Urban Structure in a Climate of Terror

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Abstract

Concerns about the impact on cities of terrorism are frequently mentioned both in popular and academic writing. Some have argued, however, that the impact must be relatively small, pointing to the reconstruction of urban systems after major wars, and continued population growth in select cities subject to terrorist attack as evidence. Despite the large amount of commentary and modest amount of theorizing, there has been surprisingly little systematic empirical examination of this question. This paper addresses this deficiency by examining a new and unique data source providing measures of urban land use in a global sample of cities.

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I. Introduction

Urban theorists and urban historians have identified a variety of reasons for the existence of cities. One of the foremost is that cities permit humans to share in the consumption of public goods that are either non-excludable or are most efficiently produced at some minimal scale that is sufficient to accommodate a large number of individuals. Perhaps original amongst these reasons was joint consumption of fortifications and other structures and mechanisms for defense.

Over time, other functions rose to importance, so that the role of the city as a center for trade and commercial interaction between producers and consumers and between different producers seemed paramount. Cities whose fortified walls were once a primary reason for existence found that economic incentives encouraged their destruction so that interaction could more freely flow between residents and those drawn to the expanding urban centers. Market forces and the growth in factor productivity made possible through interaction in urban spaces dictated an evolving urban structure in which the importance of lower transportation costs led to cities that were more open but more vulnerable as well. In usual circumstances, this vulnerability was accepted because the benefits of open cities to the wider economy were clear.

While terrorism has been a component of political struggle and social conflict for millennia (the Zealot group known as the Sicarii attacked and killed individual Roman officials and Jews they regarded as collaborators in an unsuccessful effort to resist Roman occupation), it might be argued that terrorism and its impact on cities has changed in fundamental ways during the past century. Prior to this terrorism mostly consisted of assassinations and attacks on specific target individuals and groups. The increase in destructive power of weapons that can be deployed by relatively small organizations or individuals has enabled them to affect the general climate of a community and the perceived risk of living or working in a city. It has therefore raised concerns about the fundamental viability of open cities and the central role they play in the economy.

Dedicated groups seem capable of creating a "climate of terror" that might have a significant impact on the economic viability of cities or at least the internal structure of urban areas. Thus after the September 11 attacks in New York City, several writers predicted or urged a decline in the importance of large urban centers as a result of the terrorist attacks. Thus Stephen Ambrose, writing in the *Wall*

Street Journal urged adoption of a "defensive posture" made necessary by terrorism and made possible by improved electronic communication that would allow us to dispense with dense concentrations such as lower Manhattan. Similarly Admiral William Crowe advised companies to decentralize away from dense urban centers towards low-profile locations. None of these recommendations were based on careful economic analysis, but economic concerns about the impacts of terrorism and the appropriate response continue, most recently following the July 2005 bombings in London. Thus Seager, More and Long writing in the *Guardian* quote a CEBR economist as estimating that the bombings will reduce output in London by 0.6% and national output by 0.1%. This impact would be even greater if the July attacks were followed by a sustained terrorist campaign. Other experts quoted expect little or no impact.

This paper seeks to address the question in a more systematic fashion. We use a new source of data on urban structure based on a global sample of cities located around the world. These data provide measures of urban land use in each city and different points in time. After reviewing the recent theoretical and empirical literature addressing the impact of terrorism on urban structure, and providing a description of the data used, we will provide some preliminary estimates of the impact of terrorism (or the "climate of terror") on urban structure. Following these estimates we will discuss tentative conclusions and directions for future research.

II. Theory

Despite the potential importance of the topic, there have been surprisingly few recent theoretical expositions put forward to guide our thinking, assist in the design of policies, or provide a framework for empirical analysis of the impacts of terrorism on urban form. One relatively complete analysis is provided by Rossi-Hansberg (2004), based on the dynamic models of Lucas (2001) and Lucas and Rossi-Hansberg (2002). These models concentrate on the positive externality that arises through increasing factor productivity when firms locate together in cities.

A second approach is provided by Harrigan and Martin (2002), whose analysis is based on a new economic geography model of the type used by Krugman (1991). This model concentrates on the risk of wage variability arising from shocks to individual firms, and the benefits to workers that results from locating where a large number of firms exist to smooth these fluctuations.

In addition to these theoretical approaches to the impact of terror, there is a well-defined and widely used framework for understanding the broad determinants of urban structure and urban expansion that is relevant for empirical analysis. We first review these general (non-terror related) determinants of urban structure, along with the hypotheses that would be suggested by this theory. Following this we will briefly review the Rossi-Hansberg and Harrigan and Martin analyses, identifying the suggested hypotheses concerning the effects of terrorism.

a. Determinants of urban structure and expansion

The expansion of urban areas is determined by the interaction of three broad types of phenomena: the physical constraints of geography and environment, the demand for land by the households and firms who inhabit the city, and the policy constraints that govern land use and spatial interactions in the city. The most useful models for informing public action on the management of urban expansion will be those models that incorporate each of these factors in some way, and that evaluate the relative contribution of each factor to urban expansion.

