Supplementary Appendix for

Geographic constraints shape urban and economic growth worldwide

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Section 1

1.1 Data sources

Urban boundaries. To analyze the impacts of geographic barriers on urban growth, we adopted the Global Urban Boundaries (GUB) dataset derived from the annual maps of global artificial impervious areas (GAIA)[1]. The original GAIA dataset provides high-resolution data on impervious surface extent from 1985 to 2018 in *shpfile*, and has been updated to include the year 2020 in *TIFF* format. For our analysis, we extracted urban boundaries for the years 1990, 2000, 2010, and 2020. To ensure the robustness of the analysis, we excluded urban patches smaller than 5 km². After this filtering process, 7385 urban areas were retained in the base year 1990 (10589, 13085, 16599 for the other three years). As the GAIA-derived urban boundaries do not contain explicit city identifiers, it is not possible to directly track the same city across different years. To address this issue, we used the Global Administrative Areas (GADM) dataset (version 3.6)[2] as auxiliary data. By spatially overlaying GAIA boundaries with administrative units from GADM, we assigned each urban area a corresponding city name and code based on the GADM layer. To reconstruct urban growth trajectories across time, we performed spatial overlays across consecutive time periods. For instance, if an urban area in 2000 completely encompassed an area from 1990 and both fell within the same GADM administrative unit, the 2000 boundary was considered to have developed from the 1990 boundary. This procedure was iteratively applied to identify urban growth from 1990 to 2000, 2000 to 2010, and 2010 to 2020. Through this method, we constructed a consistent panel dataset of urban expansion over time.

Barriers (Water/mountains). To capture the physical constraints on urban expansion, we incorporated two major sources of natural geographic barriers: water bodies and steep slopes. Water body data were extracted from the Global 3 arc-second Water Body Map[3], which provides comprehensive global coverage at a spatial resolution of 90 meters. This dataset allowed us to accurately delineate surface water features that potentially limit urban development. Slope information was derived from the NASA Shuttle Radar Topographic Mission (SRTM) Digital Elevation Database, version 4.1[4], which offers elevation data at the same 90-meter resolution. From this dataset, we calculated slope values for each raster cell and identified areas with slopes exceeding 15 degrees. These steep terrains are generally considered unsuitable for development and were therefore classified as geographic barriers in our analysis.

Meteorological data. Precipitation data were obtained from the WorldClim, version 2.1,[5] which provides historical monthly precipitation data from 1960 to 2021. For this study, we extracted data for the years 1990, 2000, 2010, and 2020 at a spatial resolution of 2.5 arc-minutes (approximately 21 km² at the equator). Temperature data were obtained from the ECMWF[6], ERA5 hourly data, which provides global temperature data from 1940 to present. We extracted data for the years 1990, 2000, 2010, and 2020 at a spatial resolution of 15 arc-minutes. Using ArcGIS Pro 3.2, the above two data were resampled to create 15 arc-seconds raster tiff files with annual average measurements. Elevation data were obtained from the SRTM dataset, the same as slopes. Due to the long-term stability of the elevation, we therefore treat the elevation data stable across the 30 years. To estimate the precipitation, temperature and elevation data within each urban area, we spatially overlaid the three processed grids with the GAIA-derived urban boundaries (GUB dataset). The variable data within each urban footprint was calculated by averaging the values of all intersecting grid cells. This approach enabled us to generate consistent precipitation and temperature estimates for each city across the four time periods.

Spatial and Socioeconomic factors. Gross Domestic Product (GDP) were obtained from the downscaled global dataset of Kummu, et al. [7], which provides global gridded GDP (PPP) estimates at five-year intervals from 1990 to 2022. For this study, we extracted data for the years 1990, 2000, 2010, and 2020 at a spatial resolution of 30 arc-seconds (approximately 1,000 meters). Population data were obtained from the Global Human Settlement Layer (GHSL), version R2023[8], which provides global gridded population estimates at five-year intervals from 1975 to 2020. We extracted data for the years 1990, 2000, 2010, and 2020 at a spatial resolution of 30 arc-seconds (approximately 1,000 meters). To estimate the GDP and residential population within each urban area, we spatially overlaid the grids with the GAIA-derived urban boundaries (GUB dataset). The total GDP and population within each urban footprint was calculated by summing the values of all intersecting grid cells. This approach enabled us to generate consistent GDP/population estimates and corresponding GDPPC for each city across the four time periods. Urban area was calculated directly from the GUB dataset using ArcGIS Pro 3.2. Population density was subsequently computed as the total population divided by the corresponding urban area

for each city and time point. To capture vertical urban growth, we further utilized the GHS Built-up Volume dataset, also provided by the GHSL platform. This dataset offers gridded estimates of built-up volume. For each city, the total built-up volume was computed by summing the grid values within the corresponding GUB boundary. Average built-up height was then derived by dividing the total built-up volume by the urban area. This process was repeated for all four time points, resulting in a temporal dataset of average built-up height for each city.

In our regression models, we include two sets of control variables. First, precipitation, temperature, and elevation are treated as long-term geographic and climatic controls. Rather than using single-year observations—which would be highly volatile—we compute 1990–2020 multi-year averages to capture the structural climatic environment in which cities operate. Second, for each regression we control for the corresponding 1990 baseline level of the dependent variable. This follows standard practice in long-run urban growth and development regressions, allowing us to isolate how initial conditions shape growth trajectories.

Table S1. The data sources of the major socioeconomic and natural metrics

Attributes	**Sources**	**Definition**
Urban boundaries	GUB (combine GAIA/GADM) (Gong et al., 2020; Hijmans et al., 2018)	The continuous urban boundary defined by the global definition of artificial non-permeable areas. (not less than five square kilometers)
Water barriers	Global 3 arc-second Water Body Map (Yamazaki et al., 2015)	Water bodies with a resolution of 90m (including oceans, rivers, lakes, etc.)
Slope barriers	NASA Shuttle Radar Topographic Mission (SRTM) Digital Elevation Database 4.1 (Jarvis et al., 2008)	Slopes with a resolution of 90 meters (with a slope angle greater than 15 degrees)
Precipitation	WorldClim, version 2.1 (Fick et al., 2017)	Average annual precipitation
Temperature	ECMWF, ERA5 hourly data (Hersbach et al., 2020)	Average annual temperature
Elevation	NASA Shuttle Radar Topographic Mission (SRTM) Digital Elevation Database 4.1 (Jarvis et al., 2008)	Average elevation within each urban unit
Gross Domestic Product (GDP)	the downscaled global dataset (Kummu et al., 2025)	Total GDP within each urban unit. (Per capita GDP is calculated by dividing the total GDP by the population of the urban area.)
Population	Global Human Settlement Layer (GHSL), version R2023 (Pesaresi et al., 2024)	Total population within each urban unit.
Built-up height	GHS Built-up Volume dataset (Pesaresi et al., 2024)	The average built height is calculated by dividing the total built volume within the urban unit by the urban area.

1.2 Geographic and urban growth Metrics

Elastic buffer zone. To characterize the surrounding environment of each city, we first delineated the population-weighted center for each urban area, following the algorithm proposed by Chen, et al. [9]. To account for variation in city sizes across space and time, we generated an adaptive (elastic) buffer around each city center rather than applying a fixed-radius buffer. Specifically, for each city in each time period, we calculated a circular buffer whose area is 1.5 times the urban area of the city to reflect the surrounding environment of each city. All geographic barrier metrics were computed within the elastic buffer zone.

Geographic metrics. To quantify natural geographic constraints in a consistent and scalable manner, we construct two complementary indicators, referring to our previous work[10], that capture the quantity of undevelopable land surrounding a city and the spatial continuity of the remaining developable land.

Table S2. Simply definition of the two geographic metrics

Geographic metrics	Definition	Value Range
Share of barriers	Proportion of geographic barriers within the elastic radius (a circular buffer whose area is 1.5 times the urban area of the city) radius from the city center.	0 - 1, with smaller values representing less geographic barriers.
Nonconvexity	Proportion of straight lines intersected by geographic barriers. The straight lines are connections between each pair of points located within the non-barrier area around the buffer.	0 - 1, with smaller values representing higher connectivity in and around cities.

(1) Share of barriers: this index measures the proportion of land surrounding a city that is physically unsuitable for development due to water bodies or steep slopes. For each city, we delineate an adaptive (elastic) buffer centered on the population-weighted city center. We overlay the buffer of each city with the distribution of geographic barriers in that year and remove barriers falling into the circle. The percentage of the removed barriers compared to the whole circle is calculated as the share of barriers of the city, as:

$$S_{i\_year} = \frac{\sum W_{i\_year} + \sum P_{i\_year}}{\pi \times r_{i\_year}^2} \quad (1)$$

where r_{i_year} represents the elastic radius of city *i* in a specific year, P_{i_year} is the area of steep slope fragmentations, and W_i denotes the area of water fragmentations falling into the buffer. A higher SOB indicates a larger proportion of land surrounding the city that is inaccessible for development.

(2) Nonconvexity: this index measures the degree to which the remaining developable land is partitioned into disconnected pockets by natural barriers. This metric is conceptually distinct from urban shape indicators: it describes the continuity of the remaining developable land within the city's surrounding environment, not the morphology of the built urban footprint. After removing all barrier cells from the elastic buffer, the remaining part of the circle is set as the developable land. We then generate 200 random points (as upper limit) within the developable area, with their interval should larger than 1/20 of r_i. We group them into point pairs and calculated the share of line distances intersected by geographic barriers. The average share of all combinations (e.g., 40, 000 pairs) is set as the Nonconvexity index N_{i_year} of city *i*, which can be formulated by:

$$N_{i\_year} = \frac{1}{n_{i\_year}^2} \sum \frac{l_{i\_year}}{L_{i\_year}} \quad (2)$$

where l_{i_year} represents the length of lines intersected by geographic barriers between two points, while L_{i_year} represents the straight-line distance between the points, and $n_{i\_year}^2$ denotes the number of effective number of points successfully generated within the city. A value near 0 indicates highly continuous developable land, while higher values indicate substantial partitioning of the landscape into fragmented pockets. This metric quantifies how natural barriers partition the surrounding developable landscape into disconnected pockets, thereby shaping the potential pathways for future outward growth.

Two cities may exhibit similar SOB values but differ dramatically in geographic discontinuity depending on whether barriers are clustered on one side or dispersed throughout the surrounding landscape. This distinction is critical for understanding differences in horizontal expansion, fragmentation risk, and the tendency toward vertical development. A visual example of both metrics is provided in Figure S1-S2.

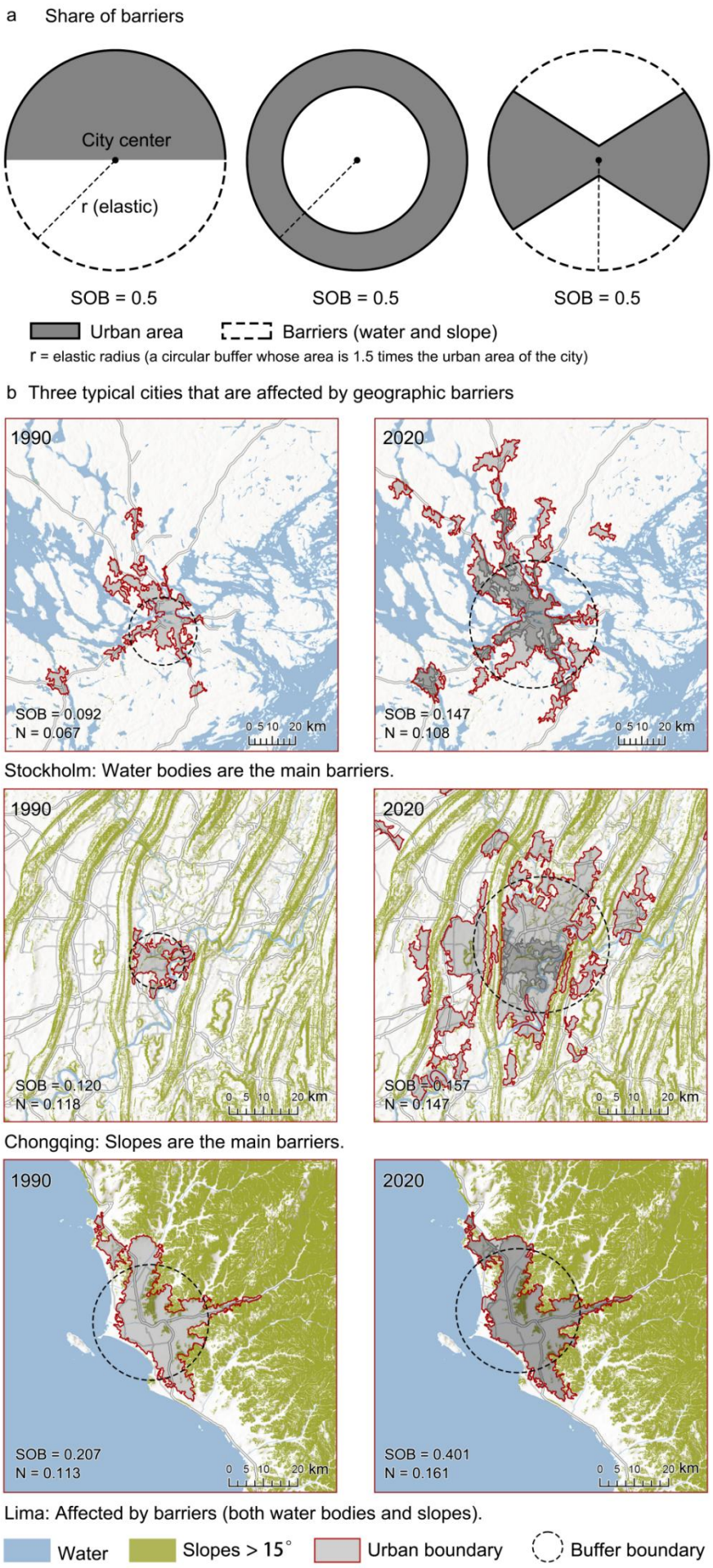
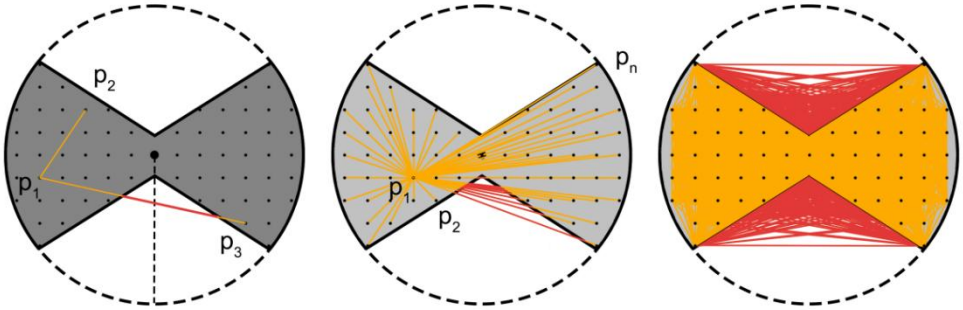


Fig.S1 | The process for the calculation of the SOB index in different urban forms. a, Three hypothetical urban forms with same share of barriers (0.5) and same city size. **b**, Three typical cities (affected by different geographical barriers).

