1} r^{1-\alpha} R(u)^{\alpha} \qquad \text{(A.20)}$$

We can see that p(u) is proportionate to R(u) raised to a power between 0 and 1. This makes sense: housing prices are high wherever land rents are high, but housing prices rise less than proportionately with land rents because when land becomes more expensive, producers substitute capital for land (build more densely). Differentiating (A.20) with respect to u, we obtain

$$p'(u) = A^{-1}\left\{\frac{\alpha r}{1-\alpha}\right\}^{1-\alpha} R(u)^{-(1-\alpha)} R'(u) \qquad \text{(A.21)}$$

Substituting equation (A.3) for $x_D(u)$ in equation (E.4), and substituting equation (A.21) for p'(u), yields

$$E^{-1} R(u)^{\beta-1} R'(u) + t = 0 \qquad \text{(A.22)}$$

where for notational convenience we define E such that

$$E^{-1} = \alpha\beta w^{\theta_1} [A\alpha^{\alpha}(1-\alpha)^{1-\alpha}]^{-(1+\theta_2)} r^{(1-\alpha)(1+\theta_2)}$$

and

$$\beta = \alpha(1+\theta_2)$$

Using the initial condition of equation (E.10), the solution is

$$R(u) = [\bar{R}^{\beta} + \beta t E(\bar{u} - u)]^{1/\beta} \qquad \text{if} \quad \beta \neq 0 \qquad \text{(A.23)}$$

and

$$R(u) = \bar{R} e^{tE(\bar{u}-u)} \qquad \text{if} \quad \beta = 0 \qquad \text{(A.24)}$$

where e is the base of the natural logarithm. (A.23) and (A.24) indicate that, when β is 0, land rent decreases exponentially as u increases. From the definition of β , β =0 when θ_2 = -1, where θ_2 is the price elasticity of demand for housing. There is some uncertainty about this parameter; while a number of studies are consistent with a price elasticity of demand for housing about -1, some of the literature suggests a lower value. For example, Mayo and Malpezzi (1987) estimate θ_2 for several developing countries and obtain values close to -1(though they pointed out that their estimation method is probably biased towards -1). On the other hand, a number of studies on U.S. data, such as Mayo (1981), suggest a lower magnitude for θ_2 , on the order of -0.5. In any event, to the extent θ_2 is reasonably close to -1, the exponential function of equation (A.24) should be a good approximation of urban land rent functions. Of course our paper focuses on population density, not land rents; but intuition suggests that a negative exponential function for land rents may in turn give rise to some similar form for our primary variable.

To demonstrate this, next we move from rent to population density. Equations (A.23) and (A.24) contain the variable $\bar{u}$, representing the radius of the urban area. From equation (E.12), we obtain:

$$N(u) = \frac{X_S(u)}{x_D(u)} \qquad \text{(A.25)}$$

From (E.7) and (E.8), $K(u)$ can be expressed in terms of $L(u)$:

$$K(u) = \frac{1-\alpha}{\alpha r} R(u)L(u) \qquad \text{(A.26)}$$

Substituting this expression in equation (A.1), yields

$$X_S(u) = A\left\{\frac{1-\alpha}{\alpha r}\right\}^{1-\alpha} R(u)^{1-\alpha} L(u) \qquad \text{(A.27)}$$

Substituting Equation (A.26) in equation (A.3), then substituting this result into (A.25) and rearranging terms, it follows that:

$$\frac{N(u)}{L(u)} = ER(u)^{1-\beta} \qquad \text{(A.28)}$$

Equation (A.28) shows how the number of resident workers per square mile varies with u. Except for a multiplicative factor equal to the reciprocal of the labor force participation rate, it is the same as population density. So (A.28) could be referred to as the population density function. When β =0, we can substitute (A.27) into (A.28), and obtain

$$\frac{N(u)}{L(u)} = D(u) = E\overline{R}\, e^{tE(\bar{u}-u)} = D_0 e^{-\gamma u} \qquad \text{(A.29)}$$

where $$D_0 = E\overline{R}e^{tE\bar{u}}$$

and

$$\gamma = tE$$

Here D_0 is the population density at the center of city, i.e. when u=0. γ is the density gradient. This is a key result for our purpose, since it shows that under simplified but reasonable assumptions a negative exponential density function can be considered an optimal outcome.

