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Kangaroos, Cities and Space: A First Approach to the Australian Urban System

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Abstract

Australia conforms a unique urban system. This paper examines the Australian urban system using data for urban centres and localities in 1996 and 2001. A summary and a basic descriptive analysis of the database is provided, followed by an examination of whether the system follows Zipf's and Gibrat's laws. The latter is found to hold for all but one of the especifiactions used while the former does not seem to apply. A Exploratory Spatial Data Analysis (ESDA) as well as a confirmatory analysis are carried out to analyize the spatial dimension of city size and growth, finding no relation for the former but a significant one for the latter.

JEL J11, R00, R12.

Keywords Australian urban system, Zipf's Law, Gibrat's Law, ESDA (exploratory spatial data analysis), spatial Gibrat.

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1 Motivation

The case of Australia is a very interesting and rare one: with an extension[1] of 7.741.220 Km^2, which represents 5,2% of the total world area, (sixth largest country in the World), it hosts 21.254.444[2] people, only about 0.32% of the total world population, which sets it in the 53th. position. Taking both measures together, this implies the Australian population density is one of 2.6 people per Km^2, which makes it rank as the seventh lowest density in the World. Australia is also one of the richest and most developped countries: by looking at the GDP/pc (nominal), it is within the first fifteen; by looking at the GDP (PPP), within the twenty richest countries; and by looking at the GDP/pc (PPP), it is within the first twenty five[3]. Finally, its condition of an island as well as its special and very unique geography have shaped the distribution of population across space in a way that most of people live by the coast (specially in the eastern one), leaving in the innerland an incredibly large empty space that may be called demographic desert.

	Area	**Population**	**Pop. Density**
Rank in World's list.	6th.	53rd.	235th.

Table 1: Australia generals

On the other hand, there is a large branch in the urban economic literature analysing both theorethically and empirically the distribution of the population within an urban system as well as its evolution over time, most of it using Zipf's and Gibrat's Law as tools to describe it: on the theoretical side, *Cï¿½rdoba(2003)*[11], *Duranton(2007)*[15], and *Gabaix&Ioannides(2004)*[19] are good examples; on the empirical side, although the main target of the studies is USA (*Beeson&DeJong(2001)*[6], *Black&Henderson(2003)*[7], *Overman&Ioannides(2001)*[35]), several other countries have been chosen, such as China (*Anderson&Ge(2005)*[1]), India (*Sharma(2003)*[37]), Malaysia (*Soo(2007)*[40]), Japan (*Davis&Weinstein(2002)*[12], *Davis&Weinstein(2004)*[13]), France (*Eaton &Eckstein(1997)*[16]), Austria (*Nitsch(2003)*[34]), Germany (*Bosker et al.(2006)* [9], *Bosker et al.(2007)*[8], *Brakman et al.(2004)*[10],), Spain (*Lanaspa et al.(2003)* [30], *Lanaspa et al.(2004)*[31]) and even some cross-country analysis(*Rosen& Resnick(1980)*[36], *Soo(2005)*[39]). However, very little papers have looked at Australia in a detailed fashion, despite its special characteristics, already noted by *Rosen&Resnick(1980)*[36].

The present paper is thought to fill that (almost) empty space: it examines the whole[4] Australian urban system in 1996 and 2001 in a detailed way displaying many features which set Australia far apart from other countries. While most of the results obtained for other countries show a Zipf coefficient around one, regressions in this paper show Australia has a much lower one, around 0.7, which means a more uneven population distribution among the cities of the system. When analyzing the relation between growth and city size, the results

[1] Area, population and population density data have been obtained from WikiPedia

[2] According to the Official Australian Population Clock, March 24, 2008.

[3] All measures taking data from the IMF, the WB and the CIA's *The World Factbook*.

[4] It takes a list of human clusters as big as possible, where the smalles centre is 200 people big.

are much more standard: Gibrat's law seems to hold almost everywhere. In addition, special emphasis is set in the spatial dimension of both variables (size and growth) to see to which extent we can speak of spatial association in the urban system. Related to this, an exploratory as well as a confirmatory spatial analysis are carried out being the main conclussion while sizes do not show any kind of autocorrelation, urban growth does appear to be spatially related. a preliminary exploration relates city sizes and urban growth to their spatial configuration, finding no degree of spatial association for the size but a positive correlation for the population growth rate.

The remainder of the paper is organised as follows: section two explains the data set, why it has been chosen this way and gives some very basic statistics to get a first feeling; section three analyses the Zipf's relation in Australia; section four looks at the link between the city size distribution and urban growth, testing whether Gibrat's law hold for the sample or not; an exploratory spatial data analysis (ESDA) to urban population and growth is applied in section five while the confirmatory analysis may be found in section six; section seven closes the paper by adding some conclussions and pointing to further steps to be taken.

2 What do we call *Australian urban system*? Dataset

Since the main purpose of this paper is to analyze the Australian urban system, the spatial unit used will be the Australian Bureau of Statistics' (ABS) "Urban Centre and Locality" (UC/L from now on), which groups Collection Districts[5] (CD's) together to form defined areas according to population size criteria by using census counts. In broad terms, an Urban Centre is considered to be a population cluster of 1.000 or more people while a Locality is a population cluster of between 200 and 999 people (thus it does not cover the entire Australia). Each UC/L has a clearly defined boundary and comprises one or more whole CDs. Appendix-1 shows the criteria the ABS uses to delimit UC/L's. The data set used for this paper contains census counts from the 2001 Census of Population and Housing and 1996 Census data based on 2001 Census geography.

Both the choice of UC/L as unit and the adjustment between 2001 and 1996 boundaries imply a drop in the final dataset size considered which makes the sample smaller than the total Australian population. Table 2. helps illustrate this loss of information; we are using 86.42% and 88.39% of the total population in 1996 and 2001, respectively.

When analysing city size distributions, one may use several measures for a city size. Three main ones have been used over the literature:

1. The **absolute** city size: $pop_i, = S_i$
2. Absolute city size over the average (**relative** size):

$$rel_i = \frac{S_i}{\overline{S_i}}$$

[5] A Collection District is the smallest ABS's spatial unit in the Australian Standard Geographical Classification, defining an area that one census collector can cover in about a ten-day period.

	1996	2001
Australia total population*	17.892.423	18.972.350
Population in UC/L 2001's Structure	15.462.315	17.012.302
% over total Australian Population	86.42	89.67
Population in the sample used	15.462.315	16.769.547
% over total population	86.42	88.39
% UC/L 2001's Structure**	100	98.57

*Estimated Resident Population, data from the Basic Community Profile, which include Overseas visitors.
**The reason why it's 100 is we have had to take out of the sample all those 2001 UC/L's not existing in 1996, but have not deleted any from 1996.

Table 2: Dataset

where $\overline{S_i} = \frac{1}{n}\sum_{i=1}^{n} S_i$, being n the total number of cities.

3. City size as a **share** of the total population

$$share_i = \frac{S_i}{\sum_{i=1}^{n} S_i}$$

While 1. may be the most intuitive way to measure the size of a city at a first sight, it encounters some problems, being the most important one it does not account for changes within the distribution, that is, it does not link the isolated size of a city with the rest of the distribution. In the end, when we examine urban systems rather than single cities, we are interested in how each city evolves in relation to the rest of cities in the system: nothing will change in the city size distribution if city i grows 30% of its absolute population from one year to the next one, if so does the rest of the system; on the contrary no growth at all for such city will imply some modifications in the whole distribution if the rest of cities keep on growing at certain rate. It could even turn more paradoxical if city i grew at say 3% from t to $t+1$ if the rest of cities did it at 4%: i would actually be relatively decreasing in size. That is the reason why we use 2. and 3., to relativize the absolute population of 1. to some measure accounting for the whole distribution. Finally, there is an additional reason to use relative measures, and it is that, as *Gabaix&Ioannides(2004)*[19] put it, *"talking about steady-state distributions requires a normalization of this type"*.

All of them have been used in the process of this work to analyse the Australian urban system. Depending on usefulness and suitability at every part, one or another, several or even all of them will be offered, when doing such a thing means some new information.

In order to get a first feeling of the Australian urban system, some descriptive analysis is offered in Table 3. As we see, the absolute average city has gone up from 1996 to 2001.

There is another interesting phenomenon in Table 3 which has to do with the growth rate: while the mean of the absolute growth rate is almost $6,1\%$, when we look at the sizes relative to either the average size or the total sum[6],

[6] The only difference is that rel is multiplied by $\frac{1}{n}$ and $share$ is not.