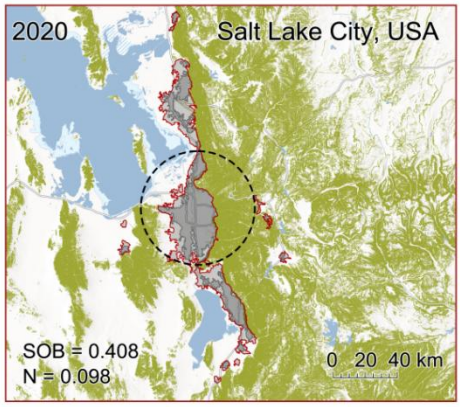
a Nonconvexity

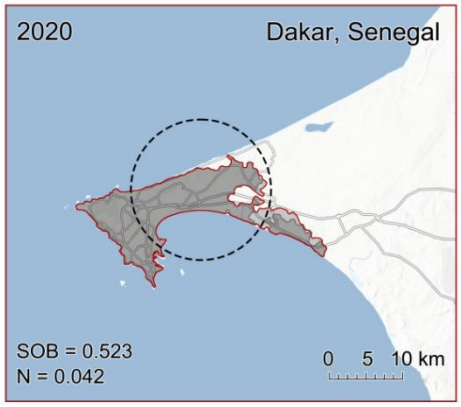


· Sampling points — Straight line connection — Intersected line

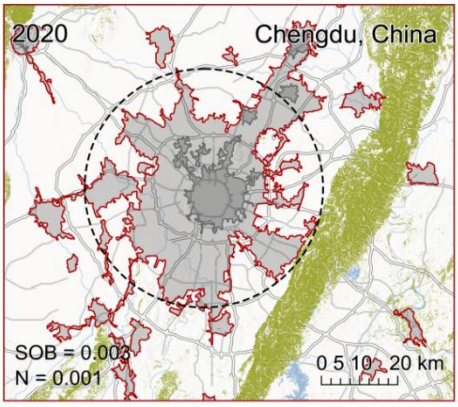
Urban area — Barriers (water and slope)

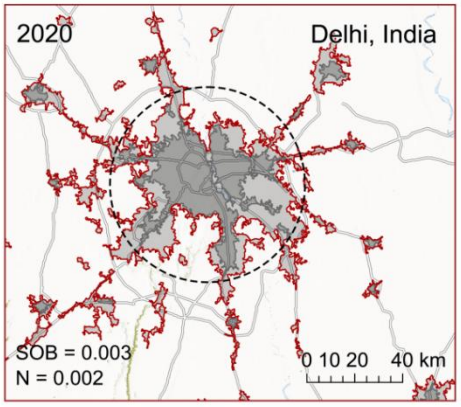
b Three main typical relationships between Nonconvexity and SOB



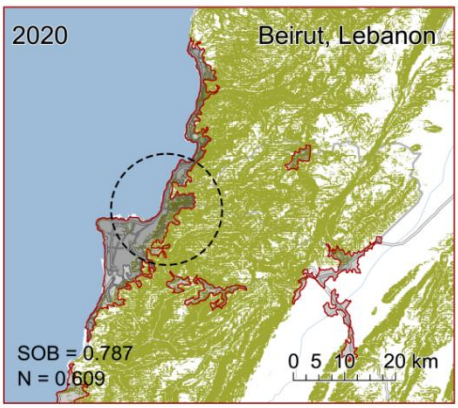


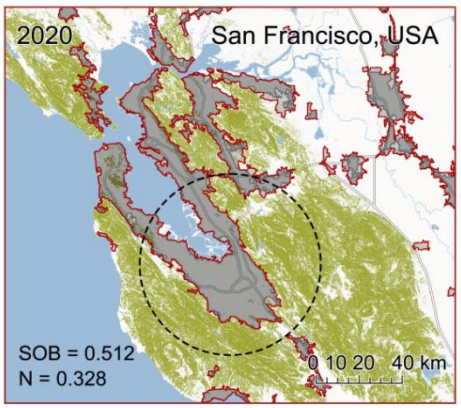
Low Nonconvexity vs high SOB





Low Nonconvexity vs low SOB





High Nonconvexity vs high SOB

Water — Slopes > 15° — Urban boundary — Buffer boundary

Fig.S2 | The process for the calculation of the nonconvexity index. a, The process for the calculation of the nonconvexity index in an urban form. **b**, Three typical patterns (linking two indices).

Urban spatial metrics. We use three metrics to describe the circular and sprawl of a city's form[11-13]. The Circular Index (CI) measures the morphological compactness of urban forms, with lower values indicating a greater deviation from a circular configuration. The Fractal Dimension (FD) characterizes the spatial complexity of urban expansion patterns, encompassing both contiguous growth and leapfrog development, where higher values reflect more intricate fractal structures. The Sprawl Index (SI) quantifies the proportional distribution of low-density urban development. These three kinds of metrics can be formulated by:

$$CI = \frac{2\sqrt{\pi \times S_{i\_year}}}{P_{i\_year}} \quad (3)$$

$$FD = \frac{2\ln P_{i\_year}}{\ln S_{i\_year}} \quad (4)$$

$$SI = \frac{A_{i\_year}}{S_{i\_year}} \quad (5)$$

where S_{i_year} represents urban area from the GUB, and P_{i_year} represents the perimeter of the city shapes in different years. A_{i_year} represents the low-density areas within the built-up area of the city, which has two predominant operational definitions (areas with a population density less than 50 persons per hectare or a floor area ratio (FAR) below 30% per hectare). These metrics constitute static quantitative metrics for analyzing urban morphological configurations in spatial studies between 1990 and 2020.

Table S3. Simply definition of the three Urban spatial metrics

Urban spatial metrics	Definition	Value Range
Circular Index (CI)	Normalized to a perfect circle, the circular index is defined as $2\sqrt{\pi \times S}$ / P, where A and P are the urban patch's area and perimeter, yielding values between 0 and 1.	0 - 1, the global mean value of the index is 0.48, with lower values indicating a greater deviation from a circular configuration.
Fractal Dimension (FD)	Twice the ratio of the natural logarithm of urban area to that of perimeter, it captures the complexity of boundary convolution and the spatial expansion morphology of cities.	> 1, At the city scale the fractal dimension typically exceeds 1.5 and can reach values above 4, where higher values reflect more intricate fractal structures.
Sprawl Index (SI)	The ratio of the low-density urban area (population or built-form density) to the total urban area, indicating the degree of urban sprawl.	0 - 1, the higher the value, the lower the city's density of development or population agglomeration.

Urban growth metrics. To examine urban development dynamics over time, we calculated growth rates for a range of key indicators between 1990 and 2020[14,15], including urban area (used to calculate the urban expansion rate and the urban expansion intensity index), population, GDP, GDP per capita (GDPPC), and average built-up height. The general formula applied is as follows:

$$GR = \frac{X_t - X_{1990}}{X_{1990}} \quad (3)$$

where X_t denotes the value of the indicator in a given year (e.g., 2000, 2010, or 2020), and X_{1990} represents the baseline value in 1990. In addition to calculating the overall growth from 1990 to 2020, we also computed growth rates for three intermediate periods: 1990–2000, 2000–2010, and 2010–2020. These sub-period calculations follow the same approach, using the earlier year in each interval as the baseline. This multi-period growth analysis enables us to explore temporal heterogeneity in urban development and assess whether certain cities or regions experienced accelerated or decelerated growth during specific decades.

Section 2

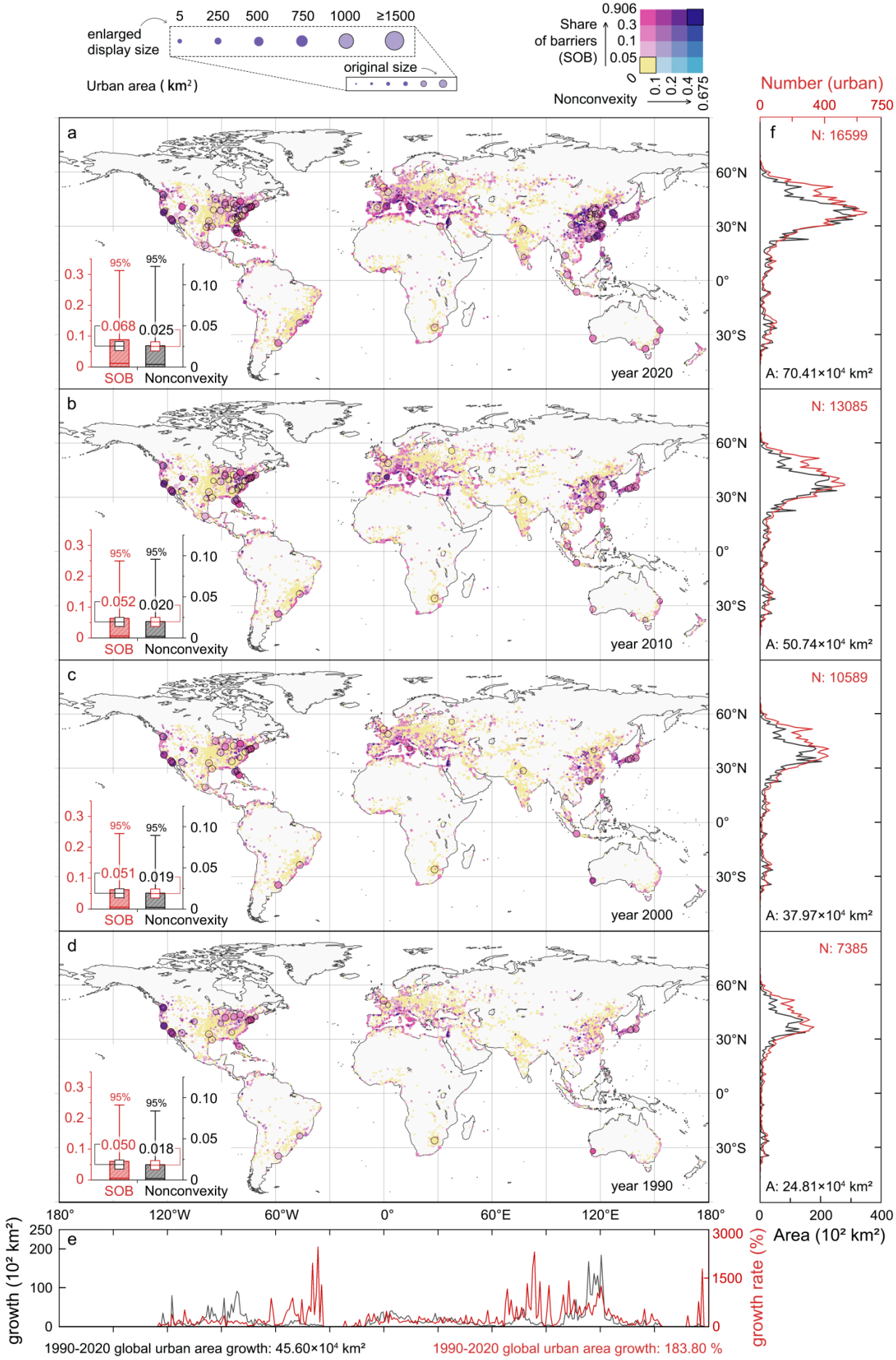


Fig.S3. Distribution of geographic barriers and urban growth across the world (1990-2020).