Furthermore, in addition to theoretical insights about one specific (and restrictive, though important) functional form, we see more clearly why and how the price gradient (which we do not observe for most of our cities) underlies the population density gradient. The gradients are not, of course, strictly proportional; how they move together will depend critically on the elasticity of substitution between land and capital (Kau and Lee 1976a). But they will move together, in well-functioning markets. This is an important reason why urban economists view situations like Moscow, where price gradients decline with distance from the center, while the population density gradient rises, as such an anomaly.

Another important result, although we will not develop it here, is that the border of the city, $\bar{u}$ can be viewed endogenous. Combining (A.25), (A.26) and (A.18), we can solve for $\bar{u}$. See Mills (1972) for details.

Final Comments

Although we have reviewed the Mills/Mills-Hamilton version of the standard urban model in some detail, many other sources can be profitably consulted. Richard Muth's *Cities and Housing* (Chicago: University of Chicago Press, 1969), presents a broadly similar derivation. In contrast to Mills, Muth assumed that there are two kinds of workers in the city: one kind working in the CBD and the other kind employed locally. Muth in effect relaxed the strong assumption that all workers commuted to the center, and in effect assumed that the density of employment is highest in the center. Even with those relaxed assumptions, Muth essentially obtained the same population density function. Interested readers can refer to *Cities and Housing*, page 70-74.

After Muth and Mills, many papers contributed extensions to the models and empirical tests of the population density functions. Among many other extensions these papers investigate the effects of:

- Subcentres, beltlines, or other employment concentrations, in addition to the CBD (White (1976), Yinger (1992), Papageorgiou (1971)).

- Households with multiple workers, some of them work in the CBD, but others elsewhere (Curran, Carlson and Ford (1982), Hotchkiss and White (1993), White (1977).

- Alternative functional forms for utility and (especially) production functions (Kau and Lee (1976, 1977)).

- Models where growth management, or other regulations, or infrastructures availability constrains location (Kim (1993), Son and Kim (1998), Hannah, Kim and Mills (1993)).

- Models where localized amenities (e.g good schools) or disamenities (e.g. high crime, poverty concentration, pollution) affect willingness to pay for some locations (Diamond and Tolley (1982), Follain and Malpezzi (1981), Wu (2002) and especially Mills and Price (1984)).

On the model generally, see Mills (1970, 1967), Turnbull (1995) and Fujita (1989). On the negative exponential function more specifically, see Brueckner (1982), Kim and McDonald (1987), Papageorgiou and Pines (1989), and Anas, Arnott and Small (2000). Brueckner (1982) presents an improved model where housing demand is a function of income net-of-commuting cost, rather than gross income as in this model. We reiterate that models yielding negative exponential land price and density gradients require strong assumptions; as the references in this paragraph elaborate. Anas, Arnott and Small present an alternative derivation of negative exponential density functions, by assuming that marginal commuting cost is proportional to income-earning potential, exponentially decreasing with distance to the CBD. For further discussion of optimal urban form in the context of related models see McDonald (2001) and Wheaton (1998).

