Global trends towards urban street-network sprawl

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Abstract

We present the first global time series of street-network sprawl — that is, sprawl as measured through the local connectivity of the street network. Using high-resolution data from OpenStreetMap and a satellite-derived time series of urbanization, we compute and validate changes over time in multidimensional street connectivity measures based on graph-theoretic and geographic concepts. We report on global, national, and city-level trends since 1975 in the Street-Network Disconnectedness Index (SNDi), based on every mapped node and edge in the world. Streets in new developments in 90% of the 134 most populous countries have become less connected since 1975, while just 29% show an improving trend since 2000. The same period saw a near doubling in the relative frequency of a street-network type characterized by high circuitry, typical of gated communities. We identify persistence in street-network sprawl, indicative of path-dependent processes. Specifically, cities and countries with low connectivity in recent years also had relatively low preexisting connectivity in our earliest time period. We discuss implications for policy intervention in road building in new and expanding cities as a top priority for sustainable urban development.

KEYWORDS: CLIMATE CHANGE POLICY, TRANSPORTATION, URBAN SPRAWL

Significance

The pattern of new urban and residential roads represents an essentially permanent backbone that shapes new urban form and land use in the world's cities. Thus, today's choices on the connectivity of streets may restrict future resilience and lock in pathways of energy use and CO₂ emissions for a century or more. In contrast to the corrective trend observed in the USA, where streets have become more connected since the late 20th century, we find that most of the world is building ever-more disconnected "street-network sprawl." A rapid policy response, including regulation and pricing tools, is needed to avoid further costly lock-in during this current, final phase of the urbanization process.

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1 Introduction

As economic growth leads to an increasingly motorized world, energy use and greenhouse gas emissions from transportation are predicted to increase dramatically. The sector’s energy use is expected to rise by ~44% between 2015 and 2040 under current policies, with CO₂ emissions from transport oil combustion rising by almost as much [1]. Global energy and integrated assessment models indicate that even under aggressive efficiency and electrification scenarios, transportation energy and emissions will see more limited reductions compared to other sectors [2, 1].

Most global analyses, however, model transportation energy demand as a function of income, energy prices, and technology, and take little to no account of how the physical structure of urban centers shapes household decisions on vehicle ownership and travel [3, 4], or of community decisions on transport infrastructure and services. While a large body of research shows that cities with high population density, connected street networks and fast and frequent public transportation systems tend to have less vehicle travel at a given income level [5, 6, 7], such insights are hard to capture in global analyses. One reason is that there is limited data on urban spatial structure at the metropolitan level, and even less at the higher-resolution neighborhood level where household travel decisions are shaped. Thus, policy makers have little insight into underlying trends and the characteristics of new development, let alone about how these trends may affect future energy use and emissions.

In previous work [8], we began to fill this gap through creating a global data set of street-network sprawl. Intuitively, connected street networks such as grids increase accessibility by walking, bicycling and public transportation, as more destinations can be reached in a given window of time. In contrast, disconnected networks that are dendritic or are dominated by culs-de-sac favor travel by the private car. In that paper, we created and reported (i) a summary measure, the Street-Network Disconnectness Index (SNDi); and (ii) a multidimensional classification of empirical types, based on analysis at the scale of individual nodes (intersections) and edges (street segments). We qualitatively validated their ability to capture and distinguish established urban planning-related characteristics of neighborhoods, globally, and showed that SNDi is associated with household car ownership and mode choice decisions in several high-income countries.

Our previous work focused on the stocks of streets, i.e. the characteristics of the entire network in a given place. In this paper, we focus on the *dynamics* of street-network sprawl and address the question of how patterns of street-network sprawl are changing among and within countries, worldwide. We couple our SNDi measure and empirical types with remote sensing data on urban growth to create a time series, and identify trends and the characteristics of new urban development from 1975–2014. We validate this approach using data on building construction dates (see [Supporting Information \(SI\)](#)).

Our paper is structured as follows. First, we discuss the connectivity of recent (post-2000) development at the national scale, as measured by low SNDi. Second, we characterize the ongoing trends in street-network sprawl in regions, countries, and cities, identifying a global decline

Figure 1: **Street-network sprawl (SNDi) for streets added years 2000-14.** The inset charts the distribution at the country level of SNDi for streets added in each of our four time periods.

in street connectivity since 1975, a peak in US street-network sprawl in 2000, and continued low levels of sprawl in places such as Japan. Third, we analyze trends in a multidimensional classification that identifies empirical street-network types, and document a rise in the prevalence of networks typical of gated communities at the expense of the irregular grid. Fourth, we explore persistence in street-network sprawl, i.e. the degree to which local- and country-level connectivity tends to reproduce itself over time, and discusses the potential role of path dependence. We conclude with implications for policy, including the potential of market-based and regulatory approaches.

2 Recent development

Environmental impacts are governed by the connectivity of the entire stock of streets, which is the product of decades or centuries of accumulated decisions by private developers and municipal governments. Policymakers, however, can normally only affect the increment of new streets that are added to the stock each year. Recently developed streets are therefore the best reflection of current urban planning policies and real-estate market forces, and we begin by discussing the considerable heterogeneity in our composite measure, SNDi, around the world in the most recent time period of our analysis, 2000–14 (Figure 1; Table 1; Table 2).

That the USA stands out for its disconnected streets comes as no surprise given the large literature on its automobile-oriented development patterns [e.g., 9]. Within the USA, the highest

	Sprawl (SNDi)				N(nodes)			
	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock
Bangkok, THAILAND	6.8	7.6	8.1	7.3	74k	30k	46k	150k
Guatemala City, GUATEMALA	3.8	5.6	7.5	4.5	22k	7.3k	4.7k	34k
Cebu City, PHILIPPINES	6.1	6.9	7.3	6.6	5.7k	2.3k	4.5k	12k
Los Angeles, UNITED STATES	3.6	6.2	6.3	3.9	250k	26k	9.7k	290k
Raleigh, UNITED STATES	4.8	5.4	6.3	5.6	11k	21k	19k	51k
Palembang, INDONESIA	4.7	5.6	6.3	5.2	15k	19k	3.9k	39k
New York, UNITED STATES	2.9	5.2	6.3	3.1	320k	42k	3.5k	360k
San Salvador, EL SALVADOR	4.4	7.1	6.1	5.0	11k	1.7k	4.7k	17k
Belgrade, SERBIA	2.9	6.6	6.0	4.2	9.1k	2.2k	4k	15k
Tijuana, MEXICO	4.3	3.6	6.0	4.4	15k	9.2k	8.5k	33k
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Gombe, NIGERIA	1.6	3.7	2.0	2.0	1.8k	560	4.5k	6.9k
Busan, SOUTH KOREA	1.3	1.6	1.8	1.4	16k	4.1k	4.2k	24k
Tokyo, JAPAN	1.1	1.6	1.8	1.1	660k	38k	97k	800k
Marrakesh, MOROCCO	1.1	1.5	1.7	1.3	6.3k	2.2k	3.6k	12k
Madrid, SPAIN	0.7	1.5	1.7	1.1	28k	12k	15k	55k
Buenos Aires, ARGENTINA	-0.1	0.9	1.6	0.3	120k	17k	26k	160k
Bamako, MALI	0.6	1.0	1.6	1.1	13k	7.5k	16k	36k
Luanda, ANGOLA	2.0	2.2	1.5	1.8	12k	10k	28k	51k
Lubumbashi, DR CONGO	1.7	1.8	1.3	1.5	6.7k	2.3k	7.7k	17k
Khartoum, SUDAN	0.2	0.6	0.7	0.5	56k	14k	38k	110k

Table 1: **Cities listed in order of recent urban street-network sprawl.** The top ten and bottom ten cities with $\geq 3,000$ street nodes, ordered by SNDi in recent development. A full list of 200 cities is in the [SI](#).

	Sprawl (SNDi)					N(nodes)				
	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock
Puerto Rico	4.9	7.7	8.9	9.4	6.5	54k	47k	12k	8.2k	120k
Ireland	5.0	6.4	7.7	7.6	5.9	57k	22k	17k	19k	120k
Guatemala	3.2	4.7	6.1	6.5	4.6	32k	41k	12k	11k	110k
Thailand	4.0	4.7	4.8	6.3	4.9	140k	470k	74k	120k	920k
Philippines	4.5	5.3	5.6	6.1	5.4	130k	200k	51k	59k	500k
Norway	4.0	4.8	5.7	6.1	4.6	62k	57k	10k	19k	170k
Sri Lanka	3.8	5.9	5.4	5.9	5.5	22k	78k	8k	26k	150k
Indonesia	5.3	4.4	5.3	5.8	5.1	660k	470k	140k	220k	1.6M
Serbia	3.0	4.3	5.3	5.8	3.8	56k	32k	4.1k	4.7k	100k
United States	2.9	4.6	6.2	5.7	3.9	5.5M	2.7M	980k	1.1M	11M
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Iraq	2.1	1.8	2.0	2.2	2.0	28k	150k	21k	110k	320k
Morocco	1.5	1.9	1.9	2.0	1.9	81k	86k	29k	59k	280k
Sudan	0.6	1.1	1.6	1.8	1.6	64k	52k	12k	92k	320k
Japan	1.1	1.5	2.2	1.8	1.3	2.8M	990k	130k	110k	4M
Taiwan, China	1.1	2.1	2.0	1.8	1.3	130k	12k	7.9k	7.5k	160k
Mozambique	2.1	1.2	1.7	1.7	1.8	16k	33k	16k	38k	130k
Senegal	0.9	1.2	1.3	1.6	1.5	30k	47k	19k	31k	150k
Peru	1.5	0.8	1.5	1.5	1.5	190k	11k	9.1k	23k	280k
Argentina	0.2	0.5	1.1	1.5	0.6	300k	310k	84k	69k	820k
Bolivia	1.3	1.1	1.0	1.2	1.5	42k	34k	26k	36k	170k

Table 2: **Countries listed in order of recent urban street-network sprawl.** The top ten and bottom ten countries and territories with $\geq 10\text{M}$ population and $\geq 100\text{k}$ street nodes, ordered by SNDi in recent development. Countries and territories with populations $> 20\text{M}$ are listed in bold. A fuller list is in the [SI](#).

levels of sprawl are found in the states of Georgia, West Virginia, Maryland, Kentucky and Virginia. Georgia is dominated by metropolitan Atlanta, which regularly features at the top of city-level sprawl rankings [e.g., 10], while urban growth in Maryland and Virginia is largely accounted for by the suburbs of Washington, DC. Los Angeles, Raleigh and New York are three of the ten most sprawling global cities identified in Table 1; this reflects recent suburban and exurban development in places like New Jersey, rather than the urban cores. (Neither Atlanta nor Washington, DC are represented separately in our cities dataset.)

Figure 1 and the tables also reveal the sprawling streets of parts of Europe such as Ireland, Norway and the Balkan region; south-east Asia, particularly Thailand, the Philippines, Sri Lanka and Indonesia; and parts of Central America. All these countries have recently built streets with average $SNDi \geq 5.5$ (See Figure 1 for the global distribution). In Ireland, for example, the 2001–08 housing boom led to an upswing in suburban development characterized by car dependency and poor public transportation service, despite moderately high densities in the form of apartment buildings and duplexes [11, 12]. In south-east Asia, developer-driven urban growth caters to a new middle-class, with access centered around the private automobile, often in the form of gated communities [e.g. 13]; we discuss the experience of countries such as Indonesia and the Philippines in more detail in [8]. In central American countries such as Guatemala and El Salvador, meanwhile, the combination of weak planning institutions and high rates of crime have led to a boom in developer-led, middle-class housing on the urban fringe, again typified by gated communities [14]. For example, Guatemala City — the second most sprawling in Table 1 — was originally established under Spanish colonial rule on a geometric grid, but the contemporary city is characterized by informal settlements, many of which arose after earthquakes in 1917–18 and 1976; and by “fortified spaces” for the wealthy that are isolated from the rest of the city [15].

The most connected streets in the recent period are found in South America, where Bolivia, Argentina, Peru and Uruguay have $SNDi \leq 2.0$. Japan, much of north Africa and the Middle East, South Korea and China also lie in the lower-quartile of $SNDi$. Most of these places were characterized by low levels of sprawl in previous time periods as well; the extent of this persistence over time is discussed further in Section 5.

3 Trends in development

An examination of trends in street-network sprawl since 1975 provides a complementary picture to the cross-sectional analysis of recent urban development, and helps indicate the direction of market preferences and planning policies. The trends for geographic regions and income groupings are shown in Figure 2A and B, while numerous details are evident at increasing levels of disaggregation (panels C and D). Plots and tabulated rankings for all countries are provided in the SI.