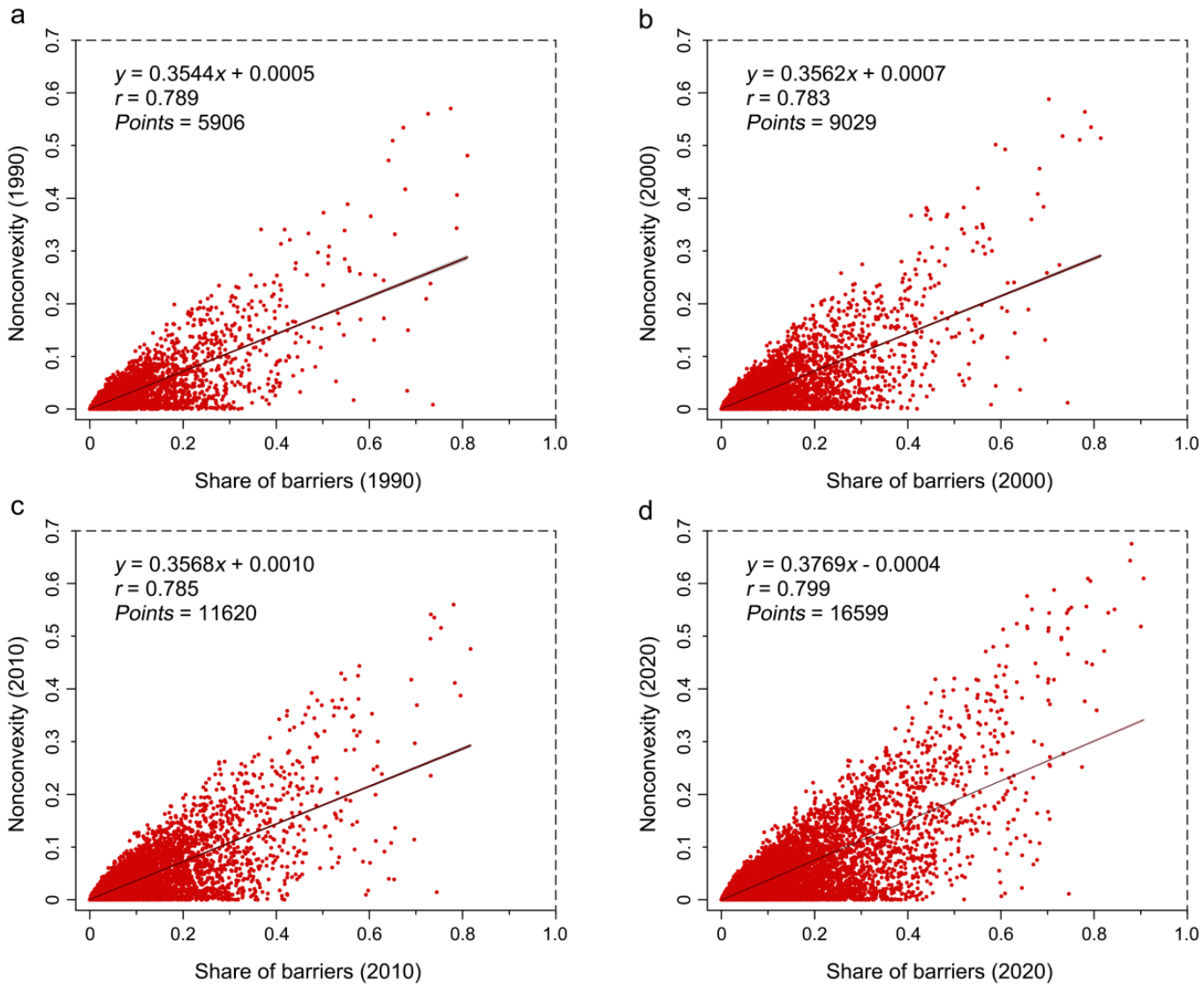


Fig.S4. The correlation between SOB and the nonconvexity index for each decade (1990-2020).

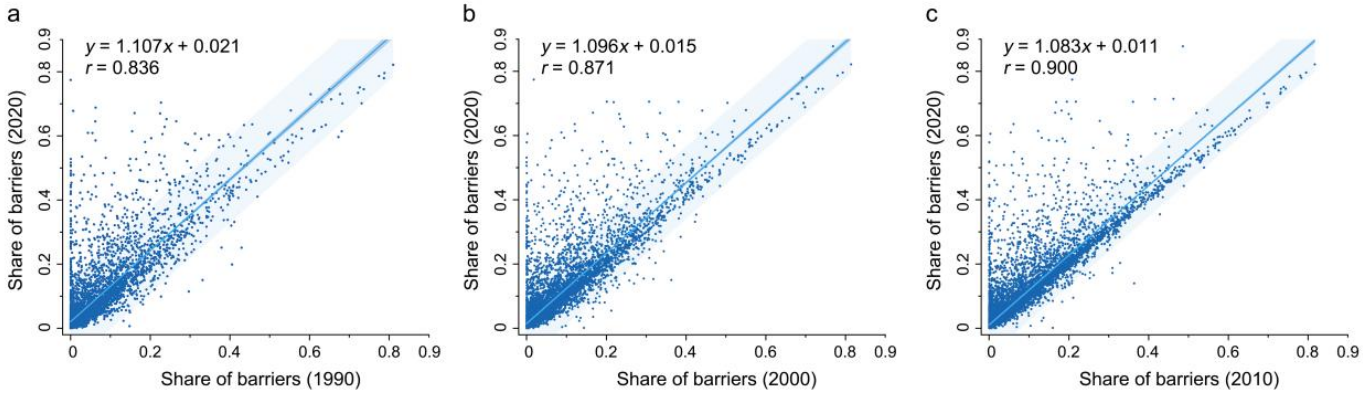


Fig.S5. The correlation of SOB across different years(1990-2020, 2000-2020, 2010-2020).

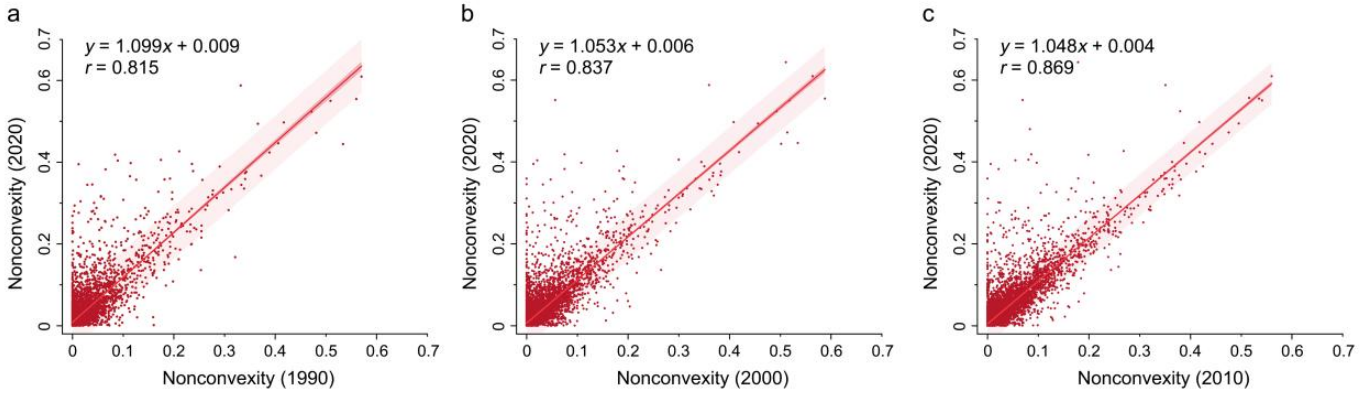


Fig.S6. The correlation of nonconvexity across different years (1990-2020, 2000-2020, 2010-2020).

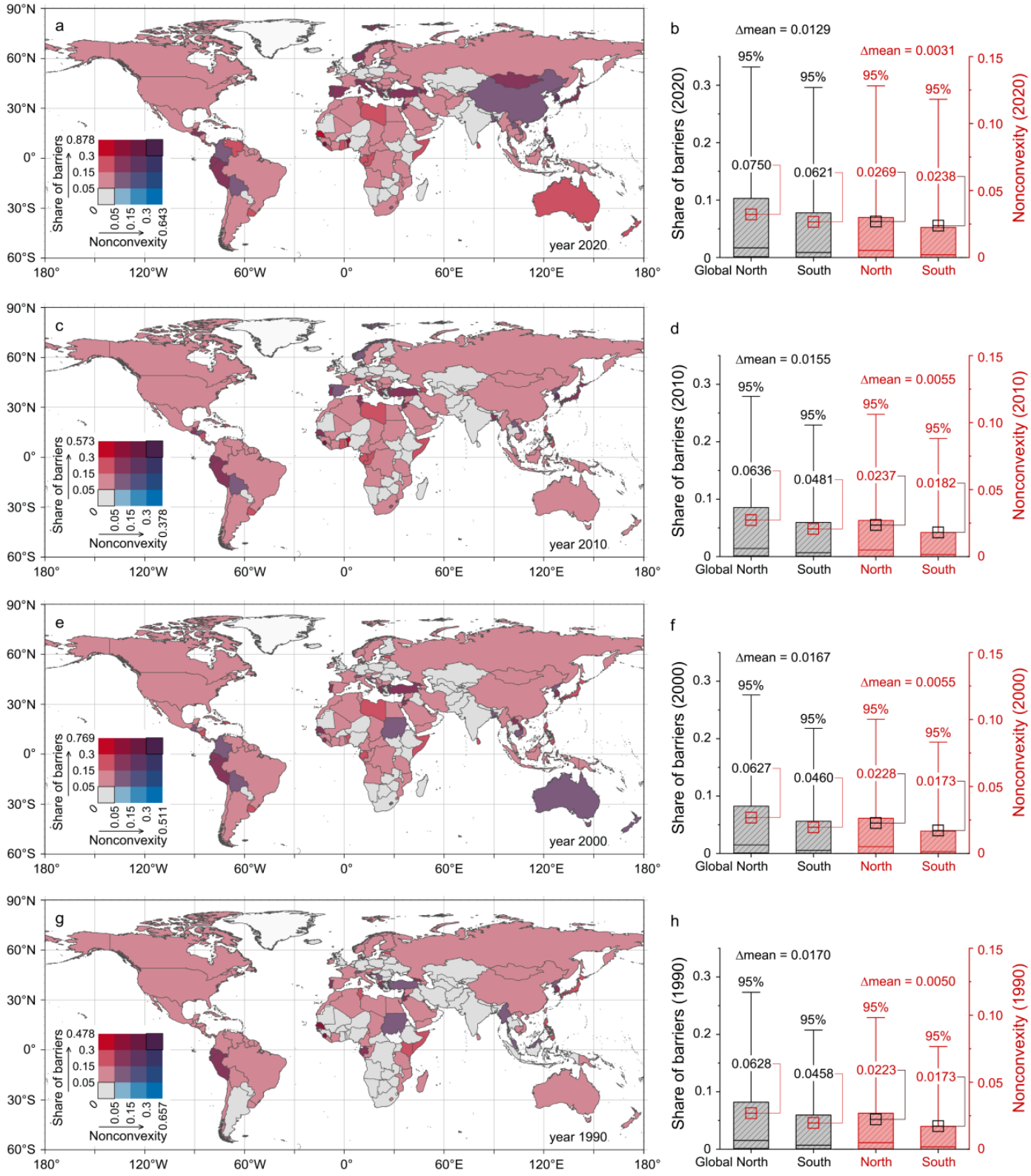


Fig.S7. The global distribution of SOB and nonconvexity in different countries and regions (Global N. vs. S, 1990-2020).

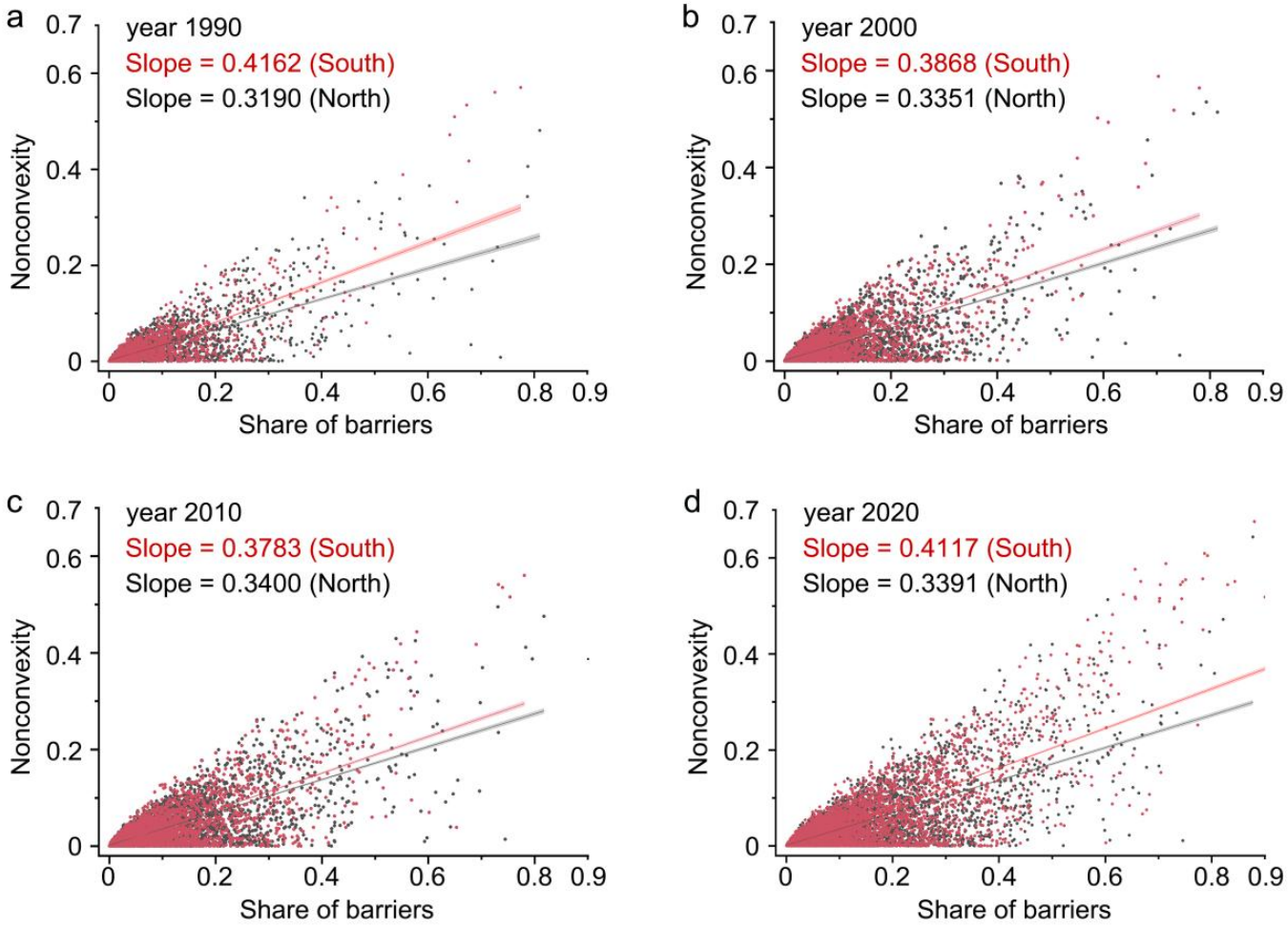


Fig.S8. The correlation between SOB and nonconvexity in different countries and regions (Global N. vs. S, 1990-2020).