	1996	**2001**	**Growth**
pop	9918.1	10756.6	6.1
rel	1.0	1.0	-2.1734
share	5.19e-05	5.18e-05	-2.1734

Table 3: Mean values

growth rates are negative. By construction, it is simple to prove that, if the average size ($\overline{S}_i$) grows over time, the average growth rate will be smaller for the relative sizes than for the absolute ones. However, it is interesting to see that this increase in the mean makes the relative measure change the sign with respect to the absolute one. Having this situation is a perfect example of what we have stated above when talking about the different size measures: here we see how, despite the average increase of 6% of the absolute sizes, since the average city ($\overline{S}_i$) has grown faster (at about 8.45%), cities in the system have relatively decreased on average. In other words, there have been *a lot of* cities in the sample growing slower than $\overline{S}_i$.

Table 4 focuses on the quartile range; by construction, $\triangle\ Q_r$ is larger for *rel* than for *share* and even larger for the absolute measure. As we see, the Interquartile Range (IQR) has increased for the absolute and for the relative population but, looking at the shares of the total population, there has been a decrease. This can be interpreted as an increase in the dispersion of city sizes and, focusing on the relative measure (the most useful one when looking at IQR's), it would mean sizes which in 1996 were at the tails of the distribution had become even larger or smaller in relation to the average city by 2001. However, such change is small and should not be used to infer any strong conclussion as it covers a short period.

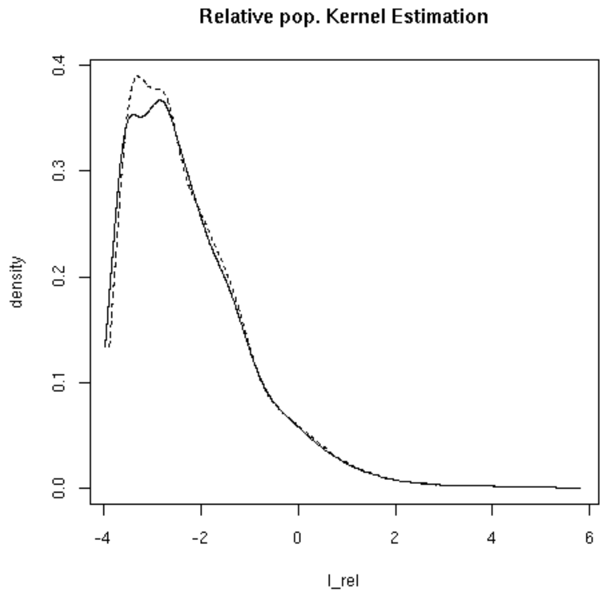
	$Q1$	Q_3	$Q_r = Q_3 - Q_1$	$\triangle\ Q_r = Q_{r,01} - Q_{r,96}$
pop96	408	2068.5	1660.5	
pop01	429	2195	1766	6.35%
rel96	0.0399	0.2041	0.1642	
rel01	0.0412	0.2086	0.1674	1.95%
share96	6,39E-52	0,00013378	1,34E-04	
share01	5,58E-52	0,00013089	1,31E-04	-2,16%

Table 4: Quartile ranges

Finally, we conclude this section with non-parametric analysis. Fig. 1 shows the estimation of the relative log-population density function for both 1996 (dotted line) and 2001 (straigh line) by means of an adaptive kernel *ï¿½-la Silverman(1986)*[38][7]. Intuitively, a kernel can be seen as the smoothing of a frequency histogram in which the width of each bar has been squeezed up to zero in the limit, so the resulting figure is a continuous function with a total probability below 1. The main feature of adaptive density estimation is that the bandwith is not fixed for the whole distribution but it varies depending on the density of each point instead, exploiting thus benefits from both a low and a

[7]The kernel was estimated with R's package "quantreg", freely available in the CRAN repositories (http://CRAN.R-project.org).

high bandwith: in points where density is low (typically in the tails), it applies a high one smoothing the estimation in order not to misslead the observer, while in points where density is high, it uses a low bandwith, allowing to see special characteristics of the density function that might be missed if a higher bandwith (like that used for the tails) was used.



Dotted line corresponds to 1996 and the straight one to 2001.

Figure 1: Kernel density plot

We may observe two main features in the figure: one dealing with the general shape of both kernels and the other regarding the evolution from 1996 to 2001. The first one is that, in both years, most of the probabilistic mass is placed on the left of zero; provided it is relative log-population, zero implies the average city and then we can see most of the australian cities have a size far below the average one. In relation to the evolution, as one might expect from a short period of time, the main conclussion is there are not big differences. However, if some, one might notice the peak has moved rightwards. This (together with the fact the average city has grown) comes from the general growth of Australian population: as more people exist, it is logical to think cities will be bigger.

3 Zipf in Australia?

3.1 Zipf's Law

A common procedure widely used in the literature to rapidly characterize an urban system is to look at how well the sample fits a power law. The theoretical basis of this practice comes from the statistical definition of Zipf's law. An urban system is said to follow Zipf's law whenever $\alpha = 1$ in

$$P(Size > S) = \frac{a}{S^{\alpha}} \tag{1}$$

When we want to apply this approach to real world, we use an approximation based on the following transformation. First we rank the sizes, assigning the first place to the largest city, the second to second largest one and so on:

$$S_1 \geqslant S_2 \geqslant S_3 \geqslant ... \geqslant S_n \tag{2}$$

Considering in the empirical distribution, the probability follows this distribution:

$$P(Size > S_R) = \frac{R}{n} \tag{3}$$

we can equalize and operate on the right sides of (1) and (3), as the left sides are equal:

$$\frac{a}{S^{\alpha}} = \frac{R}{n} \Rightarrow a\,n = R\,S^{\alpha} \Rightarrow R = \frac{a\,n}{S^{\alpha}} \tag{4}$$

If we express $a\,n$ as a constant A and take logarithms, we obtain:

$$lnRk_i = A - \alpha\,lnS_i \tag{5}$$

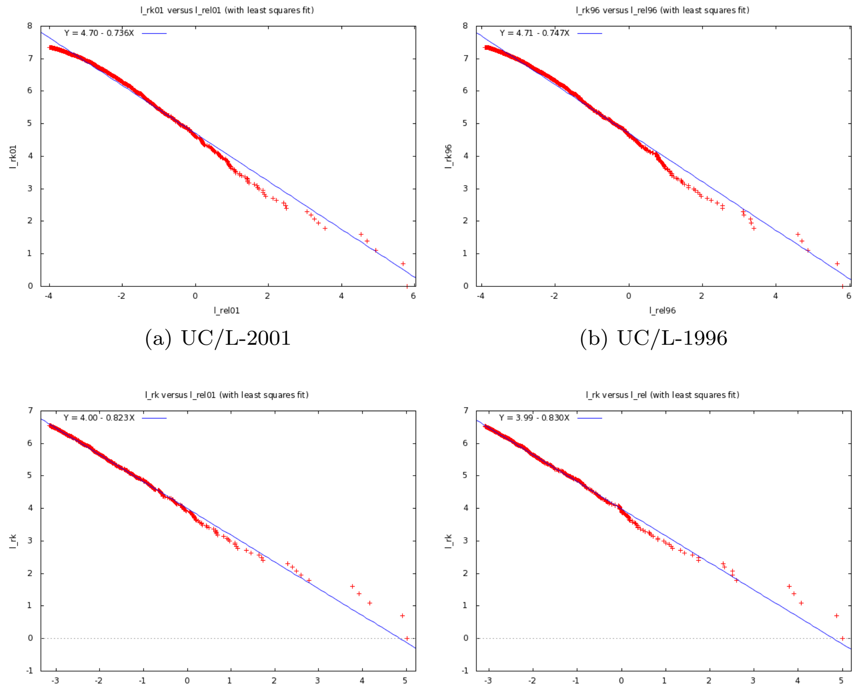
which is the common especification to test empirically Zipf's law. In (5), α can be understood as a measure of the degree of eveness in the system: extremely, if $\alpha = \infty$ the graph is a vertical line around a size and every city has that size; opposite, if $\alpha = 0$ the degree of uneveness is maximum. We call the "rank-size rule" when α is around 1 and, in such case, we consider Zipf's law holds, because the power law is just an approximation of the real Zipf's expression. As *Gabaix & Ioannides(2004)* [19] put it: "*even if Zipf's law holds perfectly, the rank-size rule would hold only approximately*". In this situation, the second largest city is half the size of the first one, the third largest one is one third the first one, and so on.

In this section, some results on the power law and Australia are offered. Since (5) is invariant to increasing monotone transformations in S_i, there is no difference between any of the three measures (absolute, relative and shares of the total) and hence only relative sizes will be extensively shown.

3.2 Basic Zipf

Figures 2(a) and 2(b) show the Zipf plots for both 1996 and 2001 for which expression (5) has been run and Table 5 displays the regression output for both years. As it may be seen, the standard error has been corrected following *Gabaix & Ioannides(2004)* [19].