The last four decades have seen a striking global trend towards increased street-network sprawl, as reflected in the rightward shift of the distributions of $SNDi$ (Figure 1 inset). More-

over, new development in almost all geographic regions shows a marked rise in SNDi, at least until the turn of the century (Figure 2A). Sprawl in Latin America, Asia, and the EU rises monotonically and, except in the EU, nearly uniformly throughout our time series. Globally (Figure 2B, broad dark line), street-network sprawl rose during the first two time periods and flattened out in the most recent one, at a level comparable to that being built in the 1980s in the United States. This corresponds to a 27% decrease (from 32.5% to 23.9%) in the fraction of urban intersections with degree-4+, and a 35% increase (from 14.4% to 19.4%) in the fraction of dead-ends (see SI). While Figure 2 shows that the node- and edge-weighted global trend in SNDi has nearly plateaued, its future trajectory will depend on the relative rate of road expansion in areas practicing high- versus low-connectivity street construction. In the SI we show cities and countries according to the estimated rate at which their street network is growing.

In 1975, the global stock of streets showed relatively little variation among income groups. Since then, however, the distribution has considerably diverged according to income levels, with higher-income countries building less-connected developments. Due to the strong reversal exhibited by North America, the recent decrease of already-low-SNDi in Japan, and the leveling-off in the EU, overall the “high income” countries have recently arrested the radically-increasing trend of low-connectivity street construction. Despite the turnaround, recent construction in these countries remains less connected than other country groups (Figure 2B).

In fact, the leveling-off in high-income countries and on Earth as a whole reflects in large part the recent decline of SNDi in North America, which accounts for 20% and 19% of mapped nodes and edges, respectively, and thus counterbalances trends elsewhere in the world. In the United States, as previously reported [10], street-network sprawl exhibited an extraordinarily steep rise until the mid-1990s, but thereafter has been in decline. Interestingly, neighboring Canada followed a similar trend to the USA, with a steep increase in SNDi followed by a turnaround in the 1990s, but it peaked at a much lower level ($\text{SNDi} = 3.7$; see SI), reflecting higher fuel prices and a more limited highway construction program in Canada, as well as differences in local land-use regulations [19, 20].

Other high-income countries and geographic regions have followed a different path from that of North America. Indeed, the high-income grouping also includes one of the least sprawling countries (Japan), with the European Union lying almost precisely midway between the USA and Japan. Nearly all European countries show increasing SNDi until the turn of the century, including the outlier Ireland (discussed in Section 2), which started and remained less connected than any other European country, but followed a parallel trajectory to Europe as a whole. This is consistent with the trend towards more car-oriented transportation and development in Europe over those decades [21]. However, the declining connectivity of new streets in many European countries has been arrested since 2000, and the UK even shows a significant shift away from sprawl (decrease in SNDi) in this time period.

For several European countries, notably Denmark and the UK, our estimates of street connectivity are strongly affected by pedestrian and bicycle paths (see Methods and SI for details of how we include them in calculating connectivity). In Denmark, where streets are becoming steadily less connected in the most recent period, bicycle and pedestrian paths appear frequently

Figure 2: Regional trends in street-network sprawl SNDi. The first three panels show levels of our composite sprawl measure for the stock of streets built prior to 1975 in urban areas, followed by the SNDi of new urban construction during each successive period, 1975–1989, 1990–1999, and 2000–2013 [16]. The vertical positions of dots denote the SNDi of the 2017 stock of streets. **A:** Urban region averages of SNDi for several geographic regions. **B:** The global urban region aggregate is shown with a broad dark line, along with trends for five World Bank-defined economic and cultural country groups [17], including the heavily indebted poor countries (HIPC). **C:** Trends for the ten largest countries by population in color, and for the next 90 largest countries in thin grey lines. **D:** Trends for ten large cities, based on time series of their urban development boundaries [18]. Note that cities are aggregated to a separate set of time periods (prior to 1990, 1990–1999, and 2000–2013); see Materials and Methods for details.

to be integrated into new developments, and significantly increase connectivity even if limited circulation is provided for cars. For example, adjacent culs-de-sac in new developments are normally connected by a foot- and cycle-way.

By contrast, Japanese street-network sprawl has remained low and recently turned around to an improving trend. We note the correspondingly low per capita CO₂ emissions in Japan [22]. Other exceptions to the dominant pattern of increasing sprawl throughout the last quarter of the 20th century are found in Africa and the Middle East, where SNDi has risen little since 1975. Correspondingly, low-income and highly-indebted poor countries have collectively shown nearly constant connectivity over time, with new developments exhibiting similar SNDi to the pre-1975 stock in North America.

Latin America was, like Japan, already considerably urbanized at the beginning of our time series, and had similar SNDi in 1975. In Latin America, this can be partly ascribed to the Spanish colonial legacy of grid-like street patterns [23]. Bolivia, Belize, Argentina, Peru, and Uruguay lie near the bottom (most connected) of a country-level ranking of SNDi in 2000–2013, with SNDi < 2.0 and average nodal degree of ~ 3.2 . Yet, streets from earlier time periods in these countries were even better connected — particularly in Argentina and Uruguay, which in 1975 had SNDi < 0.2 and nodal degree ~ 3.5 . The Latin American trend towards street-network sprawl (higher SNDi) in recent developments is among the strongest in the world, and has increased monotonically on every dimension included in SNDi.

Among more recently and rapidly urbanizing large countries, Indonesia both started (stock in 1975) and ended (development in the 2000–13 period) with the most sprawling street networks of any of the most populous countries. Another remarkable feature is the divergence of India, with increasing SNDi, and China, with the opposite trend, even though the stocks in 1975 were characterized by similar levels of connectivity. This divergence reflects in particular our graph-theoretic measures of nodal degree and the fraction of edges in the cycle basis (see SI), which remained stable in China but trended monotonically towards sprawl in India. When measuring sprawl through the geographic measures of circuitry, both countries are becoming more sprawling, but India at a faster rate. Thus, all our measures suggest the same divergence of street-network development styles between Earth’s two most populous countries. While the underlying street-network data are less complete in China [24], this finding is consistent with other evidence on Chinese urban development patterns. Indeed, many of China’s new residential developments are characterized by “super-blocks” or sparse grids, which are connected but less conducive to walking than a finer-grain network [25, 26].

City trends (Figure 2D, tabulated more completely in the SI) reflect the regional and national-level patterns, with extremely high and growing SNDi in southeast Asian cities, notably Bangkok; stable or slowly increasing SNDi in European cities along with Tokyo and Guangzhou; and rapidly-increasing SNDi in initially-well-connected Sao Paulo, Mexico City and Buenos Aires. The cities of Manchester and Sheffield, like London, have recently turned towards decreasing SNDi, as has, even more dramatically, the United Kingdom, following a long period of broader trends towards increased sprawl [27]. Seoul, and indeed South Korea as a whole, represents another example of initially high but rapidly worsening connectivity, as depicted in Figure 3,

which also shows the within-city variation at the level of individual edges and nodes. New York and Los Angeles, where recent development is less connected than in any other equally large global city in our analysis, are examples of regions with highly gridded urban cores whose suburban development in recent decades has been at the opposite extreme. Stocks and trends are tabulated and plotted for 200 cities and all countries in the [SI](#).

Recent development in some cities makes them stand out nationally. For instance, in São Paulo and, even more so, Florianópolis, recent development is characterized by extremely low connectivity ($\text{SNDi} > 5.8$, mean degree=2.6) as compared with the recent country mean in Brazil ($\text{SNDi} = 2.9$, mean degree=3.0). Interestingly, SNDi in São Paulo has evolved nearly identically to that in New York. While the older core of São Paulo is complex, it consists largely of gridded streets like those of New York, while the outer developments are increasingly circuitous. Tijuana, Mexico is another city with unusually disconnected development since 2000 ($\text{SNDi} = 6.0$), as compared with the rest of Mexico ($\text{SNDi} = 3.9$), although it is similar to the average for close-by United States ($\text{SNDi} = 5.7$). While Thailand as a whole is building low-connectivity streets (recent $\text{SNDi} \approx 6.3$), Bangkok (recent $\text{SNDi} = 8.1$) stands out within Thailand as well as globally. Fewer cities are national outliers in the other direction, i.e. with lower SNDi than the national average.

4 Dynamics according to empirical street-network types

Our composite measure (SNDi) analyzed in the preceding sections gauges the overall connectivity of the street network. In this section, we complement that composite measure with a categorical analysis, which classifies every urban grid cell into one of eight street-network types. Such a multidimensional classification enables distinctions to be drawn between places with similar overall connectivity as measured by SNDi , but where that level of connectivity is achieved through different designs. [Figure 4](#) shows the eight types as identified in [8]. Types B and C, for example, have similar levels of SNDi , but Type B achieves this through degree-3 intersections, while Type C has more degree-four intersections arranged in an irregular grid. Types E and F also have similar SNDi values, as do Types G and H.

The line plots in [Figure 4](#) show the trends in the distribution of types over time, while [Figure 5](#) shows the trends by world region. Overall, the message from the two figures reinforces the results presented above. That is, the proportion of nodes in the most disconnected types (E, F, G and H) nearly doubled between pre-1975 development and the most recent period (2000–14), with the increase particularly pronounced in Europe, Asia and Latin America. There was also a sharp increase in the prevalence of disconnected types in North America, reaching a peak of 67% of nodes in Types E, F, G and H in 1990–99. Recent additions to the street network in North America, however, show a modest shift back towards more connected types, in accordance with the fall in SNDi since 1999.

Of these disconnected types, Type E (circuitous) has shown the largest increase over the period studied, rising from 9% of nodes pre-1975 to 17% in the 2000–14 period. The proportion

Figure 3: **Map of nodal connectivity over time, Seoul.** Blue streets are the most connected. Inset plots show the distribution of nodal degree (top) and circuitry (bottom) for the three time periods. Streets built since 1990 on the urban periphery, particularly to the southeast and north-west, have become steadily more sprawling according to both of the connectivity measures illustrated here. A high-resolution version of this figure is linked in the [SI](#).

of nodes in Type E has increased in every region except Africa, and more than doubled in most regions. Type E often represents gated communities, as well as places with topographic barriers; some examples are shown in [Figure 6](#). Demand for gated communities are is often driven by a fear of crime or a search for social prestige, but many analysts have raised concerns about their consequences for social segregation and for allowing a high-income elite to opt out of municipal service provision [28], as well as for their car dependence.

At the other end of the sprawl spectrum, grids (Type A) are the most self-evidently connected type. In the pre-1975 period, North America and Latin America were home to the highest proportions of Type A (grid), at 9% and 13% respectively. Since then, grids have declined in importance in Latin America and almost disappeared entirely in recent North American development, with that decline only partially offset by a marked upswing in the East Asia & Pacific region ([Figure 5](#)). However, the global reduction in street connectivity has little to do with the abandonment of grids, which even in 1975 accounted for just 6% of nodes worldwide, declining to 3% in the 2000–14 period. Instead, the largest decrease, from 43% to 28% of nodes at the global level, has occurred in Type C (irregular grid). The small rise in Type B (degree-3), which has similar SNDi to Type C, has only partially compensated for the decline in irregular grids.

5 Persistence

We previously found that early street-network sprawl predicts the connectivity of later construction at various geographic scales within the United States [10]. In addition to a persistence of local geographic variation in prices, policy, preferences, and other drivers of development style, there are plausible path-dependent processes in which urban form tends to replicate itself in new, neighboring developments [10, 29, 8]. For instance, the connectivity of existing street networks is likely to influence neighboring development due to the availability, or expectation of future availability, of services and transit options accessible to pedestrians. Building a walkable neighborhood is more valuable if there are places to walk to.

Our findings show that the same persistence is observed at the scale of entire countries ([Table 2](#)) as well as cities ([Table 1](#)). Places ranking high in recent SNDi also had relatively high SNDi in our earliest time period. To quantify this persistence as well as the average shift over time, we estimate the relationship between SNDi stock at our earliest time points (1975 for countries, 1990 for cities) and the SNDi characterizing the most recent construction ([Table 3](#)). Both the average shift and the persistence are consistent across geographic scales and different measures comprising SNDi: they indicate an overall shift towards lower connectivity, and a strong relationship between preexisting connectivity and recent connectivity. In fact, hardly any countries or cities are building better-connected streets than they were in our earliest time periods (i.e., lie below the dark grey line in [Figure 7](#)), with China being a prominent exception. Other exceptions are mostly countries in the Middle East and Africa.

Figure 4: **Empirical street-network types.** For each type, streets in a grid cell near the cluster’s centroid are shown [8], along with a line plot of the proportion of grid cells (blue) and proportion of nodes (red) that fall into each type over time. Types are shown in order of decreasing SNDi, indicated by the blue bar and associated number. The caption indicates the (latitude, longitude) of each example grid cell as well as the country where it is located.

Metric	Scale	Shift	Persistence
Log circuitry (0.5–1km)	Cities	.037±.002	.80±.14
	Countries	.029±.002	.91±.12
Nodal degree	Cities	-.22±.013	.68±.12
	Countries	-.17±.012	.82±.10
SNDi	Cities	1.56±.081	.85±.13
	Countries	1.26±.081	.89±.10

Table 3: **Estimates of path dependence.** Mean shift ($\pm$ standard error) in connectivity measures between 1975 (countries) or 1990 (cities) and more post-2000 construction, and slope ($\pm$ standard error) of corresponding regression lines. Data and fits are displayed in Figure 7.