Unfortunately, we do not have the same level of theoretical understanding of the effects of the physical, economic, and policy environments on urban expansion. Very little work has been done on the effect of climate, ecological biomes or topography on the form of cities. And while some models of expected policy effects do exist, for the most part such analyses have been limited to an *ex post* evaluation of the extent to which a particular type of policy appears to have been effective, *ceteris paribus*, in influencing urban structure. This type of analysis remains a potentially useful exercise because it does provide important information to policy makers about where successes and failures have occurred.

The economic model of urban spatial structure is relatively well developed, though not necessarily more accurate in predicting actual outcomes. Several authors[1] provide clear expositions of the by-now familiar theory, which proceed briefly as follows: We consider an urban area with exogenously given population of L households having income y and preferences that are represented by a common

1 See, *inter alia*, Mills, E., 1972, *Studies in the Structure of the Urban Economy,* Baltimore: Johns Hopkins University Press; Henderson, J. V., 1977, *Economic Theory and the Cities,* New York: Academic Press; or Brueckner, J., 1987, "The Structure of Urban Equilibria", Chapter 20 in *Handbook of Regional and Urban Economics*, E. Mills, ed., New York: Elsevier. We use their notation and basic approach in our discussion.

quasi-concave utility function $v(c,q)$ that depends on consumption of a composite good c and housing q. Each household has a worker who is employed in the city center and must commute to the center to earn income. The household's annual transportation costs for this commute are $t \cdot x$ if it resides in a house x units of distance from the center.

Equilibrium requires that a common utility level u be achieved by a household at any location within the built-up area of the city, so that the price per square meter of housing will vary with distance x. Households will allocate their income to select the most preferred combination of the composite good and housing, so that in equilibrium we must have:

$$\max_{q} v\left(y - t \cdot x - q \cdot p(x), q\right) = u \qquad (1)$$

for all households.

Housing producers combine inputs of capital N and land l using a concave constant- returns production function $H(N, l)$ to produce square meters of housing. Housing production therefore exhibits diminishing marginal productivity of both capital and land. Constant returns to scale and free entry of housing producers is sufficient to determine an equilibrium land rent function $r(x)$ and a capital-land ratio (building density) $S(x)$ that depend upon distance x from the city center and satisfy:

$$\frac{\partial r(x)}{\partial x} < 0 \quad and \quad \frac{\partial S(x)}{\partial x}, \qquad (2)$$

so that both land value and building density decline with distance from the city center. Combining the solution for building density $S(x)$ with the housing $q(x)$ demanded by a household at distance x provides a solution for the population density $D(x,t,y,u)$ at distance x, given the exogenous levels of transport costs and income and the achieved utility level u.

The maximum extent of the urban area $\bar{x}$ depends on the ability of housing producers to bid land away from its alternative uses. Let r_A represent the alternative use value of land (often explained heuristically as the market rent of land in agricultural use). The maximum extent of the urban area is then given implicitly by:

$$r\left(\bar{x}\right) = r_A \qquad (3)$$

Finally, equilibrium requires that all households be accommodated in the urban area. If θ represents the share of land available for development at each distance, this is ensured by the following equilibrium condition:

$$\int_0^{\bar{x}} 2\pi \cdot \theta \cdot x \cdot D(x,t,y,u)\,dx = L\,. \qquad (4)$$

This basic theory provides an endogenous solution for the maximum extent of urban land use, and relates this solution to several observable characteristics of the urban area. In particular, we can derive a number of comparative static results from this model that provide clear, testable hypotheses for our analysis.

Hypotheses concerning urban spatial structure derived from the standard economic model

No.	Comparative Static Result	Description of prediction and hypothesis
1.	$\frac{\partial \bar{x}}{\partial L} > 0$	An increase in population will increase urban extent and urban expansion.
2.	$\frac{\partial \bar{x}}{\partial y} > 0$	An increase in household income will increase urban extent and urban expansion.
3.	$\frac{\partial \bar{x}}{\partial t} < 0$	An increase in transportation costs will reduce urban extent and limit urban expansion.
4.	$\frac{\partial \bar{x}}{\partial r_A} < 0$	An increase in the opportunity cost of non-urban land will reduce urban extent and limit urban expansion.
5.	$\frac{\partial \bar{x}}{\partial H_l} > 0$	An increase in the marginal productivity of land in housing production will increase urban extent and urban expansion.
6.	$\frac{\partial \bar{x}}{\partial \theta} > 0$	An increase in the share of land available for housing development will increase urban extent and urban expansion.
7.	$\frac{\partial \bar{x}}{\partial f_l} > 0$	An increase in marginal productivity of land in production of the export good will increase urban extent and urban expansion.
8.	$\frac{\partial \bar{x}}{\partial w} > 0$	An increase in the demand for (world price of) the export good will increase urban extent and urban expansion.