Table 1: Basic Data for Metropolitan-Area Analyses

City BERTCITY	Country COUNTRY	Strong Geographic Constraint GEOCON	GDP Per Capita 1993 XGDPPC	Non-Chinese Socialist Economy SOCIALST	Regulation Category REGCAT	City Population CITYPOP	Built Up Area km2 BLTAREA	People Per Hectare Built Up Area DENSITY	Dispersion Index COMPACT	Constant from Density Gradient Regression ALPHA	Estimated Pop Gradient from Density Gradient Regression BETA	Standard Error Constant from Density Gradient Regression SEALPHA	Standard Error Estimated Pop Gradient from Density Gradient Regression SEBETA	R^2 from Density Gradient Regression DENS_R2
Buenos Aires	Argentina	0	7,220	0	0	10,924,711	1,647	66	1.24	5.040	-0.038	0.0421	0.0015	93.1
Brasilia	Brazil	0	2,930	0	2	1,508,725	272	55	3.26	3.060	0.037	0.2003	0.0085	33.8
Curitiba	Brazil	0	2,930	0	2	1,497,049	276	54	1.23	4.220	-0.018	0.1635	0.0169	7.7
Rio de Janeiro	Brazil	1	2,930	0	0	5,569,898	554	101	1.97	5.240	-0.031	0.0639	0.0018	83.4
Abidjan	Cote d'Ivoire	1	630	0	1	1,826,981	127	143	1.81	4.950	-0.169	0.2626	0.0256	2.8
Marseille	France	0	22,490	0	0	800,447	151	53	0.92	5.945	-0.352	0.3166	0.0348	88.7
Paris	France	0	22,490	0	0	7,877,729	893	88	0.89	5.670	-0.097	0.0925	0.0070	90.4
Toulouse	France	0	22,490	0	0	343,952	95	36	0.79	5.211	-0.377	0.1603	0.0285	96.2
Hong Kong	Hong Kong	1	18,060	0	0	5,400,000	147	367	1.94	7.030	-0.113	0.2546	0.0143	69.0
Ahmedabad	India	0	300	0	1	2,865,386	214	134	1.09	5.480	-0.119	0.2543	0.0248	60.6
Bangalore	India	0	300	0	1	3,948,129	191	207	0.99	6.024	-0.130	0.0891	0.0121	91.9
Bombay	India	1	300	0	1	9,825,137	252	389	3.08	6.120	-0.012	0.0965	0.0038	19.2
Hyderabad	India	0	300	0	1	3,043,896	137	223	1.03	5.930	-0.114	0.0971	0.0143	87.5
Jakarta	Indonesia	0	740	0	0	8,222,000	649	127	0.89	5.810	-0.113	0.2161	0.0172	69.5
Seoul	Korea, Rep. of	0	7,660	0	2	10,287,403	319	322	1.33	5.490	0.018	0.1974	0.0193	5.5
Seoul + New Towns	Korea, Rep. of	0	7,660	0	2	13,804,242	489	282	1.53	5.840	-0.028	0.2505	0.0112	15.1
Mexico City	Mexico	0	3,610	0	0	15,566,109	1,624	96	1.06	5.078	-0.034	0.0724	0.0025	78.7
Singapore	Singapore	0	19,850	0	0	2,034,814	189	107	1.12	6.060	-0.195	0.1045	0.0083	96.7
Capetown	South Africa	0	2,980	0	2	2,264,000	701	32	1.98	3.220	0.010	0.0557	0.0024	32.4
Johannesburg	South Africa	0	2,980	0	2	5,415,060	1,027	53	1.91	4.210	-0.043	0.3945	0.0132	17.7
Barcelona	Spain	0	13,590	0	0	2,775,000	163	171	1.32	5.877	-0.100	0.1025	0.0075	89.0
Stockholm	Sweden	0	24,740	0	2	1,426,922	400	36	1.32	4.059	-0.039	0.1455	0.0078	44.3
