

**The ‘Spatial GINI’ Coefficient:
An empirical satellite imagery derived
metric characterizing the co-distribution of light and people**

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Abstract

The ‘Spatial GINI Coefficient’ is a simple, objective, spatially explicit and globally available empirical measurement of human well-being derived solely from nighttime satellite imagery and population density. There is increasing recognition that the distribution of wealth and income amongst the population in a nation or region correlates strongly with both the overall happiness of that population and the environmental quality of that nation or region. Measuring the distribution of wealth and income at national and regional scales is an interesting and challenging problem. GINI coefficients derived from Lorenz curves are a well established method of measuring income distribution. Nonetheless, there are many shortcomings of the GINI coefficient as a measure of income or wealth distribution. For example, subsidies such as food stamps may or may not be counted, availability of free public education may or may not be present or incorporated into these measures, and informal economic activity is difficult to measure and allocate amongst households. Well documented problems associated with the use of GDP/capita as an average measure of wealth also apply to measures of the distribution of wealth that use monetary metrics such as GDP. In this paper we develop an alternative measure of the distribution of wealth we choose to call the ‘Spatial GINI coefficient’ that completely avoids the use of monetary measures of wealth.

Introduction

The 'Spatial GINI Coefficient' is derived from two spatially explicit datasets that have global extent: 1) A 'Nighttime Lights of the World' dataset derived from the Defense Meteorological Satellite Program's Operational Linescan System (DMSP OLS) nighttime satellite imagery, and 2) a gridded population density of the world. These datasets are used to produce 'Spatial GINI Coefficients' for many differing levels of spatial aggregation including nations, watersheds, regions, and urban areas. Previous studies of nighttime satellite imagery have demonstrated that nighttime imagery can be used as a proxy measure of energy consumption, gross domestic product, CO₂ emissions, ecological footprints, and informal economic activity. The 'Spatial GINI Coefficient' measures how emitted light as observed by the DMSP OLS is spatially distributed relative to the spatial distribution of the human population. The data products used for this analysis have a spatial resolution of 1 km². The 'Spatial GINI Coefficient' varies from 0 to 1 as does the traditional GINI Coefficient and the Human Development Index (HDI). If one person in a nation or region had lived by themselves in the only square kilometer that produced nighttime light emissions detected by the DMSP OLS then that nation or region would have a Spatial GINI Coefficient of 1.0. If all people in a nation or region lived in areas of the country such that they all had the same average amount of nighttime light emission per person the 'Spatial GINI Coefficient' would have a value of 0. The 'Spatial GINI Coefficient' has weak correlations with traditional GINI Coefficients measured by the World Bank and the International Futures project. However, the 'Spatial GINI Coefficient' shows a strong correlation with the Human Development Index (HDI). The HDI is a composite statistic that uses life expectancy, literacy, education, and standards of living to measure human well being.

Developing a measure of human well being that is useful for policy makers can be challenging. Measures of 'happiness' at the individual level can be problematic (Gilbert, 2006); whereas, aggregate national measures of happiness perhaps capture spiritual rather than material well-being. Measures derived from actual monetary wealth (e.g. Gross Domestic Product (GDP)/capita) have come under increasing criticism for their failure to capture distributional effects and ecological impacts (e.g. depletion of natural capital). In fact, distribution (or mal-distribution) of wealth is one of the major grievances of the contemporary 'Occupy Wall Street' movement as exemplified by their characterization of themselves as the poorest 99% of the population (Citation here).

The GINI coefficient (Gini, 1936) is the most commonly used measure to characterize the distribution of wealth in a population, region, or nation. The GINI coefficient is derived from measuring the area between the Lorenz curve (Lorenz, 1905) and a line of perfectly equal distribution of wealth. The Lorenz curve is a graph of the empirically derived cumulative percentage of population (X axis) vs. cumulative percentage of income (Y axis). The line $Y=X$ is the line that characterizes a uniform distribution of wealth in which all members of the population have an equal income. The GINI coefficient is simply a measure of the area between these two curves normalized so that a maximally unequal distribution of income (e.g. one person has all the income) takes on a value of 1.0.