The parameter α, indicating the way the population is distributed across the cities in the system, shows always significative and around 0.74, which implies a



(a) UC/L-2001 (b) UC/L-1996

(c) UC-2001 (d) UC-1996

Figure 2: Zipf Plots

distribution very unequal and sets Australia far from meeting Zipf's law. Furthermore, there has been a decrease from 1996 to 2001, which would mean more inequality in the distribution. However, we can't take this result very surely since the time horizon is not long enough and urban evolution is a phenomenon which evolves basically in the long run. Also, this decrease in α might be due to the fact that we are taking only those settlements above 200 people. Since the population is increasing over time, the minimum value will always be 200 (thought there do exist smaller settlements, which are not included in the sample) but the maximum may increase. This, everything else hold constant, may cause this increase in the degree of uneveness.

3.3 (Yet) more Zipf

By looking at the two first plots in Fig. 2, we can also see the actual distribution does not exactly fit a straight line but there are several deviations. Specially, there are downwards curves at the upper and lower extremes. These departings from a straight line usually appear when not only the upper tail but the whole urban system is taken (when there is no cut-off), as *Eeckhout (2004)*[17] states. Indeed, if we shorted the data-set so that only the biggest cities are considered (upper tail), the graph would look more like a straight line. Following *Eeckhout (2004)*[17], this occurs because the underlying distribution is log-normal and

Dependent variable (2001): l_rk01

	Coefficient	Std. Error	t-statistic	p-value	Adj. S.E.	t-Stat.
const	4.70264	0.00600962	782.5182	0.0000	-	-
l_rel01	-0.736492	0.00230305	-319.7901	0.0000	0.036	-20.458
	Unadj.	R^2	0.985003	Adj.	R^2	0.984994

Dependent variable (1996): l_rk96

	Coefficient	Std. Error	t-statistic	p-value	Adj. S.E.	t-Stat.
const	4.70875	0.00554564	849.0899	0.0000	-	-
l_rel96	-0.746700	0.00215998	-345.6980	0.0000	0.036	-20.742
	Unadjusted	R^2	0.987139	Adjusted	R^2	0.987131

Table 5: Australia relative logpopulation OLS results

not Pareto as it used to be assumed. Comparing Fig. 2 (a)-(b) with Fig. 2 (c)-(d) allows the reader to notice such phenomenon.

In addition, another feature of shortening the sample is that the line becomes more steep, that is Zipf's parameter (α) increases. We can see this if we consider only the Urban Centres (setlements above 1000 people) instead of Urban Centres and Localities (above 200 people). By doing such experiment, we observe how α increases from around 0.74 up to about 0.83 (still far from Zipf's rule).

We can go even further and wonder what happens with the coefficient α as long as we progessively shorten the dataset, from the whole distribution up to the very upper tail. Fig. 3 shows the evolution of the parameter when the 2001's sample is shortened to the point in which only the ten largest cities are taken into account. As we observe, α starts low around 0.73 and increases as we take less and less (and bigger and bigger) cities to its peak at 0.82787 when only the 504 largest cities are taken. Afterwards it starts decreasing, but not much trust should be put on the last estimations as the sample size becomes too small. It is also noticeable to see that even at its peak, the urban system never gets to fulfill the rank-size rule.

Inspired by *Ellis & Andrews (2001)* [18], the Australian urban system is divided into seven sub-regions[8] and Zipf's analysis is performed again to try to verify their argument. Their idea is that, due to the fact Australia has a relatively small population spread over a large area, *"transport costs and political institutions may have induced multiple centres of economic activity"*, leading to a nationwide urban system made up of several state rank-size relations where the largest city is a primate[9] and the rest meet Zipf's Law. However, rank-size regressions were performed for each sub-region, finding roughly the same results as in the general case; the largest α coefficient was 0.75 (Sourthern Australia in 1996), which is still far from the unity. This points to the conclussion there is not such a regionalizationn of Zipf, but rather a mirroring of the general picture.

[8] Apparently, Ellis and Andrews divide it by States (which formally would make up 11 divisions, accounting for both States and Territories, according to the *Australian Standard Geographical Classification*) [5]. However, here Australia has been divided only into seven sub-groups because of three reasons: the geoeconomic reasonability of the seven divisions, the small-sized the data sets would get otherwise and the fact the Australian Bureau of Statistics handles Urban Centres and Localities this way when offering the data.

[9] A city much larger than the rest.

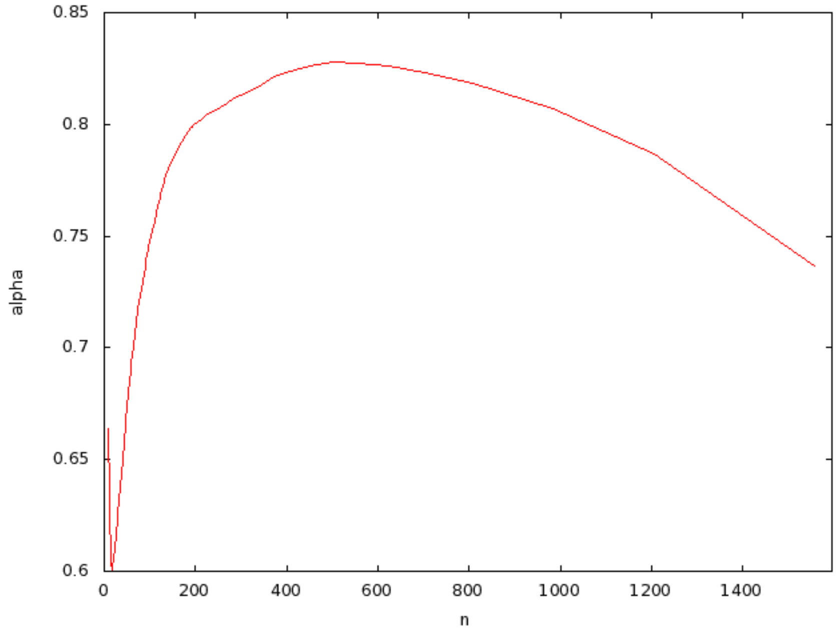


Figure 3: Shortening the data sample.

Country	$\|\alpha\|$ **coef.**	**Year**	**n**	**Reference**
Algeria	1.351**	1998	62	Soo (2005)[39]
Australia	0.8234***	2001	703	
Brazil	1.1341**	2000	411	Soo (2005)[39]
Canada	1.2445**	1996	93	Soo (2005)[39]
China	1.3**	1999	2651	Anderson&Ge (2005)[1]
India	1.1876**	1991	309	Soo (2005)[39]
Japan	1.3169**	1995	221	Soo (2005)[39]
Malaysia	0.856***	2000	171	Soo (2007)[40]
Netherlands	1.4729**	1999	97	Soo (2005)[39]
USA	1.3781**	2000	667	Soo (2005)[39]

** Significant at 5%
*** Significant at 1%
[1] Data for other countries than Australia are taken from Junius (1999)[27] and relate to 1990. Australia's index has been calculated for 1996 using the Urban Centres only.

This table tries to show the most comparable results, hence data from the UC sample are displayed for Australia and data from Soo (2005)[39] are taken for USA. In the latter case, if we considered data from Gonzï¿½lez (2007)[22] or *Eeckhout (2004)*[17] instead, the coefficient happens to be much lower due to the fact these works use the whole distribution, which implies a much larger n.

Table 6: International comparison

Finally, we zoom out to the international context. So far, we have described Australia as a *different* urban system; however, we have said nothing about other economies. Here our purpose is to confirm our suspects that it really conforms a different case. In order to compare results obtained for several different countries when applying a Zipf's regression, Table 6 picks examples spread around the world with some apparent similarities, such as area (Canada), population or GDP (Netherlands). As we see, Australia's coefficient scores as the lowest one. Since they do not take the same number of cities, nor the same cutoff, one should not directly compare results, but yet this can be taken as a sign that Australian population is distributed across the urban system very unevenly, specially when compared with other countries in the world.

4 Does size matter for speed? The Gibrat's Law

4.1 Gibrat's Law

So far, we have only analyzed the static relationship between size and rank and compare it over different points in time. Though the sample here is not the most suitable one for these purposes (only two years are certainly not enough to draw strong conclussions), it is also interesting to look at how an urban system has dynamically changed, if so. Traditionally, there are two ways in the literature to analyze dynamical processes in cities: the parametric and the non-parametric approach. The former consists of linear regressions *a-la* β-convergence, as in growth and development theory, while the later uses Markov's transition matrices or density kernels. Here we will focus on the first one.

