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CITY-SIZE OR RANK-SIZE DISTRIBUTION? AN EMPIRICAL ANALYSIS ON GREEK URBAN POPULATIONS

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Abstract
This paper examines the utility of size distribution analysis in the study of urban systems, comparing two of the most popular versions, the rank-size (RSD) and the city-size distribution (CSD). These versions are compared in accordance to their capability to illustrate patterns of hierarchy in urban systems and to include coherent socioeconomic information when decomposed into multivariate regression variables. The research questions are examined empirically on data of the 2011 Greek national census. Overall, this study concludes that size-distribution analysis is useful in the study of urban systems, is capable in illustrating patterns of hierarchy, and it contains socioeconomic information, whereas the RSD and CSD share complementary roles and should be used jointly in relevant approaches.
Keywords: Greek cities, urban units, rank size distribution, power law rule, Zipf's law.

1. INTRODUCTION

The study of Urban Systems suggests a major research field for Urban Economics and Regional Science, mainly due to the importance that population has to the configuration of cities and urban units, to their growth, and evolution (Mc Granahan et al., 2005; Polyzos, 2011; Tsiotas and Polyzos, 2013a). Generally, urban systems (Pumain, 1997; Polyzos, 2011) are spatial arrangements of interconnected urban units that lie under a complicated socioeconomic balance. Because of their interconnections (Tsiotas and Polyzos, 2013a,b), changes appearing in an urban unit proportionally affect the functionality of the other units in the system and they consequently affect its overall socioeconomic balance. A prime factor determining the functionality of such systems is the size of the urban units and particularly the cities' size (Overman and Ioannides, 2001; Tsiotas et al., 2014; Devadoss and Luckstead, 2016).

A common and popular approach for studying urban systems concerns the examination of their population size and particularly the typologies emerging from such distributions. Except the gravity rationale ruling the configuration of urban systems, size distribution analysis is established due to the availability of relevant data, which are collected periodically through national censuses, are well defined, and organized under institutional care (Tsiotas et al., 2014).

In the literature (Dziewofiski, 1972; Parr, 1976; Eaton and Eckstein, 1997; Pumain, 1997; Black and Henderson, 1999; Dobkins and Ioannides, 2000; Overman and Ioannides, 2001; Anderson and Ge, 2005; Gan et al., 2006; Benguigui and Blumenfeld-Lieberthal, 2007; Tsiotas et al., 2014), size distribution analysis on urban systems has two major forms. The first is the so called city-size distribution (CSD) and describes frequencies of urban units exceeding a certain population size. This approach is more probabilistic and detects how cities of different sizes grow relative to each other and is broadly applied in national or international sets. Relevant empirical research (Dobkins and Ioannides, 2000; Overman and Ioannides, 2001; Anderson and Ge, 2005; Gan et al., 2006; Benguigui and Blumenfeld-Lieberthal, 2007) has already shown that population growth in urban units fits well in a power-law curve, describing that the relative size and proportion of cities remain diachronically stable.

The second approach is the so called rank-size distribution (RSD) and it is also known as the Zipf's law, honorary to George Kingsley Zipf (1902-1950) who applied it on texts to detect patterns and hierarchies between words (Zipf, 1935). This law describes that the size in a set of ordered urban units also fits in a power-law curve. Particularly, when cities belonging to a certain set are placed in a descending order, the Zipf's law interprets that the size of each city is related to its position in the ranking and to the size of the larger city in the set, following a power-law pattern. Empirical research on this approach (Anderson and Ge, 2005; Gan et al., 2006; Benguigui and Blumenfeld-Lieberthal, 2007; Tsiotas et al., 2014) has shown that the power-law exponent represents the developmental potential of the urban units in the urban hierarchy. When the exponent is absolutely equal to monad ($|a|$ ~1), the urban units lie under a structural balance, whereas when it is greater than monad ($|a|$ >1) the system is controlled by the first city in the ranking.