Bangkok	Thailand	0	2,110	0	0	7,788,042	1,351	58	0.99	5.050	-0.052	0.0843	0.0029	87.3
Tunis	Tunisia	1	1,720	0	2	1,232,508	121	102	1.76	4.970	-0.036	0.1296	0.0108	37.6
London	United Kingdom	0	18,060	0	0	6,626,272	1,062	62	1.03	4.470	-0.024	0.0781	0.0046	50.9
Atlanta	United States	0	24,740	0	0	2,514,199	4,279	6	0.95	2.768	-0.036	0.0318	0.0008	96.9
Chicago	United States	0	24,740	0	0	7,294,248	4,694	16	1.08	3.650	-0.024	0.0977	0.0019	65.6
Houston	United States	0	24,740	0	0	3,796,847	3,515	11	1.09	3.150	-0.035	0.1382	0.0031	63.1
Los Angeles	United States	0	24,740	0	0	9,317,412	4,162	22	0.98	3.800	-0.026	0.0272	0.0009	94.3
New York City	United States	0	24,740	0	0	7,198,101	904	80	1.25	5.500	-0.073	0.0990	0.0039	89.5
New York CMSA	United States	0	24,740	0	0	10,752,915	2,674	40	0.94	4.790	-0.046	0.0946	0.0027	83.4
Portland	United States	0	24,740	0	1	1,230,013	888	14	1.13	2.960	-0.020	0.1236	0.0060	24.4
San Francisco	United States	1	24,740	0	1	3,018,540	1,622	19	1.38	4.210	-0.053	0.0741	0.0031	88.3
San Francisco Bay	United States	1	24,740	0	1	5,098,724	3,234	16	1.72	3.440	-0.015	0.1099	0.0024	33.2
Washington, DC	United States	0	24,740	0	0	2,835,771	1,362	21	1.07	3.920	-0.051	0.0846	0.0048	80.0
Yerivan	Armenia	0	660	1	2	1,249,406	74	168	1.33	5.480	-0.094	0.1424	0.0210	69.1
Sofia	Bulgaria	0	1,140	1	1	1,137,000	120	94	1.07	5.254	-0.140	0.1029	0.0140	91.0
Beijing	China	0	490	0	0	5,333,291	367	145	0.89	6.270	-0.174	0.1245	0.0137	92.6
Guangzhou	China	0	490	0	0	2,021,545	55	365	0.93	7.360	-0.489	0.2431	0.0432	94.8
Shanghai	China	0	490	0	0	7,396,783	258	286	0.78	7.210	-0.247	0.0480	0.0056	99.4
Tianjin	China	0	490	0	0	3,499,718	154	228	0.88	6.340	-0.153	0.1592	0.0201	84.0
Prague	Czech Republic	0	3,500	1	1	1,210,000	171	71	1.22	5.003	-0.113	0.0701	0.0059	95.0
Berlin	Germany	0	23,560	1	1	4,212,381	1,176	36	0.98	4.260	-0.043	0.1510	0.0046	61.7
Budapest	Hungary	0	3,350	1	1	1,937,162	309	63	0.96	5.064	-0.105	0.1698	0.0135	76.2
Riga	Latvia	0	2,010	1	1	759,255	119	64	1.23	4.889	-0.154	0.1992	0.0242	75.6
Cracow	Poland	0	2,260	1	1	730,600	112	65	1.18	5.050	-0.174	0.2307	0.0202	81.3
Warsaw	Poland	0	2,260	1	1	1,639,675	235	70	0.99	5.321	-0.170	0.1785	0.0165	87.0
Moscow	Russia	0	2,340	1	2	8,543,867	470	182	1.39	4.570	0.047	0.1507	0.0120	44.4
St Petersburg	Russia	0	2,340	1	1	4,241,341	351	121	1.24	5.440	-0.084	0.2457	0.0216	47.0
Ljubljana	Slovenia	0	6,490	1	1	247,969	54	46	1.21	4.630	-0.194	0.1628	0.0262	87.0