One question one might wonder about is whether the growth of a city depends on its initial size or it is independent of it. The situation of no relation between the growth rate of the city and the size is called of proporcionate growth and if that's the case, Gibrat's Law is said to hold. The conceptual Gibrat's expression to estimate is as follows:

$$\triangle\, S_i = c + \beta\, S_i \tag{6}$$

where $\triangle\, S_i$ represents the growth rate of the city i. If Gibrat's law does not hold we can consider two possibilities: either there is a positive or a negative relationship between being big or not and growing fast or not. If such relation was positive, there would be a premium for bigger cities to attract people, leading the system to an explosive path: in the limit there would be only one city hosting the whole population (that's why this possibility does not seem reasonable for real world, at least in the long run); on the contrary if smaller cities grew faster than bigger ones, the tendency would be to convergence among all of them and, in the limit, there would only be one size for all the cities. Finally, if there was proportionate growth, there would be no apparent relation between size and growth and there should also look for reasons or explanations for such phenomenon. However, one should not bring any straight conclussion to the present framework: those statements have been taken to the limit so the reader can comprehend the theoretical evolution more easily, but the fact that we find here a (very weak) positive relation between the growth from 1996 to 2001 and the size of the cities does not imply there is an explosive path underlying the Australian dynamics.

We can also interpret the processes led by each of the alternatives just considered above in terms of the Zipf's analysis. If growth-size relation was negative, this would push Zipf's parameter more and more up to a vertical line, where every city would have the same size S; however, if there was a positive relation, the Zipf plot would get flatter and flatter every period, reaching horizontality in the limit, where all the population would be concentrated in the only one city.

Gibrat's analysis tells us information about the evolution and direction of the urban system, and there are several implications for each scenario regarding economic or landscape-planning policy which make this kind of analysis of special interest to real world.

4.2 Gibrat and Australia: a relation of friendship

In order to test Gibrat's Law, this work estimates four different specifications relating it:

1. $\dfrac{S_{t+1}}{S_t} = c + \beta \, \dfrac{(S_{t+1} + S_t)}{2}$

2. $\dfrac{S_{t+1}}{S_t} = c + \beta \, S_t$

3. $\ln \dfrac{S_{t+1}}{S_t} = c + \beta \, \ln \dfrac{(S_{t+1} + S_t)}{2}$

4. $\ln \dfrac{S_{t+1}}{S_t} = c + \beta \, \ln S_t$

In this work, we have run all of them for robustness purposes[10] but we only show outputs from all of them in the case of relative sizes (Table 7); in the case of absolute and *share* populations, only first and second fashions are displayed here (Table 8). It is of interest to notice that we are mainly working with relative populations, that is the absolute size over the mean of the year. This implies that growth of a city is only important when it is larger than the average of the sample, not when it is just positive; thus, if for instance a city had a positive growth in absolute terms but its rate was smaller than the average one for that year, it would be computed as negative growth in relative terms.

The main result that can be obtained from the estimations is it seems quite reasonable to state that Gibrat's law hold for the Australian urban system: in all but one especification, the parameter for the measure of the size does not show statistically different from zero. In fact, p-values are all (but one) far from allowing to reject the null. Specifically, Fashions 1. and 2. and 4. show parameters clearly equivalent to zero. The only fashion in which parameters do prove statistically different from zero is in the third one, the one relating the log of the growth and the growth of the mean of the period. Here the relation, though weak, shows positive, implying that bigger cities tend to grow faster than smaller ones. This is in line with the tendency captured in the Zipf's

[10]Results not showed are available at request.

Variable	Coefficient	Std. Error	t-statistic	p-value
1. Dependent variable: $\frac{S_{01}}{S_{96}}$				
Variable	Coefficient	Std. Error	t-statistic	p-value
const	0.978082	0.00574430	170.2701	0.0000
$\frac{(S_{01}+S_{96})}{2}$	0.000183226	0.000466003	0.3932	0.6942
	Unadjusted R^2	9.92811e-05	Adjusted $\bar{R}^2$	-0.000542916
2. Dependent variable: $\frac{S_{01}}{S_{96}}$				
Variable	Coefficient	Std. Error	t-statistic	p-value
const	0.978121	0.00574446	170.2721	0.0000
S_{96}	1.45580e-08	4.70516e-08	0.3094	0.7571
	Unadjusted R^2	6.14804e-05	Adjusted $\bar{R}^2$	-0.000580741
3.Dependent variable: $\ln \frac{S_{01}}{S_{96}}$				
Variable	Coefficient	Std. Error	t-statistic	p-value
const	-0.00998206	0.00852034	-1.1716	0.2416
$\ln \frac{(S_{01}+S_{96})}{2}$	0.0130006	0.00329762	3.9424	0.0001
4.Dependent variable: $\ln \frac{S_{01}}{S_{96}}$				
Variable	Coefficient	Std. Error	t-statistic	p-value
const	-0.0295430	0.00854137	-3.4588	0.0006
$\ln S_{96}$	0.00421888	0.00332679	1.2682	0.2049

Table 7: Summary results for relative populations. Fashions 1 to 4

analysis in the section before: we had found the coefficient had decreased from 0.75 in 1996 to 0.74 in 2001; now we see this has been due to the faster growth of bigger cities and the relatively slower one of the lower tail of the distribution.

Considering each of the different measures for the city size, we can say results are totally robust to the use of one or another kind of size: conclussions are exactly the same whether we take relative, absolute or *share* populations. Even when estimation in the fashion 3. fails to meet Gibrat's law, it does for all of the three measures.

So far we have been using the whole sample to see how size influences growth; but one could also wonder whether winners, those which grew enough so as to reach the Urban Centre status, show a particular behaviour regarding size and growth. This is what the literature has come to call the *winners' bias.* To look at it, we shortened the sample and performed a similar analysis as above, but using only the Urban Centres (those larger than 999 people). The results obtained are fairly similar to those from the previous section: Gibrat's law seems to hold for every specification but for that one relating the log of the growth and the log of the average size. However, there is a difference, namely the coefficient in the third fashion is closer not to be rejected, which means here the proporcioinate growth law is closer to be accepted than above, making the short sample more similar to a *perfect Gibrat system.*

5 *Where?* Bringing space into action.

This paper was started by pointing to the uniqueness of Australia as an urban system, specially due to its particular geography; over the pages, we have seen many facts confirming the first, but no word about the latter yet. The picture we have drawn of Australia can be seen in Table 9: although the average city size has increased by 8,45%, as many as 619 cities (out of 1559) decreased in

Summary results for absolute and *share*, **Fashion 1** and **Fashion 2**

Absolute populations (*pop*)

1.Dependent variable: $\frac{S_{01}}{S_{96}}$

Variable	p-value	Std. Error	t-statistic	p-value
const	1.06077	0.00622993	170.2701	0.0000
$\frac{(S_{01}+S_{96})}{2}$	1.93878e-08	4.88876e-08	0.3966	0.6917

2.Dependent variable: $\frac{S_{01}}{S_{96}}$

Variable	Coefficient	Std. Error	t-statistic	p-value
const	1.06081	0.00623012	170.2721	0.0000
S_{96}	1.57887e-08	5.10295e-08	0.3094	0.7571

share **populations**

1.Dependent variable: $\frac{S_{01}}{S_{96}}$

Variable	Coefficient	Std. Error	t-statistic	p-value
const	0.978082	0.00574430	170.2701	0.0000
$\frac{(S_{01}+S_{96})}{2}$	0.285650	0.726499	0.3932	0.6942

2.Dependent variable: $\frac{S_{01}}{S_{96}}$

Variable	Coefficient	Std. Error	t-statistic	p-value
const	0.978121	0.00574446	170.2721	0.0000
S_{96}	0.225100	0.727527	0.3094	0.7571

Table 8: Summary results for absolute and share, fashions 1 and 2

population from 1996 to 2001, making up around 40% of the total sample; also, if we looked at relative sizes, it was 1089 (out of 1559) cities that experienced a negative growth rate. This leaves us with a system becoming more uneven, with a few larger cities growing so as to push the average up, and many more cities declining in population.

Growth in average Size*	N. of cities* whith growth $< -10\%$	$< 0\%$
8.45%	122	619

*Sizes are measured in absolute populations.

Table 9: Urban growth

With those numbers in hand, now we would like to be able to see *where* such changes have happened. In this section we will provide tools to visualize the spatial dimension of these phenomena by means of what is called Explotartory Spatial Data Analysis (ESDA) and will look for patterns that we will try to confirm later in section 7 when we carry out the confirmatory analysis. But, before that comes, let us briefly explain the analytical framework that will help us go through the task.

