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On the Measurement of "Grayness" of Cities*

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Abstract

We consider a situation where individuals belonging to multiple groups inhabit a space that can be divided into smaller distinguishable units, a feature characterizing many cities in the world. When data on an economic attribute (in our case, income) is available, we conceptualize a phenomenon that we refer to as "Grayness" - a combination of spatial integration based upon group-identity and income. Grayness is high when cities display a high degree of spatial co-existence in terms of both identity and income. We lay down some desirable properties of a measure of Grayness and develop a simple and intuitive index

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that satisfies them. We provide an illustration by using data from the Indian city of Hyderabad, and selected American cities.

JEL Codes: D61; D63

Keywords: Segregation, Inequality, Group-based Disparities, Cities, Grayness.

1 Introduction

It is being increasingly acknowledged that the world is predominantly urban and urbanization will continue into the foreseeable future (Davis 2007; UN 2015). This paper is therefore concerned with cities, in particular group-based ("horizontal") disparities within cities.[1] Many cities in the world are characterized by severe disparities among groups. The particular facet of group-based disparity that we are interested in can be illustrated by the following examples. Blacks and Whites live in American cities which have distinct neighborhoods or administrative divisions. Similarly, different caste groups live in Indian cities which can be divided into several wards. Across the world, different ethnic groups inhabit urban areas, which are characterized by some form of spatial division. What is common to all these examples is the presence of identity groups in an urban context with spatial heterogeneity. Apart from this, we may have information available on an economic attribute of individuals and groups, e.g. incomes or wages. Cities could dis-

[1] Following Stewart (2002), it has become customary to distinguish between interpersonal ("vertical") and group-based ("horizontal") disparities.

play various degrees of spatial co-existence (or lack of it) in terms of this attribute, e.g. the rich and poor in a city could live together in the same neighborhood or live completely apart. Combining spatial integration on income and non-income dimensions reveals certain interesting features and dynamics of cities. For example, irrespective of their ethnic identities, if the rich are separating themselves into "enclaves" or "gated-communities", whereas the poor are being pushed into "slums", then this can be understood as a process where spatial integration is low in terms of income, but not so in terms of ethnic identity. Such a phenomenon is being witnessed in India after economic reforms where initiated in the early 1990s, and such "neoliberal" cities can be distinguished from "mixed" cities that prevailed earlier.[2] Essentially, we are interested in a phenomenon that is a combination (or intersection) of spatial integration based upon identity and income (or some other economic attribute). We refer to this phenomenon as "Grayness". Grayness is high when cities display a high degree of spatial co-existence of both identity group and economic groups. When Grayness is negligibly small, cities become "stark".

Our focus on space is inspired by the recent recognition in social sciences and humanities of the importance of explicit considerations of space. Scholars have argued that such a "spatial turn" and the idea of "spatial justice" have conferred both theoretical and practical advantages, e.g. the discourse on the "right to the city" which has assumed political salience today (Soja 2009;

[2] On poverty and rising inequality in urban India since economic reforms, see Vakulabharanam and Motiram (2012).

Harvey 2013). One of the important ideas in this literature is that space and society are intricately linked ("sociospatial dialectics"). Space is not an inert given, and individuals and groups shape it, even as it influences them. Our attempt is to bring these ideas to bear on the literature in welfare economics. While the above body of knowledge has seen contributions mostly from non-economists, economists have also recognized that spatial location confers both advantages and disadvantages (see e.g. Reardon 2017; Chetty et al. 2016) and spatial patterns influence outcomes like crime (e.g. see the Lewis Mumford lecture of Amartya Sen (2007)).

