POPULATION PROJECTIONS FOR SMALL AREAS: Method and applications for districts and local population projections in Brazil *

Paulo de Martino Jannuzzi[1]

Abstract

Population projections for small areas are becoming more and more requested by public and private organizations around the world as a way to improve their planning capabilities. Most of the proposed models are data intensive, based on administrative records maintained by local agencies or governmental offices. As coverage and quality of this type of data are usually poor in great parts of underdeveloped countries, these models can not be useful. This paper presents an alternative method to produce population estimates in small areas, useful when good census data and vital statistics are available. The presented model is an integrated method of population projections using cohort-component method at regional level joined with a system of differential equations to split the total population to municipal bounds. The paper is structured in two sections. First it presents the integrated model demographic components-dynamic system, and then it brings applications at disctrict and local levels in Brazil. Although this model can be applied – in thesis - in any situation one wants to estimate the population of small areas inside a larger one, the use of the method seems more reasonable in a planning horizon of 5 to 10 years ahead and simulation purposes in gatherings urban zones or metropolitan areas - whose environmental, infrastructure and economic resources (water, transport, houses, jobs, etc) are more and more scarce and disputed by resident population.

Key words: *Demographic Projections - Small area estimation - Dynamic systems*

1. Introduction

Models on population projections for small areas are deserving growing attention by researchers in Applied Demography, as can be illustrated by the sessions dedicated to this subject on population studies seminars in the last years. In fact, in the World Conference of Population in China, in the annual meetings of the Population Association of America and of Southern Demographic Association in the USA, in CELADE publications (Latin-American Center of Demography), in the International Conference on Methods of Small Areas Estimation organized by the US Bureau of Census, one can witness a growing concern of demographers to small area population estimates around the world.

This growing interest is due to information needs for planning and strategic development by both the private and public sector at small and very small geographic areas (Granados 1989, Smith et al. 2001). Governments and governmental agencies need more precise estimates of the public to be served by different policies in order to guarantee a better social effectiveness of the available public resources, more and more scarce. The growing offer of trained technicians in Demography, the technological advances, the reduction of hardware and software prices and the availability of less complex statistical package contribute to meet this increasing demand for projections in developed and

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[1] Professor at PUC-Campinas and ENCE/IBGE.

underdeveloped countries. In Brazil, tax decentralization from the federal to states and municipal governments, the transfer of part of duties of social policies to city halls and the introduction of a constitutional article compelling the districts with more than 20 thousand inhabitants to set an urban developing plans have also been favoring the use of more complex quantitative techniques in Public Planning, such as population projections and its derivatives.

The classic techniques for population projections for small areas have been revised elsewhere by several authors (Granados 1989, Santos 1989 , Celade 1994, Smith et al 2001). In general, the regression models, correlation or partition methods based on symptomatic variables are among the most used in the international bibliography still today, as it can be seen in the papers of the cited conference organized by US Bureau of Census (Smith & Cody 1999, Hoque & Murdock 1999, Martindale 1999, Simpson 1999, Tolson 1999). Statistics of births, deaths, medical registrations and hospital attendance, building licenses, school registers, licenses of automobiles, information on tax revenues, electricity consumption and other infrastructure services are among the symptomatic variables more mentioned in applications of small areas projection in the developed countries, due, of course, by the quality and reliability of these administrative data. Linking administrative data and Geographic Information System seems to be the most promising techniques (Bell *et al.* 1997).