5.1 Our *tool shed*

A very useful concept to step forward in this direction is that of *spatial dependence*. Following *Anselin(1988)*[2], *"spatial dependence can be considered to be the existence of a functional relationship between what happens at one point in space and what happens elsewhere"*(pag. 11). Translating that into our topic, if Australian geography played any role in explaining urban outcomes (in terms of either size or growth), we should be able to see any type of spatial dependence. We can express the idea of spatial dependence in our case by means of a functional form:

$$S_i = f(S_j) \qquad \forall i \neq j \tag{7}$$

or,

$$gr_i = h(gr_j) \qquad \forall i \neq j \tag{8}$$

where *gr* is the growth rate of the population of a city. One common way to introduce space into the formal analysis and account for the functional relation in (8) is by means of the *spatial weight matrix* (W). It is an n by n matrix and is usually constructed considering relations of either physical contiguity or distance, although it can also be designed to express more complex spatial linkages such as economic or cultural distance, for instance. Every element w_{ij} of W reflects the spatial connection (or absence of it) between the observations i and j. To construct a spatial weight matrix based on contiguity, we need the space to be divided into polygons, not spattered with points. Since we are dealing with cities (which are considered to be points in a map), the first step is to convert the points into polygons. For that purspose, the usual way is to define a Thiessen/Voronoi lattice. This procedure is widely used in geography (among other disciplines) and it consists of that tesselation made out of a layer of points in which each polygon surrounds one and only one point, in a way that the closest point the whole area of the polygon has is the one inside it. Fig. 4 provides the space of polygons (plus the Australian coastal line, for ease of understanding) obtained for the sample after carrying out such conversion as well as the layer of points. Within each polygon there must be one and only one point, representing a UC/L.

In this work, we have used two types of contiguity-based spatial weight matrices, namely those based on the *rook* and the *queen* principles[11]. The first one considers as neighbors (then puts some weight on them) those cities-polygons sharing at least one edge with i, while the second one considers neighbors all those regions sharing at least one vertex or edge with i. The results prove very robust so we will only show here those for the estimations computed with the *queen* matrix.

Once we have obtained W, the next concept to introduce is that of *spatial lag*. Analytically, it is expressed as follows:

$$sl(y) = Wy \tag{9}$$

where *sl* stands for *spatial lag* and y is a variable. As *Moreno&Vaya(2000)*[33] put it: "the spatial lag consists of a weighted average of the values in the neighbor regions, taking the weights as fixed and given in an exogenous way" (page 27). This can be understood as the analog for spatial econometrics of the time series' observation of the period $t-1$ same as, within this framework too, the spatial dependence would correspond to the serial autocorrelation.

[11]The names come from the chess game and are related to the way the rook and the queen are allowed to move across the table.

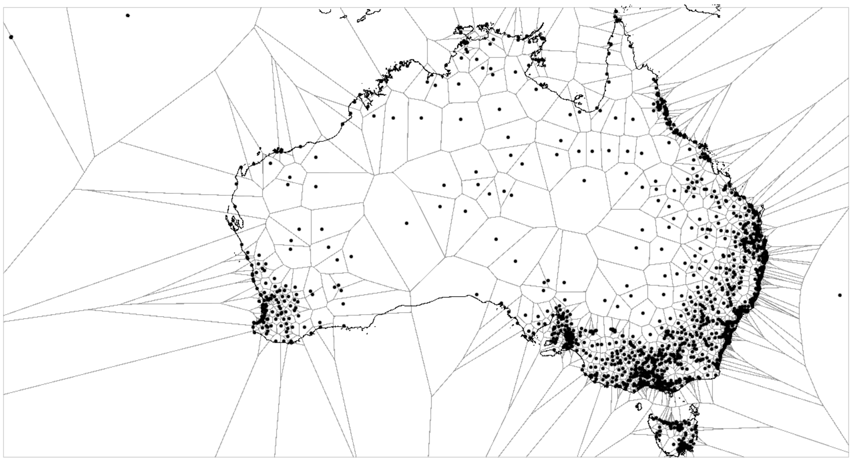


Figure 4: Voronoi polygons

There are several tests to explore the presence of spatial dependence. Here we will use the one called Moran's I, which was proposed by Moran(1948)[32] and is one of the most common ways to test for the presence of spatial dependence. The analytical expression is as follows:

$$M = \frac{N}{S_0} \frac{\sum_{ij}^{N} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{N}(x_i - \overline{x})^2} \; i \neq j \tag{10}$$

where x_i is the value of the variable in region (city, in this case) i, $\overline{x}$ is its average and w_{ij} are the spatial weights. When N is large, if M is normalized, it is asymptotically distributed as a standard normal. Moran's I can be seen as a measure of the correlation between each observation x_i and the rest of regions to which it is spatially linked.

Another simple but useful tool used here to check spatial relationships is the Moran's scatterplot. In this kind of graphs, the variable of interest is displayed on the horizontal axis against its spatial lag (Wy), allowing the observer to see if there is any consistent relation between them and, if so, what the sign of the link is. In fact, the slope of the scatterplot corresponds to the value for Global Moran's I (M).

There is one more analytical issue in relation to the global Moran's I: if the variable to be used is a rate, there is a variance instability problem (unequal precision) due to the use of rates as estimates for an underlying 'risk'. In order to correct for this problem, one can smooth the ratio by using several transformations proposed in the literature; here we will use the one following the Empirical Bayes principle, suggested by Assuncao and Reis (1999). Once the rate is transformed, the Moran's statistic can be applied as usual.

It is interesting to note that Moran's I is a global statistic and, as such, may sum up in only one number the degree of spatial correlation among all the observations in the sample. However, it is not able to distinguish those situations in which such spatial correlation is homogeneously spread among the sample from those in which it is clustered in only a few observations. For that purpose, it is necessary to use local indicators of spatial association (LISA), which allow to *decompose* a global statistic of spatial correlation (such as the global Moran's I) into sub-indexes for each observation, being very useful to identify clusters. In order to do that, the local test is computed for every observation in the sample, instead of computing a global measure of autocorrelation. Since the sample size may be large, the most common way to show the results is by means of a map in which different colours display different types of outcome.

Here we are going to use the local version of Moran's I, proposed in Anselin(1995)[**?**], whose expression is the following:

$$I_i = \frac{z_i}{\sum_i z_i^2/N} \sum_{j \in J_i} w_{ij} z_j \tag{11}$$

where z_i is the standardized Moran's I for observation i and J_i is the group i's neigboring observations.

It is possible to assume the standardized I_i is distributed as a normal with average 0 and variance 1 (N(0,1)). 'After standardizing, a positive (negative) value of I_i will imply the existence of a cluster of similar (dissimilar) values of the variable around observation i'[12].

Although there exist several spatial association local indicators, Moran's I has a nice property which makes it different from others and converts it in a proper LISA: 'departing from I_i, it is possible to know the exact contribution of each observation to the global value of Moran's I, being then possible to detect outliers. That is possible because Moran's I may be expressed as sum of the I_i's multiplied by a proportion factor γ[13]:

$$I = \sum_i I_i \gamma = \sum_i I_i [S_0 (\sum_i (x_i - \bar{x})^2/N)]^{-1} \tag{12}$$

As in the global case, if the variable to be used is a rate, the same instabiliy in the variance is encountered. There is then a need to transform the variable in the same way as with the global Moran's I. We will use the same procedure as before, namely the Empirical Bayes (EB from now on) one.

5.2 ESDA

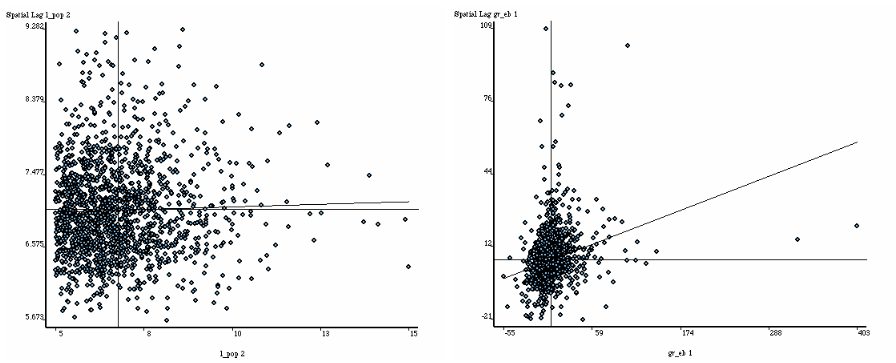
Once we have set up the theoretical background, we can delve into the australian dataset and make use of the toolbox proposed[14]. In this section, only those results for absolute log-population and absolute growth rate are shown in order to improve clarity as the conclussions do not differ very much from the other especifications.

Section 4 in this work takes a deep look at the Zipf's relation in the Australian system, examining how the size of a city and its position in the sample

[12] *Moreno y Vaya (2000)*, pag. 44.

[13] *Moreno y Vayï¿½ (2000)*, pag. 44.

[14] The spatial analysis was carried out with the open-source package STARS, freely available at the REGAL's website (http://regionalanalysislab.org/index.php/Main/STARS) and the free package GeoDa by Luc Anslin, available at the GeoDa Center for Geospatial Analysis and Computation's website (http://geodacenter.asu.edu).