The model discussed has housing producers (and agricultural producers outside of the urban area whose demand for land generates the rents r_A) as the only direct consumers of land. It is easy to generalize this model so that firms who trade in the city center are included as well, combining inputs of capital and land according to $f(N,l)$ to produce an export good for external markets sold at price w. These firms provide a separate commercial demand for land. Assuming that the cost (in terms of reduced profitability) of moving production away from the urban center is greater than the aggregate commuting cost of the households who would occupy an equal amount of land, the firms will be more centrally located than the households. In this case we can derive two additional hypotheses concerning the impact of changes in the productivity of land in export-good production, and the impact of an increase in the world demand for the export good. All of the hypotheses derived from this model of urban spatial structure are summarized and described in the table above.

b. Impacts of terrorism on urban structure

The models that serve as the foundation for the analysis in Harrigan and Martin (2002) provide less detail concerning urban structure than the traditional urban model presented above. They use both a labor pooling and core-periphery model to examine the impact of terrorist attacks on urban centers. In the labor pooling model, an increase in the probability of an attack in a particular location can introduce risk of wage variability that, because it affects all firms in the attacked region, can eliminate the advantages to workers from the labor pooling.

In both of these approaches it is important that the threat of attack be ongoing, and in this sense terrorism is fundamentally different from the impacts of those types of conflict or warfare in which armistice, victory or surrender provides an agreed and understood end to hostilities. For this reason, the observations of Davis and Weinstein (2002) concerning the recovery of the Japanese urban system to relative sizes similar to pre-war levels despite significant differences in the damage inflicted on individual cities may not be relevant for understanding the impact of terrorism. An important factor in terrorism is that the threat is persistent, and that the probability of attack may be positively related to density or the magnitude of investment.

In both the labor pooling model and the core-periphery model Harrigan and Martin find that a one-time attack will have no long run impact on the equilibrium allocation of production and capital between locations. An ongoing threat, however, acts like a tax on particular locations. The effects are particularly striking within the core-periphery model, where there may be multiple equilibria. In this case an ongoing risk of terrorism causes workers to leave the larger city and reduces the incentive for agglomeration of firms. Eventually a locally stable equilibrium is reached with equal distribution of production at all locations. Because this equilibrium is stable it persists even if the threat of terrorism is removed. Thus creation of a climate of terror leads to reduced size for the larger urban area.

The model presented in Rossi-Hansberg (2004) is more complex, providing both additional detail about the internal structure of urban areas and how they respond to an ongoing threat of terrorism, and also some policy recommendations capable of improving the economic outcome for urban residents. The cost of this complexity is some reduced specificity in the types of outcomes likely to emerge. A series of simulations are presented that indicate great sensitivity to transport costs and to the nature of interactions between nearby producers.

The interactions between firms are a central feature of the analysis and provide the basis for policy to improve the efficiency of the equilibrium outcome. A firm's productivity is positively affected when it locates near other productive firms. This means that firms have some incentive to cluster together, although because the land is owned by absentee landlords they cannot capitalize the benefits they create and so in equilibrium there "too little" clustering of firms. Policies that provide a subsidy for urban location can improve the outcome.

Rossi-Hansberg introduces the threat of terrorism by assuming that there is a risk of capital destruction at each location where the density of investment exceeds a certain level. This further reduces the incentive to cluster together, robbing the urban area of some of its ability to enhance factor productivity through agglomeration. Applying the same subsidy scheme used in the absence of terrorism can still improve the outcome, and if the policy maker has better knowledge about the probability of a terrorist attack than individual agents in the economy, there is scope for further adjustment in the subsidy policy to improve economic outcomes.

Unlike Harrigan and Martin, Rossi-Hansberg's model has a fixed population in a single urban center. He proves several propositions that are relevant for our context:

1. With no adjustment costs, the steady state capital level in residential areas is higher before than after a shock that destroys part of the capital in the city (a terrorist attack reduces investment in residential areas in a steady state).
2. With no adjustment costs, the range of steady state capital levels across locations within the city decreases after a shock that destroys part of the capital in the city (a terrorist attack makes the capital density gradient flatter).

3. In a model with adjustment costs, destruction of an area reduces productivity in nearby areas of the city and leads to a slower recovery of the destroyed area.

These provide the basis for additional hypotheses to be examined and tested empirically. Letting *T* be some measure of the level of terrorist activity, we expect:

No.	Comparative Static Result	Description of prediction and hypothesis
9.	$\frac{\partial \bar{x}}{\partial T} < 0$	An increase in the climate of terror will decrease urban expansion.
10.	$\frac{\partial^2 q}{\partial x \partial T} < 0$	An increase in the climate of terror will decrease the rate at which housing (residential capital) varies with respect to location.

In the analysis below we are able to directly test hypothesis (9), and will eventually be able to examine (10) although the results are not presented in this paper.