The GINI coefficient has been used for many years and corresponds with many existing stereotypical ideas of political economy. For example, Scandinavian countries such as Norway, Sweden, Finland, and Denmark have lower GINI coefficients which represent broader distributions of income. Brazil and Mexico have historically had relatively high GINI coefficients although Mexico's has been dropping significantly in the last few decades. The GINI coefficients of China, India, the United States, and the United Kingdom have been increasing in the last few decades. In fact, if current trends continue the GINI coefficient of the United States will surpass that of Mexico. This international comparison demonstrates some of the strengths of the GINI coefficient. It is scale-independent and population-independent (large nations can be compared to small nations and large economies can be compared to small economies), and it still functions in correct ways when money is transferred (if measured income is transferred from the rich to the poor the GINI coefficient responds appropriately by decreasing).

Despite its widespread use as a measure of distribution, the GINI coefficient has many limitations. Among these are: wealth vs. income effects, nominal income vs. purchasing power parity effects, age structure of the population effects, subsidy effects (e.g. food stamps, free universal education, etc), and non-measured income effects (e.g. informal economic activity, subsistence farming, etc.). The scale-independent nature of the GINI coefficient is both a strength and a weakness in that it can miss an aggregate level of well being associated with something like GDP/capita. For example, country 'A' may have a GINI coefficient of 0.4 and a GDP per capita of \$25,000 while country 'B' may have the same GINI coefficient of 0.4 and a per capita GDP of \$1,000. This kind of problem has motivated the development of other indices such as the Human Development Index or HDI.

The HDI was developed in 1990 to "*to shift the focus of development economics from national income accounting to people centered policies*". Several economists including Mahbub ul Haq and Amartya Sen spearheaded the effort to develop the HDI with the purpose of shifting the evaluation of development to include improvements in human well being such as life expectancy and availability of education (McGillivray and White, 2006). The HDI also has its critics including Bryan Caplan who argues that the HDI merely measures how 'Scandinavian your country is' (Caplan, 2009). Another criticism of the HDI stems from uncertainty and errors inherent in the measurements of the data required to generate the HDI (Wolff et al 2011). Other measures of human well-being attempt to move even further up Maslow's triangle (Maslow, 1943) to include many more facets of existence including creativity, imagination, and intimacy (Max-Neef, 1992). This research examines a measure of distribution derived from the spatially explicit distribution of light relative to a spatially explicit distribution of population. The measure is derived in a manner very similar to how a GINI coefficient is derived yet the values correlate strongly with national HDI measurements.

Data, Approach, and Methods

We explore a slightly different approach to generating a GINI coefficient for the nations of the world. Instead of using income as the y axis we construct a Lorenz curve using two spatially explicit datasets: 1) Global Nighttime Lights of the World, and 2) Global grid of

population density (Landsat). These two spatially explicit representations of nocturnally emitted radiation and human population density are superimposed and analyzed on a country by country basis to produce what we call a 'Lumen GINI' coefficient for each country of the world. The Lumen is a standard international unit of luminous flux which is a measure of the quantity of visible light emitted from, in this case, the surface of the earth. Our 'Lumen GINI' coefficient in essence measures the co-distribution of light and people in space.

Derivation of 'Lumen GINI' coefficients for the nations of the world – The superposition of the grid of population density and the nighttime satellite imagery allows for a numerical characterization of their relative spatial distribution in a manner very similar to the derivation of a Lorenz curve (Figure 3). All of the 'dark' pixels with a value of zero are identified and the population in those pixels are summed. The cumulative percentage of both the total light emissions and percentage of population are identified and recorded for each change in light intensity (e.g. at the dark or '0' pixels, at the '1' or dimmest pixels, and so on, finishing with the brightest pixels). Results of this analysis are plotted for six countries with their corresponding 'Lumen GINI' coefficients (China (0.791), Brazil (0.728), United States (0.542), North Korea (0.920), Norway (0.746), and Australia (0.643)) (Figure 4). We derived a 'Lumen GINI' coefficient for every nation of the world and tabulated our figures with other GINI measures (The World Bank and the International Futures Project <http://www.ifs.du.edu/>), the Human Development Index, and Global Footprint Network's 'Ecological Deficit' (Table 1).