(a) Absolute Log-Population: 2001 (b) EB transf. Absolute Population Growth

Figure 5: *Fig. 9*

Variable	Moran's I	Standard Moran's I (Z)	P-value
Log-population 1996	-0.001	-0.029	0.489
Log-population 2001	0.013	0.922	0.178
Absolute growth (EB transf.)	0.132	8.919	0.000

Table 10: Moran's I

rank are linked, being the main conclussion the overall distribution of population across the city system is very uneven. Now we wonder whether the variable size displays spatial correlation. In order to do so, we apply Moran's I to the absolute log-population. The effect seems clear: we cannot reject the null of no spatial correlation. For both years 1996 and 2001, the statistic (a standard normal, once normalized) is far within the area of no rejection of the null. The result is showed in Table 10 and may be visualized in figure 5 (a): in the first one, the p-value is clearly larger than 0.01, implying that even at the 1% level of significativity, the null cannot be rejected; if we look at the graph instead, we can see how the points are spread across the four quadrants and the fitted line mingles with the horizontal axis. This suggests there is no clear pattern for the size in the spatial configuration of the city system or, in other words, that cities are located in space without following any law regarding their sizes.

Section 5 looks at the Gibrat's relation, which links the size of a city with its rate of growth, concluding there is no relation between both variables. Parallel to the paragraph above, we try to put this phenomenon in space and see if the way nearby cities evolve has any influence on a city's growth. The results, displayed in Table 10, seem to show the other side of the coin: Moran's I shows evidence enough so as to reject the null of no autocorrelation. This means the statistic is significatively different from zero; in fact, the sign is positive, implying the growth of a city and that of its nearby partners is positively correlated and then, the growth tends to cluster in space giving room to the idea of *loser* and *winner* areas. This relation can be seen graphically in Fig. 5 (b): many points are located in the up-right and down-left quadrants, and the fitted line is clearly upwards. These results point to the suggestion that it is very important *where* a city is located and, specially, *who* it is surrounded by to understand its performance in terms of population growth.

Since the first spatial approach does not support the idea of the sizes being spatially autocorrelated, it does not make much sense to try to look for the existence of cities with similar sizes grouped nearby, that is of actual clusters in the variable size. However, we have found the growth to be spatially dependent, which means there is some degree of spatial association for cities with similar growth rates. It is then interesting to take one step forward and try to look for the *hot* and *cold spots* of the Australian urban growth and, to do so, we use the local indicators explained above (LISA). As said, the usual way to present results is by means of a map in which different colours imply different outcomes. Fig. 6 shows the cluster map for the variable growth, after applying the EB transformation to take care of the rate-related problems. Polygons in dark red rerepresent cities which experienced low growth and so their neighbors did (low-low); dark yellow polygons are the opposite, cities which had a high growth rate and a set of neighbors also growing fast (high-high); light red (yellow) represent spatial outliers, in the sense that they are cities which experienced a low (high) rate of growth while their neighbors were growing at a high (low) rate; finally, all the white polygons represent cities for which the LISA didn't prove statistically significant and thus we cannot state anything. It should also be noted that, when a polygon is coloured in dark, it is a signal for the existence of a cluster and the reader should keep in mind the cluster is not only the coloured polygon but also all its neighbors as the dark colour implies the city experienced high (yellow) or low (red) growth but, not only that, also its neighbors did.

However, due to the particular urban geography of Australia, Fig. 6 does not provide a proper way to analize the existence of spatial patterns for growth clusters. The main reason is that the majority of the cities is concentrated on the east part of the country, and this fact leads to a fuzzy polygon map featuring a lot of tiny and barely undistinguishable polygons on the east and very few and large ones in the rest of the surface, which may be missleading for the observer when it comes to withdraw real patterns. In order to deal with this situation, we propose to use what we come to call a *ClusterCart*, an alternative way of displaying a LISA index. Basically, the ClusterCart is the result of embedding the cluster results from the LISA statistic into a standard cartogram. We explain this idea more in detail below.

A cartogram is a map in which some thematic mapping variable is substituted for land area. As an example, Fig. 7 (a) shows a standard cartogram of the australian cities which has been built using a fake variable of zeros. The polygons have turned to circles of the same size (due to the fact the variable it represents is just a zero for each observation) which barely overlay each other. This produces an abstract representation which distorts the orginial shape of Australia but which, and this is why it is useful here, allows to see all the observations at a glance[15]. It also shows a great illustration of why a clustergram is useful in this case: the vast majority of points are located on the east side of the island and they all stand very close to each other. As said before, this feature

[15]The reason why the map becomes distorted is because now the points cannot cover each other and, for that to happen, they need to be slightly moved from their original position in a standard map to leave room so they all fit in.

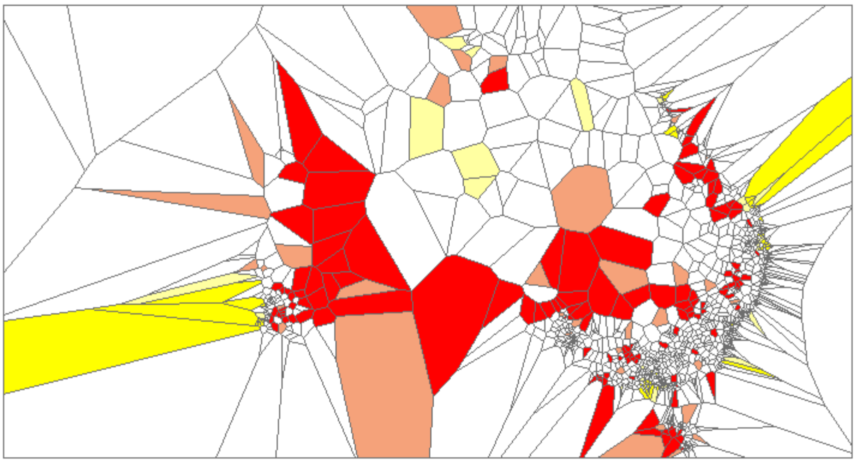


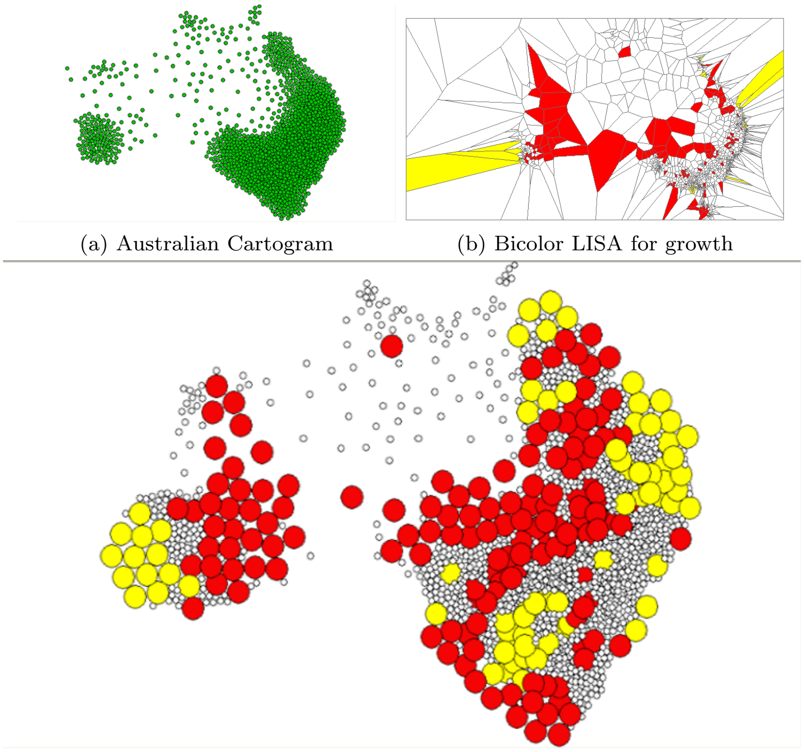
Figure 6: LISA for growth

cannot be recognized by looking at the voronoi map as the polygons on the east are too small to be noticed. However, since the clustergram gives the same size (still allowing to thematically colour it) to every city, this fact can rapidly be discovered and overcome. Figure 7 (b) simply shows the same map as in Fig. 6 but now only the results for the clustered units (high-high or low-low, the dark colours) are displayed, the light colours have been turned to white.

Figure 7 (c) shows the ClusterCart. To build it up we have created a cartogram using the cluster results so the yellow (red) circles represent the cities whith a high-hih (low-low) outcome in the LISA and the white ones are the rest of the cities. This way, we can see more easily whether there exists any pattern in the way such observations are distributed across space.

By looking at Fig. 7 (c), we can extract some insights about the urban dynamics in Australia. The first one is that a vast part of the red circles are not by the coast, except for some of them located in the South[16]. This suggests the australian population is moving outwards, there is a "push-out" effect that makes cities in the inland decline their population. The follow-up obvious question is: "if population in Australia is growing over time and the inland is decreasing, *where is growth taking place?"* The answer can be found

[16]However, ther reader should note those points are located by the coast but by tasmanian coast, not the australian one. This is due to the fact that the ClusterCart tends to group all the observations without distinction between one or another island.