A fundamental issue in the size distribution approach concerns the level of resolution and particularly the definition of the minimum size (population threshold) of the urban units participating to the analysis. The determination of this threshold is a procedure that yet lacks of universal definition (Dobkins and Ioannides, 2000; Overman and Ioannides, 2001; Anderson and Ge, 2005) and it is submitted to either practical (concerning the availability of data) (Devadoss and Luckstead, 2016), or technical (related to parametric fitting) (Stumpf and Porter, 2012), or physical (administrative or socioeconomic determination) (Anderson and Ge, 2005) constraints. Regardless the city size resolution and the univariate nature of distribution study, the size distribution analysis is proven effective in revealing

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regularities of hierarchy in urban system and in providing useful insights about their socioeconomic balance.

Within this framework, this paper compares the effectiveness of both these size distribution methods (RSD, CSD) using population data of the 2011 Greek national census (ELSTAT, 2011). The analysis includes the total of settlements recorded in the national census (zero-order resolution), provided that they have permanent (annual) residents. The geographical scale of the examined urban systems is lowered to the regional (NUTS II administrative level), instead of the national that is commonly studied in literature (Tsiotas et al., 2014). This suggests a novel approach allowing comparing size distribution outcomes with socioeconomic information that is available for the 51 Greek prefectures. Moreover, a novel decomposition rationale is applied to the size distribution alpha exponents, which describes in multivariate terms the information enclosed in the univariate size distribution data.

The remainder of this paper is organized as follows: section 2 describes the methodological framework of the study. Section 3 presents the results of the analysis, where the two approaches are compared and evaluated in terms of urban management and regional policy. Finally, in section 4 conclusions are given.

2. METHODOLOGY AND DATA

The methodological framework of the study is illustrated in figure 1. Overall, it concerns the grouping of the available urban settlements into 51 regional collections (NUTS II), the retrieval of equal in number power-law exponents from the parametric fittings and the configuration of vector variables participating to an empirical analysis based on the size-distribution and other socioeconomic data.

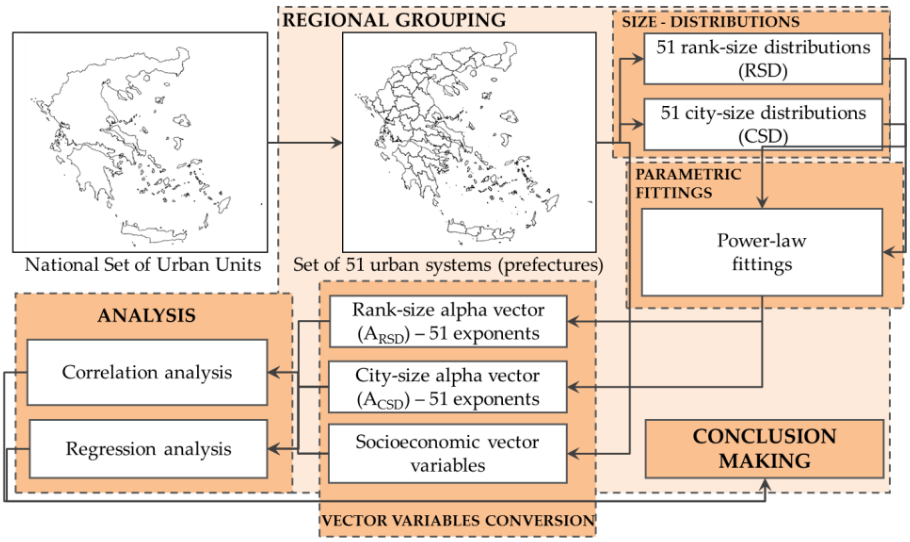

FIGURE 1 - THE METHODOLOGICAL FRAMEWORK OF THE STUDY.

In the first step, the available 12,644 urban settlements of the 2011 Greek national census (ELSTAT, 2011) are grouped into 51 prefectural sets. The names and the sizes of these groups are shown in table 1.