Correlation of 'Lumen GINI' coefficient with other variables – A correlation analysis of the 'Lumen GINI' coefficient with standard GINI coefficients, and the HDI (Figure 5). The 'Lumen GINI' coefficient does not correlate with standard GINI coefficients as measured by the World Bank and the International Futures Project ($R = 0.12$ and 0.18 respectively). However, the Spatial GINI Coefficient does strongly correlate with the Human Development Index ($R = 0.86$).

10 km x 10 km Population Grid

0	0	0	0	0	0	0	0	0	0
0	0	1	1	2	1	2	1	4	1
1	1	3	2	3	4	4	4	3	1
1	1	4	5	5	5	10	5	5	2
1	2	5	5	10	10	10	10	10	3
1	3	5	5	10	30	50	30	10	4
2	2	5	10	10	50	100	50	10	10
15	5	5	5	10	30	50	30	10	3
4	3	5	5	10	10	10	10	10	2
0	2	5	5	5	5	10	5	5	1

10 km x 10 km DMSP OLS Image

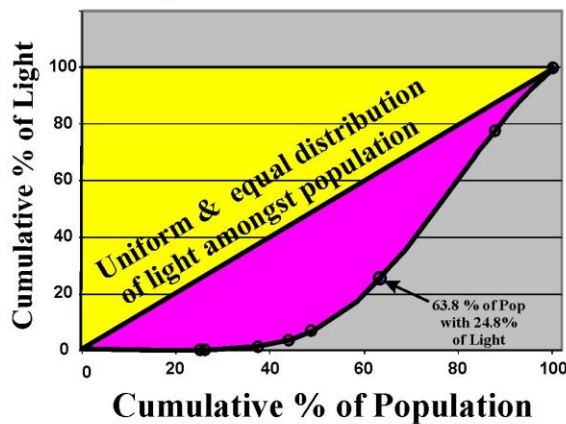
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	2	0	0	0
0	0	0	0	2	2	10	1	2	0
0	0	0	0	2	50	150	50	5	0
0	0	0	0	10	150	255	150	10	2
5	0	0	0	2	50	150	50	5	0
0	0	0	0	0	5	10	5	2	0
0	0	0	0	0	0	0	0	0	0

Analysis of the population grid relative to the light grid (above) produces a table that contrasts % of Population to % of light in any given country or area (See table below).

Light Level (DN)	Pop in DN	Cum % of Light	Cum % of Pop
0	205	0.0	25.0
1	10	0.1	26.2
2	90	1.5	37.2
5	55	3.7	43.9
10	40	7.2	48.8
50	120	24.8	63.4
150	200	77.6	87.8
255	100	100.0	100.0

Total Pop = 820 Total Light = 1137

Spatial Lorenz Curve



The "Lumen GINI" Coefficient

Pink Area

Yellow Area

A 'lumen GINI' of 1.0 implies one person lives where all the light is and everyone else is in the dark. A 'lumen GINI' value of 0.0 implies light is distributed equally amongst all people.

Figure X (3): Derivation of a 'Lumen GINI' coefficient for a 100 pixel area.