In light of the above, we consider an abstract city that is comprised of multiple spatial units. The population of the city, and in each spatial unit is divided into several groups. Apart from his/her group identity, we have information on an economic attribute (income) of an individual. We lay down the desirable properties of a "Grayness Index" and develop a simple and intuitive index which satisfies these properties. To the best of our knowledge, our paper is the first one that focuses explicitly on space and explores the interaction of spatial integration of different kinds. In doing so, it differs in spirit from the literature on spatial (residential) segregation, and adds to it. The consideration of spatial integration on different dimensions simultaneously captures an important social phenomenon that cannot be reduced to considering spatial integration on these dimensions separately and then bringing them together. The interaction among these dimensions will be lost. We will discuss this further in the next section. The paper draws upon existing literature by conceptualizing the Grayness index as a function of two components - identity group and income - these are in turn indices of spatial integration (and inverse of spatial segregation). To keep the exposition brief, we do not present a survey of the literature on segregation, but refer interested readers to Chakravarty (2009) and Silber et al. (2009). The most commonly used index of segregation is the Duncan-Duncan dissimilarity index, which is useful when there are only two groups. In our case, there can be multiple groups, so we draw upon Reardon and Firebaugh (2002). Since income is a continuous variable, we draw upon Kim and Jargowsky (2009), who demonstrate how the Gini index can be used for segregation for both continuous and binary variables.[3]

Urbanization in recent times has been driven by growth of cities in developing countries (Davis 2007). Projecting into the future, the United Nations estimates that several of the largest cities in the world will be located in the global South.[4] We therefore implement our index on an Indian city viz. Hyderabad. We show that the Grayness index of Hyderabad is high, e.g. as compared to selected American cities. We hypothesize that this maybe an important characteristic of Indian cities vis-a-vis cities in the developed world.

[3]Also see Reardon (2009) and Hutchins (2009). Reardon (2009) develops indices of segregation with multiple groups, when one of the dimensions (e.g. occupation, education) can be ordered. Hutchins (2009) develops an "augmented index" of gender-based occupational segregation where occupations can be ranked in terms of a scalar variable (e.g. average wage).

[4]The top ten urban agglomerations in 2030 are expected to be: Tokyo, Delhi, Shanghai, Beijing, Mumbai, Mexico City, Cairo, So Paulo, Osaka, and New York-Newark (UN 2015).

The remaining portion of the paper is divided into two sections. The next section develops the index and presents an illustration from the Indian city of Hyderabad and some American cities. The third section concludes with a discussion.

2 Grayness: Theory and Illustration

2.1 An Index to Measure Grayness

Consider a city which is divided into N (> 1) spatial units, which we index by m and n. $G(> 1)$ groups live in the city, and we index these groups by g. Let the shares of group g in spatial unit m, and in the city be denoted by p_g^m and p_g^c, respectively. If p_g^m is less (more) than p_g^c, then group g is considered to be underrepresented (overrepresented) in the spatial unit m. Let $P^m = (p_1^m, p_2^m, \ldots, p_G^m)$ denote the vector of group shares in spatial unit m. Let $P = (P^1, P^2, \ldots, P^N)$ denote a vector that captures the spatial distribution of group shares for the entire city. Let $P^c = (p_1^c, p_2^c, \ldots, p_G^c)$ denote the vector of city shares. Let Y_g^m denote the income distribution of group $g = 1, \ldots, G$ in spatial unit $m = 1, \ldots, N$. We could consider the income distribution for either individuals or households. Let $I = ((Y_1^1, Y_2^1, \ldots, Y_G^1), \ldots, (Y_1^N, Y_2^N, \ldots, Y_G^N))$ denote the vector of income distributions for the entire city. Let $S = (T, s^1, \ldots, s^N)$ where T (> 0) denotes the total population of the city, and $s^m, m = 1, \ldots, N$ denotes the fraction of the population of the city that resides in the spatial unit m. We conceptualize the Grayness Index (GI) as a function, $GI : (P, P^c, S, I) \rightarrow [0, 1]$ that combines spatial integration on identity groups and income.

Formally, we can think of GI as a function (f) of a "Group Component (GC)" and an "Income Component (IC)" where these two components measure spatial integration on identity groups and income, respectively. We will discuss the properties of GC and IC later. It suffices here to point out that since they are measures of spatial integration, they lie in $[0, 1]$. We propose that GI satisfies the following properties/axioms in terms of its components:

(A1) Minimum Grayness

GI is at its minimum value of zero if and only if GC and IC are both at their minimum values of zero, i.e. there is complete lack of spatial integration in terms of both group-identity and income.