Figure 5: **Trends in empirical types by world region.** The fraction of nodes that fall into each of the empirical types is given for selected World Bank-defined regions. Plots for additional regions, for both the fraction of nodes and the fraction of grid cells that fall into each type, are shown in the [SI](#).

Figure 6: **Gated community examples.** These examples are from grid cells close to the centroid of Type E.

6 Policy and conclusion

In this paper, we use a globally consistent composite measure, SND_i , to quantify trends in street-network sprawl in countries and large cities worldwide. While sprawl has increased in many of the “usual suspects” such as São Paulo, Los Angeles and Lagos, our findings show that some of the least connected street networks are found in places that have received less attention in the literature. The growth of large cities in China has been the subject of considerable media and academic interest, but these urban centers have moderate and relatively stable levels of street connectivity. In contrast, the most sprawling cities on the planet — and those that are trending towards even greater extremes — are found in southeast Asia, and have attracted more limited attention.

We also identify the diversity of ways in which street networks can grow in a connected or less connected pattern. Gridded street networks are a primary means through which Latin American countries such as Bolivia, Argentina, and Peru have maintained their high levels of connectivity — and the move away from the grid characterizes sprawl in large Brazilian cities such as São Paulo. However, Japan has maintained low levels of sprawl via a more organic, irregular grid pattern. Northern European countries such as Germany, Denmark and the UK, meanwhile, have maintained moderate levels of street connectivity through dedicated pedestrian and bicycle pathways, meaning that the network for non-motorized travel is far more connected than that for cars and trucks.

Our work has some natural limitations. First, our rationale for prioritizing a street-network measure of sprawl is in part based on causal pathways which still require further empirical

Figure 7: **Path dependence in street-network sprawl.** SNDi of recent (2000–2013) construction is closely correlated with that of the earlier road stock in 1975 (countries, A) and 1990 (cities, B). Circle size denotes the length of original road stock, while color indicates the scale of recent construction. Only cities and countries with at least 100 km of new roads are shown. Linear fits characterizing the persistence relationship (gray shaded confidence region) are nearly parallel to the 45 degree line of perfect persistence (dark grey line) indicating a relatively uniform shift (on average $\Delta\text{SNDi} = +1.56$ for cities, $+1.26$ for countries; see Table 3) away from earlier high connectivity. A zoomable version of this figure with labels for cities and countries is in the SI.

investigation. While SNDi and its constituent components, along with related measures of urban form such as density and housing type, are strong predictors of current car ownership and travel behavior [29, 8, 30, 31, 32], the relationship between initial street-network connectivity and the subsequent long-run evolution of density remains a ripe subject for future work. Our global SNDi time series should facilitate such research.

Second, an important premise of our current analysis is a sufficient completeness of the underlying street-network database, which we take from OpenStreetMap (OSM). We have demonstrated elsewhere that OSM is relatively complete [24], but those estimates excluded pedestrian and bicycle paths and service roads, which we incorporate in our measure of SNDi because they are demonstrably important to connectivity in some places. This leaves our work dependent also on the sufficient completeness of OSM’s pedestrian and bicycle path records. Nevertheless, our inspections suggest that where such paths are numerous, they are well mapped in OSM. Where they are prominent, but possibly incompletely recorded in OSM, we may be underestimating connectivity.

Worsening sprawl and its consequences

Overall, our analysis shows that in large parts of the world, recent urban growth has increasingly resulted in inflexible and disconnected street networks. Countries with road networks that are among both the fastest-growing and the most disconnected include Thailand, the Philippines, Indonesia, and the United States, while cities of the same description include Bangkok, Johannesburg, Raleigh, Los Angeles, New York, Ho Chi Minh City, and São Paulo. However, our data reveal variation in development style within countries as well as within cities.

Our network-centered approach to quantifying sprawl therefore breaks from the dominant extant emphasis on low density and land use dispersal [33]. Urban outcomes in the short term have to do with much more than the street network. However, in the long run, sidewalk and transit provision, densities, land uses and both formal and informal rule enforcement are malleable to social, economic, and policy influences. By contrast, streets are a more permanent feature of cities; once laid down, their routes almost never change, even in the face of natural disasters such as earthquakes or fires [34]. Given that many cities will continue to grow for decades, density may change and outlying regions may be subsumed into more continuous development, but disconnected street routes will remain as a fundamental constraint. Thus we have previously conjectured that in the long term, low-connectivity street networks lack *resilience* to adapt to changing pressures and resources and ultimately densify towards mixed-use, transit-integrated, energy-efficient urban form. In this sense, they are effectively “density-proof,” i.e., resistant to changing the mix of uses, modes of transportation, and density [29]. In addition, in a practical policy context, the regulation of development style and infrastructure is somewhat separable from decisions about the conversion of agricultural and natural lands into urban use. Based largely on this logic, we expect our street-network measure to be a key predictor of future climate, energy, health, and social outcomes related to urban form.

The impact of today’s street connectivity decisions on climate and other outcomes is ampli-

fied by the tendency of new development to mimic existing urban form (Table 3). One mechanism we have proposed for this [10, 29] is a spatial spillover from existing settlement structure onto the choices of future, neighbouring land developers. A neighbourhood with highly permeable streets is more likely to allow transit to access an adjacent future development, more likely to contain local services and jobs accessible to pedestrians living nearby, and so on. Building high-connectivity, pedestrian-navigable streets in the adjacent development therefore has economic complementarities with the connectivity of the existing street network. In other words, one interpretation of our findings of persistence is a long-run path-dependence in urban evolution, rendering any initial design decision all the more pivotal for future human and environmental outcomes.

In our categorical analysis of street-network types, gated communities arose as a particularly illustrative instance of low-connectivity planning. While gated communities have been documented across every continent, including in Istanbul, Indonesia, the United Kingdom and the United States, and single-country or qualitative studies have suggested their increasing prevalence [35, 28, 13], ours is the first global analysis that documents the extent of their reach. In addition to their association with low walkability, car orientation, and land-use segregation, gated communities have obvious significance for other global challenges related to economic disparities and social segregation.

The need for policy attention

What, then, do these widespread trends imply for policy, especially given the rapid pace of urban road construction in many parts of the world — a process that is likely to be largely completed this century? The costs of high street-network sprawl are largely externalized to neighboring developments and to future generations, so regulatory intervention is a natural approach. Several feasible policies might be sufficient to increase connectivity in new developments. The simplest would be to require that, where possible, new communities are completely gridded, given that grids do well according to all of our street-network sprawl metrics. An alternative requirement would be a “three-ways-out” rule, which requires that three non-touching routes exist from every new intersection to points outside a new development. Gated communities could be discouraged or outright prohibited.

Market approaches can be used in place of regulatory policies, or in combination with them. For example, a tax on dead-ends and 3-way intersections, which we call a “cul-de-tax”, could internalize some of the external costs of street-network sprawl. Moreover, broader environmental tax policies – such as carbon taxes, motor fuel taxes or congestion pricing – have led to increased residential densities and decreased construction on the urban periphery [6]; they might reasonably be expected to encourage developers to build more connected street networks as well.

Design guidance can also play a role. For example, the turnaround in the United Kingdom as a whole and in several British cities occurred in 2000, when new national planning guidance emphasized the importance of permeability for pedestrians in site design, and called for the

creation of well-connected streets that avoid “introverted” dead-end layouts [36]. A subsequent design manual further emphasized the need to encourage walking and cycling through “networks of streets that provide permeability and connectivity to main destinations and a choice of routes,” and presented a hierarchy of road users with pedestrians at the top [37]. In Ahmedabad, India, where recent development has been among the most connected of all Indian cities, boundaries of private landholdings are adjusted to allow for the creation of a regular grid as the city expands [38]. In neighboring Bhuj, post-earthquake planning efforts led to the interconnection of all culs-de-sac, motivated in part by the lack of access to dead-end streets that were blocked by falling rubble in the 2001 earthquake [39]. In China, while much post-1949 development consists of often-gated superblocks, guidelines issued by the Chinese State Council in 2016 call for a reversal of that approach, promoting a more fine-grained network and urging a cessation of enclosed (i.e. gated) residential neighborhoods [40].

Some policies are likely to be more internationally transferable than others. Fundamentally, however, the examples of Japan and many countries in the Middle East, along with the historical street patterns in Latin America, show that street-network sprawl is far from inevitable. Their experience suggests that building connected streets can achieve not just environmental goals, but contribute to vibrant, economically prosperous urban centers. The world has much to learn from cities and countries that have turned the corner and are building more connected street networks – and from those that, often with little fanfare, have been doing so all along.

Materials and Methods

We calculate properties named dendricity and sinuosity for street-network edges and properties named circuitry and nodal degree associated with street-network nodes. These measures address both graph-theoretic and more geographic concepts of street-network connectivity. A summary measure, derived through principal components analysis and dubbed the Street-Network Disconnectedness index (SNDi), best captures the global, high-resolution variance of the constituent connectivity measures. Full details are provided in the SI accompanying [8]. Also described in [8] is a classification of all ~ 4.1 million 30-arc second ($\sim 1\text{km}^2$) urban grid cells into eight empirical types using k -means cluster analysis.

We make use of two time series derived from satellite remote sensing data, the Global Human Settlement Layer (GHSL) [16] and the Atlas of Urban Expansion [41, 18], to classify each street segment as to (i) whether it forms part of a built-up development or not, and (ii) the time period when it was developed. The GHSL approach yields four epochs (<1975 , 1975–1990, 1990–1999 and 2000–14), while the Atlas approach yields three (<1990 , 1990–1999 and 2000–13). Our method makes use of the permanence of roads, once built. However, we also validate our approach to assigning development dates using an independent method available in the USA [10], and through analyzing the consistency of the time series developed through GHSL and the Atlas methods (see SI).

The majority of our analysis employs the time series from GHSL, an open-data project pro-

viding global spatial information about the human presence on the planet over time [16]. Data are available online (<http://ghsl.jrc.ec.europa.eu>). We use the built-up grid which is derived from analysis of Landsat image collections, and provides built-up year classifications with approximately 38 m resolution. Pixels are classified as follows: land not built-up in any epoch; built-up from 2000 to 2014 epochs; built-up from 1990 to 2000 epochs; built-up from 1975 to 1990 epochs; built-up before 1975 epoch. For computational reasons, we aggregate to 306 m resolution, and calculate the built-up year of the aggregated grid cells as the modal built-up year of individual pixels. Each edge and node is assigned the modal epoch of the intersecting pixels.

Our city-level aggregations utilize the time series from [Atlas of Urban Expansion](#) [41, 18], an open-data online database of city boundaries. The Atlas includes a sample of 200 of the world’s metropolitan areas that had 100,000 people or more in 2010 and provides urban extents at three time points: circa 1990, circa 2000, and circa 2013. We calculate spatial differences between successive time points in order to generate boundaries for new development during the periods 1990–1999 and 2000–2013. We then aggregate our street-level metrics to these regions to characterize development over time in these cities.

The [SI](#) reports results for all areas (including non-urban), and discusses our methods in detail, including extensive robustness checks. Complete open-source computer code for quantifying street-network sprawl and reproducing our results are, along with our resulting dataset, linked from the [SI](#).

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A Urban development time series

We obtain time-of-construction information from two sources, the Global Human Settlement Layer (GHSL) and the Atlas of Urban Expansion, described further in the main text. Here, we analyze the consistency of the development dates from each source, through comparing them to each other, and to our earlier work in the USA.

Figure S1 shows the consistency of our two data sources where they overlap. The GHSL dataset tends to assign an earlier year-built to each node, but the trends are consistent.

For the USA, we also compare the GHSL-based method of generating a time series to our earlier work, which used census and county parcel assessment data [Barrington-Leigh and Millard-Ball, 2015]. The census-based method covers the entire USA and assigns to each block group households’ median report of the year when their house was constructed. The parcel-based method covers only about a third of the USA but makes use of county records’ building construction date for every residential property in order to assign an original construction date for each street segment. As shown in Figure S2, the methods assign closely matching dates to road segments, even though the data sources are completely independent: one relies solely on remote sensing data, while the others rely on self-reported house construction dates. For years through 1999, the inter-quartile range of the census- and parcel-data methods matches GHSL almost exactly. For the most recent period (2000-13), while the median years align (solid red lines), the inter-quartile range does not fully overlap. This is likely due to aggregation bias in census geography, as the block group boundaries do not reflect more recent development.

Consistency in the time series of road network evolution translates into consistency in our main results, which concern the evolution of connectivity over time. Figure S3 presents comparisons of trends in mean degree and fraction of deadends, the two metrics used to characterize sprawl by Barrington-Leigh and Millard-Ball [2015], for the entire USA and for one metropolitan region with good coverage by parcel-based data.

Figure S1: **Comparison of GHSL and Atlas.** Each plot shows the cumulative number of nodes within the Atlas cities, for the entire world and by select World Bank-defined regions. By construction, the cumulative number is equal in 2014.

