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Building functional cities *Science* 19/4/2016

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Most cities in the developed world use land in an orderly pattern that allows cities to achieve high productivity. For example, businesses mainly reside in a central business district (CBD), and residential neighborhoods have regular layouts with high densities near the center and lower densities further out *(1)*. In contrast, many cities in developing nations have office towers bordered by slums, scattered fringe developments, and a consequent lack of connectivity between firms, workers, and consumers. Such cities are viewed as quite non-functional *(2),* with large numbers of people in informal settlements [62% of the African urban population according to *(3)],* poor transport infrastructure and ability to commute *(4),* and low worker productivity *(5)*.

Here we explore factors that may underlie non-functionality of many cities in the developing world. We analyse how construction decisions made under weak and corrupt institutions can be a driver of non-functionality. The built environment resulting from these decisions accounts for two-thirds of produced capital in developing countries *(6)* and is long lived. As such, weak institutions undermine the competitiveness of cities, and bad decisions made today thus have effects lasting for generations. We first discuss recent model results and then use Nairobi, Kenya—a city of about 5 million people that is growing at a rate of 3 to 4% per year—to map out how the built environment has changed, and explore ways in which it appears to deviate from an efficient pattern, with insufficient building volume through most of the city.

In a recent study (hereafter referred to as HRV) *(7)*, we developed a general model of the dynamics of economically efficient urban land-use and of key elements that impede efficient urban development. To do so we adapted a standard urban model to a growth context and the circumstances of developing

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countries. The model captures rapid population growth and two types of housing technology: Formal housing, in which capital is sunk, buildings are long-lived, and construction decisions (such as building height) are based on expectations of future rents; and informal, or slum settlement, where construction is flexible or adjustable over time (e.g. through use of corrugated iron sheets), building a single story is cheap, but building high is very expensive. This distinction is illustrated in Nairobi, where 57% of slum dwellings are made of sheet metal and 15% of mud and wood, whereas 90% of formal residences are made of stone, brick, or cement block *(8)*.

In the efficient outcome in the model, slums form at the edge of the city, where land is cheap. As the city grows, old slums are converted to formal settlement and new ones form on the edge. Formal sector development is then subject to periodic demolition and reconstruction, becoming successively taller and denser as the city grows and land values increase. If slum housing is inherently of lower quality, then slums will eventually be phased out entirely as incomes grow, just as 19th-century tenements and shacks in London and New York disappeared decades ago. Our model (7) analyzes two main sources of inefficiency in the dynamics of city development. One arises from the difficulty of forming expectations; for example, pessimism about future city growth undermines willingness to invest and leads to a lower, more sprawling city. The other is institutional obstacles in the process of converting slum developments to formal sector usage.

There are many such institutional obstacles. Formal sector development requires financing and enforcement of contracts, which in turn requires land ownership rights to be formalized to mitigate the risk of expropriation. Land rights are often unclear because of co-existing systems of private ownership (some illegal or quasi legal), communal ownership, and government ownership. Competing claims may result in lengthy court cases. Slum areas are particularly complex, with "planning or regulatory powers... split between a galaxy of private sector actors, landlords, chiefs and bureaucrats, and gangs" *(9)*. Land administration is subject to corruption. The Kenyan elite has been guilty of land-grabbing, with a government inquiry alleging that the land allocation process has been subject to corrupt and fraudulent practises and 'outright plunder' *(10)*. As a result, the cost and feasibility of conversion to legal formal usage varies depending on a plot's history; plots with high conversion costs remain informal much longer. A spatial jumble of land rights and conversion costs results in a hotchpotch of uses, land-use intensities and stages of redevelopment through the city, including close to the centre.

Studying these inefficiencies requires data on individual buildings and the ability to track them through time to quantify the potential loss of building space and economic efficiency. Such data are generally difficult to obtain. For our Nairobi study, we used a building footprint data set based on extremely high-resolution aerial photos (well under 50 cm resolution), which allows clear demarcation even of buildings in slums, satellite data to derive road coverage, and LIDAR data for building heights (*7*). We used city studies that mapped slums in 2003/04 *(11)* and slums and ownership/land rights in 2012 *(12)*. For the later time period, house and land prices are available from surveys or scraping the web. We developed novel methods to integrate and analyse these data, including overlaying building footprints of the city at different points in time to define infill, reconstruction, demolition and no change.