III. Data

The data used for the empirical analysis combine information on urban land cover in a global sample of cities, population for jurisdictional areas within each city, measures of income and relevant economic variables for the country in which each city is located, and measures of the number of terrorist incidents in each country. Use of national (rather than local) level variables for economic variables and the level of terrorism serve two important functions. First, they permit us to cover a much larger number of cities including those in countries where local level income, transport cost, or land value data are not available. Second, using these data allows us to estimate the impact of a “climate” of terror more extensive than the direct experience of terrorism within the city where investment and urban expansion decisions are being made. For example, recent experience in the United States has shown that cities very far removed from New York and Washington, including cities so much smaller and remote that they would presumably be exposed to very little risk of terrorist attack, have nevertheless devoted considerable effort towards “preparing” for a terrorist attack. Presumably these preparations signal a level of concern that could also distort investment activity and as a result affect the level of urban development and urban land cover.

Our data are collected for a sample of 120 cities randomly selected from a larger random sample constructed by UN Habitat for data collection in connection with their Urban Observatory program.

The larger sample has been constructed to be representative of the global urban population in cities having population over 100,000 persons. Our sample of 120 cities was stratified so that it is representative of the global urban population by region, by income class of country, and by size or metro areas. The map below shows the global distribution of the sample and lists the entire sample of cities.

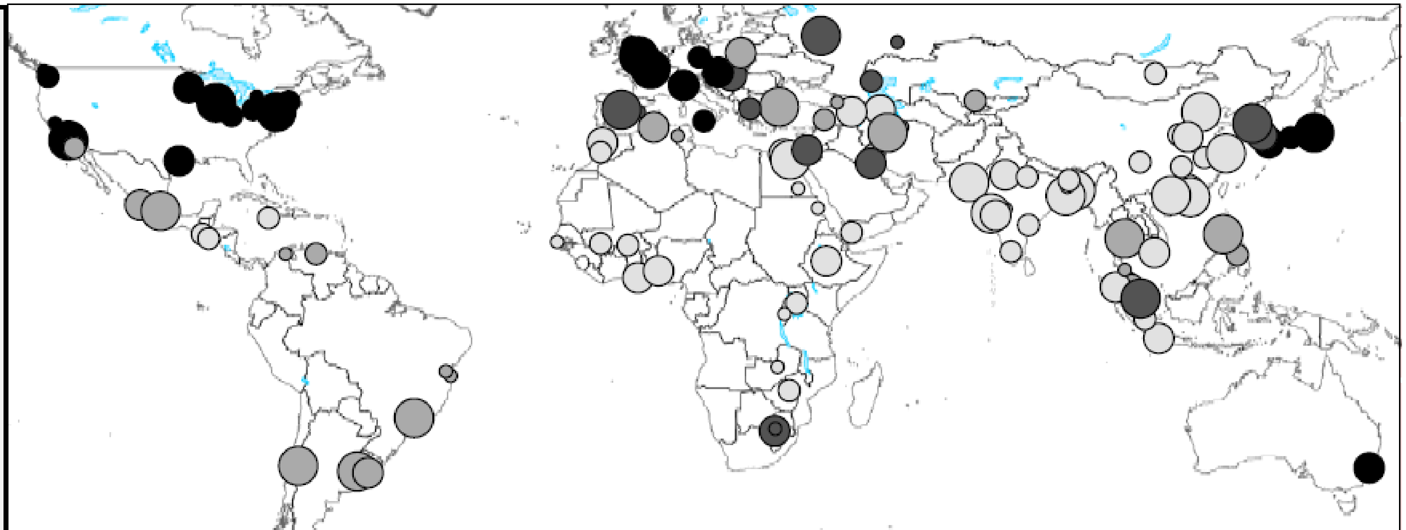
City Sample by Size and Income

93,000 - 500,000
- $610 - $3600
- $3601 - $8500
- $8501 - $18000
- $18001 - $30000

500,000 - 1.5 mil
- $610 - $3600
- $3601 - $8500
- $8501 - $18000
- $18001 - $30000