Section 3

Table.S4. Impacts of difficult geography (share of slope barriers) of the year 1990 on socioeconomic metrics in 2020.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	log_POP_	log_urbanArea_	log_GDP_	log_BV_mean	log_pop_	Circular Index	Fractal Dimension	Sprawl Index of	Sprawl Index of FAR
VARIABLES	1000m_2020	2020	sum_2020	_2020	density_2020	(2020)	(2020)	Population (2020)	(2020)
share_slope_1990	-0.371***	-0.681***	-0.246**	0.128***	0.501***	-0.0289	0.228***	-0.0892***	-0.0479*
	(0.0948)	(0.111)	(0.106)	(0.0226)	(0.0840)	(0.0226)	(0.0511)	(0.0238)	(0.0254)
log_PRE_mean_90_20	0.000994	0.0927***	-0.0172	-0.00880**	0.00521	-0.0214***	-0.0138	-0.0144***	0.00400
	(0.0168)	(0.0199)	(0.0218)	(0.00412)	(0.0145)	(0.00412)	(0.00891)	(0.00439)	(0.00447)
log_TEM_mean_90_20	0.0645***	0.0586***	0.115***	-0.00597**	-0.0118	-0.00827**	-0.0120*	0.00913***	-0.00361
	(0.0139)	(0.0175)	(0.0184)	(0.00299)	(0.0118)	(0.00356)	(0.00617)	(0.00321)	(0.00373)
log_DEM_mean_90_20	-0.0167***	-0.0127*	-0.00891	0.000246	-0.000289	0.00516***	-0.00104	-0.00596***	-0.00258*
	(0.00556)	(0.00655)	(0.00666)	(0.00109)	(0.00463)	(0.00120)	(0.00253)	(0.00128)	(0.00132)
log_POP_1000m_1990	0.991***								
	(0.00561)								
log_urbanArea_1990		0.955***							
		(0.00567)							
log_GDP_sum_1990			0.975***						
			(0.00547)						
log_BV_mean_1990				0.833***					
				(0.00843)					
log_pop_density_1990					0.640***				
					(0.0119)				
Circular Index (1990)						0.655***			
						(0.0118)			
Fractal Dimension									
(1990)							0.488***		
							(0.00778)		
Sprawl Index of									
Population (1990)								0.521***	
								(0.0113)	

Sprawl Index of FAR (1990)									0.655***
									(0.00979)
Constant	0.480***	0.284**	1.501***	0.298***	2.611***	0.254***	1.113***	0.507***	0.183***
	(0.136)	(0.143)	(0.193)	(0.0320)	(0.129)	(0.0296)	(0.0621)	(0.0332)	(0.0321)
Observations	5,721	5,721	5,721	5,721	5,721	5,721	5,721	5,721	5,721
R-squared	0.930	0.824	0.896	0.916	0.882	0.518	0.570	0.843	0.774
Ajusted R2	-0.0177	-0.0177	-0.0177	-0.0177	-0.0177	-0.0177	-0.0177	-0.0177	-0.0177

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table.S5. Impacts of difficult geography (share of water barriers) of the year 1990 on socioeconomic metrics in 2020.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	log_POP_1000m_2020	log_urbanArea_2020	log_GDP_sum_2020	log_BV_mean_2020	log_pop_density_2020	Circular Index (2020)	Fractal Dimension (2020)	Sprawl Index of Population (2020)	Sprawl Index of FAR (2020)
Share_water_1990	-0.182*	-0.698***	-0.224**	0.121***	0.538***	0.0376*	0.309***	-0.0972***	-0.0814***
	(0.0935)	(0.112)	(0.111)	(0.0196)	(0.0815)	(0.0196)	(0.0560)	(0.0213)	(0.0243)
log_PRE_mean_90_20	-0.00259	0.0866***	-0.0192	-0.00791*	0.00901	-0.0219***	-0.0121	-0.0151***	0.00356
	(0.0167)	(0.0196)	(0.0217)	(0.00419)	(0.0147)	(0.00412)	(0.00881)	(0.00440)	(0.00446)
log_TEM_mean_90_20	0.0633***	0.0535***	0.113***	-0.00502*	-0.00762	-0.00798**	-0.00965	0.00840***	-0.00421
	(0.0139)	(0.0174)	(0.0184)	(0.00298)	(0.0117)	(0.00356)	(0.00612)	(0.00321)	(0.00372)
log_DEM_mean_90_20	-0.0232***	-0.0315***	-0.0152**	0.00356***	0.0140***	0.00562***	0.00669***	-0.00853***	-0.00450***
	(0.00605)	(0.00696)	(0.00713)	(0.00115)	(0.00490)	(0.00127)	(0.00250)	(0.00138)	(0.00140)
log_POP_1000m_1990	0.989***								
	(0.00558)								
log_urbanArea_1990		0.951***							
		(0.00556)							
log_GDP_sum_1990			0.974***						
			(0.00542)						
log_BV_mean_1990				0.835***					
				(0.00836)					
log_pop_density_1990					0.641***				
					(0.0117)				
Circular Index (1990)						0.659***			
						(0.0117)			
Fractal Dimension (1990)							0.488***		
							(0.00772)		
Sprawl Index of Population (1990)								0.520***	

								(0.0113)	
Sprawl Index of FAR (1990)									0.653***
									(0.00979)
Constant	0.555***	0.437***	1.569***	0.269***	2.493***	0.250***	1.057***	0.527***	0.198***
	(0.135)	(0.142)	(0.191)	(0.0319)	(0.130)	(0.0298)	(0.0620)	(0.0338)	(0.0324)
Observations	5,721	5,721	5,721	5,721	5,721	5,721	5,721	5,721	5,721
R-squared	0.930	0.824	0.896	0.916	0.883	0.518	0.572	0.843	0.774
Ajusted R2	-0.0177	-0.0177	-0.0177	-0.0177	-0.0177	-0.0177	-0.0177	-0.0177	-0.0177

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table.S6. Impacts of difficult geography (share of slope barriers) of the year 1990 on dynamics of urban metrics (1990-2020).

	(1)	(2)	(3)	(4)	(5)
VARIABLES	log_urban_growth_change_20_90	log_pop_growth_change_20_90	log_gdp_growth_change_20_90	log_per_gdp_change_20_90	log_bv_growth_change_20_90
share_slope_1990	-1.552***	-0.734**	-0.426**	0.0962	-2.679
	(0.234)	(0.306)	(0.189)	(0.160)	(2.318)
log_PRE_mean_90_20	0.371***	-0.0334	-0.0537	-0.0122	-0.180
	(0.0534)	(0.0373)	(0.0330)	(0.0342)	(0.197)
log_TEM_mean_90_20	0.0622*	0.137***	0.155***	0.0116	-0.264
	(0.0342)	(0.0481)	(0.0335)	(0.0217)	(0.343)
log_DEM_mean_90_20	-0.00806	-0.0380***	-0.0104	-0.0243***	0.00378
	(0.0132)	(0.0146)	(0.0106)	(0.00932)	(0.100)
log_urbanArea_1990	-0.0495***				
	(0.0116)				
log_POP_1000m_1990		0.00253			
		(0.0133)			
log_GDP_sum_1990			-0.0310***		
			(0.00846)		
log_PER_GDP_1990				-0.720***	
				(0.0341)	
log_BV_mean_1990					-0.243
					(0.623)
Constant	-2.401***	-0.669**	1.202***	6.564***	-1.614
	(0.367)	(0.313)	(0.288)	(0.402)	(1.895)
Observations	5,716	4,895	5,401	5,256	200
R-squared	0.313	0.296	0.689	0.771	0.357
Ajusted R2	0.129	0.129	0.129	0.129	0.129

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table.S7. Impacts of difficult geography (share of water barriers) of the year 1990 on dynamics of urban metrics (1990-2020).

	(1)	(2)	(3)	(4)	(5)
VARIABLES	log_urban_growth_change_20_90	log_pop_growth_change_20_90	log_gdp_growth_change_20_90	log_per_gdp_change_20_90	log_bv_growth_change_20_90
Share_water_1990	-1.896***	-0.369	-0.428**	-0.256	-3.000
	(0.268)	(0.262)	(0.204)	(0.162)	(2.154)
log_PRE_mean_90_20	0.358***	-0.0379	-0.0567*	-0.00976	-0.204
	(0.0525)	(0.0373)	(0.0328)	(0.0340)	(0.200)
log_TEM_mean_90_20	0.0482	0.135***	0.152***	0.00957	-0.381
	(0.0338)	(0.0481)	(0.0336)	(0.0218)	(0.332)
log_DEM_mean_90_20	-0.0568***	-0.0502***	-0.0218*	-0.0282***	-0.0614
	(0.0131)	(0.0157)	(0.0112)	(0.00969)	(0.111)
log_urbanArea_1990	-0.0578***				
	(0.0115)				
log_POP_1000m_1990		-0.00196			
		(0.0132)			
log_GDP_sum_1990			-0.0331***		
			(0.00834)		
log_PER_GDP_1990				-0.719***	
				(0.0341)	
log_BV_mean_1990					-0.224
					(0.637)
Constant	-2.018***	-0.534*	1.328***	6.573***	-0.884
	(0.360)	(0.313)	(0.286)	(0.401)	(1.913)
Observations	5,716	4,895	5,401	5,256	200
R-squared	0.316	0.295	0.689	0.771	0.357
Ajusted R2	0.130	0.130	0.130	0.130	0.130

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table.S8. Pearson correlation test of dynamic panel factors.

Factors	Urban growth rate (UGR)	POP growth rate (POP GR)	GDP growth rate (GDP GR)	GDP per capita growth rate (GDP pc GR)	Average built-up height (ABH GR)
UER					
UEII	0.571***				
POP GR	0.524***				
GDP GR	0.481***	0.749***			
GDP pc GR	0.174***	0.075***	0.605***		
ABH GR	-0.319***	0.058***	-0.038***	-0.134	

* p<0.1; **p<0.01; ***p<0.001

Table.S9. Pearson correlation test of static panel factors.

Factors	City area	POP	POP density	GDP	GDP per capita (GDP pc)	Average built-up height (ABH)	Circular Index (CI)	Fractal Dimension (FD)	Population sprawl Index (SI pop)	Floor-area-ratio sprawl Index (SI far)
City area										
POP	0.722***									
POP density	-0.006	0.200***								
GDP	0.791***	0.814***	0.055***							
GDP pc	0.098***	-0.027***	-0.413***	0.119***						
ABH	0.091***	0.202***	0.476***	0.134***	-0.215***					
CI	-0.262***	-0.224***	0.091***	-0.207***	-0.199***	-0.091***				
FD	-0.286***	-0.264***	-0.066***	-0.221***	0.003	-0.211***	0.083***			
SI pop	0.016***	-0.161***	-0.830***	-0.048***	0.475***	-0.519***	-0.115***	0.093***		
SI far	0.009	-0.095***	-0.471***	-0.042***	0.223***	-0.603***	-0.135***	0.110***	0.613***	

* p<0.1; **p<0.01; ***p<0.001

Table.S10. The various data of the dynamic fixed-effect regression model.

dynamic		Urban growth rate (UGR)	POP growth rate (POP GR)	GDP growth rate (GDP GR)	GDP per capita growth rate (GDP pc GR)	Average built-up height (ABH GR)**
Share of barriers	p	0.000	0.000	0.369	0.118	0.000
	coef.	-1.182	-0.451	-0.099	0.053	2.233
	R^2	0.478	0.334	0.496	0.613	0.365
Nonconvexity	p	0.000	0.001	0.422	0.128	0.041
	coef.	-1.524	-0.934	-0.186	0.109	1.983
	R^2	0.474	0.334	0.496	0.613	0.363

The fixed-effect regression model adjusted the time effect (year) and individual effect (country and climate zone), and also adjusted the corresponding temperature, precipitation and elevation of the city. Among them, the fixed-effect regression model marked with ** did not adjust for the individual effect of the climate zone.

Table.S11. The various data of the static fixed-effect regression model.

static		City area	POP	POP density	GDP	GDP per capita (GDP pc)	Average built-up height (ABH)	Circular Index (CI)	Fractal Dimension (FD)	Population sprawl Index (SI pop)	Floor-area-ratio sprawl Index (SI far)
Share of barriers	p	0.000	0.341	0.000	0.330	0.214	0.000	0.000	0.000	0.001	0.372
	coef.	-0.208	0.030	0.241	0.040	0.032	0.061	-0.134	0.114	-0.052	0.024
	R^2	0.867	0.946	0.920	0.905	0.904	0.944	0.567	0.674	0.816	0.767
Nonconvexity	p	0.008	0.379	0.000	0.075	0.011	0.000	0.000	0.000	0.154	0.000
	coef.	-0.203	0.059	0.345	0.157	0.145	0.081	-0.382	0.150	-0.050	0.279
	R^2	0.867	0.946	0.920	0.905	0.904	0.944	0.568	0.674	0.816	0.768

The fixed-effect regression model adjusted the time effect (year) and individual effect (country and climate zone), and also adjusted the corresponding temperature, precipitation and elevation of the city.