Table 2: Summary Statistics on Density Gradients and Compactness Measures

			Data by Regulatory Category			Data by Socialist/Nonsocialist	
		All Cities	REGCAT=0 Market-Oriented Planning	REGCAT=1 Mixed Cases	REGCAT=2 Nonmarket Planning	Nonsocialist (and Chinese)	Socialist (Not Chinese)
Density Gradient	Mean	-0.10	-0.13	-0.11	-0.01	-0.10	-0.11
	Std Dev	0.11	0.13	0.06	0.05	0.12	0.07
	Median	-0.08	-0.09	-0.12	-0.02	-0.05	-0.11
	Q3	-0.03	-0.03	-0.07	0.02	-0.03	-0.08
	Q1	-0.15	-0.17	-0.16	-0.04	-0.13	-0.17
	Max	0.05	-0.02	-0.01	0.05	0.04	0.05
		(Moscow)	(London)	(Mumbai)	(Moscow)	(Brasilia)	(Moscow)
	Min	-0.49	-0.49	-0.19	-0.09	-0.49	-0.19
		(Guangzhou)	(Guangzhou)	(Ljubjana)	(Yerivan)	(Guangzhou)	(Ljubjana)
	N	47	22	16	9	36	11
Predicted Density at City Center (From city-specific density gradient estimation)	Mean	263	377	194	107	295	157
	Std Dev	322	432	125	84	362	55
	Median	158	216	157	68	172	156
	Q3	334	428	235	144	378	204
	Q1	68	87	118	58	172	103
	Max	1572	1572	455	242	1572	240
		(Guangzhou)	(Guangzhou)	(Mumbai)	(Seoul)	(Guangzhou)	(Yerivan)
	Min	16	16	19	21	16	71
		(Atlanta)	(Atlanta)	(Portland)	(Brasilia)	(Atlanta)	(Berlin)
	N	47	22	16	9	36	11
R^2 of Density Gradient Regression	Mean	68.6	84.2	67.3	32.5	66.9	74.1
	Std Dev	28.2	13.0	29.1	20.0	30.8	17.1
	Median	80.0	88.9	78.8	33.8	81.7	76.2
	Q3	90.4	94.3	87.9	44.3	91.2	87.0
	Q1	47.0	78.7	53.8	17.7	41.0	61.7
	Max	99.4	99.4	95.0	69.1	99.4	95.0
		(Shanghai)	(Shanghai)	(Prague)	(Yerivan)	(Shanghai)	(Prague)
	Min	2.8	50.9	2.8	5.5	2.8	44.4
		(Abidjan)	(London)	(Abidjan)	(Seoul)	(Abidjan)	(Moscow)
	N	47	22	16	9	36	11
Dispersion Measure	Mean	1.28	1.09	1.29	1.72	1.32	1.16
	Std Dev	0.51	0.31	0.52	0.64	0.57	0.14
	Median	1.12	1.01	1.16	1.39	1.09	1.21
	Q3	1.33	1.12	1.24	1.91	1.36	1.24
	Q1	0.98	0.89	1.01	1.33	1.09	0.99
	Max	3.26	1.97	3.08	3.26	3.26	0.96
		(Brasilia)	(Rio de Janeiro)	(Mumbai)	(Brasilia)	(Brasilia)	(Budapest)
	Min	0.78	0.78	0.96	1.23	0.78	0.96
		(Shanghai)	(Shanghai)	(Budapest)	(Curitiba)	(Shanghai)	(Budapest)
	N	47	22	16	9	36	11

Table 3: Ordered Probit Model, Determinants of Regulatory Category

Dependent Variable:		REGCAT, Regulatory Category		
Number of Observations:		47		
Log Likelihood:		-44.83377661		
Response Profile:	Ordered Value	Total REGCAT	Frequency	
	1	0	22	
	2	1	16	
	3	2	9	

Note: PROC PROBIT models the probability of having a lower (less stringent) value of REGCAT.

Type III Analysis of Effects

Wald Effect	DF	Chi-Square	Pr > ChiSq
social2	1	4.716	0.0299
lgdppc	1	2.5464	0.1105

	Parameter	Standard Error	95% Confidence Limits		Chi-Square	Prob > ChiSq
Intercept	-1.3536	0.9523	-3.22	0.5129	2.02	0.1552
Intercept2	1.0499	0.2259	0.6073	1.4926	21.61	<.0001
Socialist (Not Chinese) Dummy	-0.8384	0.3861	-1.5951	-0.0817	4.72	0.0299
Log GDP Per Capita	0.1799	0.1127	-0.0411	0.4008	2.55	0.1105

Table 4: Regression, Simple Determinants of Density Gradient, by Regulation Category, and Socialist/Nonsocialist