1.5 mil- 4 mil
- $610 - $3600
- $3601 - $8500
- $8501 - $18000
- $18001 - $30000

4 mil - 32 mil
- $610 - $3600
- $3601 - $8500
- $8501 - $18000
- $18001 - $30000



Eastern Asia	**Europe, Cont.**	**Northern Africa**	**South and Central Asia**	**Southeast Asia, Cont.**
Shanghai, China	Thessaloniki, Greece	Cairo, Egypt	Mumbai, India	Cebu, Philippines
Beijing, China	Palermo, Italy	Alexandria, Egypt	Kolkota, India	Ipoh, Malaysia
Seoul, Korea	Sheffield, UK	Casablanca, Morocco	Dhaka, Bangladesh	Bacolod, Philippines
Hong Kong, China	Astrakhan, Russia	Algiers, Algeria	Teheran, Iran	Songkhla, Thailand
Guangzhou, China	Leipzig, Germany	Marrakech, Morocco	Hyderabad, India	**Sub-Saharan Africa**
Pusan, Korea	Le Mans, France	Port Sudan, Sudan	Pune, India	Addis Ababa, Ethiopia
Zhengzhou, China	Castellon , Spain	Aswan, Egypt	Kanpur, India	Johannesburg, South Africa
Yulin, China	Oktyabrsky, Russia	Tébessa, Algeria	Jaipur, India	Accra, Ghana
Yiyang, China	**Latin America & Caribbean**	**Other Developed**	Coimbatore, India	Harare, Zimbabwe
Leshan, China	Mexico City, Mexico	Tokyo, Japan	Vijayawada, India	Ibadan, Nigeria
Ulan Bator, Mongolia	Sao Paolo, Brazil	Los Angeles, USA	Rajshahi, Bangladesh	Pretoria, South Africa
Changzhi, China	Buenos Aires, Argentina	Chicago, USA	Ahvaz, Iran	Kampala, Uganda
Anqing, China	Santiago, Chile	Philadelphia, USA	Shimkent, Kazakhstan	Bamako, Mali
Ansan, Korea	Guadalajara, Mexico	Houston, USA	Jalna, India	Ouagadougou, Burkina Faso
Chinju, China	Guatemala City, Guatemala	Sydney, Australia	Gorgan, Iran	Ndola, Zambia
Chonan, Korea	Caracas, Venezuela	Minneapolis, USA	Saidpur, Bangladesh	Banjul, Gambia
Europe	San Salvador, El Salvador	Pittsburgh, USA	**Southeast Asia**	Kigali, Rwanda
Paris, France	Montevideo, Uruguay	Cincinnati, USA	Manila, Philippines	**Western Asia**
Moscow, Russia	Tijuana, Mexico	Fukuoka, Japan	Bangkok, Thailand	Istanbul, Turkey
London, UK	Kingston, Jamaica	Tacoma, USA	Ho Chi Minh City, Vietnam	Tel Aviv, Israel
Milan, Italy	Ribeirão Preto, Brazil	Springfield, USA	Singapore, Singapore	Baku, Azerbaijan
Madrid, Spain	Valledupar, Colombia	Modesto, USA	Bandung, Indonesia	Sana'a, Yemen
Warsaw, Poland	Guarujá, Brazil	St. Catharine's, Canada	Medan, Indonesia	Yerevan, Armenia
Vienna, Austria	Ilhéus, Brazil	Victoria, Canada	Palembang, Indonesia	Kuwait City, Kuwait
Budapest, Hungary	Jequié, Brazil	Akashi, Japan	Kuala Lumpur, Malaysia	Malatya, Turkey
				Zugdidi, Georgia

Sources:
World Development Indicators
National Censuses and
Author's Calculations

For each of the cities in our sample, we obtained Landsat thematic mapper satellite images for dates that are near the national census dates and for which cloud-free images are available. Images were obtained for two time periods: approximately 1990 and approximately 2000. The images provide data on reflected light intensity in 7 spectral bands (3 visual and 4 infrared). These data are used to classify each point as urban (covered with impervious built structures or surfaces), water, or non-urban (everything else) in each time period.

Commercial products are available that provide this information, but the usual practice is to "fill in" small interior open spaces and classify them as urban. Our approach has been to regard such spaces as non-urban so that eventually we can distinguish between new capital investment and building at the urban periphery and "infill" development building inside the built up area. The contrast can be seen immediately in a side-by-side comparison of an image showing estimated urban land cover from one of these commercial products and the estimate obtained for analysis used in this paper. An example showing Addis Ababa, Ethiopia is available online at [*editor: please insert appropriate URL here*]. Such a comparison shows solid urban land cover within the boundaries of the city for the commercial product, versus a more mottled pattern of urban land cover in the data used here, reflecting the presence of open spaces within the urban areas that provide the potential for infill development. Further details concerning the remote sensing data and classification procedure are provided in Angel, Sheppard and Civco (2005).

The remote sensing data provide us with measures of total urban land use at two points in time. These measures are then matched with population data for jurisdictional boundaries in each area, obtained from the Center for International Earth Science Information Network's Global Rural-Urban Mapping Project. Using growth rates observed for each jurisdiction during 1980 through 2000 we interpolate to obtain population estimates for the dates of each image. Similarly, we interpolate national per capita GDP to provide an estimate of income levels in each city at the date of the image. Data on biome type, availability of shallow groundwater aquifer, air transport links, national share of global IP address space, and the value of agricultural land (approximated by agricultural output per hectare) were obtained from World Development Indicators or from sources described more fully in Angel, Sheppard and Civco (2005).