(a) Australian Cartogram

(b) Bicolor LISA for growth

(c) ClusterCart

Figure 7: ClusterCart and is composition

if we look at the yellow circles: basically, it is coastal and well-watered places those displaying positive growth clusters, which is in line with the ideas stated in Hugo(2002)[24]. But, if we look at it more in detail, we can also see most of the yellow clusters locate around some the largest cities in the country: the one in the west is around Perth's area, the one in the South around Melbourne's and the one in the west corresponds to Brisbane. This leads to think that it is in big metropolitan areas, rather than uniformly around the country, where the phenomenon of growth is taking place. However, this is not the same as stating that growth occurs in larger cities. If that was true, Gibrat's law wouldn't hold and we would find signigficative and positive correlation between growth and size; but, as we have seen in section 5, that is not the case. Instead, these results point to the power of larger cities to attract people around their *orbits of influence*, people who do not live in the inner city but who interact with it (e.g. commute for work). Looking for the reasons underlying such phenomenons are beyond the aim of this study, but it certainly represents and interesting road to walk down for future research.

This first spatial exploration of the Australian urban system started by looking at whether urban size and growth showed any kind of spatial dependence, in global terms. We found no correlation in sizes but a significant one among growth rates. The next step was to discern if such phenomenon was taking place uniformly or we could observe regions displaying high and low clustered values. By using LISA indicators displayed in an alternative visualization tool we called ClusterCart, we discovered that a great deal of the declining cities are grouped in the inland while the areas around some of the largest cities in the country are the ones experiencing grouped growth. However, this is only an exploratory approach, meant to suggest directions to follow but which does not provide any insight about the underlying spatial process. For the latter, we need to walk further and step into the confirmatory analysis. That is what next section is about.

6 The spatial Gibrat: space becomes Space

Section 6 brings the role of space into the analysis, considering whether there is any influence of the actual location of cities in both their size and urban growth. They way that is done is by means of both global and local spatial autocorrelation tests, which are used to analyze the degree of spatial association present in both urban size and growth and to see where the important values are located. In spatial analysis, this procedure is known as exploratory spatial data analysis (ESDA) and it is meant to shed some lights about what the data set looks like and what spatial properties it might have (are observations spatially correlated? If so, what is the sign of such correlation? can we talk of clustering? where does it take place?).

One of the main results is that while there is no apparent correlation between sizes, there seem to be spatial dependence in the growth rates. If the former is true and there is spatial dependence, OLS estimates become biased and inconsistent[17]. In section 5, we have used the OLS procedure to estimate the Gibrat equation in different flavours. Now in this section, our main purpose is to carry out the confirmatory (as opposed to exploratory) analysis by explicitly introducing space into the regression analysis and to try to correct for the spatial dependence found in the urban growth rates; this is what we call the spatial Gibrat.

Gibrat's law looks at the relation between urban growth and city size. To do so, the conceptual expression used is:

$$\triangle\, S_i = c + \beta\, S_i + u_i \tag{13}$$

where S_i represents the relative size of city i, $\triangle\, S_i$ its growth and u_i is i.i.d. If β shows not signigicative, then Gibrat's law is said to hold and we talk about proportionate growth.

However, this expression is *non-spatial* in the sense it does not account for any kind of spatial interaction between the cities: it does not matter whether a city is surrounded by a group of very *active* cities which are growing fast or it is in the middle of an *urban desert* where no one seems to be moving. But as we have seen before, there is such kind of spatial interaction that needs to be taken into consideration. In order to do that, we will implement a Spatial Auto-Regresive Auto-Regresive model of first order (SARAR(1,1)) and estimate it by the Feasible Generalized Spatial Two Stages Least Squares (FGS2SLS) found in

[17] Anselin (1988)[2], pages 58-59.

Kelejian&Prucha(1998)[28] and Kelejian&Prucha(1999)[29]. The counter-part of (13) would now be:

$$\triangle\, S_i = c + \beta_{FGS2SLS}\, S_i + \rho_1 W \,\triangle\, S_i + u_i \tag{14}$$

$$u_i = \rho_2 W u_i + \epsilon \tag{15}$$

where W is the spatial weights matrix, ρ_1 and ρ_2 are parameters, u_i is the error term and ϵ is i.i.d. This way, we can account for the spatial autocorrelation which might exist in the dependent variable as well as for that which might come out of other reasons not taken into account (error term).

The purpose of such a model is twofold: first, by allowing for spatial autocorrelation, we ensure the estimates for the coefficients (in this case, the one for the urban size, S_i) are consistent and cuasi-efficient[18]; second, we set up an appropriate framework to further study the resuls from the ESDA stage since, if statistically different, both ρ_1 and ρ_2 have meaning by themselves, and interpretting it may be of interest.

We will run the same different specifications as in section five but now accomodating the spatial terms both in the right-hand side and in the error, as shown in equations (14) and (15)[19]. In this section, only the absolute population is considered.

As said before, the algorithm used to compute the estimates is the FGS2SLS. This procedure involves the following steps:

1. First is to perform *two stages least squares* estimation of the inital model, accounting thus for the endogeneity created by the spatial lag on the right-hand side.

2. Then *GMM estimation of* ρ_2 by using the residuals from 1. is computed.

3. Next, $\hat{\rho_2}$ is used to apply a *spatial Cochrane-Orcutt transformation*, by multiplying the model on both sides by $(I - \hat{\rho_2} W)$ and thus eliminating the spatial autocorrelation in the error.

4. Finally, the transformed model is employed to run *two stages least squares* and obtain consistent estimates for all the parameters left.

By using it, we ensure that the spatial autocorrelation in the disturbances and the endogeity caused by the dependent variable on the right-hand side are accounted for and the estimates are thus consistent and cuasi-efficient.

Table 11 presents the main results of the regression for fashion 1; there are mainly two comments that need to be made about it. First, it is important to note that both spatial terms ($\hat{\rho_1}$ and $\hat{\rho_2}$) are statistically significant and distant from zero (0.9 and -0.8); the meaning behind those numbers is the spatial processes we included in the model (Wy on the right-hand side and Wu on the error term) prove important to understand the phenomenon or, putting it in other words, we confirm the results on the ESDA about the importance of space in urban growth. Also, another implication of this result is that we now know

[18] See Kelejian&Prucha(1999).

[19] This results in the same expression as (15), but the term $\triangle\, S_i$ is substituted by the different definitions offered in section 5.

	Estimate	Std. Error	t-value	P-value
$\hat{\rho_1}$	0.8901	0.2575	3.4566	0.0005
c	0.2107	0.4887	0.4313	0.6662
$\hat{\beta}_{FGS2SLS}$	0.0000	0.0000	-0.2628	0.7927
$\hat{\rho_2}$	-0.7934	-	-	-

Table 11: Estimation results for the FGS2SLS

OLS estimates (those from the non-spatial part) are biased and inconsistent and thus we should not look at them to draw conclussions but rather at those from the FGS2SLS procedure.

If we now take the spatial coefficients one by one, we can extract different interpretations for each of them. The estimate $\hat{\rho_1}$ represents the importance of the spatial lag (Wy), that is how relevant the growth of the surrounding cities is to explain growth in a city; derived from the results, it seems to be an important factor. The positive sign implies neighbors tend to have similar values, giving room to think of the existence of regional (orr spatially differentiated) dynamics in urban growth, in the sense that nearby cities tend to have similar growth (or decline). These results also point to the presence of spillovers or externalities which in turn foster or discourage urban growth. A couple of examples of that could be the interaction due to commuting for work that takes place between a large city and the surrounding *satellite* cities or the positive knowledge spillovers that a city may benefit from if a neighboring one establishes a university or a research institute.

The error term can be seen as a black box fitting inside of it all kind of measurement errors plus relevant variables which were omitted in the regression. The significant spatial coefficient[20] here ($\hat{\rho_2}$) means there's also a spatial dimension in those variables, that is at least some of them are also spatially correlated. However, the sign is negative implying that nearby observations tend to have disimilar values. The concept of negative spatial dependence is a little bit more complicated to understand than the positive one; it refers to those situations where there is a pattern of repulsion and thus similar values tend to be far apart from each other.

The second comment relates to the coefficient of the size ($\hat{\beta}_{FGS2SLS}$). Same as in the *non-spatial* approach, it is clearly statistically undistinguishable from zero, which implies there is no relation between the city size and its growth, even when one controls for the spatial effects in growth. This leads to conclude that Gibrat's law seems to be a robust result and thus urban growth does not depend on size in the Australian cities, in the period between 1996 and 2001.