Table S12. Impacts of difficult geography (nonconvexity) of the year 1990 on socioeconomic metrics in 2000.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	log_POP_2000	log_urbanArea_2000	log_GDP_sum_2000	log_BV_mean_2000	log_pop_density_2000	Circular Index (2000)	Fractal Dimension (2000)	Sprawl Index of Population (2000)	Sprawl Index of FAR (2000)
Nonconvexity_90	-0.263***	-0.553***	-0.290***	0.104***	0.410***	0.00376	0.204***	-0.0337	-0.0108
	(0.0778)	(0.0896)	(0.0924)	(0.0169)	(0.0827)	(0.0261)	(0.0667)	(0.0210)	(0.0223)
log_PRE_90_00	-0.00896	0.0439***	-0.00886	-0.00743**	-0.00501	-0.0102***	-0.00918	-0.00582**	0.00606**
	(0.0114)	(0.0125)	(0.0155)	(0.00360)	(0.00916)	(0.00320)	(0.00718)	(0.00255)	(0.00256)
log_TEM_90_00	0.0369***	0.0137	0.0358***	0.00107	0.0128*	-0.00164	-0.00636	-0.00260	-0.00707***
	(0.00893)	(0.00911)	(0.0111)	(0.00143)	(0.00725)	(0.00224)	(0.00564)	(0.00199)	(0.00191)
log_DEM_90_00	-0.00679*	-0.0104***	-0.0131***	0.000486	0.00609**	0.00252***	0.000925	-0.00368***	-0.00202***
	(0.00356)	(0.00365)	(0.00416)	(0.000575)	(0.00272)	(0.000873)	(0.00203)	(0.000835)	(0.000754)
log_POP_90	0.995***								
	(0.00379)								
log_urbanArea_90		0.983***							
		(0.00352)							
log_GDP_sum_90			0.986***						
			(0.00359)						
log_BV_mean_90				0.932***					
				(0.00486)					
log_pop_density_90					0.823***				
					(0.00863)				
CI_90						0.792***			
						(0.00889)			
Fractal Dimension (90)							0.686***		
							(0.00697)		
Sprawl Index of Population (90)								0.814***	
								(0.00783)	
Sprawl Index of FAR (90)									0.868***
									(0.00672)
Constant	0.296***	0.151*	0.762***	0.147***	1.304***	0.141***	0.714***	0.202***	0.0363**
	(0.0892)	(0.0850)	(0.131)	(0.0250)	(0.0911)	(0.0225)	(0.0503)	(0.0203)	(0.0181)
Observations	5,723	5,723	5,723	5,723	5,723	5,717	5,717	5,717	5,717
R-squared	0.968	0.929	0.957	0.976	0.958	0.677	0.765	0.941	0.927

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S13. Impacts of difficult geography (nonconvexity) of the year 1990 on socioeconomic metrics in 2010.

VARIABLES	(1) log_POP_2010	(2) log_urbanArea_2010	(3) log_GDP_sum_2010	(4) log_BV_mean_2010	(5) log_pop_density_2010	(6) Circular Index (2010)	(7) Fractal Dimension (2010)	(8) Sprawl Index of Population (2010)	(9) Sprawl Index of FAR (2010)
Nonconvexity_90	-0.485***	-0.970***	-0.379***	0.177***	0.654***	0.00109	0.326***	-0.111***	-0.0344
	(0.102)	(0.133)	(0.122)	(0.0267)	(0.109)	(0.0318)	(0.0743)	(0.0322)	(0.0325)
log_PRE_90_10	-0.0164	0.0550***	-0.0465**	-0.00443	0.00885	-0.0161***	-0.00504	-0.0141***	0.000876
	(0.0148)	(0.0168)	(0.0198)	(0.00448)	(0.0123)	(0.00382)	(0.00848)	(0.00379)	(0.00354)
log_TEM_90_10	0.0542***	0.0237*	0.0714***	-0.00196	0.0126	6.50e-05	-0.00775	0.00346	-0.00413
	(0.0102)	(0.0130)	(0.0127)	(0.00273)	(0.0112)	(0.00309)	(0.00548)	(0.00272)	(0.00384)
log_DEM_90_10	-0.0142***	-0.0226***	-0.0175***	0.00195**	0.0139***	0.00381***	0.00491**	-0.00773***	-0.00497***
	(0.00465)	(0.00537)	(0.00544)	(0.000817)	(0.00365)	(0.00108)	(0.00238)	(0.00112)	(0.00114)
log_POP_90	0.992***								
	(0.00481)								
log_urbanArea_90		0.976***							
		(0.00479)							
log_GDP_sum_90			0.970***						
			(0.00449)						
log_BV_mean_90				0.881***					
				(0.00783)					
log_pop_density_90					0.717***				
					(0.0106)				
CI_90						0.701***			
						(0.0110)			
Fractal Dimension (90)							0.585***		
							(0.00779)		
Sprawl Index of Population (90)								0.665***	
								(0.0103)	
Sprawl Index of FAR (90)									0.758***
									(0.00889)
Constant	0.508***	0.355***	1.711***	0.203***	1.973***	0.199***	0.854***	0.391***	0.131***
	(0.115)	(0.117)	(0.166)	(0.0318)	(0.111)	(0.0269)	(0.0589)	(0.0288)	(0.0258)
Observations	5,589	5,589	5,589	5,589	5,589	5,589	5,589	5,589	5,589
R-squared	0.949	0.876	0.924	0.954	0.931	0.572	0.662	0.898	0.861

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S14. Impacts of difficult geography (nonconvexity) of the year 1990 on socioeconomic metrics in 2020.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	log_POP_2020	log_urbanArea_2020	log_GDP_sum_2020	log_BV_mean_2020	log_pop_density_2020	Circular Index (2020)	Fractal Dimension (2020)	Sprawl Index of Population (2020)	Sprawl Index of FAR (2020)
Nonconvexity_90	-0.658***	-1.278***	-0.435***	0.237***	0.903***	0.0323	0.408***	-0.168***	-0.106***
	(0.133)	(0.168)	(0.147)	(0.0348)	(0.133)	(0.0365)	(0.0777)	(0.0372)	(0.0404)
log_PRE_90_20	0.00127	0.0939***	-0.0170	-0.00879**	0.00473	-0.0219***	-0.0141	-0.0142***	0.00422
	(0.0168)	(0.0198)	(0.0217)	(0.00413)	(0.0145)	(0.00412)	(0.00890)	(0.00438)	(0.00448)
log_TEM_90_20	0.0642***	0.0578***	0.115***	-0.00587**	-0.0113	-0.00826**	-0.0118*	0.00903***	-0.00369
	(0.0139)	(0.0175)	(0.0184)	(0.00299)	(0.0118)	(0.00356)	(0.00615)	(0.00321)	(0.00374)
log_DEM_90_20	-0.0194***	-0.0175***	-0.0107	0.00119	0.00332	0.00488***	0.000607	-0.00660***	-0.00292**
	(0.00551)	(0.00646)	(0.00660)	(0.00107)	(0.00457)	(0.00118)	(0.00248)	(0.00127)	(0.00132)
log_POP_90	0.991***								
	(0.00560)								
log_urbanArea_90		0.955***							
		(0.00560)							
log_GDP_sum_90			0.975***						
			(0.00545)						
log_BV_mean_90				0.831***					
				(0.00846)					
log_pop_density_90					0.639***				
					(0.0119)				
CI_90						0.659***			
						(0.0120)			
Fractal Dimension (90)							0.488***		
							(0.00776)		
Sprawl Index of Population (90)								0.521***	
								(0.0113)	
Sprawl Index of FAR (90)									0.656***
									(0.00975)
Constant	0.492***	0.306**	1.507***	0.296***	2.593***	0.255***	1.103***	0.510***	0.184***
	(0.135)	(0.142)	(0.192)	(0.0318)	(0.129)	(0.0297)	(0.0621)	(0.0331)	(0.0321)
Observations	5,721	5,721	5,721	5,721	5,721	5,721	5,721	5,721	5,721
R-squared	0.930	0.825	0.896	0.916	0.883	0.518	0.571	0.843	0.774

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S15. Impacts of difficult geography (share of barriers) of the year 1990 on socioeconomic metrics in 2000.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	log_POP_2000	log_urbanArea_2000	log_GDP_sum_2000	log_BV_mean_2000	log_pop_density_2000	Circular Index (2000)	Fractal Dimension (2000)	Sprawl Index of Population (2000)	Sprawl Index of FAR (2000)
Share_barriers_90	-0.0986**	-0.285***	-0.140***	0.0469***	0.229***	-0.00810	0.160***	-0.0206**	-0.0123
	(0.0415)	(0.0441)	(0.0490)	(0.00819)	(0.0338)	(0.0111)	(0.0289)	(0.00959)	(0.00974)
log_PRE_90_00	-0.00928	0.0442***	-0.00883	-0.00740**	-0.00546	-0.0100***	-0.0100	-0.00576**	0.00616**
	(0.0114)	(0.0125)	(0.0155)	(0.00359)	(0.00918)	(0.00320)	(0.00716)	(0.00255)	(0.00256)
log_TEM_90_00	0.0362***	0.0115	0.0347***	0.00142	0.0147**	-0.00172	-0.00496	-0.00277	-0.00718***
	(0.00896)	(0.00911)	(0.0111)	(0.00143)	(0.00729)	(0.00225)	(0.00566)	(0.00200)	(0.00192)
log_DEM_90_00	-0.00800**	-0.0138***	-0.0148***	0.00105*	0.00881***	0.00244***	0.00279	-0.00392***	-0.00216***
	(0.00364)	(0.00366)	(0.00424)	(0.000589)	(0.00279)	(0.000884)	(0.00202)	(0.000860)	(0.000769)
log_POP_90	0.994***								
	(0.00380)								
log_urbanArea_90		0.983***							
		(0.00351)							
log_GDP_sum_90			0.986***						
			(0.00360)						
log_BV_mean_90				0.933***					
				(0.00483)					
log_pop_density_90					0.824***				
					(0.00860)				
CI_90						0.791***			
						(0.00881)			
Fractal Dimension (90)							0.685***		
							(0.00692)		
Sprawl Index of Population (90)								0.814***	
								(0.00783)	
Sprawl Index of FAR (90)									0.868***
									(0.00672)
Constant	0.309***	0.176**	0.778***	0.142***	1.285***	0.142***	0.703***	0.204***	0.0370**
	(0.0891)	(0.0850)	(0.131)	(0.0248)	(0.0910)	(0.0225)	(0.0502)	(0.0203)	(0.0182)
Observations	5,723	5,723	5,723	5,723	5,723	5,717	5,717	5,717	5,717
R-squared	0.968	0.930	0.957	0.976	0.958	0.677	0.766	0.941	0.927

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S16. Impacts of difficult geography (share of barriers) of the year 1990 on socioeconomic metrics in 2010.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	log_POP_2010	log_urbanArea_2010	log_GDP_sum_2010	log_BV_mean_2010	log_pop_density_2010	Circular Index (2010)	Fractal Dimension (2010)	Sprawl Index of Population (2010)	Sprawl Index of FAR (2010)
Share_barriers_90	-0.212***	-0.546***	-0.221***	0.0888***	0.394***	-0.000533	0.236***	-0.0701***	-0.0382***
	(0.0535)	(0.0614)	(0.0635)	(0.0114)	(0.0451)	(0.0135)	(0.0332)	(0.0139)	(0.0140)
log_PRE_90_10	-0.0164	0.0570***	-0.0456**	-0.00456	0.00705	-0.0160***	-0.00661	-0.0137***	0.00129
	(0.0148)	(0.0168)	(0.0199)	(0.00446)	(0.0124)	(0.00382)	(0.00846)	(0.00380)	(0.00354)
log_TEM_90_10	0.0532***	0.0204	0.0700***	-0.00149	0.0151	5.68e-05	-0.00610	0.00301	-0.00446
	(0.0102)	(0.0129)	(0.0128)	(0.00272)	(0.0111)	(0.00310)	(0.00544)	(0.00272)	(0.00384)
log_DEM_90_10	-0.0168***	-0.0291***	-0.0201***	0.00301***	0.0186***	0.00381***	0.00770***	-0.00856***	-0.00542***
	(0.00473)	(0.00539)	(0.00551)	(0.000835)	(0.00369)	(0.00110)	(0.00234)	(0.00115)	(0.00116)
log_POP_90	0.992***								
	(0.00480)								
log_urbanArea_90		0.976***							
		(0.00476)							
log_GDP_sum_90			0.970***						
			(0.00449)						
log_BV_mean_90				0.880***					
				(0.00779)					
log_pop_density_90					0.717***				
					(0.0105)				
CI_90						0.701***			
						(0.0109)			
Fractal Dimension (90)							0.584***		
							(0.00772)		
Sprawl Index of Population (90)								0.665***	
								(0.0103)	
Sprawl Index of FAR (90)									0.758***
									(0.00887)
Constant	0.528***	0.390***	1.724***	0.197***	1.950***	0.200***	0.842***	0.395***	0.132***
	(0.115)	(0.117)	(0.166)	(0.0315)	(0.111)	(0.0269)	(0.0587)	(0.0288)	(0.0258)
Observations	5,589	5,589	5,589	5,589	5,589	5,589	5,589	5,589	5,589
R-squared	0.949	0.876	0.925	0.955	0.932	0.572	0.664	0.898	0.861

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S17. Impacts of difficult geography (share of barriers) of the year 1990 on socioeconomic metrics in 2020.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	log_POP_2020	log_urbanArea_2020	log_GDP_sum_2020	log_BV_mean_2020	log_pop_density_2020	Circular Index (2020)	Fractal Dimension (2020)	Sprawl Index of Population (2020)	Sprawl Index of FAR (2020)
Share_barriers_90	-0.288***	-0.704***	-0.249***	0.126***	0.516***	0.0122	0.278***	-0.0894***	-0.0670***
	(0.0668)	(0.0786)	(0.0764)	(0.0150)	(0.0570)	(0.0151)	(0.0372)	(0.0161)	(0.0178)
log_PRE_90_20	0.00126	0.0962***	-0.0161	-0.00904**	0.00277	-0.0219***	-0.0157*	-0.0140***	0.00452
	(0.0168)	(0.0197)	(0.0217)	(0.00411)	(0.0145)	(0.00413)	(0.00886)	(0.00440)	(0.00448)
log_TEM_90_20	0.0622***	0.0527***	0.113***	-0.00498*	-0.00750	-0.00818**	-0.00970	0.00839***	-0.00418
	(0.0139)	(0.0173)	(0.0184)	(0.00296)	(0.0116)	(0.00356)	(0.00610)	(0.00320)	(0.00372)
log_DEM_90_20	-0.0228***	-0.0257***	-0.0136**	0.00266**	0.00930**	0.00504***	0.00379	-0.00764***	-0.00368***
	(0.00565)	(0.00652)	(0.00671)	(0.00109)	(0.00461)	(0.00120)	(0.00243)	(0.00130)	(0.00134)
log_POP_90	0.991***								
	(0.00560)								
log_urbanArea_90		0.955***							
		(0.00557)							
log_GDP_sum_90			0.975***						
			(0.00546)						
log_BV_mean_90				0.830***					
				(0.00842)					
log_pop_density_90					0.640***				
					(0.0118)				
CI_90						0.659***			
						(0.0118)			
Fractal Dimension (90)							0.488***		
							(0.00768)		
Sprawl Index of Population (90)								0.521***	
								(0.0113)	
Sprawl Index of FAR (90)									0.655***
									(0.00974)
Constant	0.521***	0.354**	1.524***	0.288***	2.558***	0.254***	1.088***	0.517***	0.188***
	(0.135)	(0.141)	(0.192)	(0.0315)	(0.129)	(0.0297)	(0.0619)	(0.0333)	(0.0322)
Observations	5,721	5,721	5,721	5,721	5,721	5,721	5,721	5,721	5,721
R-squared	0.930	0.826	0.896	0.917	0.883	0.518	0.574	0.843	0.774

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S18. Impacts of difficult geography (nonconvexity) of the year 1990 on dynamics of urban metrics (1990-2020).