TABLE 1 - THE GREEK URBAN SYSTEMS PARTICIPATING IN THE ANALYSIS AND THEIR SIZE

Label	Prefecture	Size*	Label	Prefecture	Size	Label	Prefecture	Size
1	Achaias	506	18	Grevenon	113	35	Lesvou	210
2	Aitoloakarnanias	532	19	Heleias	394	36	Leykados	66
3	Argoleedos	175	20	Hemathias	105	37	Magnesias	218
4	Arkadias	410	21	Herakleeou	421	38	Messeenias	488
5	Artas	282	22	Ioanninon	486	39	Pellas	130
6	Attikhs	412	23	Karditsas	271	40	Pierias	89
7	Chalkidikhs	153	24	Kastorias	109	41	Prevezas	136
8	Chanion	464	25	Kavalas	138	42	Rethymnou	276
9	Chiou	115	26	Kefallonias	151	43	Rodophs	174
10	Dodekaneesou	161	27	Kerkyras	287	44	Samou	190
11	Dramas	119	28	Kilkis	163	45	Serron	188
12	Evoias	383	29	Korinthias	200	46	Thespotias	167
13	Evroy	169	30	Kozanhs	212	47	Thessalonikhs	162
14	Eyrytanias	166	31	Kykladon	484	48	Trikalon	230
15	Florinas	102	32	Lakonias	412	49	Veotias	118
16	Fokidos	135	33	Larisis	259	50	Xanthis	162
17	Fthiotidos	267	34	Lasithiou	292	51	Zakeenthou	78

*. number of urban units (settlements) included in each prefecture

At the second step, the size-distributions of the urban systems are constructed. RSDs are constructed by putting the available urban units into descending (according to their population size) order, then plotting the population sizes in a logarithmic diagram, and finally by fitting a power-law curve of the form (Anderson and Ge, 2005; Gan et al., 2006; Benguigui and Blumenfeld-Lieberthal, 2007; Tsiotas et al., 2014):

$$S_r = S_o \cdot r^{-a_{RSD}} \quad (1)$$

where So is the population of the biggest city in the prefecture and Sr is the population of the r-th city in the ranking.

On the other hand, CSDs are constructed by calibrating the population range and measuring the frequencies of cities that exceed each score, according to the formula (Overman and Ioannides, 2001; Anderson and Ge, 2005; Gan et al., 2006; Benguigui and Blumenfeld-Lieberthal, 2007, Tsiotas et al., 2014):

$$n_j(S \geq s) = n_j \cdot s^{-a_{CSD}} \Rightarrow P(S \geq s) = s^{-a_{CSD}} \quad (2)$$

where n_j is the size of the *j*th prefecture, $n_j(S \geq s)$ is the frequency of the urban units exceeding the population s, and a is a power-law exponent.

At the third step the alpha exponents of the available size-distributions are estimated using parametric fitting. This technique fits a proper power-law function $f(x)=bx\text{-}a$ in the observations, then it applies a logarithmic transformation $\ln f(x)$ to the model (Overman and Ioannides, 2001; Anderson and Ge, 2005; Benguigui and Blumenfeld-Lieberthal, 2007), and then estimates the power-law exponents using the ordinary least square method (OLS), where the square differences between the observed $F(x)$ and the theoretical $\hat{F}(x)$ distributions $\left(\hat{F}(x_i)-F(x_i)\right)^2$ are minimized (Norusis, 2004).

At the next step the RSD and CSD exponent collections configure respective A_{RSD} and A_{CSD} vector variables of 51 elements. These variables along with the other socioeconomic variables shown in table 2 participate to the empirical analysis.