(A2) Maximum Grayness

GI is at its maximum value of one if and only if GC and IC are both at their maximum values of one, i.e. there is complete spatial integration in terms of both group-identity and income.

(A3) Monotonicity: Grayness as an Increasing Function of Spatial Integration

GI increases (decreases) if spatial integration increases (decreases) either among identity groups or on the income dimension, i.e. $\frac{\partial GI}{\partial GC} > 0$ and $\frac{\partial GI}{\partial IC} > 0$.

The above axioms are straightforward. (A3) considers the impact on Grayness of spatial integration on one dimension. How do we consider the impact on Grayness of spatial integration on multiple dimensions, and how does this compare with the situation depicted in (A3)? A simple example can be used to explore this question. Let us imagine three cases: (1) $GC = 0.8, IC = 0$, (2) $GC = 0, IC = 0.8$, and (3) $GC = 0.4, IC = 0.4$. In Cases (1) and (2), there is complete lack of spatial integration on one dimension and high spatial integration on the other, whereas in Case (3), there is modest spatial integration on both dimensions. Starting from a situation where there is complete lack of spatial integration on both dimensions ($GC = 0$ and $IC = 0$), we can imagine three different processes: A, B, and C, that can result in Cases (1), (2) and (3), respectively. A is a process that increases cohesion among identity groups while preserving income-based/class-based exclusions and prejudices. B is a process similar to A, except that the roles of identity groups and income are interchanged. C is a process that promotes cohesion on both identity group and income dimensions, albeit in a modest manner. We believe that a city can be considered to be more spatially integrated in Case (3) as compared to Cases (1) and (2). In other words, process C contributes more to spatial integration and Grayness compared to processes A and B. Essentially, for a given "total spatial integration" ($GC + IC$), we consider a city to be more spatially integrated if the "mix" of spatial integration on multiple dimensions is better. This idea is analogous to the preference for variety in international trade under monopolistic competition (see e.g. Grossman (1992)). The axiom below captures this idea more formally:

(A4) Preference for Mix of Spatial Integration on Multiple Dimensions

For a given total spatial integration ($GC + IC$), consider a process that increases spatial integration on the dimension that has lower integration (say by $\delta > 0$) and decreases spatial integration on the other dimension by an equal amount (i.e. by δ). Such a process will result in a better mix of spatial integration on the two dimensions, and thereby increase GI.

Note the similarity with the ideas of "mean-preserving spread" and "Dalton-Pigou transfer principle" in the measurement of risk and inequality, respectively (see e.g. Chakravarty (2009) for a discussion). In a way, we are applying these ideas to GC and IC. Finally, we would like to consider the interaction of the two components explicitly. It is reasonable to argue that the phenomenon of interest to us should depend upon the interaction of the two components, and not just upon "pure" spatial integration among either identity groups or on income. This is formalized in the axiom below:

(A5) Interaction: GI depends upon interaction of GC and IC, i.e. $\frac{\partial^2 GI}{\partial GC \partial IC} \neq 0$

We can consider several functional forms for f, although some simple ones like the arithmetic mean or geometric mean of GC and IC are ruled out because they violate one or more of the above axioms. Interestingly, a "Mean-Variance" form satisfies the above axioms, and we propose it:

$$GI = \alpha \frac{(GC + IC)}{2} - \beta [\frac{(GC^2 + IC^2)}{2} - (\frac{GC + IC}{2})^2] \tag{1}$$