	REGCAT=0 Market-Oriented Planning	REGCAT=1 Mixed Cases	REGCAT=2 Nonmarket Planning	All Metropolitan Areas	Socialist (Not Chinese)	Nonsocialist and Chinese	All Metropolitan Areas
Intercept							
Coefficient	-2.2824	-1.0267	-0.4580	-1.5694	-1.0031	-1.1644	-1.1443
Std Error	0.3228	0.1576	0.2782	0.2003	0.1860	0.3397	0.2564
t-Statistic	-7.07	-6.51	-1.65	-7.84	-5.39	-3.43	-4.46
Prob >|t|	<.0001	<.0001	0.1508	<.0001	0.0007	0.0016	<.0001
Log GDP Per Capita							
Coefficient	0.0404	0.0199	0.0069	0.0282	0.0021	0.0176	0.0163
Std Error	0.0106	0.0055	0.0159	0.0069	0.0126	0.0105	0.0089
t-Statistic	3.82	3.65	0.43	4.08	0.16	1.69	1.84
Prob >|t|	0.0012	0.0029	0.6798	0.0002	0.8739	0.1013	0.0731
Std Coef	0.4887	0.5552	0.1507	0.4153	0.0281	0.2589	0.2403
Log City Population							
Coefficient	0.1177	0.0529	0.0264	0.0780	0.0616	0.0609	0.0603
Std Error	0.0189	0.0097	0.0184	0.0117	0.0121	0.0209	0.0158
t-Statistic	6.22	5.45	1.44	6.67	5.1	2.91	3.82
Prob >|t|	<.0001	0.0001	0.2007	<.0001	0.0009	0.0065	0.0004
Std Coef	0.7955	0.8282	0.4996	0.6946	0.8730	0.4465	0.5365
Mixed Cases: Alternating Moderate and Stringent Regulation Dummy							
Coefficient				0.1160			
Std Error				0.0261			
t-Statistic				4.45			
Prob >|t|				<.0001			
Std Coef				0.5255			
Primarily Stringent Regulation Dummy							
Coefficient				0.1765			
Std Error				0.0279			
t-Statistic				6.33			
Prob >|t|				<.0001			
Std Coef				0.6640			
Socialist (Not Chinese) Dummy							
Coefficient							0.0475
Std Error							0.0350
t-Statistic							1.36
Prob >|t|							0.182
Std Coef							0.1924
Geographic Constraint							
Coefficient							
Std Error							
t-Statistic							
Prob >|t|							
Std Coef							
Observations	22	16	9	47	11	36	47
Adjusted R^2	0.67	0.68	0.07	0.60	0.71	0.19	0.23

Table 5: Regression, Simple Determinants of Predicted Log Central Density, by Regulation Category, and Socialist/Nonsocialist