Figure S2: **Comparison of GHSL with parcel- and census-based measures, USA.** The units of analysis are census block groups in urban areas. We take the median GHSL year of each node with a block group, and compare that to the median year built of residential units within the block group (“census data”), and the median year of nodes within the block group, calculated from parcel assessment data on construction years (“parcel data”). Note that the census data have complete coverage, while the parcel-data sample accounts for about one-third of the urban US [Barrington-Leigh and Millard-Ball, 2015].

Figure S3: **Validation of connectivity time series, using house construction dates.** The time series of street-network sprawl (measured by the fraction of deadends) in our earlier work [Barrington-Leigh and Millard-Ball, 2015] is consistent with that generated by the remote-sensing method (GHSL) used in our global analysis. We show two connectivity measures calculated for the urban USA in our earlier work (top plots), as well as for the metropolitan area (Minneapolis-St Paul) where tax parcel data have the greatest coverage. For parcel and census data, thin lines show yearly averages (smoothed in the case of Minneapolis) while bars show period averages for comparison with GHSL. The first period average is the stock value up to 1974.

B Persistence

Figure S4: **Path dependence in street-network sprawl.** This figure is repeated from the main text, with the addition of small labels on cities and countries (three-letter ISO) visible by zooming in. SNDi of recent (2000–2013) construction is closely correlated with that of the earlier road stock in 1975 (countries, A) and 1990 (cities, B). Circle size denotes the length of original road stock, while color indicates the scale of recent construction. Only cities and countries with at least 100 km of new roads are shown. Linear fits characterizing the persistence relationship (gray shaded confidence region) are nearly parallel to the 45 degree line of perfect persistence (dark grey line) indicating a relatively uniform shift (on average $\Delta\text{SNDi} = +1.56$ for cities, $+1.26$ for countries) away from earlier high connectivity.

C Sensitivity analysis

C.1 Inclusion of non-urban roads

While our preferred metrics are based only on the portions of road network we classify as urban, which account for 75% of nodes and 77% of edges (see [Barrington-Leigh and Millard-Ball \[2019\]](#) for details), we also calculate all measures on the full global set of nodes and metrics. Figure S5 and Figure S6 (top-right panels) compare this analysis to the corresponding figures from the main text (top-left panels), and show that including the remaining non-urban nodes and edges makes no qualitative, and only subtle quantitative, differences. There is a small rightward shift in the distribution of SNDi, shown in the inset to Figure S5, particularly in Russia and some countries in northern South America, indicating that non-urban streets tend to be less connected. The qualitative conclusions, however, are unchanged.

C.2 Buffer radius used to separate nodes/junctions

We reran our entire analysis using a radius of 7 m for merging intersections into nodes in our network representation (lower-left panels in Figure S5 and Figure S6). Aggregate findings are nearly identical to the 10 m version used in our primary analysis.

C.3 Exclusion of walking and cycling paths

Our main results aggregate the properties of only those edges and nodes that are accessible by motor vehicle. However, walking and cycling paths, as well as service roads such as driveways, are considered when calculating connectivity. For example, two adjacent culs-de-sac that are connected by a pedestrian path would not be considered deadends. (See [Barrington-Leigh and Millard-Ball \[2019\]](#) for details.) Figure S5 and Figure S6 (lower-right panels) show the results of an analysis that excludes all walking and cycling paths and driveways. Several countries and cities, particularly in the UK, Scandinavia and other parts of Europe, show substantially higher SNDi when the extra paths are completely excluded, indicating that such paths make a major contribution to the connectivity of the street network. The increase in SNDi in London is particularly marked. The discussion in the main text elaborates on the implications for policy.

Figure S5: **Sensitivity analysis for Figure 1 from the main text.** The top-left map reproduces Figure 1, recent SNDi, from the main text. At top-right is a version calculated using all (i.e., urban and non-urban) nodes and edges, rather than only those we designate as "urban." The lower left map is a version calculated with an alternative intersection buffer radius (7 m), and the lower right one is calculated with the exclusion of walking and bicycling paths and service roads.

Figure S6: Top left: **Sensitivity analysis for Figure 2 from the main text.** The top-left set of panels reproduces Figure 2, trends in SNDi, from the main text. At top-right is a version calculated using all (i.e., urban and non-urban) nodes and edges, rather than only those we designate as “urban.” The lower left panels are a version calculated with an alternative intersection buffer radius (7 m), and the lower right set are calculated with the exclusion of walking and bicycling paths and service roads. In each panel, the left two sub-plots share an ordinate scale, and the right two share a separate ordinate scale.

D Data and code release

All data used for this work are open. Freely available sources are listed under “Data Release” in Barrington-Leigh and Millard-Ball [2019] and in the Materials and Methods section of the main text. Our code to reproduce the data and analysis, which itself leverages exclusively open-source tools, is released under the [GNU General Public License v3.0](#) as an open source project, permanently available at:

<https://alum.mit.edu/www/cpbl/publications/draft2019sprawl/code>

That site includes the following description of the code:

<https://gitlab.com/cpbl/global-sprawl-2019/blob/master/README.md>

In addition, we provide the data corresponding to our street-network sprawl metrics aggregated to various levels described in more detail in Barrington-Leigh and Millard-Ball [2019]. Data are served from the following site:

<https://alum.mit.edu/www/cpbl/publications/draft2019sprawl/data>

Moreover, an interactive map interface to our high-resolution results, with links to data downloads, is available at <http://sprawl.research.mcgill.ca/worldmap/>.

E Citation and contact

For any use of the data or code, please cite the main paper.

For further questions, please contact:

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F Supplemental reference book: results

The sections which follow contain more detailed tabular and graphical renditions of our findings. In addition, extensive online visualizations of our results are available at:

<https://alum.mit.edu/www/cpbl/publications/draft2019sprawl>

including an interactive map interface to our high-resolution results at:

<http://sprawl.research.mcgill.ca/worldmap/>.

F.1 Distribution of empirical street-network types

Figure S7 shows the trends over time in the distribution of empirical street-network types by World Bank-defined regions; it is similar to the plot in the main text, but includes additional regions. Figure S8 repeats the figure, but shows the distribution according to the fraction of grid cells (rather than the fraction of nodes) that fall into each cluster.

Figure S7: **Distribution of nodes by empirical type, by World Bank-defined region and year.** The bars represent the fraction of nodes in each type.

Figure S8: **Distribution of grid cells by empirical type, by World Bank-defined region and year.** The bars represent the fraction of grid cells in each type. (The two types that were dropped are not shown; hence, the bars do not add up to 100%.)

Figure S9: **Global shifts over time.** Curves show kernel density estimates of unweighted country-level means over urban nodes/edges, using built-up year classifications based on GHSL.

F.2 Trends and global distributions of key variables

Our analysis emphasizes our aggregate (first principal component) measure of street-network sprawl, SNDi. Figure S9 shows how the global distributions of SNDi and five of its individual connectivity measures have evolved over time. In each case, there is a significant shift towards lower connectivity, but with a partial leveling off in the latest time period.

F.3 Summary trend plots for selected street-network sprawl measures

The following pages contain plots in the format of Figure 2 in the main text, but show trends of individual connectivity metrics making up our SNDi index. In each plot, the left two panels share a vertical axis, and the right two panels share a separate vertical axis.

Frc non-cycle (length)

Log Circuity (0.5-1km)

Frc non-cycle (N edges)

F.4 Road growth rates and connectivity

Our aggregations from individual road segments (edges) according to GHSL-determined epochs naturally produce estimates of the rate of road growth in each GADM region, grid cell, and Atlas of Urban Expansion city. Of course, these estimates are subject to the same uncertainties as our other calculations, namely the completeness of the OSM street database and the accuracy of GHSL and Atlas classifications.

Because global trends are driven by the size of additions to road stock, we explore the relationship between SNDi and the length of recent additions to the road stock, by city and by country (Figure S10 top row). There is no statistical relationship across cities, and only a weak one across countries. The countries with the largest road growth — China, India, United States, Nigeria, Indonesia, and South Africa — span the range of relatively low to relatively high SNDi. China’s construction of 655,000 km of urban roads during this period is equal to nearly half the entire urban stock in the USA in 1975. Among cities, Bangkok and Tokyo stand out again; Bangkok is among the fastest growing cities, as well as an outlier in the low connectivity of its new street development. Meanwhile, Tokyo and Guangzhou are examples of equally fast or faster growth but with high connectivity. Houston appears to be a (fast-growing) low-connectivity city in the global picture.

In addition to analyzing SNDi against the *magnitude* of growth in roads, we compare it to the *rate* of growth. We define the growth rate of road networks as $R/(S - R)$, where R is the addition to length in the most recent period (2000-2013) and S is the length of the current stock. Figure S10 (bottom row) shows the relationship between recent SNDi and the road growth rate. Faster-growing cities tend to be building more-connected roads, perhaps largely due to the existence of rapidly-growing, initially-small cities in China. While a relationship holds also across countries, it does not hold statistically within any of our world regions (not shown). In terms of growth rate, the largest countries are in Africa. Similarly, as measured by road length per capita (not shown), African countries make up ten of the top 14 fastest builders. Notably, China is a significant investor in growing African infrastructure.

Figure S10: **Rate of road growth and SNDi.** Relationships between recently-constructed (2000–2013) street-network sprawl and (top row) recent additions to road stock or (bottom row) recent growth rate of road stock. Cities are shown on the left, and countries on the right. Coefficients (b) from OLS fits are shown with 95% confidence range. Colors in the lower panels are defined by the abscissa of the upper ones.

F.5 Countries ranked by urban street-network sprawl (SNDi) of recent road development

Table S1: **Countries listed in order of recent urban street-network sprawl (SNDi).** Countries with large (>20M) population are listed in bold.

	Sprawl (SNDi)					Nodal degree					N(nodes)				
	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock
Puerto Rico	4.9	7.7	8.9	9.4	6.5	2.7	2.4	2.3	2.3	2.5	54k	47k	12k	8.2k	120k
Virgin Islands (U.S.)	4.9	7.9	8.1	8.6	7.4	2.8	2.4	2.4	2.4	2.5	1.1k	2.5k	880	690	5.3k
Trinidad and Tobago	6.1		7.4	8.5	6.2	2.5		2.3	2.3	2.5	28k		750	470	30k
Ireland	5.0	6.4	7.7	7.6	5.9	2.7	2.5	2.4	2.4	2.6	57k	22k	17k	19k	120k
Barbados	6.1		7.2	7.6	6.4	2.5		2.4	2.3	2.4	9.3k		960	2k	13k
Gabon	5.5	5.8	5.8	7.2	5.9	2.6	2.5	2.5	2.4	2.5	3.3k	8.1k	2.3k	500	15k
Liberia	6.2	7.7	7.6	7.1	6.9	2.6	2.4	2.4	2.4	2.5	13k	2.4k	2.4k	3k	22k
Panama	3.2	4.7	6.1	6.8	4.6	3.0	2.8	2.6	2.5	2.8	15k	9.3k	7.1k	4.8k	37k
Montenegro	3.4	5.0	5.9	6.7	4.5	2.9	2.6	2.5	2.3	2.7	3.7k	3.7k	310	340	8.6k
Lebanon	2.1	5.5	6.3	6.7	3.9	3.0	2.6	2.5	2.5	2.7	17k	18k	4k	3.9k	45k
Jamaica	5.2	6.3	6.3	6.6	5.6	2.6	2.5	2.5	2.5	2.6	19k	5.5k	3.8k	3.2k	33k
Papua New Guinea	6.0	5.5	7.1	6.6	6.5	2.6	2.6	2.4	2.7	2.6	3.7k	870	270	250	6.2k
Kosovo	5.5	6.8	7.1	6.6	6.4	2.5	2.3	2.3	2.4	2.3	14k	18k	2.3k	3.5k	41k
Cyprus	2.8	4.0	5.6	6.5	4.2	2.8	2.7	2.6	2.5	2.7	6.7k	26k	4.8k	2.9k	41k
Brunei Darussalam	6.1	7.4	7.0	6.5	6.7	2.5	2.3	2.4	2.5	2.4	6.2k	5.3k	1.5k	610	14k
Guatemala	3.2	4.7	6.1	6.5	4.6	3.0	2.9	2.7	2.7	2.9	32k	41k	12k	11k	110k
Bahamas, The	4.8	4.5	6.2	6.3	4.8	2.7	2.8	2.6	2.6	2.7	4.8k	3.1k	630	320	9.2k
Thailand	4.0	4.7	4.8	6.3	4.9	2.8	2.8	2.7	2.6	2.7	140k	470k	74k	120k	920k
Sierra Leone	4.5	6.6	6.0	6.2	5.7	2.7	2.5	2.5	2.5	2.6	8.7k	3.2k	2.6k	9k	25k
Philippines	4.5	5.3	5.6	6.1	5.4	3.0	2.8	2.8	2.8	2.8	130k	200k	51k	59k	500k
Macedonia, FYR	4.0	4.7	5.3	6.1	4.6	2.7	2.6	2.5	2.4	2.6	9k	24k	1.3k	800	36k
Norway	4.0	4.8	5.7	6.1	4.6	2.9	2.7	2.6	2.6	2.8	62k	57k	10k	19k	170k
Madagascar	4.1	4.6	7.3	6.0	5.3	3.1	2.8	2.6	2.6	2.7	5.8k	8.7k	1.6k	2.1k	39k
Sri Lanka	3.8	5.9	5.4	5.9	5.5	2.7	2.5	2.6	2.5	2.5	22k	78k	8k	26k	150k
Indonesia	5.3	4.4	5.3	5.8	5.1	2.7	2.7	2.7	2.6	2.7	660k	470k	140k	220k	1.6M
Korea, Dem. People's Rep.	5.1	6.1	5.1	5.8	5.4	2.6	2.5	2.6	2.5	2.6	39k	7.2k	2.2k	2.8k	58k
Serbia	3.0	4.3	5.3	5.8	3.8	2.9	2.7	2.5	2.5	2.8	56k	32k	4.1k	4.7k	100k
Bosnia and Herzegovina	3.9	5.3	4.9	5.7	4.8	2.8	2.6	2.6	2.5	2.6	19k	17k	1.7k	2k	42k