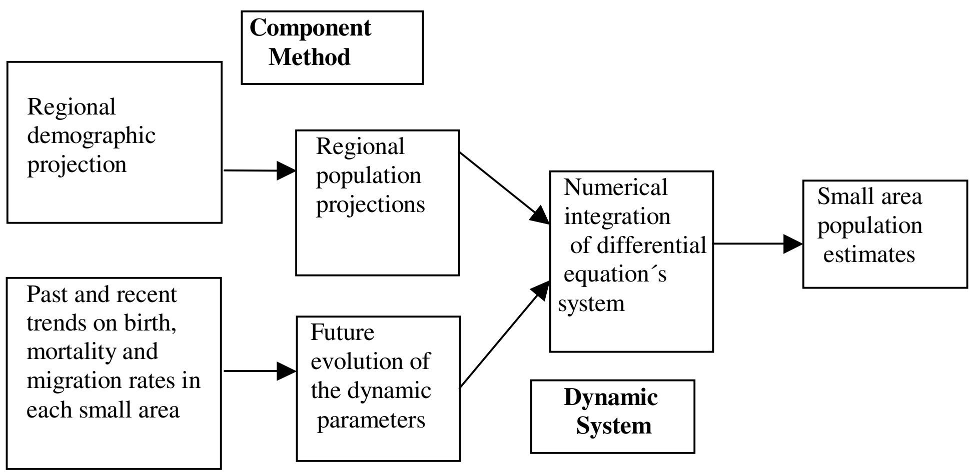
In Brazil and other countries of the Third World there are also experiences of application of data brought from administrative registers in local projections (Jardim 1992, Celade 1994, Waldvogel 1998), but certainly it is not a practice that can be generalized for the whole context, as a consequence of the lack or low reliability of the requested information.

This paper aims to present a contribution for small area projections, introducing an alternative method that uses census data and vital statistics - information assumed to be more reliable than other administrative data in Brazil. The model presented is an integrated method of population projections using the demographic component method at regional level and a system of differential equations to split the total to municipal bounds, using a model of competitive species in Ecology. This paper is structured in two sections: first, it is presented the integrated model (demographic components-dynamic system), and then it is shown two applications of the model.

2. Linking the cohort-component method with the dynamic ecological system

In general, population projection models for small areas presuppose there is available the total population of the large area they are placed. In the integrated model of projection presented here, the regional demographic projection is also necessary. To guarantee the consistency of age structure, it is important that the regional projections have been elaborated by cohort-component methods. Such projection method certainly does not need further explanations, since its extensive and old dissemination in the field. It consists applying the basic compensation equations of the population dynamic for each cohort, combining different hypotheses on the evolution of the level and structures of the fertility, mortality and migration in the projection horizon. The performance of projected figures depends, beyond the quality of data on the demographic structure at the beginning of the planning horizon, of the consistency of the hypotheses related to the future evolution of the demographic components in the region. Consistent hypotheses depends, on its turn, on the availability of demographic models that allow to specify fertility, mortality and migration levels and age/sex patterns according to the region caractheristics.

Diagram 1: Combining cohort-component method and the dynamic system for small area projection



After estimating, by the cohort-components method, the total population of a region with its age and sex structure for each five years, the dynamic system is applied to estimate the population of the sub-areas inside the major area in study (Diagram 1). This last model is based on a system of differential equations used in Ecology to represent the population dynamics of competitive species inside a closed *habitat*, with limited support capacity. Inside the *habitat* the growth of each species depends on its natural growth rate (births less deaths) and on the form of interaction with the other existent species (competition, parasitism or predatory forms) (Dajoz 1983).

The use of this model representing the population dynamics of small areas in a large region is intuitively simple, and was implemented previously by Szwarcwald & Castilho (1989) for computing annual estimates of municipal populations of a Brazilian state between 1980 and 1990. In such applications, the populations of the small areas represent the “species”, and the area, the “*habitat*”, with its physical and limited resources of space, public roads, infra-structure, jobs, etc. The population growth rate of each small area will depend on its natural growth and its attractiveness degree inside the larger area, due to its several economic advantages or disadvantages (level of wages, jobs opportunities, land and dwelling prices, pollution, transport costs, etc).

Box 1:System of differential equations of the population dynamics inside the region

$dP_1/dt = a_1 P_1(t) + b_1 P_1(t) T(t)$

$dP_2/dt = a_2 P_2(t) b_2 P_2(t) T(t)$

....

$dP_n/dt = a_n P_n(t) b_n P_n(t) T(t)$

subject to the contour condition $\Sigma P_i(t) = T(t)$,
where
T(t): total population of the area in the year t
Pi (t): population of small area i in the year t
a_i : natural growth rate of the population of the area i
b_i : factor related to the migratory attractiveness of the area i

As represented in the differential equations system (Box 1), the parameters a_i are related to to the specific natural growth of area i, while the parameters b_i refers to the attractiveness potential of area i related to the others (that is, the migratory competitiveness of each area in relation to the population of the larger area). It is a model that discriminates, for each area, the contribution of the natural growth and of the migratory balance in the population growth.