Note that the first term $\frac{(GC+IC)}{2}$ is the mean spatial integration (i.e. average of GC and IC) and the second term $[\frac{(GC^2+IC^2)}{2} - (\frac{GC+IC}{2})^2]$ is the variance between the two components of spatial integration (GC and IC). As we show in the proposition below, when $\alpha = 1$ and $0 < \beta < 1$, GI satisfies the axioms $(A1) - (A5)$. An interesting result concerns the decomposition properties of GI. We can show that:

$$GI = f(GC, IC) = \alpha \frac{GC}{2} - \beta[\frac{GC^2}{2} - (\frac{GC}{2})^2] + \alpha \frac{IC}{2} - \beta[\frac{IC^2}{2} - (\frac{IC}{2})^2] + \beta \frac{GC * IC}{2} \quad (2)$$

$$= f(GC, 0) + f(0, IC) + \beta \frac{GC * IC}{2} \quad (3)$$

$f(GC, 0)$ and $f(0, IC)$ represent pure spatial integration, in terms of identity groups and income, respectively. Hence, we can see that GI can be decomposed into three parts, representing pure spatial integration in terms of identity groups, pure spatial integration in terms of income, and interaction between spatial integration on identity groups and income.The parameter β captures the strength of interaction between the two components (we will see this more clearly below) and the impact of interaction will vanish if $\beta = 0$.

Proposition 1: If $\alpha = 1$ and $0 < \beta < 1$ then GI satisfies $(A1) - (A5)$.

Proof: It is easy to establish that GI satisfies $(A1)$. If $GC = IC = 1$, then $GI = \alpha$. Hence, if $\alpha = 1$, then GI satisfies $(A2)$. $\frac{\partial GI}{\partial GC} = \frac{1}{2} - \beta \frac{(GC - IC)}{2}$. Since the maximum value that $(GC - IC)$ can take is 1, the condition $\beta < 1$ ensures that $\frac{\partial GI}{\partial GC} > 0$. On similar lines, we can show that it ensures that $\frac{\partial GI}{\partial IC} > 0$. As long as $\beta > 0$, the process referred to in (A4) reduces the variance between GC and IC and thereby increases GI. Hence, if $\beta > 0$, GI satisfies $(A4)$. From equation (3), we can see that $\frac{\partial^2 GI}{\partial GC \partial IC} = \frac{\beta}{2} \neq 0$. Hence, GI satisfies $(A5)$. ■

Note that in general (i.e. given that $GC \in [0,1]$ and $IC \in [0,1]$), β needs to be less than one. But, for particular values of GC and IC, we can work with higher values of β. For example, for modest values of GC and IC (less than 0.5), we can use values of β in excess of 1, but less than 2. Having characterized GI, we will now move to its components, GC and IC. Let $Gini_a$ denote the Gini index of average incomes of spatial units and $Gini_t$ denote the Gini index for the income distribution in the city. Spatial integration on income can be considered as the inverse of income-based spatial segregation. Income is a continuous variable, and we can draw upon the literature on segregation for continuous variables. In particular, Kim and Jargowsky (2009) demonstrate that the ratio $Gini_a/Gini_t$ can be considered as an index of segregation which lies in $[0,1]$. Following this, we can characterize IC as:

$$IC = 1 - \frac{Gini_a}{Gini_t} \tag{4}$$

Note that IC lies in $[0,1]$. It takes the maximum value of 1 when the city is completely spatially integrated in terms of income, i.e. all the spatial units have identical average incomes. It takes the minimum value of zero when the city is completely spatially segregated (or atomized) in terms of income, i.e. each spatial unit comprises of just one individual or household.

Since we have characterized IC using the Gini index, it would be advantageous to consider a Gini-based characterization for GC too. As in the case of IC, we can consider spatial integration among identity groups as the opposite of group-based spatial segregation. Since the number of groups can be greater than two, we draw upon the literature on multi-group segregation indices. Reardon and Firebaugh (2009) present a comprehensive overview of this issue, including the various notions of segregation. They demonstrate how an index of segregation based upon the Gini index can be constructed by comparing the group proportions across all organizational (in our case, spatial) units, and for all groups. Following them, we characterize GC as:

$$GC = 1 - \frac{\Sigma_{g=1}^{G} p_g^c \Sigma_{m=1}^{N} \Sigma_{n=1}^{N} s^m s^n |p_g^m / p_g^c - p_g^n / p_g^c|}{2\Sigma_{g=1}^{G} p_g^c (1 - p_g^c)} \tag{5}$$

As in the case of IC, GC lies in $[0, 1]$. It takes the maximum value of 1 if the city is completely spatially integrated in terms of the identity group, i.e. for each group, its share in every spatial unit is the same as its city share. It takes the minimum value of zero if the city is completely segregated in terms of the identity group, i.e. each spatial unit comprises of just one group.