	Sprawl (SNDi)					Nodal degree					N(nodes)				
	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock
United States	2.9	4.6	6.2	5.7	3.9	3.0	2.8	2.6	2.7	2.9	5.5M	2.7M	980k	1.1M	11M
Malaysia	4.5	5.6	5.2	5.7	4.9	2.9	2.7	2.8	2.8	2.8	270k	49k	47k	45k	420k
Albania	4.7	4.6	5.4	5.7	4.9	2.6	2.7	2.6	2.5	2.6	8.3k	21k	5.6k	2.6k	41k
Costa Rica	4.4	5.1	5.1	5.7	4.7	2.8	2.7	2.6	2.6	2.7	35k	17k	3.9k	2.6k	61k
El Salvador	3.4	4.3	5.1	5.7	4.3	2.9	2.8	2.7	2.6	2.8	16k	30k	10k	6.6k	66k
West Bank and Gaza	2.9	4.4	5.2	5.4	4.5	2.9	2.6	2.6	2.5	2.6	8.3k	29k	9.4k	6.2k	55k
New Zealand	3.7		5.6	5.2	4.0	2.8		2.6	2.7	2.8	75k		4.9k	5k	96k
Ghana	3.7	4.4	5.0	5.2	4.6	2.8	2.7	2.6	2.6	2.7	39k	25k	26k	36k	130k
Slovenia	4.2	5.5	5.5	5.1	4.5	2.7	2.5	2.6	2.6	2.6	40k	16k	1.1k	2.5k	61k
Bangladesh	4.2	5.1	5.1	5.1	5.3	2.7	2.7	2.6	2.6	2.6	16k	36k	7.7k	26k	160k
Venezuela, RB	3.3		4.1	5.1	3.4	3.0		2.9	2.8	3.0	240k		23k	15k	290k
Libya	1.7	2.4	4.1	5.1	2.3	3.1	3.0	2.8	2.7	3.0	46k	25k	5.2k	8.5k	86k
Guinea	2.5	3.6	4.0	5.0	4.0	3.0	2.9	2.8	2.7	2.8	13k	12k	8k	14k	52k
Cameroon	3.7	3.7	5.0	5.0	4.5	2.9	2.8	2.6	2.6	2.7	36k	34k	34k	28k	150k
Honduras	2.3	3.3	3.8	4.9	3.4	3.2	3.1	3.0	2.8	3.1	23k	21k	18k	9.4k	75k
Congo, Rep.	2.0	2.7	3.8	4.9	2.7	3.2	3.0	2.9	2.7	3.1	33k	6k	5.5k	8.1k	53k
Ukraine	2.6	3.3	4.3	4.9	3.4	3.0	2.9	2.7	2.6	2.8	230k	370k	37k	28k	760k
Slovak Republic	2.8	4.2	5.1	4.8	3.5	2.9	2.6	2.5	2.6	2.8	58k	39k	3.3k	5k	110k
Suriname	3.1		4.9	4.8	3.2	2.9		2.7	2.7	2.9	8.4k		270	570	9.4k
Romania	2.7	3.7	4.6	4.7	3.4	2.9	2.7	2.6	2.6	2.7	150k	160k	17k	24k	370k
Switzerland	1.8	3.8	4.7	4.7	2.6	3.1	2.8	2.7	2.6	3.0	120k	68k	6.2k	7k	210k
United Kingdom	3.8	5.2	5.8	4.7	4.1	2.7	2.5	2.5	2.6	2.7	1.3M	240k	42k	44k	1.6M
Georgia	3.8	4.1	5.1	4.7	4.1	2.7	2.7	2.5	2.6	2.7	54k	27k	2.8k	2.2k	95k
Russian Federa- tion	2.4	3.4	4.4	4.7	3.7	3.1	2.9	2.8	2.8	2.9	620k	600k	140k	100k	1.9M
Cote d'Ivoire	2.8	2.8	4.2	4.7	3.3	3.0	2.9	2.7	2.6	2.9	51k	9.6k	7k	8.4k	79k
Bahrain	2.1	2.7	3.5	4.7	2.5	3.1	3.0	2.9	2.9	3.0	17k	11k	1.6k	690	30k
Armenia	3.4	3.8	3.9	4.7	3.8	2.9	2.8	2.8	2.7	2.8	21k	17k	2.6k	1.4k	46k
Haiti	3.6	4.6	5.1	4.6	4.6	3.0	2.7	2.7	2.7	2.7	10k	12k	3.4k	7.1k	40k
Vietnam	3.9	4.2	4.4	4.6	4.4	2.8	2.7	2.8	2.8	2.8	67k	99k	28k	68k	290k
Lao PDR	3.3	3.7	4.5	4.4	4.0	2.8	2.7	2.7	2.7	2.7	4.7k	4.8k	2.4k	2.5k	18k
Israel	2.0	3.2	4.4	4.4	3.3	3.1	2.9	2.8	2.8	2.9	17k	53k	16k	12k	99k
Nicaragua	1.6	2.5	3.7	4.4	2.8	3.3	3.1	2.9	2.8	3.0	17k	14k	7.6k	6.2k	49k
Croatia	3.1	4.4	5.1	4.3	3.7	2.9	2.6	2.6	2.7	2.7	46k	32k	2.7k	2.7k	87k
Azerbaijan	4.8	4.5	4.4	4.3	4.6	2.6	2.7	2.7	2.7	2.6	39k	53k	7k	20k	130k

	Sprawl (SNDi)					Nodal degree					N(nodes)				
	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock
India	3.2	3.3	3.8	4.3	3.7	2.9	2.9	2.8	2.7	2.8	510k	740k	320k	550k	2.4M
Bulgaria	1.6	1.7	4.1	4.2	1.8	3.1	3.0	2.7	2.7	3.0	98k	110k	4.2k	4k	230k
Uganda	4.2	3.4	3.9	4.2	4.7	2.7	2.8	2.8	2.7	2.6	11k	4.4k	11k	15k	120k
South Africa	3.0	3.8	3.7	4.2	3.6	3.0	2.9	2.9	2.8	2.9	170k	240k	110k	110k	660k
Austria	2.5	3.4	4.6	4.2	2.9	3.0	2.8	2.7	2.7	2.9	150k	76k	13k	13k	260k
Lithuania	1.6	2.7	3.7	4.2	2.9	3.2	3.0	2.8	2.8	2.9	16k	15k	3.6k	1.9k	57k
Nepal	3.8	3.2	2.9	4.1	4.0	2.8	2.8	2.9	2.7	2.7	19k	9.6k	3.6k	5.3k	63k
Denmark	2.5	3.1	3.6	4.1	2.9	2.9	2.8	2.8	2.7	2.9	130k	77k	9.7k	19k	240k
Jordan	2.8	2.6	3.5	4.1	3.0	3.0	3.0	2.8	2.8	2.9	5.4k	56k	13k	11k	93k
Italy	2.2	3.5	4.0	4.1	2.8	3.0	2.8	2.8	2.7	2.9	790k	580k	60k	74k	1.5M
Australia	2.7	4.5	5.3	4.1	3.5	3.0	2.7	2.6	2.8	2.9	380k	220k	42k	64k	710k
Poland	1.9	3.0	3.9	4.0	2.6	3.1	2.9	2.7	2.7	2.9	230k	210k	25k	39k	530k
Tanzania	3.0	2.4	3.8	4.0	3.5	2.9	2.9	2.8	2.8	2.8	25k	13k	20k	31k	110k
France	2.3	3.6	3.9	4.0	2.9	3.0	2.8	2.7	2.7	2.9	1.1M	780k	140k	150k	2.2M
Czech Republic	2.0	3.2	3.7	4.0	2.6	3.0	2.8	2.7	2.7	2.9	150k	89k	7.4k	15k	270k
Mexico	1.7	2.4	3.1	3.9	2.6	3.2	3.1	3.0	3.0	3.1	430k	760k	240k	280k	1.9M
Mongolia	3.4	4.2	4.6	3.9	3.7	2.8	2.7	2.8	2.8	2.8	1.5k	6.5k	830	3.4k	27k
Finland	2.0	2.8	3.5	3.9	3.1	3.2	3.0	2.9	2.9	2.9	54k	40k	11k	15k	160k
Mauritius	2.9			3.9	3.0	2.9			2.8	2.8	17k			3k	21k
Estonia	1.5	2.4	4.1	3.9	2.6	3.2	3.0	2.8	2.9	3.0	12k	9.6k	1.2k	1.5k	33k
Hong Kong SAR, China	1.1	2.1	1.5	3.9	1.4	3.3	3.2	3.4	3.1	3.3	7.5k	3k	530	130	11k
Uzbekistan	3.2	3.1	3.9	3.9	3.5	2.9	2.9	2.8	2.7	2.8	78k	65k	13k	18k	210k
Cambodia	2.3	2.8	3.2	3.9	3.3	3.1	2.9	2.9	2.9	2.9	2.5k	11k	4.4k	12k	41k
Tajikistan	3.8	3.3	3.5	3.8	4.0	2.8	2.9	2.8	2.8	2.8	9.9k	8.3k	1.5k	4.1k	33k
Dominican Republic	1.7	3.1	2.8	3.7	2.7	3.2	3.0	3.0	2.9	3.0	35k	43k	20k	12k	110k
Malawi	3.8	3.6	3.9	3.7	3.7	2.8	2.8	2.7	2.7	2.8	11k	6.1k	6.6k	23k	58k
Portugal	2.8	3.2	3.8	3.7	3.1	3.0	2.9	2.8	2.8	2.9	170k	140k	45k	33k	390k
Moldova	2.3	2.7	3.1	3.7	2.6	2.9	2.9	2.8	2.7	2.9	29k	54k	2.6k	1.4k	88k
Myanmar	2.8	2.8	2.0	3.7	3.0	3.0	3.0	3.1	2.9	2.9	30k	49k	29k	35k	180k
Hungary	1.6	2.8	3.5	3.6	2.3	3.1	2.9	2.8	2.7	2.9	120k	86k	8.8k	11k	230k
Sweden	2.0	3.1	3.6	3.6	2.6	3.1	2.9	2.9	2.9	3.0	170k	61k	11k	15k	300k
Greece	0.9	2.4	3.2	3.6	1.5	3.2	2.9	2.8	2.8	3.1	200k	140k	13k	11k	380k
Malta	1.0	1.9	3.1	3.6	1.7	3.3	3.1	2.9	2.8	3.1	4.5k	7.2k	290	580	13k
Kenya	4.5	4.1	4.9	3.6	4.1	2.8	2.8	2.7	2.8	2.7	3.2k	12k	7.5k	20k	58k