TABLE 2 - VECTOR VARIABLES PARTICIPATING IN THE ANALYSIS

Symbol	Variable's name	Description
		Size-distribution variables
A_{RSD}(a)	Rank-size distribution exponent	Rank-size distribution exponents describing the distribution of urban units included in each of the 51 Greek prefectures.
A_{CSD}(a)	City-size distribution exponent	City-size distribution exponents describing the distribution of urban units included in each of the 51 Greek prefectures.
		Socioeconomic variables
SIZE(a)	Number of cities, villages or settlements	The number of cities, villages and settlements per prefecture (2011 national census).
CAP(a)	Capital City's Population Percentage	The percentage of the capital city's population to the total prefecture's population.
DEN(a)	Population Density	The population density of each prefecture (number of citizens/km^2)
GDP(b)	Gross Domestic Product	The proportion of the prefecture's GDP to the Gross National Product (GNP).
A_{SEC}(b)	Participation of the primary sector	The participation of the primary sector in the GDP of each prefecture.
C_{SEC}(b)	Participation of the tertiary sector	The participation of the primary sector in the GDP of each prefecture.
RPD(b)	Regional Productive Dynamism	Complex factor depicting developments in employment, level of production and productive structure of the local economy for each prefecture.
DPP(b)	Direct Population Potential	The self-potential of a prefecture, describing the accessibility of each prefecture to its interior productivity.
WELF(b)	Welfare Index	Composite index illustrating the level of living of each prefecture.
Q(b)	Quality Index	Composite index, illustrating the population's quality of each prefecture, based on the educational level.

a. Self-edited from source ELSTAT (2011)
b. source: Tsiotas et al. (2014)

Finally, the available variables participate to the empirical analysis consisting of two parts, correlation and linear regression analysis. In the first part, the *Pearson's bivariate coefficients of correlation* (Norusis, 2004; Devore and Berk, 2012) are calculated, aiming to detect linear relations between a pair of variables *X,Y*. In the second part, the socioeconomic variables of table 2 are set as predictors in a pair of linear regression models, according to the relation:

$$\begin{cases} A_{RSD} = f(x_1, x_2, ..., x_{10}) = c_{RSD} + \sum_{10} b^{(RSD)} \cdot x_i \\ A_{CSD} = f(x_1, x_2, ..., x_{10}) = c_{CSD} + \sum_{10} b^{(CSD)} \cdot x_i \end{cases} \quad (3)$$

where $x_i \in X_{SDV}$={*SIZE*, *CAP*, *DEN*, *GDP*, A_{SEC}, C_{SEC}, *RPD*, *DPP*, *WELF*, *Q*}.

After defining the alpha exponents as linear functions of the predictor variables the power-law size distribution curves are transformed respectively into:

$$S_r = S_o \cdot r^{-a_{RSD}} = S_o \cdot r^{-f(x_1, x_2, ..., x_{10})} = S_o \cdot r^{-\left(c_{RSD} + \sum_{10} b^{(RSD)} \cdot x_i\right)} \quad (4)$$

and

$$P(S \geq s) = s^{-a_{CSD}} = s^{-f(x_1, x_2, ..., x_{10})} = s^{-\left(c_{RSD} + \sum_{10} b^{(RSD)} \cdot x_i\right)} \quad (5)$$

The relations (4) and (5) are multivariate decompositions of the univariate, population-controlled, size-size distributions (1) and (2), including further socioeconomic information. These expressions are compared and evaluated in the following section.

3. RESULTS AND DISCUSSION

Initially, the values of the RDS and CSD exponent variables are being classified into five ordinal categories and their spatial distributions (per prefecture) are compared, according to the results shown in the maps of figure 2. Overall, the comparative consideration of these distributions produces a quite diverse picture. This observation indicates the existence of different structural characteristics between the RSD and CSD approaches and verifies the research orientation of this study aiming to detect the amount and type of information included in each case.

However, a common feature that can be found in both cases is that these distributions tend to form clusters with geographical relevance, regardless the different scores observed for certain prefectures in the majority of cases. This observation illustrates the interactive role between space and population implying that the organization and evolution of urban systems is submitted to spatial constraints, which complies with relevant theoretical approaches (Barthelemy, 2011; Polyzos, 2011; Ducruet and Beauguitte, 2014).