The above formulation of GI attaches equal weightage to the two different kinds of spatial integration, i.e. to GC and IC. It is easy to see that this is not necessary, and we could privilege one kind of spatial integration over another. Let w_g and w_i denote the weights on GC and IC, respectively, where $(w_g + w_i) = 1$. In the analysis above, we have considered: $w_g = w_i = 0.5$. A general formulation would be:

$$GI = (w_g GC + w_i IC) - \beta[(w_g GC^2 + w_i IC^2) - (w_g GC + w_i IC)^2] \tag{6}$$

Before moving on to the illustration of GI, it is worthwhile to point out that the index can be extended to spatial integration on more than two dimensions. This can be done by simply considering a mean-variance form for the multiple components. For example, if there are three dimensions (say race, religion, and income) for which the components are GC_1, GC_2, and IC, then the index can be expressed as:

$$GI = \frac{GC_1 + GC_2 + IC}{3} - \beta[\frac{GC_1^2 + GC_2^2 + IC^2}{3} - (\frac{GC_1 + GC_2 + IC}{3})^2] \quad (7)$$

2.2 An Illustration of Grayness

We will now illustrate the above analysis by considering the cases of Hyderabad city in India and some American cities. The data for Hyderabad comes from a spatially representative household survey conducted by us during 2015-17. The survey is described in detail in Motiram and Vakulabharanam (2017), and we briefly discuss the relevant features here. The survey focuses on the completely urban part of Hyderabad city (viz., the district of Hyderabad). The methodology is a multistage stratified one which draws upon the latest (2011) decennial Indian Census. The survey comprises of 1000 households which are spread across 100 Enumeration Blocks (EBs) - 10 households in each EB. To ensure spatial representation, the 16 subdistricts of Hyderabad are treated as strata and the EBs are spread across them. For the computation of the Grayness Index, we consider Census wards as the spatial units. The Census ward is a larger area compared to the EB, but is smaller than the subdistrict. We divide the population of Hyderabad into two groups based upon their caste status: Dalits (Scheduled Castes and Tribes) and Non-Dalits. We could use household per-capita income (total monthly household income/household size) or household income. The former is defined at the individual level, whereas the latter is defined at the household level. Since the literature on US income inequality that draws upon Census data has largely used the household as the unit of analysis, we focus on the former. The ranking of groups in terms of household income is as expected: Dalits - Rs. 20,613.62, and Non-Dalits - Rs. 23,400.71.[5] This difference would be much starker in other Indian cities since Hyderabad has a substantially larger proportion of Muslims, who are mostly included under Non-Dalits, and whose economic status in urban India is quite low.

We present estimates for two American cities: Chicago (Chicago-Naperville-Elgin IL-IN-WI Metropolitan Statistical Area), and New York (New York-Newark-Jersey City-NY-NJ-PA Metropolitan Statistical Area).[6] We use Census tracts as the spatial units and use the American Consumer Survey 2016, 5-year estimates (i.e. 2012-16) from the Factfinder site of US Census Bureau.[7]. Analogous to the analysis from Hyderabad, we consider two racial groups: Black or African American alone and White alone, and Black or African American alone and Others. On the average, the household incomes

[5]The corresponding figures for per-capita income are also on expected lines: Dalits - Rs. 4,858.43, and Non-Dalits - Rs. 5,534.04.

[6]We have also conducted analysis for several other American cities, and they turn out to have a smaller Grayness index than Hyderabad, i.e. our main finding is not altered if we include some more American cities.