	Sprawl (SNDi)					Nodal degree					N(nodes)				
	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock
Afghanistan	5.6	3.8	5.3	3.6	4.8	2.6	2.8	2.6	3.0	2.7	6k	13k	2.1k	8.3k	97k
Central African Re- public	2.9	3.7	3.9	3.6	3.6	3.0	3.0	3.0	3.0	3.0	5.3k	1.3k	2.3k	1.5k	12k
Canada	2.2	3.2	3.7	3.5	2.7	3.1	3.0	2.9	3.0	3.0	370k	190k	49k	66k	720k
Rwanda	2.5	3.4	3.5	3.5	3.7	3.0	2.9	2.9	2.9	2.8	470	3.6k	1.2k	7.3k	15k
Belgium	1.6	2.8	3.4	3.5	2.2	3.1	2.9	2.8	2.7	3.0	160k	93k	15k	18k	290k
Latvia	1.5	2.3	3.7	3.5	2.6	3.2	3.0	2.8	2.9	2.9	14k	13k	2.2k	1.5k	46k
Kazakhstan	2.9	2.5	3.2	3.5	3.0	3.0	3.1	3.0	3.0	3.0	33k	64k	9.4k	15k	150k
Zambia	2.4	2.9	3.3	3.5	3.3	3.0	3.0	2.9	2.9	2.9	27k	9.7k	4k	15k	73k
Congo, Dem. Rep.	3.0	3.2	3.3	3.5	3.6	3.1	3.1	3.0	2.9	2.9	86k	55k	36k	63k	290k
Pakistan	2.2	2.8	3.6	3.5	2.8	3.1	2.9	2.9	2.9	3.0	78k	78k	23k	53k	250k
Nigeria	2.5	3.4	4.2	3.4	3.5	2.9	2.8	2.7	2.8	2.8	160k	260k	110k	430k	1.3M
Chile	2.0	2.6	3.2	3.4	2.6	3.1	3.0	2.9	2.9	3.0	130k	80k	46k	51k	320k
Oman	3.7	2.8	3.5	3.4	3.4	2.7	3.0	2.8	2.9	2.8	7.7k	11k	8.4k	7.6k	53k
Colombia	1.6	-0.1	2.8	3.4	1.8	3.2	3.3	3.0	2.9	3.2	290k	120	22k	23k	350k
Zimbabwe	2.5	3.0	3.4	3.4	3.1	3.0	2.9	2.9	2.9	2.9	8k	25k	14k	9.6k	66k
Egypt, Arab Rep.	3.5	3.1	3.4	3.3	3.4	2.8	2.9	2.8	2.9	2.9	240k	110k	31k	54k	460k
Togo	2.1	2.0	2.3	3.3	2.6	3.0	3.0	3.0	2.8	2.9	14k	12k	8.1k	11k	53k
Cuba	0.9	2.2	2.7	3.3	1.4	3.3	3.0	2.9	2.8	3.1	60k	37k	3k	2.3k	100k
Luxembourg	2.0	2.9	3.2	3.2	2.4	3.1	2.9	2.9	2.8	3.0	8.3k	5.3k	1.3k	910	16k
Germany	1.9	3.0	3.2	3.2	2.3	3.1	2.9	2.8	2.8	3.0	1.4M	640k	100k	110k	2.3M
Benin	1.3	2.1	2.3	3.2	2.5	3.1	3.0	3.0	2.8	2.9	12k	18k	15k	17k	68k
Cabo Verde	2.6			3.2	2.8	3.1			3.0	3.1	3.3k			480	5.7k
Lesotho	3.5	2.8	2.7	3.1	3.4	2.8	2.9	2.9	2.9	2.8	800	8.4k	9.1k	12k	43k
Yemen, Rep.	3.3	2.2	3.4	3.1	3.3	3.0	3.1	3.0	3.0	3.0	4k	13k	3k	19k	48k
Qatar	2.4	3.0	3.2	3.1	2.9	3.1	3.0	3.0	3.0	3.0	7.5k	17k	1.6k	4.2k	33k
Burundi	2.4	3.2	3.7	3.1	3.3	3.2	2.9	2.9	2.9	2.9	1.5k	2.7k	2.7k	6.9k	20k
Kyrgyz Republic	2.9	3.2	3.0	3.1	3.2	2.9	2.9	2.9	2.9	2.9	11k	17k	5.3k	13k	52k
Namibia	2.0	2.2	3.4	3.1	2.8	3.1	3.1	2.9	3.0	3.0	2.3k	5k	4k	3.9k	18k
Iran, Islamic Rep.	3.5	2.7	3.0	2.9	3.0	2.7	2.9	2.9	2.9	2.9	210k	370k	79k	200k	950k
Syrian Arab Re- public	1.3	1.8	2.3	2.9	1.7	3.1	3.1	2.9	2.9	3.0	81k	70k	12k	17k	190k
Brazil	1.8	2.2	2.3	2.9	2.1	3.2	3.1	3.1	3.0	3.1	1.6M	820k	430k	280k	3.4M

	Sprawl (SNDi)					Nodal degree					N(nodes)				
	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock
Saudi Arabia	2.0	2.3	2.8	2.8	2.9	3.2	3.1	3.1	3.1	3.1	58k	160k	40k	66k	420k
China	2.9	3.0	2.7	2.8	3.1	3.0	3.0	3.1	3.1	3.0	340k	520k	220k	460k	1.9M
Iceland	1.9		3.3	2.8	2.5	3.1		2.9	3.0	3.0	5.6k		960	2.4k	12k
United Arab Emirates	1.7	1.2	2.2	2.8	1.9	3.2	3.2	3.1	3.1	3.1	40k	11k	5.4k	9.3k	90k
Algeria	2.5	2.1	2.1	2.8	2.3	3.0	3.1	3.1	3.0	3.0	35k	240k	63k	57k	410k
Tunisia	1.7	2.0	1.9	2.7	1.9	3.1	3.0	3.1	3.0	3.0	37k	83k	21k	9.5k	150k
Ethiopia	2.8	2.5	2.4	2.7	2.7	3.0	3.0	3.1	3.1	3.0	6.7k	23k	21k	99k	190k
Angola	2.8	3.4	3.4	2.6	2.9	3.0	2.9	3.0	3.1	3.0	27k	24k	11k	59k	150k
Turkey	1.6	1.5	2.1	2.6	1.9	3.1	3.1	3.1	3.0	3.1	260k	510k	150k	100k	1.1M
Ecuador	2.0		2.5	2.6	2.2	3.1		3.1	3.1	3.1	150k		12k	17k	210k
Belarus	1.8	2.2	2.7	2.6	2.8	3.2	3.0	3.0	3.0	2.9	39k	34k	8.6k	6.7k	160k
Spain	1.2	2.1	2.6	2.6	1.8	3.2	3.0	3.0	3.0	3.1	580k	470k	130k	110k	1.4M
Kuwait	2.7	4.1	3.1	2.5	3.0	3.2	3.2	3.2	3.2	3.2	20k	10k	2k	2.5k	37k
Netherlands	1.5	2.2	2.2	2.5	1.9	3.2	3.1	3.1	3.0	3.1	260k	140k	52k	54k	500k
Turkmenistan	1.9	2.3	2.1	2.4	2.4	3.2	3.1	3.1	3.1	3.1	5k	7.1k	2.7k	3.6k	26k
Korea, Rep.	0.9	1.4	2.0	2.4	1.4	3.2	3.2	3.1	3.1	3.2	160k	120k	37k	37k	370k
Gambia, The	0.5	1.5	1.6	2.3	1.4	3.2	3.1	3.1	2.9	3.1	5.7k	5.1k	4.8k	1.6k	19k
Iraq	2.1	1.8	2.0	2.2	2.0	3.1	3.1	3.0	3.0	3.1	28k	150k	21k	110k	320k
Botswana	1.8	2.3	2.7	2.2	2.2	3.0	3.0	2.9	3.0	3.0	4.3k	20k	14k	11k	71k
Paraguay	1.1	1.5	1.6	2.1	1.4	3.3	3.2	3.2	3.2	3.2	34k	21k	9.8k	7.7k	89k
Morocco	1.5	1.9	1.9	2.0	1.9	3.2	3.1	3.1	3.1	3.1	81k	86k	29k	59k	280k
Uruguay	-0.3	0.5	1.7	2.0	0.4	3.5	3.3	3.1	3.0	3.4	24k	29k	6.9k	2.9k	66k
Mali	0.7	1.0	1.5	1.9	1.5	3.3	3.2	3.2	3.1	3.2	7.8k	33k	8.8k	28k	89k
Niger	0.2	0.6	1.3	1.8	1.4	3.3	3.3	3.2	3.2	3.2	4.2k	8.1k	4.5k	17k	46k
Sudan	0.6	1.1	1.6	1.8	1.6	3.3	3.4	3.3	3.3	3.3	64k	52k	12k	92k	320k
Japan	1.1	1.5	2.2	1.8	1.3	3.2	3.1	3.1	3.1	3.1	2.8M	990k	130k	110k	4M
Taiwan, China	1.1	2.1	2.0	1.8	1.3	3.2	3.1	3.2	3.2	3.2	130k	12k	7.9k	7.5k	160k
Mozambique	2.1	1.2	1.7	1.7	1.8	3.1	3.1	3.1	3.0	3.0	16k	33k	16k	38k	130k
Senegal	0.9	1.2	1.3	1.6	1.5	3.3	3.3	3.2	3.1	3.2	30k	47k	19k	31k	150k
South Sudan	0.9	0.6	2.4	1.6	1.9	3.4	3.4	3.4	3.3	3.3	2k	1.2k	1.1k	11k	21k
Eritrea	3.6	2.6	3.0	1.6	2.6	3.0	3.1	3.1	3.2	3.1	2.2k	1.7k	630	2.4k	18k
Peru	1.5	0.8	1.5	1.5	1.5	3.2	3.3	3.2	3.2	3.2	190k	11k	9.1k	23k	280k
Argentina	0.2	0.5	1.1	1.5	0.6	3.5	3.4	3.3	3.3	3.4	300k	310k	84k	69k	820k
Burkina Faso	0.6	1.3	1.4	1.5	1.5	3.3	3.2	3.2	3.1	3.1	16k	10k	12k	28k	74k
Belize	1.4	2.1	2.8	1.5	2.2	3.1	3.1	3.0	3.1	3.0	2.7k	1.6k	2.1k	620	9k

	Sprawl (SNDi)					Nodal degree					N(nodes)				
	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock	<1975	75–89	90–99	2000–13	Stock
Bolivia	1.3	1.1	1.0	1.2	1.5	3.3	3.3	3.3	3.3	3.2	42k	34k	26k	36k	170k
Singapore	1.9		1.3	1.1	1.9	3.3		3.4	3.5	3.3	17k		380	170	18k
Chad	0.0	1.2	1.0	1.1	1.2	3.4	3.4	3.3	3.3	3.3	5.6k	3.1k	4.9k	12k	34k
Somalia	0.9	0.9	1.6	1.0	1.1	3.4	3.3	3.3	3.3	3.3	16k	16k	4.7k	19k	60k
Mauritania	0.1	0.2	0.5	0.5	0.6	3.4	3.3	3.3	3.3	3.3	5.8k	3.5k	2.1k	4.1k	26k
Maldives	-0.6			-0.3	0.7	3.3			3.3	3.0	440			280	7k

F.6 Cities ranked by urban street-network sprawl (SNDi) of recent road development

Table S2: Cities listed in order of their recent urban street-network sprawl (SNDi).

	Sprawl (SNDi)				Nodal degree				N(nodes)			
	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock
Suva, FIJI	3.5	8.4	10.4	8.2	2.9	2.3	2.1	2.4	150	1.4k	150	1.7k
Caracas, VENEZUELA	4.9	10.4	10.1	5.3	2.8	2.3	2.3	2.8	11k	770	540	12k
Bangkok, THAILAND	6.8	7.6	8.1	7.3	2.5	2.5	2.4	2.5	74k	30k	46k	150k
Guatemala City, GUATEMALA	3.8	5.6	7.5	4.5	3.0	2.8	2.5	2.9	22k	7.3k	4.7k	34k
Cebu City, PHILIPPINES	6.1	6.9	7.3	6.6	2.6	2.5	2.6	2.6	5.7k	2.3k	4.5k	12k
Gorgan, IRAN	3.6	5.8	6.7	3.9	2.7	2.5	2.4	2.7	3.3k	470	240	4k
Los Angeles, UNITED STATES	3.6	6.2	6.3	3.9	2.9	2.6	2.6	2.9	250k	26k	9.7k	290k
Raleigh, UNITED STATES	4.8	5.4	6.3	5.6	2.8	2.7	2.5	2.6	11k	21k	19k	51k
Palembang, INDONESIA	4.7	5.6	6.3	5.2	2.6	2.5	2.5	2.6	15k	19k	3.9k	39k
New York, UNITED STATES	2.9	5.2	6.3	3.1	3.0	2.7	2.5	2.9	320k	42k	3.5k	360k
San Salvador, EL SALVADOR	4.4	7.1	6.1	5.0	2.8	2.5	2.6	2.7	11k	1.7k	4.7k	17k
Belgrade, SERBIA	2.9	6.6	6.0	4.2	3.0	2.3	2.4	2.7	9.1k	2.2k	4k	15k
Tijuana, MEXICO	4.3	3.6	6.0	4.4	2.9	3.0	2.7	2.9	15k	9.2k	8.5k	33k
Florianopolis, BRAZIL	2.9	5.9	5.9	4.1	2.9	2.5	2.6	2.8	7.2k	2.5k	3.2k	13k
Pune, INDIA	3.4	5.0	5.9	4.9	2.8	2.6	2.5	2.7	6.3k	15k	10k	31k
Sao Paulo, BRAZIL	2.1	4.9	5.8	2.5	3.1	2.8	2.6	3.0	150k	23k	5.5k	180k
Medan, INDONESIA	4.0	5.2	5.8	4.9	2.7	2.5	2.5	2.6	20k	29k	16k	64k
Gainesville, UNITED STATES	3.0	6.4	5.6	3.8	3.1	2.7	2.8	3.0	3.9k	800	1.2k	5.8k
Johannesburg, SOUTH AFRICA	2.9	4.1	5.5	3.8	3.0	2.9	2.8	2.9	63k	16k	30k	110k
Dhaka, BANGLADESH	3.3	4.9	5.5	4.0	2.9	2.7	2.6	2.8	14k	5.5k	6.6k	26k
Kolkata, INDIA	3.2	4.6	5.4	3.9	2.9	2.7	2.6	2.8	20k	10k	6.4k	36k
Pematangsiantar, INDONESIA	3.2	4.6	5.4	3.7	2.9	2.8	2.6	2.9	1.5k	300	280	2.1k
Ulaanbaatar, MONGOLIA	4.1	4.8	5.3	4.5	2.8	2.6	2.6	2.7	5.9k	1.4k	3.1k	10k
Kampala, UGANDA	4.9	5.6	5.3	5.1	2.6	2.5	2.6	2.6	8.4k	3.8k	3.2k	15k
Houston, UNITED STATES	2.9	5.1	5.3	3.9	3.1	2.8	2.8	2.9	88k	31k	45k	160k
Philadelphia, UNITED STATES	2.3	4.9	5.2	2.8	3.1	2.8	2.7	3.0	120k	25k	15k	160k
Victoria, CANADA	2.9	4.6	5.2	3.3	2.9	2.7	2.8	2.9	6.6k	1.8k	450	8.8k
Ho Chi Minh City, VIET NAM	1.8	4.2	5.2	4.6	3.2	2.8	2.6	2.7	6.1k	13k	45k	64k
Manila, PHILIPPINES	3.9	5.1	5.1	4.4	3.0	2.9	2.9	2.9	62k	26k	29k	120k
Sheffield, UNITED KINGDOM	3.4	5.1	5.1	3.5	2.8	2.5	2.5	2.7	29k	2.5k	810	32k
Rawang, MALAYSIA	3.5	4.7	5.0	4.7	3.0	3.0	2.9	2.9	540	820	3.8k	5.1k
Pokhara, NEPAL	3.2	4.5	5.0	3.6	2.7	2.6	2.5	2.7	1.8k	280	470	2.6k
Baku, AZERBAIJAN	4.1	5.2	5.0	4.6	2.8	2.5	2.6	2.7	11k	7.4k	5.1k	23k