As can be seen in the three-dimensional map (Figure 1), building heights vary widely throughout Nairobi, reflecting formal and informal housing. The city is monocentric, constrained by national parks to the north and south; undefined spaces within the city include an airport, golf course, and the President's complex. Slums include the 1000-acre slum of Kibera, to the south-west of the city center that we discuss below.

2015 land prices decline sharply with distance from the CBD. There are no slums in the CBD, and the proportion of developed land occupied by slums peaks at 45% at a distance of 5km out from the CBD. In Nairobi, slums are not concentrated at the edge (which, according to the model, would be economically efficient), although city mapping may underrepresent emerging slums at the fringe. More to the point, slums appear in a scattered fashion throughout, even near the CBD, indicating potentially significant land market frictions. Building heights in the formal sector average about 23 meters in the CBD, in contrast to expectations that there would be overall less height in Nairobi. Heights fall to about 6 to 7 meters at a distance of 10 km from the CBD. Slums have similar height throughout the city and, at about 5 meters, are less tall than formal buildings, as modelled. Despite the lack of roads and green space and intense crowding of buildings in slums, height in the formal sector trumps intense footprint coverage in slums, so that building volume (height x footprint) per unit land in slums is always lower than in formal developments. An implication is that the presence of slums near the CBD has a large impact on building volume. At 2, 3 and 4 km from the center, conversion of slums to formal usage would increase building volumes in those slum areas by 148%, 95% and 53% respectively, one indication of potentially inefficient land use.

Turning to dynamics, we determined the volume of infill (new buildings where there were none in 2004), net redevelopment (new building where there had been an earlier structure) and demolition (buildings demolished and not yet replaced) as a fraction of initial volume (Figure 2). In the 0 to 1 km ring at the CBD, use is locked in by roads, colonial buildings, and tall complexes built over the last 40 years. Total road area declines sharply with distance from the center, as modelled by Solow and Vickrey *(13)*. Between 1and 5km, as the model suggests, there is substantial net redevelopment in the face of escalating land prices, with new buildings taller than their older neighbours. The volume of net redevelopment peaks at 4km out, where it amounts to over 30% of old volume. Beyond 5km, volume changes are dominated by infill.

What about slums? Up to about 2km from the CBD slums are demolished and redeveloped. Beyond that there is less redevelopment than might be expected. Why? In HRV, we argue that remaining slums nearer the CBD like Kibera have high costs of conversion to formal usage. Slum land near the center including Kibera is government owned *(12)*—a code word for conflicting private claims, with the government having seized ownership but not responsibility. Slum landlords there make high profits and much of the land is controlled by political figures with a vested interest not to develop the land; redevelopment would take away their profits on land to which they have no legal claim. Nearer the fringe land ownership in slums becomes increasingly private.

The constraint on slum redevelopment nearer the center has significant welfare costs: there is lost volume of space due to not building high as we described above, and the quality of the built space and unit rents are low, compared to the formal sector. We hypothesize that slum landlords have invested little in land improvements such as infrastructure and regularized lay-out near the center, because they cannot capture those returns when housing spaces are redeveloped. A simple calculation (reported in HVR) suggests that lack of redevelopment reduces land values in Kibera by the order of about $1b. Such a magnitude of potential gain from redevelopment indicates the potential for a political solution: to buy-out the actors inhibiting redevelopment and help relocate tenants.

In summary, Nairobi has many of the features of a 'normal' city: high buildings in the Central Business District and declining heights and land prices away from the center. Yet there is substantial evidence of inefficient land-use. The low volume intensity of slums and the persistence of slums relatively close to the center lead to a substantial loss of housing capacity. We argue that such persistence is due to the myriad of institutional and political obstacles to redevelopment.