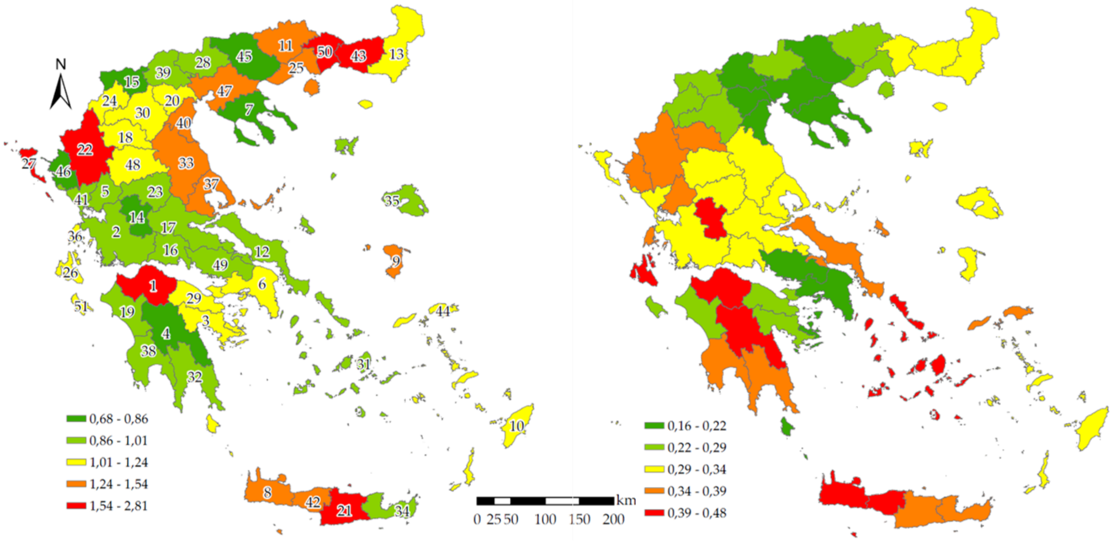

FIGURE 2 - SPATIAL DISTRIBUTION OF THE RSD (LEFT) AND CSD (RIGHT) EXPONENTS THROUGHOUT THE 51 GREEK PREFECTURES (SEE PREFECTURE NAMES IN TABLE 1).

Correlation Analysis

Figure 3 shows the results of the correlation analysis illustrated in heat plots that are color-calibrated. The plot on the left shows the results of the coefficient of correlation, whereas this on the right depicts their respective significances. Statistical significance is considered up to the 0.1 level and insignificant cases are shown in the plots as white (null) color cells. According to the correlation analysis, variables A_{RSD} and A_{CSD} seem to share complementary roles in the socioeconomic information that they include.

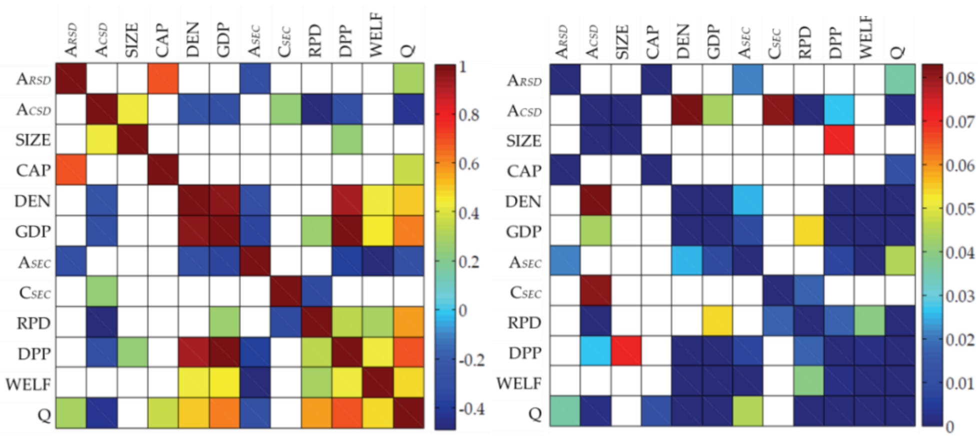

FIGURE 4 - HEAT PLOTS OF THE SIGNIFICANT CORRELATION COEFFICIENTS (LEFT) AND OF THEIR SIGNIFICANCE LEVELS (RIGHT).