	Sprawl (SNDi)				Nodal degree				N(nodes)			
	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock
Lagos, NIGERIA	4.2	4.6	5.0	4.5	2.8	2.6	2.6	2.7	24k	22k	19k	65k
Vijayawada, INDIA	2.8	4.1	4.9	3.2	3.0	2.7	2.6	2.9	6.9k	1.4k	730	9k
Sialkot, PAKISTAN	2.7	4.9	4.9	4.0	3.0	2.6	2.6	2.8	1.6k	2.3k	320	4.3k
Rajshahi, BANGLADESH	1.4	3.7	4.9	3.9	3.1	2.7	2.6	2.7	130	1.6k	710	2.4k
Cirebon, INDONESIA	2.7	4.2	4.9	4.5	2.9	2.7	2.7	2.7	1.1k	2.3k	7.9k	11k
Portland, UNITED STATES	3.0	4.9	4.8	3.4	3.0	2.7	2.7	2.9	51k	10k	6.1k	67k
Cleveland, UNITED STATES	2.8	5.4	4.8	3.8	3.0	2.7	2.8	2.9	24k	9.5k	14k	47k
Tyumen, RUSSIA	1.7	4.5	4.8	3.0	3.3	2.8	2.8	3.1	2.3k	920	1.2k	4.4k
Mexico City, MEXICO	1.8	4.0	4.8	2.7	3.2	2.8	2.7	3.0	120k	32k	40k	190k
Algiers, ALGERIA	3.9	3.8	4.7	4.1	2.9	2.9	2.8	2.9	12k	10k	8.9k	31k
Minneapolis, UNITED STATES	2.8	4.6	4.7	3.3	3.1	2.8	2.7	3.0	63k	14k	11k	88k
Kaunas, LITHUANIA	2.2	5.3	4.7	2.7	3.2	2.7	2.8	3.1	3.2k	170	680	4k
Coimbatore, INDIA	3.5	4.2	4.7	3.9	2.8	2.8	2.7	2.8	7.2k	5.3k	3.4k	16k
Arusha, TANZANIA	1.4	4.5	4.7	3.6	3.1	2.6	2.7	2.8	270	400	250	910
Manchester, UNITED KINGDOM	4.0	5.2	4.6	4.0	2.7	2.5	2.6	2.7	71k	2.5k	220	74k
Springfield, UNITED STATES	3.0	4.7	4.6	3.7	2.9	2.8	2.7	2.9	9.6k	7.1k	2.2k	19k
Mumbai, INDIA	3.3	4.3	4.6	3.7	2.9	2.8	2.7	2.8	23k	2.5k	8.4k	34k
Astrakhan, RUSSIA	2.0	3.5	4.6	2.5	3.1	2.8	2.6	3.0	3.7k	2.4k	150	6.2k
Toledo, UNITED STATES	2.1	4.2	4.6	2.8	3.2	2.9	2.8	3.0	9.9k	3.4k	2.8k	16k
Kozhikode, INDIA	1.7	3.8	4.5	3.5	3.0	2.7	2.6	2.7	340	530	970	1.8k
Parepare, INDONESIA	2.4	3.8	4.4	3.3	3.0	2.7	2.7	2.8	750	300	520	1.6k
Guadalajara, MEXICO	1.7	3.8	4.4	2.5	3.2	3.0	2.9	3.1	46k	8.8k	21k	75k
Chicago, UNITED STATES	2.6	4.6	4.4	2.9	3.1	2.8	2.8	3.0	170k	30k	13k	210k
Jequeie, BRAZIL	1.2	1.9	4.4	1.5	3.2	3.1	2.9	3.2	2.4k	840	240	3.4k
Santiago, CHILE	1.5	2.1	4.4	1.9	3.1	3.1	2.9	3.1	66k	14k	13k	93k
Cabimas, VENEZUELA	2.4	2.8	4.3	2.6	2.9	3.0	2.7	2.9	6.4k	1.3k	700	8.4k
Tashkent, UZBEKISTAN	2.7	4.3	4.3	3.3	3.0	2.8	2.7	2.9	17k	8.6k	4.1k	30k
Bacolod, PHILIPPINES	2.6	5.1	4.3	4.2	3.1	2.9	3.1	3.0	1.1k	1.7k	870	3.7k
Ipoh, MALAYSIA	3.6	4.4	4.3	3.8	2.9	2.8	2.9	2.9	11k	3.3k	1.5k	16k
Ahvaz, IRAN	1.8	3.7	4.3	2.4	3.2	2.8	2.8	3.1	9.2k	2.3k	1.8k	13k
Killeen, UNITED STATES	2.7	3.5	4.3	3.4	3.0	2.9	2.8	2.9	4.1k	710	3.2k	8k
Singrauli, INDIA	4.7	4.0	4.3	4.2	2.8	2.9	2.9	2.9	220	780	420	1.4k
Accra, GHANA	3.3	3.5	4.2	3.9	2.9	2.8	2.7	2.8	7.9k	18k	31k	57k
Sydney, AUSTRALIA	3.0	5.2	4.2	3.3	2.9	2.7	2.9	2.9	61k	7.8k	7.8k	76k
Bogota, COLOMBIA	1.2	2.0	4.2	1.3	3.2	3.1	2.8	3.2	44k	4.7k	1.1k	50k
Quito, ECUADOR	1.9	4.0	4.1	3.3	3.1	2.9	2.8	2.9	10k	6k	16k	32k

	Sprawl (SNDi)				Nodal degree				N(nodes)			
	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock
Moscow, RUSSIA	1.3	3.3	4.1	2.2	3.4	3.0	2.9	3.2	30k	11k	13k	54k
Ibadan, NIGERIA	4.1	3.7	4.1	4.0	2.7	2.8	2.7	2.7	20k	12k	16k	47k
Belo Horizonte, BRAZIL	1.5	3.7	4.1	1.8	3.2	2.9	2.9	3.2	42k	4.7k	2.8k	50k
London, UNITED KINGDOM	3.3	4.3	4.1	3.4	2.8	2.7	2.7	2.8	150k	25k	2.8k	180k
Saidpur, BANGLADESH	2.7		4.0	3.2	2.8		2.6	2.8	270	19	130	420
Istanbul, TURKEY	1.0	1.6	4.0	1.5	3.2	3.2	2.8	3.2	76k	48k	21k	140k
Warsaw, POLAND	1.5	2.5	4.0	2.2	3.3	3.0	2.7	3.1	17k	6.9k	5.3k	29k
Curitiba, BRAZIL	1.8	3.0	4.0	2.4	3.2	3.0	2.8	3.1	23k	15k	6.8k	45k
Sana, YEMEN	1.1	2.5	4.0	1.5	3.2	3.0	2.8	3.1	9.2k	1.1k	1.1k	11k
Tehran, IRAN	2.4	3.5	3.9	2.6	3.0	2.9	2.8	2.9	63k	11k	7.7k	82k
Hyderabad, INDIA	2.6	3.1	3.8	3.1	2.9	2.9	2.8	2.9	53k	41k	43k	140k
Halle, GERMANY	1.1	2.9	3.8	1.5	3.3	3.0	2.8	3.2	2.9k	960	180	4.1k
Modesto, UNITED STATES	3.1	3.6	3.7	3.4	2.9	2.8	2.8	2.8	7.3k	3.2k	2.6k	13k
Rovno, UKRAINE	2.3	3.1	3.7	3.0	3.1	2.8	2.8	2.9	930	250	1.3k	2.5k
Milan, ITALY	1.9	3.6	3.7	2.9	3.1	2.8	2.7	2.9	58k	48k	31k	140k
Lausanne, SWITZERLAND	1.3	2.7	3.7	1.8	3.4	3.1	2.8	3.2	2.6k	1.1k	290	4.1k
Haikou, CHINA	2.8	2.6	3.7	3.0	3.1	3.1	2.9	3.0	1.2k	460	1k	2.6k
Hong Kong, CHINA	0.7	1.7	3.7	0.9	3.4	3.3	3.0	3.4	5.1k	820	220	6.1k
Auckland, NEW ZEALAND	3.2	4.0	3.7	3.3	2.9	2.9	3.0	2.9	17k	1.8k	1.7k	20k
Osaka, JAPAN	1.2	2.8	3.7	1.3	3.2	3.0	2.9	3.2	160k	12k	2.7k	180k
Kabul, AFGHANISTAN	3.6	3.7	3.6	3.6	2.8	2.8	2.8	2.8	12k	1.9k	7k	21k
Qom, IRAN	1.9	2.3	3.6	2.2	3.1	3.1	2.9	3.0	7.2k	1.7k	2.2k	11k
Malatya, TURKEY	1.1	2.6	3.6	1.6	3.2	3.0	2.8	3.1	3.8k	730	830	5.3k
Jaipur, INDIA	2.6	3.1	3.6	3.1	3.0	2.9	2.8	2.9	8.6k	19k	13k	40k
Nakuru, KENYA	1.8	3.5	3.5	2.5	3.1	2.9	2.8	3.0	820	180	650	1.6k
Shymkent, KAZAKHSTAN	3.6	3.3	3.5	3.5	2.9	2.9	2.9	2.9	4.3k	830	4.4k	9.5k
Kigali, RWANDA	3.0	3.3	3.5	3.3	3.0	2.9	2.9	2.9	980	1.9k	1.7k	4.6k
Culiacan, MEXICO	0.7	2.0	3.5	1.5	3.4	3.2	3.0	3.3	8.2k	3.6k	3.5k	15k
Beira, MOZAMBIQUE	2.5	4.5	3.5	3.2	3.0	2.9	2.8	2.9	1.3k	110	2k	3.4k
Tangshan, CHINA	2.9	3.1	3.4	3.3	3.0	3.0	2.8	2.9	1.7k	870	3.1k	5.6k
Tel Aviv, ISRAEL	1.1	2.5	3.4	2.0	3.2	3.1	3.0	3.1	9.6k	14k	4.2k	28k
Hindupur, INDIA			3.4	2.7			3.0	3.0	32	42	250	320
Myeik, MYANMAR	1.9	3.3	3.3	2.4	3.1	2.8	2.8	3.0	720	140	500	1.4k
Palermo, ITALY	2.2	6.4	3.3	2.6	3.0	2.5	2.8	2.9	7.1k	220	3.5k	11k
Montreal, CANADA	1.8	3.5	3.3	1.9	3.3	3.0	3.1	3.2	45k	2.4k	4.7k	52k
Port Elizabeth, SOUTH AFRICA	2.3	4.2	3.3	2.7	3.0	2.8	3.0	3.0	9.1k	990	6.3k	16k