Taking both aspects together would yield a map of Australia with *active* and *run-down* areas of cities growing with similar trends. These dynamics would be independent of size but dependent of space, meaning that growth does not happen evenly across the urban system but only in certain regions, while some others experience decreases of population. This, together with the confirmation of the non-spatial results on Gibrat's law, proving them as robust to space,

[20] The reason why the standard error, and the t and p values are not provided is that this parameter was calculated by a different procedure than the rest and hence those numbers were not provided by the software.

would be the main contribution of the confirmatory approach to the analysis of the australian urban system.

Last, a final comment regarding the results from the other fashions is needed. Although only the first one is shown, the four especifications were computed, yielding almost all of them similar conclussions. The only one not displaying exactly the same behaviour was the third fashion, in which both spatial terms were significative, but so the intercept and the β were at the 5% level (not at the 1% level though). The interesting part here is that the sign of the coefficient for size is positive (we found it to be 0.0068), which would invalidate Gibrat's law. This actually confirms the results from the non-spatial approach in Section 5, which also found significant and positive the size coefficient for that espcification, but now it proves robust to space. Moreover, we can link this insight to the ESDA in section 5, where we were finding clusters of high growth rates near to large cities (e.g. Perth, Melbourne or Brisbane); this would speak in favour of big cities as attraction poles for people who see them as a greater range of opportunities rather than as nodes of congestion and then tends to prefer them. Nevertheless this result, although interesting, must be taken with precaution as it is the only one out of four especitifications and it is not significant at the 1% level.

7 Conclussions and future steps: *there is, there is not and there will be*

The present paper examines in a descriptive and detailed way the Australian urban system for the years 1996 and 2001. To do so, it uses the largest data set available so that the whole distribution (starting at 200 people) is covered and three different measures of the city size are used, namely the absolute population, the relative one and the size as a share of the total population. Australia is a very unique example of low population density, and its very special geography has shaped the distribution in a way that makes it very appealing for the urban researcher.

We first characterize the data set, and it already shows that, despite the short period chosen, some noticeable changes can be perceived. Then Zipf's analysis is carried out in order to see if the $rank - size$ parameter is around one, but the evidence points to a much lower value (around 0.74), which implies a very uneven distribution of the population over the system and confirms what we had already sketched about Australia being a very unique case. Moreover, we can see how, from one year to another one, such coefficient has even decreased, deepening the inequality across cities. Besides the basic Zipf's analysis, we also look at whether results vary substantially when the sample is shortened, so only the largest cities (*Urban Centres*) are considered, and subdivide Australia into regions to check the existence of sub-systems with a primate city and Zipf's law applying for the rest.

After having realized Zipf does not hold for Australia, we look at the dynamic processes behind the city system to examine the relation between growth and size by means of Gibrat's law. We use different especifications and find strong evidence to state Gibrat's law holds and thus Australia experienced proporcionate growth between 1996 and 2001. We find these results robust to the especification (only one out of four especifications fails to meet Gibrat's condition), to the measure of size used and to the shortening of the sample (*winner's bias*).

The next step is to bring the role of space into the analysis. To do so, we begin with an exploratory spatial data analysis (ESDA) procedure in which we try to determine whether there is any degree of global spatial dependence. The main conclussion is that although urban sizes are not spatially correlated, growth rates do show association in space. We then try to locate clusters of high and low growth by means of LISA indicators and an alternative visualization tool we call ClusterCart. This step shows declining cities are located mainly in the inland while the growing centres tend to cluster around large cities by the coast.

We follow the exploratory by the confirmatory analysis; to do so we especify a Gibrat equation including both spatial lag and error to correct for the spatial effects. There are two main results: on the one hand, we find significative spatial effects present both in urban growth and in, at least, some of the variables which were not taken into account (error term); on the other one, Gibrat's law proves robust to space and keeps holding when the spatiall effects are taken into account.

The main picture we can draw after this study has a non-spatial and a spatial side, and we can find some similarities between both views. On the non-spatial world, Zipf's analysis sheds a very uneven distribution of people across the urban system, with city sizes more diverse than in other countries in the world; moreover, Gibrat's approach unfastens size from growth so it doesn't matter how big a city is to explain its growth. Once we go down on surface to the spatial world, we also find a very unequal distribution of cities across the australian geography and a very unbalanced but space-led distribution of growth among cities.

In order to conclude the paper, here we suggest two directions which could be followed to expand the study of Australia: the one would be to take the data set further back in time and the second one to dig into the causes which give rise this outcome. Although they certainly give useful information, two points in time with a five-year lag in-between are certainly not enough to study long-term processes such as the evolution of a city system. That is why this paper should be seen rather as a static picture; covering more years would bring the whole movie and would surely shed more light about the dynamical processes underlying the outcome pictured here. On the other hand, this study is rather descriptive in the sense that it focuses on characterizing Australia and on withdrawing systematic patterns in the way Australian cities are configured but it falls short in explaining why such trends and distributions are so. Mining possible explanatory variables to get deeper into the causes would surely be of great interest.

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Appendix

Appendix 1: Delimitation Criteria for Urban Centres and Localities[21]

The delimitation criteria for UC/Ls are based on those developed in 1965 by Dr G.J.R. Linge from the Australian National University. The criteria that are currently in force have been adopted and subsequently amended by the Conferences of Statisticians of Australia in 1965 and 1969 and the Review of ABS Statistical Geography in 1988.

Delimitation of Urban Centres with 20,000 or more people

Each Urban Centre with a population of 20,000 or more is to consist of a cluster of contiguous urban CDs and other urban areas. CDs classified as urban include the following:

- All contiguous CDs which have a population density of 200 or more persons per square kilometre shall be classified as urban. Consequently State, SD, LGA and other administrative boundaries shall be disregarded in determining whether a CD should be included within the Urban Centre.

- A CD consisting mainly of land used for factories, airports, small sports areas, cemeteries, hostels, institutions, prisons, military camps or certain research stations shall be classified as urban if contiguous with CDs which are themselves urban.

[21] ***Sources***

- Australian Standard Geographical Classifiaction. Jul, 2007.
- Australian Bureau of Statistics website (www.abs.gov.au).

- A CD consisting mainly of land used for large sporting areas, large parks, explosives handling and munitions areas, or holding yards associated with meatworks and abattoirs shall be classified as urban only if it is bordered on three sides by CDs which are themselves classified as urban.

- Any area which is completely surrounded by CDs which are urban must itself be classified as urban.

- Where an Urban Centre of 20,000 or more population is separated from another urban area by a gap in urban development of less than three kilometres (by the shortest railway or road distance), the gap shall be bridged by classifying a connecting CD as urban, and therefore treating the urban areas as one. If the gap is three or more kilometres (and whether or not it is comprised mainly of reserved land or a natural barrier) the urban areas shall remain separate.

- Any area included in an Urban Centre in 1971 or thereafter under the provisions of these criteria shall continue to be so included, unless the population of the Urban Centre falls below 20,000, in which case these criteria will cease to apply.

- If a CD was incorrectly included (for whatever reason) in a Linge area at a previous census, then it should be excluded at the next census unless it now meets the criteria.

- Large peripheral CDs in growth areas may be fragmented; and insofar as the availability of visible boundary features allows, the fragments so created shall be as near square-shaped as possible, contain at least 100 persons at the next census and be of such a size that they will contain a collector?s workload when fully developed. For the purpose of delimiting Urban Centres such fragments shall be regarded as CDs.

<u>Delimitation of Urban Centres with 1,000 to 19,999 people</u>

Each Urban Centre with a population between 1,000 and 19,999 is to be delimited as follows:

- The Urban Centre shall be delimited subjectively by the inspection of aerial photographs, by field inspection and/or by consideration of any other information that is available.

- All contiguous urban growth is to be included (even if this would not necessarily occur if the density criterion were applied), together with any close but non-contiguous development which could be clearly regarded as part of the Urban Centre. However, for urban centres which contain a population approaching 20,000 the objective criteria applied for urban centres with 20,000 people should also be considered.

<u>Delimitation of Localities</u>

Localities are to be delimited as follows: All population clusters of less than 1,000 population and whose population is expected to reach 200 by the next census are to be examined for boundary delineation.

- The following criteria must be satisfied before a boundary is drawn around a Locality. It must:
- contain a non-farm population of at least 200 people but not more than 999 by the next census;
- have a minimum of 40 occupied non-farm dwellings with a discernible urban street pattern; and
- have a discernible nucleus of population.
- If there is some doubt that a Locality will reach the minimum population of 200 people then a boundary should still be drawn around the Locality.
- Where, in the case of defence camps, construction camps, etc. it is anticipated that the cluster will not exist at two consecutive censuses, these camps should not be bounded.
- The Localities shall be delimited subjectively, by the use of the latest available aerial photographs, by field inspection and/or by consideration of any other information that is available.