Our data on terrorism and terrorist incidents come from the Memorial Institute for the Prevention of Terrorism Knowledgebase, which combines data from the RAND Terrorism Chronology and RAND-MIPT Terrorism Incident databases. These provide data from 1968 to the present on a variety of terrorist incidents, numbers of persons injured and numbers of fatalities associated with each incident categorized by country. The data are collected from open, publicly available sources, with information collected in an effort to capture all terrorist acts. They define terrorism as " … violence, or the threat of violence, calculated to create an atmosphere of fear and alarm. These acts are designed to coerce others into actions they would not otherwise undertake, or refrain from actions they desired to take."

An argument could be made for seeking out (or collecting) data that would give information on the number of terrorist incidents in the individual cities themselves, and using this as an independent variable in the model. In addition to posing greater problems of endogeneity, using city specific measures may significantly understate the "climate of terror" or "atmosphere of fear and alarm" that seems intrinsic to the problem of terrorism. Recent experience in both the US and UK, for example, suggests that individuals and organizations in cities far removed (and less significant) than the cities actually attacked still behave *as if* they were confronted by a serious risk of attack. Including the combined experience of the entire country may provide a better representation. We sum all of the terrorist incidents (or injuries or fatalities) that have occurred in the decade preceding the date of the image and associate that with the measure of urban structure, population, income, etc.

Variables Used in Models

Variable	Mean	σ	Min	Max
Total urban land cover	402.805	635.114	8.92	4268.00
Population	3363025.000	4459765.000	93041	27200000
Income	9914.078	9916.698	609.88	35354.00
Terrorist incidents	52.608	88.276	1.00	622.00
Air linkages	108.208	133.390	0.00	659.00
IP Share	0.058	0.163	0.00	0.59
Agricultural land value	3347.646	12569.780	68.84	150542.90
Fuel cost	0.620	0.357	0.02	1.56
Wage per KM	0.245	0.301	0.01	1.73
East Asia	0.133	0.341	0	1
Europe	0.133	0.341	0	1
Latin America	0.133	0.341	0	1
North Africa	0.067	0.250	0	1
Other Developed	0.133	0.341	0	1
South Central Asia	0.133	0.341	0	1
Southeast Asia	0.100	0.301	0	1
Sub-Saharan Africa	0.100	0.301	0	1
West Asia	0.067	0.250	0	1

IV. Impact Estimates

The data assembled allow us to test several of the hypotheses related to urban structure and urban extent identified in section II above. Specifically, we use the cross-section data to estimate models to provide tests of hypotheses 1, 2, 4, 5, 7, 8 and 9. The table below presents our main model estimates (models 1, 2 and 3) as well as a series of intermediate specifications that provide some insights into the robustness of parameter estimates to various specifications of the model.

All of the models relate the logarithm of total urban cover (in either T_1 or T_2) with the logarithm of the variables (or value of dichotomous variables). There are three possible measures of terrorism that are available for use: the number of terrorist incidents, the number of injured persons in all terrorist incidents, and the number of fatalities. Each of these measures was tested using our data. Qualitatively, all performed similarly. The greater number of incidents and the much greater cross-sectional variation provided more precise estimates of the impact of incidents than of the impact of injuries or fatalities. The results reported below all use the number of incidents during the decade prior to the measurement of urban land cover as the measure of terrorism

We also investigated using each of these measures on a per-capita basis (number of incidents per person). While this might serve as a better measure of "risk" to an individual, it is interesting to note that the per-capita versions of these variables do not perform as well (either in terms of the precision of the parameter estimates or the fit of the overall model). In part, this is likely due to the logarithmic functional form and the fact that population is separately entered into the model. It may also be attributed to the particular way in which terrorism affects urban structure. These acts create a "climate of terror" that is translated into estimates of personal and commercial risk through interaction and social-psychological processes. This type of "climate" – just like other environmental factors – has the nature of a public good and is subject to little or no congestion. It is therefore makes sense that the appropriate way to measure the impact is to measure the total contribution towards creating this climate of terror rather than the per capita contribution.

Models 3 through 9 are standard OLS estimates. Model 9 provides the simplest possible model, expressing total urban land cover as a function of population, income and the level of terrorism. Model 8 adds controls for regions of the world, having as datum the "other developed countries" region that includes the U.S., Canada, Japan, Australia and New Zealand. Models 7 and 6 add controls for the extent to which the city is linked to the global economy and hence may experience an effective increase in the world price for its export good or an increase in the productivity of land for production of the export good. This linkage is measured by using the number of air linkages (the number of direct flights to airports out of the country from the municipal airport) and the share of global IP addresses assigned to internet users within the country. Model 5 adds a control for the value of agricultural land surrounding the city (measured by the value added in agriculture per hectare of arable land). Model 4 adds a control for the productivity of land in providing housing services by having an indicator for the presence of shallow aquifers that permit the easy construction of wells for water and permit house building that is unbound from the constraints of water supply infrastructure. Model 3 adds a control for the impact of travel costs as measured by the price (in PPP constant dollars) of refined motor fuel.