	(1)	(2)	(3)	(4)	(5)
	log_urban_growth_	log_pop_growth	log_gdp_growth	log_per_gdp	log_bv_growth
VARIABLES	90_20	_90_20	_90_20	_90_20	_90_20
Nonconvexity_90	-2.984***	-1.325***	-0.751***	0.244	0.237***
	(0.365)	(0.418)	(0.259)	(0.238)	(0.0348)
log_PRE_ 90_20	0.374***	-0.0319	-0.0531	-0.0127	-0.00879**
	(0.0531)	(0.0373)	(0.0329)	(0.0342)	(0.00413)
log_TEM_ 90_20	0.0604*	0.136***	0.155***	0.0117	-0.00587**
	(0.0341)	(0.0481)	(0.0335)	(0.0217)	(0.00299)
log_DEM_ 90_20	-0.0190	-0.0431***	-0.0134	-0.0236**	0.00119
	(0.0129)	(0.0146)	(0.0105)	(0.00917)	(0.00107)
log_urbanArea_90	-0.0476***				
	(0.0115)				
log_POP_90		0.00259			
		(0.0132)			
log_GDP_sum_90			-0.0309***		
			(0.00841)		
log_PER_GDP_90				-0.721***	
				(0.0341)	
log_BV_mean_90					-0.169***
					(0.00846)
Constant	-2.353***	-0.646**	1.215***	6.568***	0.296***
	(0.364)	(0.312)	(0.286)	(0.401)	(0.0318)
Observations	5,716	4,895	5,401	5,256	5,721
R-squared	0.316	0.297	0.689	0.771	0.501

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S19. Impacts of difficult geography (nonconvexity)of the year 1990 on dynamics of urban metrics (1990-2000).

	(1)	(2)	(3)	(4)	(5)
	log_urban_growth_	log_pop_growth	log_gdp_growth	log_per_gdp	log_bv_growth
VARIABLES	90_00	_90_00	_90_00	_90_00	_90_00
Nonconvexity_90	-2.544***	-1.304***	-0.910***	-0.0168	0.374
	(0.354)	(0.474)	(0.242)	(0.219)	(1.935)
log_PRE_ 90_00	0.354***	-0.0117	0.00561	0.0385	-0.286
	(0.0570)	(0.0379)	(0.0408)	(0.0393)	(0.199)
log_TEM_ 90_00	0.0555	0.0500	0.0682**	-0.0424**	-0.194
	(0.0371)	(0.0459)	(0.0276)	(0.0204)	(0.173)
log_DEM_ 90_00	-0.0441***	-0.0483***	-0.0116	-0.0357***	-0.0250
	(0.0129)	(0.0136)	(0.0101)	(0.00832)	(0.0656)
log_urbanArea_90	0.000692				
	(0.0119)				
log_POP_90		0.0603***			
		(0.0130)			
log_GDP_sum_90			-0.0311***		
			(0.00907)		
log_PER_GDP_90				-0.380***	
				(0.0334)	
log_BV_mean_90					-0.478
					(0.432)
Constant	-3.382***	-2.125***	-0.0635	2.349***	-1.048
	(0.384)	(0.306)	(0.320)	(0.424)	(1.373)
Observations	5,707	4,905	5,045	4,680	475
R-squared	0.192	0.308	0.441	0.552	0.203

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S20. Impacts of difficult geography (nonconvexity) of the year 1990 on dynamics of urban metrics (2000-2010).

	(1)	(2)	(3)	(4)	(5)
	log_urban_growth_	log_pop_growth	log_gdp_growth	log_per_gdp	log_bv_growth
VARIABLES	00_10	_00_10	_00_10	_90_20	_90_20
Nonconvexity_90	-3.415***	-1.987***	-0.356	0.591**	0.397
	(0.470)	(0.433)	(0.295)	(0.301)	(2.987)
log_PRE_ 00_10	0.186***	-0.0580*	-0.0415	0.00534	-0.356**
	(0.0641)	(0.0324)	(0.0369)	(0.0363)	(0.176)
log_TEM_ 00_10	-0.0330	0.0401	0.0300	-0.0430	-0.344
	(0.0360)	(0.0361)	(0.0281)	(0.0274)	(0.248)
log_DEM_ 00_10	-0.0217	-0.0511***	-0.0311***	-0.0349***	0.00519
	(0.0156)	(0.0136)	(0.00999)	(0.0112)	(0.0751)
log_urbanArea_00	0.133***				
	(0.0134)				
log_POP_00		0.0606***			
		(0.0126)			
log_GDP_sum_00			-0.0317***		
			(0.00842)		
log_PER_GDP_00				-0.610***	
				(0.0405)	
log_BV_mean_00					-0.115
					(0.750)
Constant	-3.380***	-2.242***	0.0974	4.689***	-2.095
	(0.430)	(0.271)	(0.303)	(0.464)	(1.937)
Observations	5,269	4,274	4,934	4,496	260
R-squared	0.316	0.272	0.543	0.606	0.342

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S21. Impacts of difficult geography (nonconvexity) of the year 1990 on dynamics of urban metrics (2010-2020).

	(1)	(2)	(3)	(4)	(5)
	log_urban_growth_	log_pop_growth	log_gdp_growth	log_per_gdp	log_bv_growth
VARIABLES	10_20	_10_20	_10_20	_10_20	_10_20
Nonconvexity_90	-2.833***	-1.414***	-0.0991	0.0132	-4.114
	(0.353)	(0.495)	(0.340)	(0.385)	(4.172)
log_PRE_ 10_20	0.412***	-0.0181	0.0519	-0.00736	-0.342
	(0.0568)	(0.0403)	(0.0438)	(0.0441)	(0.327)
log_TEM_ 10_20	0.115***	0.0851*	0.104***	0.0661**	0.0968
	(0.0320)	(0.0507)	(0.0306)	(0.0262)	(0.393)
log_DEM_ 10_20	0.0708***	-0.0323**	-0.000706	0.00160	-0.00201
	(0.0122)	(0.0144)	(0.0121)	(0.0126)	(0.200)
log_urbanArea_10	0.0672***				
	(0.0118)				
log_POP_10		0.101***			
		(0.0122)			
log_GDP_sum_10			0.0313***		
			(0.00920)		
log_PER_GDP_10				-0.361***	
				(0.0455)	
log_BV_mean_10					0.288
					(1.027)
Constant	-5.178***	-3.418***	-2.643***	1.652***	-3.852
	(0.387)	(0.333)	(0.357)	(0.544)	(3.616)
Observations	5,726	4,377	4,523	3,997	111
R-squared	0.353	0.245	0.449	0.525	0.357

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S22. Impacts of difficult geography (share of barriers) of the year 1990 on dynamics of urban metrics (1990-2020).

	(1)	(2)	(3)	(4)	(5)
	log_urban_growth_	log_pop_growth	log_gdp_growth	log_per_gdp	log_bv_growth
VARIABLES	90_20	_90_20	_90_20	_90_20	_90_20
Nonconvexity_90	-1.750***	-0.571***	-0.436***	-0.0855	0.126***
	(0.176)	(0.199)	(0.136)	(0.116)	(0.0150)
log_PRE_ 90_20	0.381***	-0.0321	-0.0515	-0.00942	-0.00904**
	(0.0531)	(0.0374)	(0.0329)	(0.0342)	(0.00411)
log_TEM_ 90_20	0.0475	0.133***	0.152***	0.0110	-0.00498*
	(0.0336)	(0.0480)	(0.0335)	(0.0217)	(0.00296)
log_DEM_ 90_20	-0.0392***	-0.0496***	-0.0181*	-0.0243***	0.00266**
	(0.0126)	(0.0150)	(0.0106)	(0.00923)	(0.00109)
log_urbanArea_90	-0.0471***				
	(0.0114)				
log_POP_90		0.00148			
		(0.0132)			
log_GDP_sum_90			-0.0309***		
			(0.00841)		
log_PER_GDP_90				-0.719***	
				(0.0341)	
log_BV_mean_90					-0.170***
					(0.00842)
Constant	-2.241***	-0.589*	1.242***	6.538***	0.288***
	(0.362)	(0.312)	(0.286)	(0.400)	(0.0315)
Observations	5,716	4,895	5,401	5,256	5,721
R-squared	0.322	0.296	0.689	0.771	0.504

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S23. Impacts of difficult geography (share of barriers) of the year 1990 on dynamics of urban metrics (1990-2000).

	(1)	(2)	(3)	(4)	(5)
	log_urban_growth_	log_pop_growth	log_gdp_growth	log_per_gdp	log_bv_growth
VARIABLES	90_00	_90_00	_90_00	_90_00	_90_00
Nonconvexity_90	-1.518***	-0.427**	-0.530***	-0.127	-0.333
	(0.171)	(0.213)	(0.129)	(0.0962)	(0.924)
log_PRE_ 90_00	0.358***	-0.0140	0.00659	0.0404	-0.287
	(0.0568)	(0.0379)	(0.0411)	(0.0393)	(0.199)
log_TEM_ 90_00	0.0430	0.0480	0.0640**	-0.0436**	-0.189
	(0.0370)	(0.0459)	(0.0276)	(0.0204)	(0.171)
log_DEM_ 90_00	-0.0621***	-0.0534***	-0.0178*	-0.0371***	-0.0270
	(0.0128)	(0.0140)	(0.0102)	(0.00837)	(0.0658)
log_urbanArea_90	0.00131				
	(0.0118)				
log_POP_90		0.0583***			
		(0.0129)			
log_GDP_sum_90			-0.0313***		
			(0.00907)		
log_PER_GDP_90				-0.379***	
				(0.0333)	
log_BV_mean_90					-0.443
					(0.431)
Constant	-3.266***	-2.061***	-0.0175	2.342***	-1.090
	(0.382)	(0.307)	(0.320)	(0.422)	(1.375)
Observations	5,707	4,905	5,045	4,680	475
R-squared	0.197	0.307	0.442	0.552	0.203

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S24. Impacts of difficult geography (share of barriers) of the year 1990 on dynamics of urban metrics (2000-2010).

	(1)	(2)	(3)	(4)	(5)
	log_urban_growth_	log_pop_growth	log_gdp_growth	log_per_gdp	log_bv_growth
VARIABLES	00_10	_00_10	_00_10	_00_10	_00_10
Nonconvexity_90	-2.054***	-1.044***	-0.272*	0.213	-1.267
	(0.217)	(0.190)	(0.143)	(0.150)	(1.191)
log_PRE_ 00_10	0.200***	-0.0535	-0.0386	0.00614	-0.371**
	(0.0628)	(0.0327)	(0.0370)	(0.0364)	(0.175)
log_TEM_ 00_10	-0.0433	0.0364	0.0284	-0.0424	-0.338
	(0.0363)	(0.0362)	(0.0282)	(0.0274)	(0.246)
log_DEM_ 00_10	-0.0466***	-0.0639***	-0.0342***	-0.0323***	-0.0160
	(0.0151)	(0.0138)	(0.00993)	(0.0112)	(0.0822)
log_urbanArea_00	0.133***				
	(0.0132)				
log_POP_00		0.0601***			
		(0.0125)			
log_GDP_sum_00			-0.0313***		
			(0.00835)		
log_PER_GDP_00				-0.608***	
				(0.0404)	
log_BV_mean_00					0.0439
					(0.757)
Constant	-3.294***	-2.181***	0.0951	4.657***	-2.155
	(0.421)	(0.272)	(0.301)	(0.463)	(1.850)
Observations	5,269	4,274	4,934	4,496	260
R-squared	0.323	0.273	0.543	0.606	0.346

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table S25. Impacts of difficult geography (share of barriers) of the year 1990 on dynamics of urban metrics (2010-2020).