[7]https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml

of Blacks are considerably lower than those of Whites, e.g. for New York city the average annual household incomes in 2016 inflation adjusted dollars are \$24,103 and \$45,952 for Blacks and Whites, respectively (Table S1902, U.S Census Bureau).

In table 1, we present the estimates of GI and its components for various values of β.[8] As we discussed above, given the particular estimates for GC and IC, we can experiment with values of β that are greater than 1. The estimates for GC are slightly higher for Hyderabad as compared to the American cities. This reflects the fact that Dalit and Non-Dalit spatial integration in Hyderabad is much better than race-based spatial integration in American cities. To shed further light on this, we also present the Duncan-Duncan dissimilarity index, which confirms this observation. The estimates of IC for Hyderabad are slightly lower compared to the same for American cities. However, this is more than compensated by higher GC in Hyderabad and the lower variance component. Consequently, the Grayness Index GI for Hyderabad is higher. Note that as the value of β rises, the importance of the variance component increases and the value of the Grayness Index falls.

Insert table 1 here

[8] For the computation of GC, we use "seg", the module in Stata that computes various segregation indices with multiple groups.

3 Discussion and Conclusions

Recent scholarship in several social sciences has emphasized the centrality of space and the need to incorporate spatial considerations explicitly. In the above analysis, we have taken this idea seriously and considered a feature that characterizes many cities. We examine the existence of identity groups in cities that are internally spatially heterogeneous by considering a phenomenon ("Grayness") that is a combination of spatial integration based upon identity and income. We develop an index of "Grayness" that satisfies several desirable properties. We illustrate this index by applying it to the Indian city of Hyderabad and some American cities.

The spatial units or identity groups in a city could be ordered on some attribute (e.g. average income, educational opportunities) and this ordering can be explicitly incorporated in the analysis. While we have not addressed this, it can be taken up in future research. Also, we have focused on measurement issues only, but it would be quite fascinating to examine the interrelationship between Grayness and outcomes and the mechanisms through which these relationships work.

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Table 1: Estimates of Grayness Index and its Components

β	City	D	GC	IC	Mean	Variance	GI
0.95	Hyderabad	0.5327	0.3154	0.3854	0.3504	0.0012	0.3492
	Chicago (B-W)	0.7256	0.1249	0.4443	0.2846	0.0255	0.2604
	Chicago (B-O)	0.7105	0.1395	0.4443	0.2919	0.0232	0.2698
	New York (B-W)	0.7059	0.1446	0.4727	0.3087	0.0269	0.2831
	New York (B-O)	0.6349	0.2023	0.4727	0.3375	0.0183	0.3201
1.0	Hyderabad	0.5327	0.3154	0.3854	0.3504	0,0012	0.3492
	Chicago (B-W)	0.7256	0.1249	0.4443	0.2846	0.0255	0.2591
	Chicago (B-O)	0.7105	0.1395	0.4443	0.2919	0.0232	0.2687
	New York (B-W)	0.7059	0.1446	0.4727	0.3087	0.0269	0.2817
	New York (B-O)	0.6349	0.2023	0.4727	0.3375	0.0183	0.3192
1.5	Hyderabad	0.5327	0.3154	0.3854	0.3504	0.0012	0.3485
	Chicago (B-W)	0.7256	0.1249	0.4443	0.2846	0.0255	0.2464
	Chicago (B-O)	0.7105	0.1395	0.4443	0.2919	0.0232	0.2571
	New York (B-W)	0.7059	0.1446	0.4727	0.3087	0.0269	0.2683
	New York (B-O)	0.6349	0.2023	0.4727	0.3375	0.0183	0.3101

Note: Authors' computations using household survey data for Hyderabad and American Community Survey (ACS) 2016, 5-year estimates. For IC, estimates of Gini are from table B19083, US Census Bureau. D: Duncan-Duncan Dissimilarity index, B-W: Black-White, B-O: Black-Others.