A central concern that confronts any attempt to estimate the determinants of urban land use using cross-section data is the problem of endogeneity. Variables such as population, income, the number of air linkages, and terrorist incidents may all have an impact on total urban land use, but they will also in turn be affected by the level of urban land cover. If a city has, for some random reason, a large positive shock to its total stock of build urban space, the space may serve to attract new residents, to create new income-earning opportunities, to justify improved air service, and to provide attractive targets to terrorists. To the extent that this is true, there is correlation between the "independent" variables and the regression error, resulting in biased and inconsistent estimates.

Models 1 and 2 address this concern by providing instrumental variables estimates of the model, taking all the model variables except the region indicators used to correct for fixed effects as endogenous. In addition to the included region instruments, other instruments used are latitude and longitude, the slope of the land, and the biome (an indicator of the type of flora and fauna that inhabit the natural surroundings where the city is located).

Model Estimates: urban structure and the impact of terrorism

Total Urban Land Cover Model Number	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Population	0.5923***	0.4731***	0.7734***	0.7762***	0.774***	0.7656***	0.8135***	0.7926***	0.7677***
σ	0.093	0.114	0.063	0.065	0.064	0.065	0.032	0.036	0.04
Income	0.6737**	0.5114***	0.5134***	0.4959***	0.4957***	0.5124***	0.5161***	0.3447***	0.4964***
σ	0.277	0.071	0.065	0.068	0.068	0.069	0.069	0.078	0.057
Terrorism	**-0.2251*** **	**-0.1861*** **	**-0.0317**	**-0.0383**	**-0.0453**	**-0.0249**	**-0.0291**	**-0.0445**	**-0.0679** **
σ	**0.058**	**0.053**	**0.028**	**0.027**	**0.027**	**0.026**	**0.025**	**0.029**	**0.03**
Air Linkages	0.0947	0.1147*	-0.2094***	-0.2202***	-0.217***	-0.2446***	-0.2417***		
σ	0.064	0.063	0.038	0.038	0.037	0.038	0.04		
IP Share	1.6991***	1.7226***	0.0335	0.0296	0.0273	0.038			
σ	0.508	0.459	0.045	0.045	0.045	0.046			
Agricultural Land Value	-0.235***	-0.1515***	1.1378***	1.3384***	1.3505***				
σ	0.061	0.035	0.349	0.336	0.356				
Fuel Cost		-0.0199	-0.1204*						
σ		0.063	0.067						
Wage Cost per KM	-0.164								
σ	0.246								
Shallow Ground Water			0.119	0.1195					
σ			0.128	0.129					
			Regional Fixed Effects						
East Asia			0.1443	0.1594	0.164	-0.0995	-0.1904	-0.7207***	
σ			0.222	0.229	0.235	0.247	0.224	0.263	
Europe			0.028	0.0123	-0.0053	-0.3974***	-0.4031***	-0.4757**	
σ			0.15	0.148	0.156	0.136	0.135	0.183	
Latin America			-0.0706	-0.0397	-0.0233	-0.3804**	-0.3941**	-0.6743***	
σ			0.186	0.186	0.196	0.175	0.19	0.22	
North Africa			-0.0848	-0.0104	-0.0435	-0.4021	-0.4056	-0.8175**	
σ			0.301	0.286	0.286	0.282	0.293	0.315	
South Central Asia			-0.2306	-0.19	-0.2225	-0.5781**	-0.6457***	-0.9489***	
σ			0.229	0.247	0.253	0.246	0.235	0.299	
Southeast Asia			-0.1234	-0.0579	-0.0654	-0.3961	-0.4382*	-0.9505***	
σ			0.23	0.235	0.247	0.244	0.247	0.274	
Sub-Saharan Africa			0.3375	0.3161	0.3446	-0.0073	0.0006	-0.2439	
σ			0.206	0.217	0.223	0.208	0.212	0.284	
West Asia			0.42*	0.4532**	0.4194*	0.0678	0.0539	-0.402*	
σ			0.216	0.227	0.225	0.222	0.228	0.239	

Total Urban Land Cover Model Number	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Constant	-7.588**	-4.9061***	-9.0663***	-8.7964***	-8.7244***	-8.2869***	-8.8601***	-8.4225***	-9.8926***
σ	3.001	1.571	1.033	1.03	1.011	1	0.736	0.908	0.792
Observations	198	240	240	240	240	240	240	240	240
F	44.84	36.82	72.81	75.42	84.02	77.52	83.27	58.24	155.02
R^2	0.7652	0.7586	0.8461	0.8429	0.8417	0.8362	0.8346	0.8005	0.7536
Anderson LR	23.331	21.999							
Anderson LR P-value	0.1052	0.232							
Hansen J	11.712	12.791							
Hansen J P-value	0.7007	0.7501							
Cragg-Donald	24.76	23.04							
Cragg-Donald P-value	0.0741	0.1891							

Note: All models estimated with robust standard errors, clustered by city. Levels of significance are indicated by *, with *** implying significance at the 1% level or better, ** indicating significance at the 5% level, and * indicating significance at the 10% level.