	Sprawl (SNDi)				Nodal degree				N(nodes)			
	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock
Paris, FRANCE	1.8	3.0	3.3	2.0	3.1	2.9	2.8	3.1	120k	13k	11k	140k
Alexandria, EGYPT	0.7	2.3	3.3	1.1	3.3	3.0	2.9	3.2	8.2k	1.2k	1.8k	11k
Antwerp, BELGIUM	1.5	2.8	3.2	1.9	3.2	2.9	2.8	3.1	16k	6.2k	1.1k	23k
Ahmedabad, INDIA	2.5	3.5	3.2	2.7	3.0	2.8	2.9	2.9	8.9k	1.5k	1.5k	12k
Saint Petersburg, RUSSIA	0.5	3.4	3.2	1.9	3.6	2.9	3.0	3.3	9.6k	3.6k	6.8k	20k
Palmas, BRAZIL	3.1	3.5	3.2	3.3	3.1	2.9	3.1	3.0	1.2k	3k	1.1k	5.3k
Lahore, PAKISTAN	2.3	2.8	3.2	2.5	3.0	2.9	3.0	3.0	25k	6k	8.7k	40k
Oyo, NIGERIA	3.4	3.4	3.2	3.3	2.7	2.8	2.8	2.8	1.5k	780	2.3k	4.5k
Kinshasa, DR CONGO	2.1	3.2	3.2	2.7	3.2	3.0	2.9	3.1	19k	13k	15k	46k
Shanghai, CHINA	1.6	2.9	3.1	2.1	3.3	3.1	3.1	3.2	22k	10k	4.3k	36k
Zunyi, CHINA	3.6	3.4	3.1	3.3	2.9	3.0	3.1	3.0	450	210	400	1.1k
Seoul, SOUTH KOREA	0.9	2.3	3.1	1.2	3.2	3.1	3.0	3.2	87k	23k	15k	130k
Guixi, CHINA	1.3		3.1	2.5	3.0		2.8	2.9	120	98	150	370
Vienna, AUSTRIA	0.5	2.3	3.0	1.0	3.4	3.0	2.9	3.3	16k	5.9k	1.5k	23k
Tebessa, ALGERIA	2.0	2.6	3.0	2.2	3.1	3.1	2.9	3.1	2.5k	850	370	3.8k
Shenzhen, CHINA	2.5	2.6	3.0	2.7	3.1	3.1	3.0	3.1	6.8k	10k	5.6k	23k
Reynosa, MEXICO	1.9	2.9	3.0	2.2	3.2	3.2	3.0	3.2	7.5k	720	3k	11k
Oldenburg, GERMANY	2.0	3.0	3.0	2.2	3.2	3.0	2.9	3.1	2.5k	670	400	3.5k
Guangzhou, CHINA	1.8	2.8	2.9	2.8	3.2	3.0	3.0	3.0	5.6k	34k	33k	73k
Baghdad, IRAQ	2.1	3.3	2.9	2.2	3.1	2.8	2.9	3.1	45k	800	1.1k	47k
Gomel, BELARUS	1.6	2.4	2.9	2.0	3.3	3.0	2.9	3.1	1.4k	1.1k	190	2.7k
Riyadh, SAUDI ARABIA	1.7	2.7	2.9	2.1	3.2	3.1	3.1	3.1	50k	14k	26k	90k
Qingdao, CHINA	1.6	1.0	2.8	2.4	3.2	3.2	3.0	3.0	2.7k	2.3k	14k	19k
Singapore, SINGAPORE	1.9	1.5	2.8	1.9	3.3	3.4	3.2	3.3	14k	2.3k	620	17k
Cochabamba, BOLIVIA	0.6	2.2	2.8	1.6	3.4	3.1	3.0	3.2	9.5k	6.2k	5.8k	21k
Cairo, EGYPT	1.4	2.2	2.7	2.1	3.2	3.1	3.1	3.1	23k	5.1k	33k	62k
Cordoba, ARGENTINA	0.6	2.3	2.7	1.0	3.4	3.2	3.1	3.3	22k	2.4k	4.5k	29k
Xingping, CHINA	2.4		2.7	2.5	3.0		2.9	2.9	110	34	260	410
Beijing, CHINA	2.0	2.7	2.7	2.3	3.2	3.1	3.1	3.1	19k	4.6k	15k	39k
Bukhara, UZBEKISTAN	0.9	2.9	2.7	2.5	3.3	2.9	2.9	2.9	380	910	1.3k	2.6k
Belgaum, INDIA	1.2	2.1	2.7	2.2	3.1	3.1	3.0	3.1	560	740	1.5k	2.8k
Taipei, CHINA	0.4	1.9	2.6	1.2	3.4	3.1	3.0	3.2	15k	9.3k	7.7k	33k
Yulin, CHINA	2.7	2.1	2.5	2.7	2.9	3.1	2.9	3.0	210	320	300	820
Bicheng, CHINA	0.2	0.4	2.5	1.7	3.3	3.3	3.1	3.1	150	130	630	910
Zwolle, NETHERLANDS	2.0	1.6	2.5	1.9	3.1	3.3	3.0	3.1	3.1k	470	200	3.7k
Tianjin, CHINA	1.7	2.9	2.5	2.3	3.3	3.1	3.1	3.1	5k	1.2k	14k	20k

	Sprawl (SNDi)				Nodal degree				N(nodes)			
	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock
Yucheng, CHINA	3.0	2.8	2.5	2.8	2.9	2.8	2.9	2.9	310	290	250	850
Hangzhou, CHINA	1.1	1.9	2.5	2.0	3.4	3.3	3.1	3.2	2.7k	7.9k	11k	22k
Kayseri, TURKEY	1.2	1.4	2.5	1.7	3.2	3.2	3.0	3.1	1.7k	6.6k	4.1k	12k
Chengdu, CHINA	2.0	2.9	2.4	2.5	3.1	3.1	3.1	3.1	4.5k	6.7k	10k	21k
Yamaguchi, JAPAN	2.5	2.5	2.4	2.5	2.9	3.1	3.0	2.9	11k	850	240	12k
Ndola, ZAMBIA	2.1	2.2	2.4	2.1	3.0	3.0	2.9	3.0	2.7k	980	450	4.2k
Wuhan, CHINA	2.0	2.4	2.3	2.3	3.1	3.1	3.0	3.1	5.5k	2k	7.9k	15k
Leshan, CHINA	0.6	1.5	2.3	1.4	3.2	3.1	3.0	3.1	200	190	200	590
Yiyang, CHINA	1.1	1.9	2.3	1.8	3.3	3.2	3.0	3.1	270	200	260	730
Karachi, PAKISTAN	1.8	1.4	2.3	1.8	3.2	3.2	3.2	3.2	20k	9k	7.5k	36k
Changzhou, CHINA	1.6	1.9	2.3	2.0	3.2	3.2	3.2	3.2	810	2k	2.9k	5.7k
Le Mans, FRANCE	1.6	2.7	2.3	1.7	3.2	3.2	3.0	3.2	4.2k	130	490	4.8k
Okayama, JAPAN	1.6	2.4	2.3	1.6	3.1	3.1	3.1	3.1	51k	1.6k	3.4k	56k
Zhengzhou, CHINA	2.4	2.3	2.2	2.4	3.2	3.2	3.2	3.2	2.9k	1.1k	5.4k	9.4k
Budapest, HUNGARY	0.5	1.3	2.2	1.2	3.4	3.1	3.0	3.2	20k	640	14k	34k
Changzhi, CHINA	0.8	3.3	2.2	1.8	3.4	3.1	3.0	3.2	370	180	310	860
Zhuji, CHINA	1.3	2.1	2.1	1.8	3.1	3.1	3.0	3.1	900	800	340	2k
Addis Ababa, ETHIOPIA	2.6	2.2	2.1	2.3	2.9	3.1	3.1	3.0	16k	11k	16k	43k
Ribeirao Preto, BRAZIL	1.1	3.0	2.1	1.4	3.3	3.0	3.1	3.3	9.3k	1.6k	1.5k	12k
Berlin, GERMANY	0.3	1.0	2.1	0.9	3.5	3.3	3.1	3.3	18k	11k	11k	40k
Thessaloniki, GREECE	0.1	1.9	2.1	0.5	3.4	3.2	3.1	3.3	11k	1.2k	2.5k	14k
Fukuoka, JAPAN	1.1	1.8	2.0	1.2	3.2	3.1	3.1	3.2	47k	6.7k	2.7k	56k
Gombe, NIGERIA	1.6	3.7	2.0	2.0	3.2	2.9	3.1	3.1	1.8k	560	4.5k	6.9k
Valledupar, COLOMBIA	-0.2	0.6	2.0	0.2	3.5	3.4	3.2	3.5	3k	1.1k	650	4.8k
Gwangju, SOUTH KOREA	0.4	1.3	1.9	0.9	3.4	3.2	3.2	3.3	5.3k	2.7k	2.3k	10k
Anqing, CHINA	0.5		1.9	1.0	3.3		3.1	3.2	200	96	260	560
Busan, SOUTH KOREA	1.3	1.6	1.8	1.4	3.2	3.1	3.2	3.2	16k	4.1k	4.2k	24k
Gaoyou, CHINA			1.8	1.8			3.1	3.1	83	32	150	260
Kanpur, INDIA	2.1	3.2	1.8	2.1	3.0	2.9	3.1	3.0	4.6k	440	420	5.5k
Tokyo, JAPAN	1.1	1.6	1.8	1.1	3.2	3.1	3.1	3.1	660k	38k	97k	800k
Marrakesh, MOROCCO	1.1	1.5	1.7	1.3	3.2	3.2	3.2	3.2	6.3k	2.2k	3.6k	12k
Leon, NICARAGUA	1.0	3.2	1.7	1.5	3.3	2.9	3.1	3.2	1.1k	380	390	1.9k
Madrid, SPAIN	0.7	1.5	1.7	1.1	3.4	3.3	3.2	3.3	28k	12k	15k	55k
Buenos Aires, ARGENTINA	-0.1	0.9	1.6	0.3	3.6	3.5	3.3	3.5	120k	17k	26k	160k
Suining, CHINA			1.6	1.0			3.2	3.3	51	61	120	230
Bamako, MALI	0.6	1.0	1.6	1.1	3.3	3.2	3.1	3.2	13k	7.5k	16k	36k

	Sprawl (SNDi)				Nodal degree				N(nodes)			
	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock	<1990	90-99	'00-13	Stock
Jinju, SOUTH KOREA	0.8	2.4	1.6	1.2	3.3	3.2	3.1	3.2	2.5k	120	2.5k	5.1k
Luanda, ANGOLA	2.0	2.2	1.5	1.8	3.0	3.0	3.1	3.1	12k	10k	28k	51k
Cheonan, SOUTH KOREA	0.2	0.7	1.3	0.8	3.4	3.4	3.2	3.3	1.6k	1.2k	2.6k	5.3k
Vinh Long, VIET NAM			1.3	1.4			3.1	3.2	72	99	160	330
Lubumbashi, DR CONGO	1.7	1.8	1.3	1.5	3.1	3.0	3.1	3.1	6.7k	2.3k	7.7k	17k
Jinan, CHINA	1.8	1.5	1.2	1.7	3.2	3.3	3.3	3.2	4.3k	620	990	5.9k
Yanggu, CHINA			0.7	0.4			3.3	3.4	79	66	130	280
Khartoum, SUDAN	0.2	0.6	0.7	0.5	3.4	3.3	3.3	3.3	56k	14k	38k	110k
Xucheng, CHINA			0.5	0.8			3.6	3.5	12	51	260	330

F.7 City maps

Maps for a number of cities are available as a ~ 300 MB PDF at:

<https://alum.mit.edu/www/cpbl/publications/draft2019sprawl/SI/all-citymaps-10.pdf>

F.8 World maps

World maps for our sprawl metrics will be available at:

<https://alum.mit.edu/www/cpbl/publications/draft2019sprawl/SI/world-maps>

F.9 World region trend plots

In the following pages, trends of individual countries (in each region or group) are represented by colored lines, and their distribution in each time range is summarized in a box plot. Each dotted line shows the latest stock value for all nodes in the group of countries. Country ISO codes are marked in microfont. Region classifications are from the World Bank [2016]. For more detail, see the tabular data.

The following pages show results only for SNDi. Other metrics are available online at:

<https://alum.mit.edu/www/cpbl/publications/draft2019sprawl>.

F.10 Country trend plots with sub-national regional distributions

In the following pages, box plots are used to describe the distribution, within each time period in each country, of the metric over sub-national regions (i.e., GADM level 1). The blue shaded region shows the full extent of the minimum and maximum value across these sub-national regions. The dark line shows the mean over the entire country.

The following pages show results only for SNDi. Other metrics are available online at: <https://alum.mit.edu/www/cpbl/publications/draft2019sprawl>.

F.11 City trend plots (by region)

The following plots show city trends in each region. Each line represents one city; in some cases there is more than one city per country. For more detail, see the tabular data. The following pages show results only for SNDi. Other metrics are available online at:

<https://alum.mit.edu/www/cpbl/publications/draft2019sprawl>.

F.12 City trend plots (by country)

In the plots below, the widest gray line is centered on the trend for the entire country's urban street network, while the less wide gray line is the node-weighted average over only the cities shown (i.e., all those available in the Atlas of Urban Expansion). Quantities are exact; line width does *not* represent confidence intervals. Countries are ordered by the number of nodes in the 2018 road stock. For more detail, see the tabular data.

The following pages show results only for SNDi. Other metrics are available online at:
<https://alum.mit.edu/www/cpbl/publications/draft2019sprawl>.