In particular, for the RSD exponent variable, a strong correlation is observed with the variable CAP. Although a functional relation between these variables is obvious by the definition given in relation (1), the correlation results show that this relation transforms to positive linear when it is spatially distributed throughout the prefectural cases. This observation illustrates the gravitational role that capital city have in the configuration of the structure of urban systems and interprets that the heavy-populated capital cities undermine the evolution of other competitive and cause an abrupt decay of the RSD curve. Additionally, A_{RSD} is negatively correlated with the A_{SEC} and slightly positively with Q. These results imply that urban systems with high RSD exponent (small number of small cities and relatively heavy-populated capital city) are more likely to be less specialized in the primary sector (urbanized structure) and to have more educated population.

Regarding the CSD exponent variable, a considerable correlation is observed with the variable SIZE, which is also expected due to the definition given in relation (2). This observation interprets that the Greek prefectures of great size (number of urban units) are more likely to have many in number heavy-populated cities, implying that when the number of units increases in an urban system, it is more likely for the system to develop gravity hierarchies (strong capital city and few heavy-populates cities that dominate to the other cities). Moreover, the correlation (A_{CSD}, C_{SEC}) illustrates that the prefectures with high CSD decay are more likely to be specialized in the tertiary sector, implying that the urban productivity in Greece is based on provision of services.

Finally, A_{CSD} is negatively correlated with the variables DEN, GDP, RPD and DPP. The correlation with DEN is trivial expressing that prefectures with abrupt slope in their CSD curve are less likely to be dense. More interestingly, such prefectures are less likely to have high GDP, RPD, and DPP, an observation that links negatively the gravitational structure with the domestic productivity and dynamism. Jointly, these correlations (A_{CSD}~ GDP, RPD, and DPP) imply that in the prefectures with gravity structure (a dominant capital city, few moderate, and more small) the capital city dominates on the productivity of others undermining their growth, dynamism and accessibility to interior productivity.

Linear Regression Analysis

In this part of the analysis each or the SD exponent variables (A_{RSD}, A_{CSD}) are set as dependent variables in a corresponding linear regression model, where all the socioeconomic variables shown in table 2 participate as predictors. The results of the analysis are shown in table 3 and are being compared.

Table 3 - a. Model Summary

Model*	R	R^2	Adjusted R^2	Std. Error of the Estimate
RSD	.783	.613	.516	.384
CSD	.844	.713	.641	.044