The data we use and the models we estimate are sufficient to provide direct tests of hypotheses 1, 2, 3, 4 and 9, and (subject to interpretation) tests of hypotheses 5, 7 and 8. Analysis of hypothesis 6, concerning the impacts of transport costs and the share of land available for residential development respectively, is not discussed here but is dealt with in Angel, Sheppard and Civco (2005). Testing of hypothesis 10 (that terrorism flattens the density gradient) is not discussed here but will be dealt with in a separate paper. We will address this issue further in the following section.

Regarding the confirmation of the implications of the models discussed above, the first thing to note is that the models perform very well. A relatively large share of the cross-sectional variance in urban expansion and the amount of land in urban use is explained by these models. Furthermore, the parameters are estimated with high precision. Most of the estimates are significant at the 10% level or better, and in the more complete specifications all of the key variables are correctly signed and comfortably significant.

Every model estimated has correctly signed and precisely estimated impacts for population and income. There is unambiguous support for hypotheses 1 and 2. Every model that includes the value of agricultural land provides a parameter estimate that is also significant and signed as would be predicted by hypothesis 4.

Hypothesis 5 asserts that an increase in the productivity of land in production of housing should increase the amount of land in urban use. The impact of available groundwater provides an indirect or partial test of this assertion, since in settings with shallow aquifers housing can be constructed without the added cost of providing piped water. A result of this nature has been found in the North American case by Burchfeld, Overman, Puga and Turner (2003). Our analysis provides only partial support for this, with parameter values in models 3 and 4 being qualitatively as expected by not statistically significant.

Hypotheses 7 and 8 relate to the productivity of land in producing the export good in the city, and the impact of world demand for the output of producers in the city. The “connectedness” of producers in the city (via air transport and the Internet) can be interpreted as indicative of both of these. The impact of both of these is correctly signed in all models where they are included. Interestingly, in the OLS models the impact of air linkages is statistically significant, while the impact of IP share is often not.

In models 1 and 2 where endogeneity is accounted for using IV estimates, the IP Share greatly increases in importance and is significant, while the air linkages, although still of the expected sign, are estimated with less precision.

What about our central question: the impact of terrorism on urban structure? The empirical analysis provides clear evidence – particularly in models 1 and 2 – that terrorism reduces urban land use. This almost certainly implies reduced investment in residential capital and very likely implies reduced investment in productive capital. This is consistent with hypothesis 9, and provides support for the models discussed in section II.

It is interesting to note that models 1 and 2, estimated using instrumental variables, shows a much larger impact of terrorism than the other models. This suggests some endogeneity in the level of terrorism to which a city is subject, which is not at all surprising. Correcting for this to the extent allowed by our instruments reveals a startling fact: doubling the amount of terrorist incidents is associated, ceteris paribus, with an 18 to 22 percent decline in urban land cover. Apparently a decade of terrorist attacks is a powerful deterrent to urban investment.

It should be noted that this impact is after adjusting for population and income. In that sense the analysis we provide is most directly linked to the model of Rossi-Hansberg, and provides some empirical basis for further consideration of the policy prescription he derives.

V. Conclusions

The analysis has provided strong empirical support both for general predictions of urban models and for specific predictions concerning the impact of ongoing terrorism. Contrary to what is sometimes asserted, or what is inferred from urban reconstruction after traditional warfare, the impact of terrorism appears to be large. A doubling in the number of terrorist incidents (which is not uncommon) is associated with at least a 3% to 6% reduction in development of land for urban purposes, and perhaps as much as a 22% reduction in such development after accounting for the feedback between city size and terrorism.

These effects are noted after accounting for the impacts of population, income, and a variety of other relevant variables. Terrorism may indeed reduce the population in vulnerable cities (as suggested for example by the Harrigan and Martin models) but aside from this, terrorism has an impact on urban structure and the investment that creates the built environment. This shows up clearly in the cross-sectional data we use for this study.

Our analysis provides at least tentative support for the models of Rossi-Hansberg and Harrigan and Martin. This supports the idea that terrorism be regarded as a type of tax on urban producers and residents. Such taxes can cause distortion, and there may be a useful role for public policy to be designed to correct these distortions and improve economic efficiency.

In section III above we noted that the measurement of urban land use has been undertaken so as to clearly identify unbuilt land in the interior of the urban area. While this measurement is not yet complete, this capability of the data will eventually provide for the possibility of testing hypothesis 10, concerning the impact of terrorism on the range of densities of investment in the urban area. Higher levels of terrorism should be associated with relatively more new development at the urban periphery and relatively less new development in the open areas within the interior of the city.

We are left with a tentative conclusion: terrorism appears to have a significant impact on urban structure. The theoretical models with which our data are consistent also suggest that public policy can play a useful role in correcting the distortions caused by this tactic of political struggle.

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