While the data are specific to Nairobi, the modelling and analysis are more general. Weak and corrupt land market institutions are common throughout much of Africa, suggesting aspects of our findings for Nairobi have more general applicability. While the focus has been the built environment and much of data is a view from the sky, our continuing work combines this with economic and population censuses and surveys, in order to give detail for what is happening to people and firms on the ground. Combining data sources and institutional details of specific cities will help inform urban policy to improve functionality, as the African urban population trebles over the next three decades.

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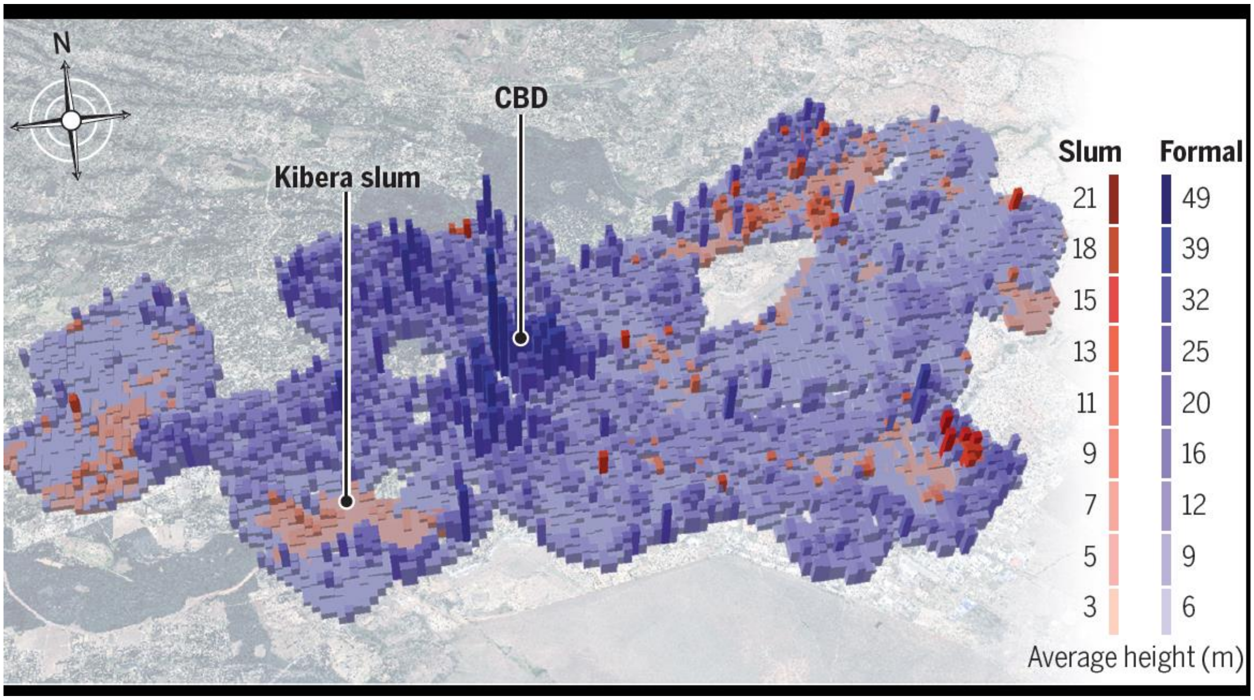
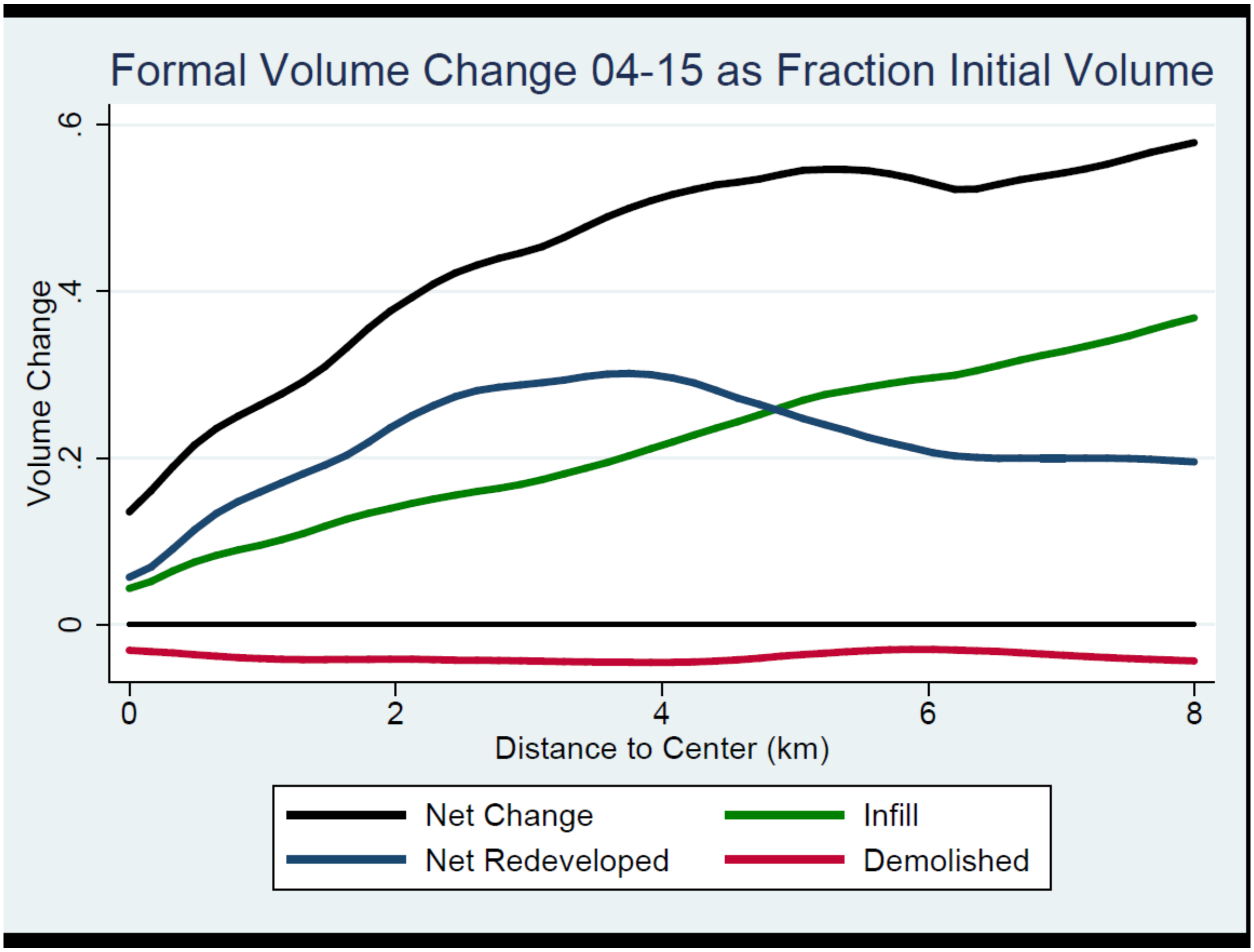
Figure 1



This 3-D map of Nairobi shows average built height in 2015 by 150x150 metre cells split across the formal and slum sectors. The compass in the upper left corner points north in green and upward (for heights) in purple. The location of the Kibera slum and the city center (the CBD) are marked. The boundary of the city spans about 22km E to W and 11km N to S; map tilt may distort the appearance of distances. Background imagery copyright Airbus Defence and Space 2016 taken from the SPOT5 satellite the 20th September 2004. Modified from HRV.

Figure 2 caption



This plot shows formal sector volume change from 2004 to 2015 as a fraction of initial coverage by distance. The ratio of net volume to initial volume is broken down into change due to infill redevelopment and demolition as defined in HRV. This sample excludes cells that had no buildings in both 2015 and 2004. Modified from HRV.