	(1)	(2)	(3)	(4)	(5)
	log_urban_growth_	log_pop_growth	log_gdp_growth	log_per_gdp	log_bv_growth
VARIABLES	10_20	_10_20	_10_20	_10_20	_10_20
Nonconvexity_90	-1.569***	-0.537**	-0.101	-0.0729	-4.025
	(0.177)	(0.215)	(0.173)	(0.184)	(2.984)
log_PRE_ 10_20	0.419***	-0.0186	0.0529	-0.00629	-0.320
	(0.0566)	(0.0403)	(0.0437)	(0.0441)	(0.333)
log_TEM_ 10_20	0.102***	0.0815	0.103***	0.0655**	0.0664
	(0.0325)	(0.0505)	(0.0306)	(0.0263)	(0.389)
log_DEM_ 10_20	0.0528***	-0.0383**	-0.00169	0.000983	-0.0620
	(0.0120)	(0.0149)	(0.0121)	(0.0126)	(0.191)
log_urbanArea_10	0.0655***				
	(0.0117)				
log_POP_10		0.0986***			
		(0.0121)			
log_GDP_sum_10			0.0314***		
			(0.00918)		
log_PER_GDP_10				-0.360***	
				(0.0454)	
log_BV_mean_10					0.330
					(0.981)
Constant	-5.079***	-3.354***	-2.643***	1.646***	-3.571
	(0.385)	(0.333)	(0.356)	(0.541)	(3.623)
Observations	5,726	4,377	4,523	3,997	111
R-squared	0.357	0.244	0.449	0.525	0.369

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table.S26. The various data of the dynamic fixed-effect regression model (Global North).

Dynamic north		Urban growth rate (UER)	POP growth rate (POP GR)	GDP growth rate (GDP GR)	GDP per capita growth rate (GDP pc GR)	Average built-up height (ABH GR)**
Share of barriers	p	0.000	0.015	0.175	0.505	0.000
	coef.	-1.286	-0.387	-0.206	-0.015	3.003
	R^2	0.404	0.279	0.206	0.238	0.209
Nonconvexity	p	0.000	0.074	0.411	0.736	0.000
	coef.	-1.556	-0.727	-0.299	0.018	3.637
	R^2	0.395	0.279	0.206	0.238	0.202

The fixed-effect regression model adjusted the time effect (year) and individual effect (country and climate zone), and also adjusted the corresponding temperature, precipitation and elevation of the city. Among them, the fixed-effect regression model marked with ** did not adjust for the individual effect of the climate zone.

Table.S27. The various data of the dynamic fixed-effect regression model (Global South).

Dynamic south		Urban growth rate (UER)	POP growth rate (POP GR)	GDP growth rate (GDP GR)	GDP per capita growth rate (GDP pc GR)	Average built-up height (ABH GR)**
Share of barriers	p	0.000	0.014	0.422	0.210	0.227
	coef.	-0.815	-0.460	-0.128	0.099	0.603
	R^2	0.524	0.303	0.474	0.629	0.7390
Nonconvexity	p	0.001	0.008	0.261	0.305	0.444
	coef.	-1.176	-1.017	-0.311	0.155	0.837
	R^2	0.523	0.303	0.4740	0.629	0.738

The fixed-effect regression model adjusted the time effect (year) and individual effect (country and climate zone), and also adjusted the corresponding temperature, precipitation and elevation of the city. Among them, the fixed-effect regression model marked with ** did not adjust for the individual effect of the climate zone.

Table.S28. Statistics on urban growth and geographic metrics at the national and region level.

country and region	urban area (1990)	urban area (2020)	growth rate (%)	Global North/South	year 1990		year 2000		year 2010		year 2020	
					share of barriers	nonconvexity	share of barriers	nonconvexity	share of barriers	nonconvexity	share of barriers	nonconvexity
Afghanistan	46.508	132.588	185.08	S	0.0003	0.0000	0.0003	0.0000	0.0006	0.0006	0.0560	0.0298
Albania	45.391	199.683	339.92	S	0.0638	0.0113	0.1083	0.0277	0.1180	0.0475	0.1696	0.0575
Algeria	675.305	2443.802	261.88	S	0.0702	0.0296	0.1130	0.0363	0.1114	0.0363	0.1346	0.0346
Angola	71.549	798.863	1016.53	S	0.0274	0.0037	0.1255	0.0039	0.1247	0.0098	0.1055	0.0045
Argentina	2815.363	4541.887	61.33	S	0.0447	0.0056	0.0902	0.0040	0.0889	0.0054	0.0809	0.0065
Armenia	21.882	138.185	531.50	S	0.0078	0.0040	0.0270	0.0177	0.0294	0.0171	0.1010	0.0703
Aruba	8.711	27.652	217.42	N	0.0007	0.0000	0.0559	0.0020	0.0437	0.0019	0.0597	0.0019
Australia	4605.686	10197.256	121.41	N	0.1400	0.0305	0.1448	0.0581	0.0942	0.0256	0.1720	0.0290
Austria	519.418	922.642	77.63	N	0.0721	0.0324	0.0786	0.0347	0.0822	0.0351	0.0914	0.0432
Azerbaijan	391.968	860.250	119.47	S	0.1207	0.0427	0.1224	0.0437	0.2008	0.0420	0.2168	0.0573
Bahamas	56.271	119.912	113.10	N	0.0231	0.0035	0.0800	0.0113	0.1041	0.0119	0.1148	0.0101
Bahrain	/	131.947	/	N	/	/	0.0692	0.0240	0.0713	0.0257	0.0686	0.0273
Bangladesh	64.738	418.243	546.06	S	0.0414	0.0181	0.1134	0.0720	0.1693	0.1278	0.1422	0.0915
Barbados	28.578	33.012	15.52	S	0.2934	0.0053	0.2934	0.0047	0.3015	0.0015	0.3118	0.0012
Belarus	503.358	1714.019	240.52	S	0.0065	0.0049	0.0069	0.0047	0.0087	0.0058	0.0114	0.0067
Belgium	752.776	2656.495	252.89	N	0.0289	0.0263	0.0252	0.0177	0.0257	0.0191	0.0300	0.0168
Belize	/	9.665	/	S	/	/	0.0793	0.0000	0.1342	0.0022	0.1629	0.0025
Benin	33.469	340.959	918.74	S	0.0041	0.0000	0.2486	0.0143	0.4357	0.0256	0.4534	0.0510
Bolivia	448.293	912.741	103.60	S	0.0863	0.0447	0.1064	0.0526	0.1118	0.0751	0.1245	0.0542
Bosnia and Herzegovina	14.877	109.037	632.94	S	0.0004	0.0000	0.0005	0.0000	0.0005	0.0000	0.0674	0.0342
Botswana	221.716	467.023	110.64	S	0.0100	0.0044	0.0095	0.0033	0.0097	0.0047	0.0102	0.0042
Brazil	6055.273	20957.083	246.10	S	0.0773	0.0279	0.0520	0.0215	0.0514	0.0230	0.0691	0.0239
Brunei	/	166.114	/	S	/	/	0.0402	0.0023	0.0464	0.0090	0.0615	0.0084
Bulgaria	407.021	770.996	89.42	S	0.0491	0.0176	0.0574	0.0192	0.0724	0.0248	0.1120	0.0314
Burkina Faso	53.070	381.029	617.98	S	0.0134	0.0071	0.0156	0.0123	0.0084	0.0061	0.0073	0.0056
Cambodia	12.204	279.503	2190.19	S	0.0779	0.0199	0.1456	0.0846	0.0505	0.0205	0.0620	0.0264
Cameroon	230.267	321.210	39.49	S	0.0548	0.0197	0.0571	0.0224	0.0577	0.0256	0.0595	0.0199
Canada	6861.754	13487.698	96.56	N	0.1059	0.0276	0.1209	0.0309	0.1162	0.0288	0.1321	0.0387

Cayman Islands	/	9.111	/	N	/	/	0.0604	0.0016	0.0599	0.0013	0.1965	0.0015
Central African Rep.	45.388	71.586	57.72	S	0.0459	0.0119	0.0686	0.0307	0.0686	0.0209	0.0808	0.0189
Chad	26.129	85.967	229.01	S	0.0599	0.0195	0.0778	0.0237	0.0777	0.0273	0.0649	0.0412
Chile	534.665	1564.817	192.67	S	0.0551	0.0165	0.0929	0.0266	0.1041	0.0276	0.1385	0.0442
China	20532.617	162651.312	692.16	S	0.0512	0.0244	0.0633	0.0308	0.0763	0.0407	0.1181	0.0579
Colombia	703.623	1510.343	114.65	S	0.1325	0.0481	0.1315	0.0503	0.1298	0.0380	0.1369	0.0514
Congo, Dem. Rep.	465.697	885.198	90.08	S	0.0239	0.0255	0.0679	0.0166	0.0693	0.0218	0.0682	0.0177
Congo, Rep.	129.454	241.160	86.29	S	0.0986	0.0064	0.1368	0.0158	0.1500	0.0175	0.1629	0.0231
Costa Rica	222.245	451.374	103.10	S	0.0768	0.0175	0.1430	0.0309	0.1479	0.0211	0.1523	0.0442
Côte d'Ivoire	68.511	752.381	998.19	S	0.0769	0.0160	0.0740	0.0473	0.1016	0.0319	0.1105	0.0469
Croatia	157.323	440.333	179.89	N	0.1532	0.0553	0.1392	0.0595	0.1824	0.0618	0.1828	0.0645
Cuba	188.238	417.137	121.60	S	0.0580	0.0081	0.0825	0.0080	0.1027	0.0102	0.1092	0.0090
Curacao	28.532	36.910	29.36	N	0.2900	0.0433	0.2959	0.0487	0.2977	0.0284	0.3567	0.0381
Cyprus	141.919	278.628	96.33	N	0.0747	0.0068	0.0868	0.0097	0.0992	0.0168	0.1154	0.0169
Czech	524.835	1218.827	132.23	N	0.0300	0.0220	0.0355	0.0237	0.0345	0.0257	0.0382	0.0291
Denmark	603.721	1041.585	72.53	N	0.0701	0.0129	0.0766	0.0165	0.1079	0.0138	0.1111	0.0172
Dominican	112.115	488.741	335.93	S	0.1419	0.0013	0.1592	0.0012	0.1713	0.0027	0.1686	0.0059
Ecuador	171.980	975.742	467.36	S	0.2229	0.1037	0.1764	0.0961	0.1780	0.1049	0.1960	0.1021
Egypt	1206.841	3800.836	214.94	S	0.0511	0.0282	0.0615	0.0260	0.0623	0.0272	0.0585	0.0217
El Salvador	84.667	178.660	111.02	S	0.0903	0.0262	0.1162	0.0539	0.1138	0.0780	0.1068	0.0750
Equatorial Guinea	/	9.361	/	S	/	/	/	/	/	/	0.0130	0.0012
Estonia	56.273	108.050	92.01	N	0.1569	0.0453	0.1577	0.0207	0.1597	0.0309	0.1458	0.0487
Eswatini	/	38.832	/	S	/	/	0.0746	0.0481	/	/	0.0909	0.0453
Ethiopia	38.570	272.341	606.09	S	0.0313	0.0081	0.0396	0.0167	0.0399	0.0198	0.0454	0.0196
Finland	50.063	630.484	1159.39	N	0.0648	0.0266	0.0472	0.0146	0.0405	0.0200	0.1000	0.0372
France	5282.010	14520.702	174.91	N	0.0648	0.0284	0.0774	0.0374	0.0778	0.0387	0.0964	0.0402
Gabon	82.030	112.018	36.56	S	0.1789	0.0636	0.2555	0.0076	0.2555	0.0066	0.2555	0.0079
Georgia	110.803	287.628	159.59	S	0.1563	0.0721	0.1524	0.0802	0.0427	0.0104	0.1982	0.1111
Germany	4614.589	11610.536	151.60	N	0.0261	0.0177	0.0288	0.0181	0.0308	0.0199	0.0388	0.0245
Ghana	241.772	2061.369	752.61	S	0.0268	0.0016	0.1421	0.0058	0.1636	0.0106	0.1600	0.0128
Greece	536.728	1185.803	120.93	N	0.2191	0.0621	0.2609	0.0877	0.2567	0.0762	0.2710	0.0900
Guam	7.077	7.272	2.75	N	0.0542	0.0057	0.0542	0.0051	0.0542	0.0058	0.0531	0.0024