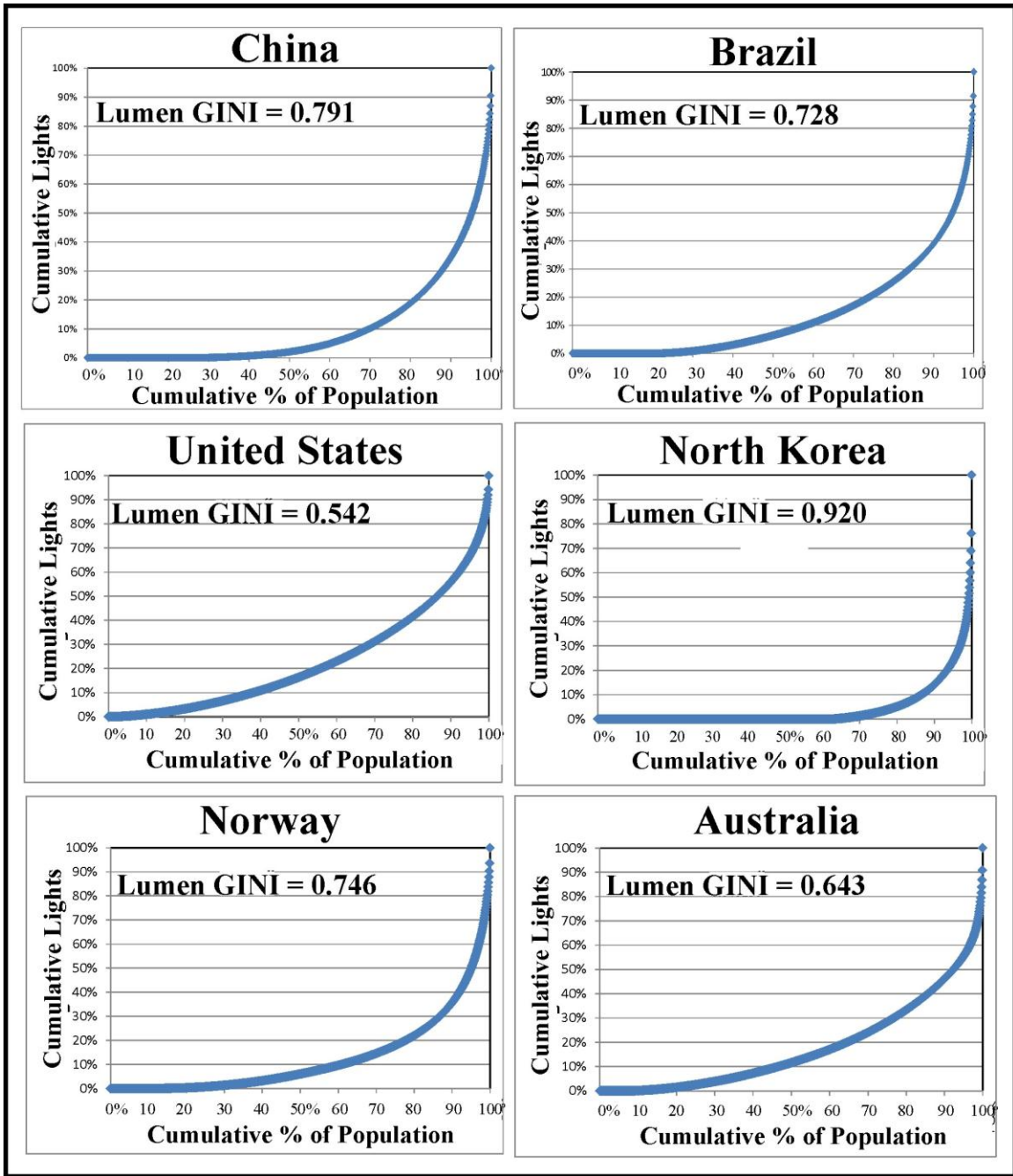
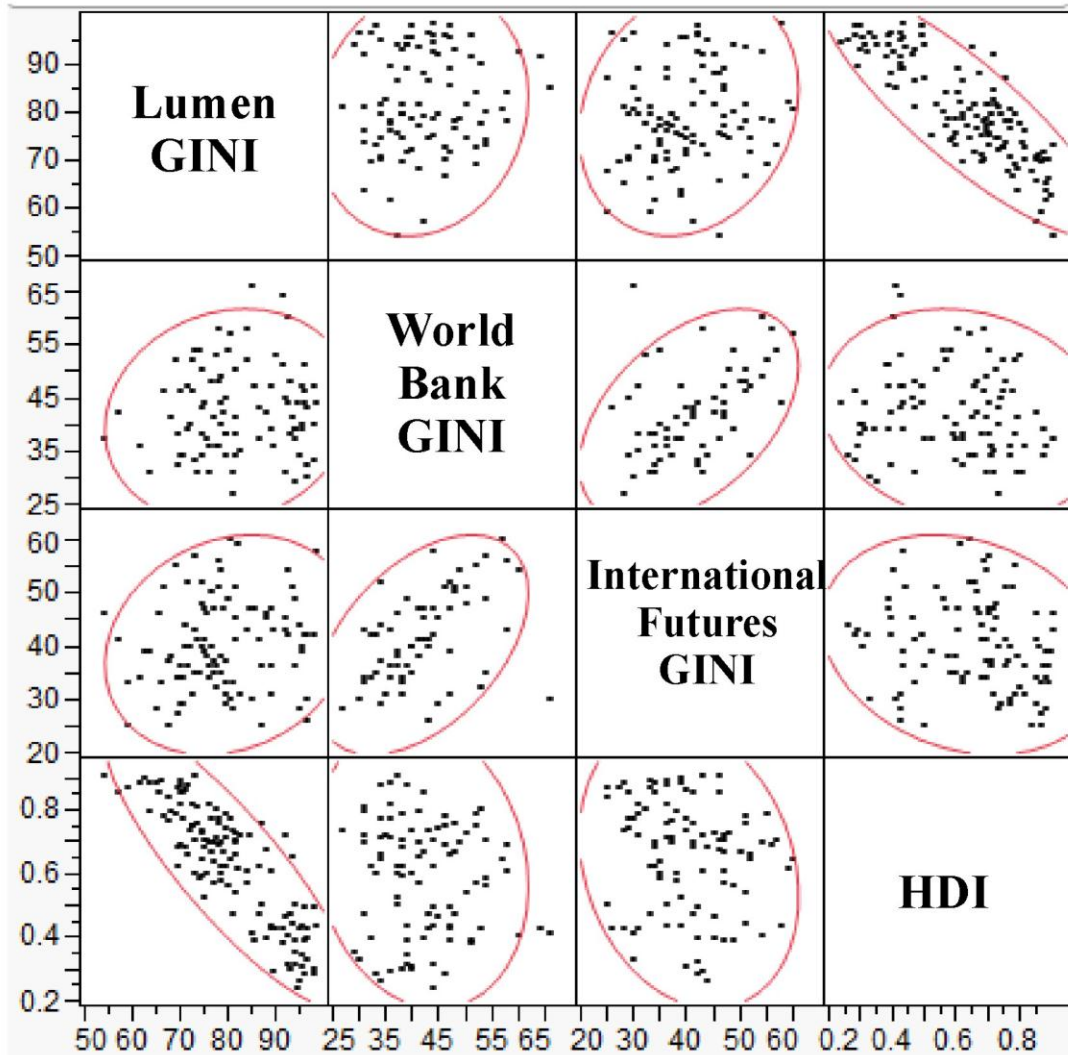