	REGCAT=0 Market-Oriented Planning	REGCAT=1 Mixed Cases	REGCAT=2 Nonmarket Planning	All Metropolitan Areas	Socialist (Not Chinese)	Nonsocialist and Chinese	All Metropolitan Areas
Intercept							
Coefficient	15.1254	5.6398	-0.2444	9.9780	7.5186	5.0592	5.8578
Std Error	4.3313	2.1556	6.5393	2.5412	1.3736	3.6214	2.7032
t-Statistic	3.49	2.62	-0.04	3.93	5.47	1.4	2.17
Prob >|t|	0.0026	0.0225	0.9716	0.0003	0.0006	0.1720	0.0360
Log GDP Per Capita							
Coefficient	-0.5152	-0.4076	-0.2003	-0.4363	-0.3128	-0.3358	-0.3388
Std Error	0.1415	0.0702	0.3515	0.0873	0.0927	0.1121	0.0942
t-Statistic	-3.64	-5.81	-0.57	-5	-3.37	-3	-3.6
Prob >|t|	0.0019	<.0001	0.5934	<.0001	0.0097	0.0052	0.0008
Std Coef	-0.6480	-0.8162	-0.2292	-0.6247	-0.7689	-0.4628	-0.4851
Log City Population							
Coefficient	-0.3527	0.1758	0.4150	-0.0574	-0.0038	0.1820	0.1308
Std Error	0.2543	0.1353	0.4183	0.1491	0.0893	0.2227	0.1660
t-Statistic	-1.39	1.3	0.99	-0.38	-0.04	0.82	0.79
Prob >|t|	0.1824	0.2185	0.3667	0.7022	0.9668	0.4198	0.4352
Std Coef	-0.2477	0.1980	0.4098	-0.0497	-0.0098	0.1253	0.1133
Mixed Cases: Alternating Moderate and Stringent Regulation							
Coefficient				-0.8615			
Std Error				0.3328			
t-Statistic				-2.59			
Prob >|t|				0.0133			
Std Coef				-0.3800			
Primarily Stringent Regulation							
Coefficient				-1.2856			
Std Error				0.3524			
t-Statistic				-3.65			
Prob >|t|				0.0007			
Std Coef				-0.4709			
Socialist (Not Chinese) Dummy							
Coefficient							-0.0526
Std Error							0.3771
t-Statistic							-0.14
Prob >|t|							0.8897
Std Coef							-0.0207
Geographic Constraint							
Coefficient	1.0633	-0.1834	0.8869	0.4067	NA	0.2738	0.2712
Std Error	0.7479	0.2842	1.0918	0.3771		0.4973	0.4384
t-Statistic	1.42	-0.65	0.81	1.08		0.55	0.62
Prob >|t|	0.1722	0.5308	0.4535	0.2872		0.5858	0.5395
Std Coef	0.2479	-0.0943	0.3394	0.1263		0.0843	0.0842
Observations	22	16	9	47	11	36	47
Adjusted R^2	0.37	0.73	-0.20	0.39	0.49	0.19	0.20

Table 6: Regression, Simple Determinants of Fit of Simple Density Gradient, by Regulation Category, and Socialist/Nonsocialist

	REGCAT=0 Market-Oriented Planning	REGCAT=1 Mixed Cases	REGCAT=2 Nonmarket Planning	All Metropolitan Areas	Socialist (Not Chinese)	Nonsocialist and Chinese	All Metropolitan Areas
Intercept							
Coefficient	176.654	152.783	224.934	215.046	261.693	-14.867	68.004
Std Error	55.251	144.689	146.468	58.500	61.066	101.313	78.967
t-Statistic	3.20	1.06	1.54	3.68	4.29	-0.15	0.86
Prob >|t|	0.005	0.312	0.185	0.001	0.003	0.884	0.394
Log GDP Per Capita							
Coefficient	-2.065	-0.040	-6.722	-1.942	0.511	1.935	1.333
Std Error	1.805	4.711	7.874	2.010	4.121	3.135	2.751
t-Statistic	-1.14	-0.01	-0.85	-0.97	0.12	0.62	0.48
Prob >|t|	0.2676	0.9933	0.4323	0.3396	0.9045	0.5415	0.6306
Std Coef	-0.251	-0.002	-0.334	-0.107	0.028	0.106	0.073
Log City Population							
Coefficient	-4.814	-5.470	-9.300	-7.336	-13.449	4.548	-0.602
Std Error	3.243	9.085	9.369	3.432	3.969	6.229	4.850
t-Statistic	-1.48	-0.60	-0.99	-2.14	-3.39	0.73	-0.12
Prob >|t|	0.1551	0.5583	0.3665	0.0386	0.0095	0.4706	0.9018
Std Coef	-0.327	-0.166	-0.399	-0.245	-0.773	0.125	-0.020
Mixed Cases: Alternating Moderate and Stringent Regulation							
Coefficient				-23.645			
Std Error				7.660			
t-Statistic				-3.09			
Prob >|t|				0.0036			
Std Coef				-0.401			
Primarily Stringent Regulation							
Coefficient				-56.541			
Std Error				8.113			
t-Statistic				-6.97			
Prob >|t|				<.0001			
Std Coef				-0.797			
Socialist (Not Chinese) Dummy							
Coefficient				-56.541			4.170
Std Error				8.113			11.015
t-Statistic				-6.97			0.38
Prob >|t|				<.0001			0.7069
Std Coef				-0.797			0.063
Geographic Constraint							
Coefficient	-7.397	-32.862	-6.823	-17.732	NA	-18.998	-19.429
Std Error	9.541	19.075	24.455	8.681		13.913	12.806
t-Statistic	-0.78	-1.72	-0.28	-2.04		-1.37	-1.52
Prob >|t|	0.4482	0.1106	0.7914	0.0476		0.1816	0.1367
Std Coef	-0.167	-0.455	-0.114	-0.212		-0.233	-0.232
Observations	22	16	9	47	11	36	47
Adjusted R^2	0.04	0.12	-0.14	0.52	0.49	0.00	-0.01