Predictors

*. (Constant), QUALITY, URB, SIZE, A_{SEC}, C_{SEC}, CAP, DEN, WELFARE, RPD, DPP

b. Linear Regression Coefficients

Model/ Predictors		Coefficients: Unstandardized B	S.E.	Standardized B	t	Sig.
RSD[a]	(Constant)	-.173	.870		-.199	.843
	SIZE*	**.001**	**.000**	**.226**	**1.996**	**.053**
	CAP	**.031**	**.008**	**.527**	**3.835**	**.000**
	DEN	.001	.001	.769	1.301	.201
	GDP	-.066	.142	-.642	-.464	.645
	A_{SEC}	**-3.011**	**1.110**	**-.338**	**-2.712**	**.010**
	C_{SEC}	-.236	.556	-.053	-.424	.674
	RPD	-.007	.008	-.134	-.885	.381
	DPP	-.003	.008	-.367	-.376	.709
	WELF	-.006	.004	-.232	-1.653	.106
	QUALITY	**.023**	**.013**	**.412**	**1.842**	**.073**
CSD[b]	(Constant)	**.695**	**.099**		**7.024**	**.000**
	SIZE	**.000**	**.000**	**.576**	**5.920**	**.000**
	CAP	**.003**	**.001**	**.337**	**2.847**	**.007**
	DEN	.000	.000	-.529	-1.040	.304
	GDP	.013	.016	.946	.794	.432
	A_{SEC}	-.176	.126	-.150	-1.396	.170
	C_{SEC}	-.016	.063	-.028	-.260	.796
	RPD	-.001	.001	-.120	-.922	.362
	DPP	-.001	.001	-.595	-.709	.482
	WELF	**.001**	**.000**	**.284**	**2.351**	**.024**
	QUALITY	**-.005**	**.001**	**-.680**	**-3.532**	**.001**

a. Dependent Variable: A_{RSD}
b. Dependent Variable: A_{CSD}

*. Significant predictors at the 0.1 level are shown in bold

First, according to the R^2 results, the CSD model outperforms 7% in the determination ability the RSD model. For the certain socioeconomic framework, this observation illustrates a determination advantage of the probabilistic in comparison with the rank-size consideration. Without being exhaustive, this better performance may be a result of the direct construction mechanism of CSD, since the RSD is subjected to data ordering and thus to a transformation. On the other hand, a common characteristic between these two models is that they have the same number of significant predictors (shown in bold), among which the CAP, SIZE and Q are common. However, the participation of the common predictors to these models is inverse, an observation that verifies the respective correlation results.

In the RSD model, the variable CAP has stronger participation than this of SIZE (b_{CAP}=0.527 > b_{SIZE}=0.226), whereas in the CSD model this inequality is inverse (b_{CAP}=0.337 < b_{SIZE}=0.576), verifying the respective correlation results. Additionally, the significant analogies captured in the correlation analysis between (A_{RSD}, A_{SEC}) and (A_{RSD}, Q) are also verified by the RSD linear regression model, retaining the same signs. The picture of the CSD model is somehow diverse, since the significant correlations captured between A_{CSD} and each of the variables DEN, GDP, RPD and DPP are now absent, implying collinearity effects.

Overall, the linear regression analysis verify the potential to mine multivariate socioeconomic information from SDs along with the complementary role that the RSD and CSD exponents share.

4. CONCLUSIONS

This paper studied the size distributions of the Greek prefectures, the rank-size (RSD) and the city-size distribution (CSD), examining their capability to illustrate patterns of hierarchy in urban systems and to include coherent socioeconomic information when decomposed into multivariate regression variables. The research questions were examined empirically on data of the 2011 Greek national census. The overall consideration indicated the existence of different structural characteristics between the RSD and CSD approaches verifying the research orientation of this study to detect the amount and type of information included in each case. A common feature emerged in both cases is that both distributions tend to form clusters with geographical relevance, complying to the theory stating that the organization and evolution of urban systems is submitted to spatial constraints.

According to the correlation analysis, the RSD and CSD variables showed complementary roles in the socioeconomic information that they include. On the one hand, the prefectures with abrupt decay in the RSD curve have heavy-populated capital cities undermining the evolution of other competitive cities. These cases are more likely to be less specialized in the primary sector (urbanized structure) and to have more educated population. On the other hand, the analysis captured a positive analogy between the CSD exponent and the urbanization and gravitational hierarchy pattern.

The prefectures with high CSD decay are more likely to specialize in the tertiary sector, illustrating the service orientation of the urban productivity in Greece. In the prefectures with gravitational structure, the capital city dominates on the productivity of others undermining their growth, dynamism and accessibility to interior productivity.

Overall, this study concludes that size-distribution analysis is useful in the study of urban systems, is capable in illustrating patterns of hierarchy, and it contains socioeconomic information, whereas the RSD and CSD share complementary roles and should be used jointly in relevant approaches.

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