Figure X (4): 'Lumen GINI' coefficients for six different countries

Correlation Matrix



	GINI_dmsp	GINI_wb	GINI_ifs	HDI_2010
GINI_dmsp	1.0000	0.1293	0.1834	-0.8572
GINI_wb	0.1293	1.0000	0.4715	-0.1436
GINI_ifs	0.1834	0.4715	1.0000	-0.2119
HDI_2010	-0.8572	-0.1436	-0.2119	1.0000

Figure 5: Correlation Matrix of 'Lumen GINI' with standard GINI Coefficients and HDI

Conclusion

Our 'Spatial GINI Coefficient' provides an inexpensive, annually collectable, spatially explicit, and interesting measure of human well being in a world that seems to be increasingly less able and/or willing to make social science measurements of phenomena such as poverty rates, distribution of wealth, and the size and nature of the informal economy. In addition, the construct validity of GDP (as measured in dollars) as a measure of wealth may come under increasing criticism in light of the debt crisis and peak oil. Nocturnal satellite observations of emitted light may prove to be a very simple and increasingly legitimate measure of the spatial distribution of wealth in the near future. We believe that in the future we may have to rely on several inexpensive and uncertain measures of complex phenomena rather than single expensive measures. The benefits of these multiple inexpensive measures are cost of acquisition, global availability, and robustness of validity.

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