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Table 7: Regression, Simple Determinants of Dispersion Index, by Regulation Category, and Socialist/Nonsocialist

	REGCAT=0 Market-Oriented Planning	REGCAT=1 Mixed Cases	REGCAT=2 Nonmarket Planning	All Metropolitan Areas	Socialist (Not Chinese)	Nonsocialist and Chinese	All Metropolitan Areas
Intercept							
Coefficient	-0.3025	1.2573	4.5122	0.4057	1.4879	1.6510	1.5764
Std Error	0.5429	1.8247	5.4047	1.1440	0.7218	1.6603	1.2398
t-Statistic	-0.56	0.69	0.83	0.35	2.06	0.99	1.27
Prob >|t|	0.5842	0.5039	0.4418	0.7246	0.0732	0.3275	0.2106
Log GDP Per Capita							
Coefficient	0.0454	-0.0794	-0.0597	-0.0078	-0.0700	-0.0307	-0.0333
Std Error	0.0177	0.0594	0.2906	0.0393	0.0487	0.0514	0.0432
t-Statistic	2.56	-1.34	-0.21	-0.20	-1.44	-0.6	-0.77
Prob >|t|	0.0196	0.2064	0.8454	0.8438	0.1884	0.5546	0.4457
Std Coef	0.2308	-0.2389	-0.0927	-0.0238	-0.4577	-0.0904	-0.1014
Log City Population							
Coefficient	0.0597	0.0317	-0.1552	0.0448	0.0160	-0.0139	-0.0075
Std Error	0.0319	0.1146	0.3457	0.0671	0.0469	0.1021	0.0762
t-Statistic	1.87	0.28	-0.45	0.67	0.34	-0.14	-0.10
Prob >|t|	0.0776	0.7865	0.6723	0.5082	0.7413	0.8924	0.9216
Std Coef	0.1692	0.0537	-0.2082	0.0827	0.1088	-0.0205	-0.0139
Mixed Cases: Alternating Moderate and Stringent Regulation							
Coefficient				0.1447			
Std Error				0.1498			
t-Statistic				0.97			
Prob >|t|				0.3396			
Std Coef				0.1360			
Primarily Stringent Regulation							
Coefficient				0.6309			
Std Error				0.1587			
t-Statistic				3.98			
Prob >|t|				0.0003			
Std Coef				0.4922			
Socialist (Not Chinese) Dummy							
Coefficient							-0.0075
Std Error							0.0762
t-Statistic							-0.1
Prob >|t|							0.9216
Std Coef							-0.0361
Geographic Constraint							
Coefficient	0.9279	0.9411	-0.1311	0.6309	NA	0.7919	-0.0075
Std Error	0.0937	0.2406	0.9024	0.1587		0.2280	0.0762
t-Statistic	9.90	3.91	-0.15	3.98		3.47	-0.10
Prob >|t|	<.0001	0.0021	0.8902	0.0003		0.0015	0.9216
Std Coef	0.8739	0.7275	-0.0682	0.4922		0.5210	0.5231
Observations	22	16	9	47	11	36	47
Adjusted R2	0.84	0.56	-0.52	0.44	0.01	0.23	0.23