Guatemala	166.649	384.150	130.51	S	0.1295	0.0410	0.1435	0.0782	0.1653	0.0911	0.1780	0.1090
Guinea	47.105	252.152	435.29	S	0.0005	0.0002	0.0897	0.0176	0.0818	0.0028	0.0854	0.0032
Guinea-Bissau	19.397	33.146	70.88	S	0.0004	0.0000	0.0003	0.0000	0.0003	0.0000	0.0040	0.0005
Guyana	5.057	10.153	100.78	S	0.0782	0.0000	0.1211	0.0010	0.1211	0.0001	0.1211	0.0004
Haiti	85.807	174.794	103.71	S	0.1666	0.0217	0.1981	0.0325	0.2065	0.0464	0.2080	0.0250
Honduras	89.653	268.735	199.75	S	0.0916	0.0304	0.1282	0.0357	0.1337	0.0543	0.1503	0.0622
Hong Kong, China	86.507	198.953	129.99	N	0.3394	0.1669	0.2925	0.1293	0.2978	0.1454	0.3171	0.1476
Hungary	593.037	1416.319	138.82	N	0.0370	0.0184	0.0375	0.0218	0.0339	0.0229	0.0373	0.0243
Iceland	9.928	26.937	171.31	N	0.0210	0.0030	0.0213	0.0060	0.0212	0.0067	0.0351	0.0075
India	5698.537	23855.243	318.62	S	0.0348	0.0086	0.0356	0.0101	0.0356	0.0117	0.0371	0.0124
Indonesia	1841.431	7943.940	331.40	S	0.0495	0.0090	0.0746	0.0046	0.0717	0.0080	0.0724	0.0123
Iran	1674.915	3969.852	137.02	S	0.0156	0.0041	0.0526	0.0138	0.0763	0.0226	0.0781	0.0265
Iraq	1280.898	3381.214	163.97	S	0.0129	0.0102	0.0130	0.0100	0.0160	0.0116	0.0292	0.0173
Ireland	219.581	480.286	118.73	N	0.1342	0.0216	0.1036	0.0347	0.0943	0.0210	0.0964	0.0240
Israel	452.834	1190.586	162.92	N	0.1088	0.0530	0.0989	0.0508	0.1106	0.0621	0.1490	0.0764
Italy	4636.496	12727.915	174.52	N	0.1472	0.0372	0.1334	0.0413	0.1272	0.0411	0.1982	0.0696
Jamaica	122.850	259.103	110.91	S	0.1357	0.0289	0.1261	0.0353	0.2185	0.0512	0.1816	0.0460
Japan	9479.605	16145.149	70.31	N	0.1505	0.0482	0.1653	0.0471	0.1724	0.0570	0.1836	0.0557
Jordan	606.506	1876.019	209.32	S	0.1960	0.1392	0.1878	0.1297	0.1924	0.1440	0.2190	0.1350
Kazakhstan	546.617	3183.636	482.42	S	0.0287	0.0103	0.0299	0.0106	0.0376	0.0195	0.0438	0.0224
Kenya	11.863	306.138	2480.68	S	0.1828	0.0158	0.0311	0.0025	0.0172	0.0012	0.0222	0.0032
Kuwait	486.565	582.736	19.77	N	0.1695	0.0110	0.1894	0.0257	0.1896	0.0256	0.2157	0.0196
Kyrgyzstan	112.082	536.858	378.99	S	0.0004	0.0004	0.0246	0.0064	0.0305	0.0125	0.0312	0.0097
Laos	/	102.023	/	S	/	/	0.1668	0.0873	0.0918	0.0581	0.0857	0.0554
Latvia	108.837	191.384	75.84	S	0.1239	0.0363	0.1192	0.0295	0.1207	0.0347	0.1045	0.0566
Lebanon	142.992	386.173	170.07	S	0.6568	0.4778	0.6007	0.4020	0.5728	0.3776	0.5287	0.3671
Lesotho	28.700	87.881	206.20	S	0.0737	0.0491	0.0729	0.0541	0.0687	0.0588	0.0582	0.0576
Liberia	164.213	208.265	26.83	S	0.1494	0.0444	0.1034	0.0086	0.0989	0.0144	0.1506	0.0012
Libya	529.991	1125.741	112.41	S	0.1483	0.0076	0.1517	0.0076	0.1629	0.0088	0.1896	0.0049
Lithuania	117.172	343.534	193.19	N	0.0298	0.0214	0.0353	0.0251	0.0321	0.0267	0.0328	0.0230
Luxembourg	17.529	75.569	331.10	N	0.0863	0.0678	0.0912	0.0723	0.0845	0.0615	0.0689	0.0518
Madagascar	43.154	131.544	204.83	S	0.0574	0.0356	0.0408	0.0245	0.0372	0.0255	0.0380	0.0224

Malawi	22.692	130.233	473.91	S	0.0131	0.0088	0.0288	0.0069	0.0451	0.0426	0.0678	0.0381
Malaysia	830.907	5448.242	555.70	S	0.0906	0.0555	0.0853	0.0339	0.0940	0.0333	0.1220	0.0354
Mali	7.647	311.882	3978.48	S	0.0006	0.0000	0.0898	0.0404	0.0683	0.0431	0.0688	0.0379
Malta	40.923	101.053	146.93	N	0.1214	0.0501	0.1496	0.0300	0.1536	0.0239	0.1610	0.0241
Mauritania	66.516	82.188	23.56	S	0.0003	0.0001	0.0002	0.0001	0.0003	0.0002	0.0020	0.0000
Mauritius	/	36.483	/	S	/	/	/	/	0.1311	0.0416	0.1361	0.0406
Mexico	3052.408	11566.017	278.91	S	0.0808	0.0372	0.0758	0.0368	0.0814	0.0430	0.0824	0.0420
Moldova	117.806	327.013	177.59	S	0.0152	0.0092	0.0287	0.0178	0.0309	0.0204	0.0346	0.0267
Monaco	/	16.762	/	N	/	/	0.7691	0.5108	0.4860	0.1787	0.8776	0.6433
Mongolia	59.656	268.570	350.19	S	0.0948	0.0237	0.0948	0.0257	0.0985	0.0286	0.1607	0.0663
Montenegro	8.038	57.188	611.43	S	0.0356	0.0275	0.0562	0.0329	0.0619	0.0377	0.1009	0.0554
Morocco	757.614	1564.627	106.52	S	0.0729	0.0193	0.0901	0.0174	0.1275	0.0204	0.1496	0.0276
Mozambique	35.894	329.665	818.45	S	0.1087	0.0070	0.1018	0.0280	0.0984	0.0337	0.0937	0.0150
Myanmar	138.792	321.757	131.83	S	0.0920	0.0659	0.0654	0.0375	0.0636	0.0326	0.0661	0.0288
Namibia	21.047	79.396	277.24	S	0.0145	0.0043	0.0146	0.0066	0.0133	0.0053	0.0131	0.0094
Nepal	37.560	100.387	167.27	S	0.0149	0.0141	0.0398	0.0065	0.0391	0.0084	0.0426	0.0129
Netherlands	945.518	3558.093	276.31	N	0.0416	0.0274	0.0359	0.0255	0.0365	0.0299	0.0401	0.0256
New Zealand	152.824	1531.209	901.94	N	0.0529	0.0265	0.1140	0.0561	0.1472	0.0382	0.1560	0.0465
Nicaragua	59.656	119.678	100.61	S	0.1413	0.0053	0.1596	0.0012	0.1509	0.0022	0.1410	0.0009
Niger	27.258	98.892	262.79	S	0.0325	0.0122	0.0311	0.0158	0.0363	0.0300	0.0285	0.0233
Nigeria	861.496	4593.112	433.16	S	0.0122	0.0040	0.0357	0.0050	0.0424	0.0062	0.0448	0.0079
North Korea	84.545	180.927	114.00	S	0.1151	0.0831	0.0849	0.0572	0.1153	0.0752	0.1278	0.0781
North Macedonia	68.232	216.753	217.67	S	0.0694	0.0249	0.1247	0.0429	0.1334	0.0405	0.1449	0.0508
Norway	148.020	885.283	498.08	N	0.0660	0.0295	0.1245	0.0450	0.1150	0.0603	0.1782	0.0797
Pakistan	1259.785	3825.242	203.64	S	0.0125	0.0054	0.0134	0.0053	0.0149	0.0049	0.0263	0.0084
Palestine	264.895	594.740	124.52	S	0.3211	0.2500	0.3271	0.2512	0.3149	0.2359	0.3307	0.2497
Panama	107.845	458.699	325.33	S	0.1160	0.0125	0.1238	0.0114	0.1132	0.0109	0.1040	0.0177
Papua New Guinea	20.133	50.964	153.13	S	0.0776	0.0418	0.0750	0.0481	0.0740	0.0369	0.0696	0.0431
Paraguay	73.600	260.070	253.36	S	0.0319	0.0082	0.0376	0.0064	0.0405	0.0062	0.0444	0.0127
Peru	778.529	1226.947	57.60	S	0.1863	0.0964	0.1584	0.0764	0.1546	0.0809	0.2603	0.1060
Philippines	467.686	1545.469	230.45	S	0.2455	0.0115	0.2758	0.0362	0.2851	0.0347	0.2889	0.0854
Poland	1526.725	4376.680	186.67	N	0.0093	0.0051	0.0089	0.0055	0.0093	0.0059	0.0113	0.0064

Portugal	454.372	2542.024	459.46	N	0.2256	0.0585	0.2171	0.0740	0.2072	0.0945	0.2063	0.0958
Puerto Rico	118.766	617.216	419.69	S	0.1023	0.0251	0.1235	0.0362	0.1852	0.0336	0.1677	0.0318
Qatar	404.267	470.515	16.39	N	0.0590	0.0104	0.0647	0.0106	0.0631	0.0058	0.0626	0.0076
Romania	770.607	2206.455	186.33	S	0.0361	0.0166	0.0411	0.0183	0.0508	0.0193	0.0586	0.0246
Russia	7619.643	22323.760	192.98	S	0.0500	0.0224	0.0523	0.0232	0.0535	0.0258	0.0620	0.0288
Rwanda	19.939	84.340	323.00	S	0.0645	0.0332	0.0425	0.0280	0.0416	0.0273	0.0581	0.0267
San Marino	/	8.296	/	N	/	/	0.0248	0.0039	0.0608	0.0258	0.2134	0.1197
Saudi Arabia	1661.752	2604.344	56.72	N	0.0533	0.0105	0.0779	0.0100	0.0835	0.0088	0.0862	0.0111
Senegal	181.291	224.910	24.06	S	0.3120	0.0943	0.2711	0.0742	0.2712	0.0989	0.3965	0.0319
Serbia	125.186	782.417	525.00	S	0.0965	0.0500	0.0797	0.0395	0.0690	0.0388	0.0682	0.0352
Sierra Leone	37.046	79.918	115.73	S	0.4435	0.1435	0.1522	0.1037	0.3621	0.2754	0.4544	0.2552
Singapore	375.448	430.607	14.69	N	0.3998	0.0552	0.3958	0.0646	0.3978	0.0746	0.3997	0.0783
Slovakia	228.546	512.993	124.46	N	0.0569	0.0293	0.0622	0.0326	0.0609	0.0340	0.0606	0.0278
Slovenia	78.309	140.467	79.37	N	0.0665	0.0477	0.0689	0.0447	0.0692	0.0288	0.0962	0.0501
Somalia	52.647	58.757	11.60	S	0.1799	0.0001	0.1736	0.0002	0.1736	0.0003	0.1747	0.0022
South Africa	5506.464	10149.142	84.31	S	0.0384	0.0096	0.0471	0.0108	0.0564	0.0118	0.0554	0.0126
South Korea	968.952	3992.859	312.08	N	0.2461	0.1431	0.2466	0.1438	0.2347	0.1652	0.2864	0.1702
South Sudan	/	20.562	/	S	/	/	/	/	/	/	0.0184	0.0024
Spain	2845.364	10181.403	257.82	N	0.0881	0.0349	0.0779	0.0308	0.1476	0.0614	0.1877	0.0564
Sri Lanka	18.372	306.469	1568.15	S	0.0817	0.0192	0.1514	0.0065	0.0448	0.0073	0.2191	0.0086
Sudan	347.101	568.321	63.73	S	0.0707	0.0563	0.0632	0.0566	0.0624	0.0461	0.0557	0.0405
Suriname	49.095	51.692	5.29	S	0.0692	0.0252	0.0694	0.0141	0.0694	0.0213	0.0686	0.0156
Sweden	682.915	1805.536	164.39	N	0.0723	0.0229	0.0582	0.0212	0.0790	0.0371	0.0993	0.0359
Switzerland	390.141	864.010	121.46	N	0.1419	0.0690	0.1480	0.0691	0.1928	0.0913	0.2191	0.0986
Syria	373.273	692.249	85.45	S	0.0733	0.0276	0.0760	0.0463	0.0743	0.0373	0.0725	0.0344
Taiwan, China	713.012	3279.919	360.01	N	0.0567	0.0351	0.0768	0.0447	0.0823	0.0131	0.2440	0.0461
Tajikistan	/	407.775	/	S	/	/	0.0450	0.0220	0.0579	0.0247	0.0888	0.0451
Tanzania	265.761	534.895	101.27	S	0.0791	0.0098	0.0743	0.0154	0.0720	0.0146	0.0933	0.0184
Thailand	632.090	4023.178	536.49	S	0.0224	0.0209	0.0328	0.0189	0.0471	0.0226	0.0684	0.0196
Togo	42.939	305.630	611.78	S	0.0452	0.0055	0.1367	0.0185	0.1178	0.0099	0.1038	0.0085
Tunisia	586.494	1202.599	105.05	S	0.1677	0.0225	0.1345	0.0401	0.1566	0.0668	0.1707	0.0458
Turkey	2335.177	5814.364	148.99	S	0.1425	0.0537	0.1598	0.0802	0.1698	0.0770	0.2071	0.0876

Turkmenistan	425.822	880.255	106.72	S	0.0357	0.0136	0.0331	0.0121	0.0447	0.0101	0.0623	0.0114
U.S. Virgin Islands	/	9.906	/	N	/	/	/	/	0.0006	0.0000	0.0013	0.0008
Uganda	176.143	361.499	105.23	S	0.0212	0.0061	0.0345	0.0061	0.0428	0.0064	0.0545	0.0122
Ukraine	2217.822	6243.061	181.50	S	0.0372	0.0135	0.0399	0.0161	0.0488	0.0177	0.0650	0.0239
United Arab Emirates	251.208	348.125	38.58	N	0.0981	0.0238	0.1283	0.0358	0.1273	0.0341	0.1219	0.0295
United Kingdom	6810.951	11634.598	70.82	N	0.0294	0.0102	0.0354	0.0116	0.0359	0.0113	0.0476	0.0126
United States	104496.158	200272.458	91.66	N	0.1076	0.0413	0.1059	0.0400	0.1068	0.0409	0.1117	0.0413
Uruguay	184.720	278.470	50.75	S	0.1245	0.0043	0.1527	0.0033	0.1561	0.0094	0.1662	0.0081
Uzbekistan	558.141	2515.260	350.65	S	0.0016	0.0013	0.0045	0.0022	0.0055	0.0036	0.0062	0.0028
Venezuela	814.353	2324.999	185.50	S	0.1435	0.0380	0.1279	0.0395	0.1347	0.0444	0.1707	0.0491
Vietnam	348.982	3156.756	804.56	S	0.0897	0.0429	0.0745	0.0468	0.0718	0.0396	0.1016	0.0439
Yemen	47.990	77.107	60.67	S	0.0914	0.0135	0.0920	0.0271	0.0943	0.0251	0.1000	0.0221
Zambia	360.072	645.316	79.22	S	0.0100	0.0046	0.0080	0.0052	0.0090	0.0061	0.0088	0.0064
Zimbabwe	171.108	443.801	159.37	S	0.0021	0.0015	0.0014	0.0010	0.0020	0.0013	0.0019	0.0008

A total of data from 170 countries and regions were collected.

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