Szwarcwald & Castilho (1989) shows that is possible to find a recurrent algebraic solution for the system of equations, taking the regional population as an exogenous variable –defined by the cohort-component projection - and supposing specific trends for the natural growth rate and for the degree of attractiveness of each small area (Box 2). With that it is possible to estimate the total population for each small area for the near future (five to ten years).

Box 2 Recurrent solution of the system of differential equations

If $P_i(t)$ is the population of the area i in the moment t, then:

$P_i(t) = P_i(0) + \Delta P_i$

$\Delta P_i = \Delta P F_i(t) P_i(0) / \Sigma F_i(t) P_i(0)$

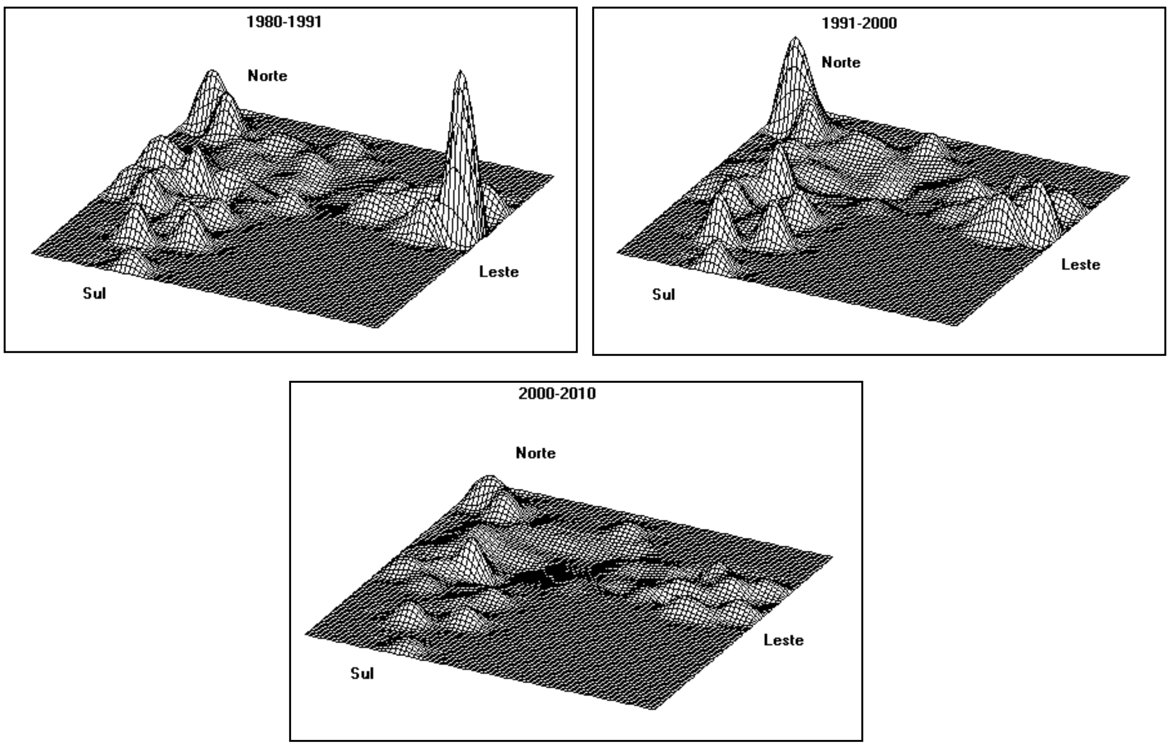
with $F_i(t) = \exp(a_i + b_i(\ln(T(t)/T(0))(T(t) - T(0))) - 1$

where T(t): total population of the area, projected by components
a_i: parameter associated to the natural increase rate
$= \ln(1 + \text{birth rate}_i - \text{mortality}_i)$
bi: migratory attractiveness of the area i
$= \{a_i + [\ln(P_i(t) / P_i(0)]\}/\{[\ln(T(t)/T(0))] \times [T(t) - T(0)]\}$

3. Population projections for small areas : applications at different scales

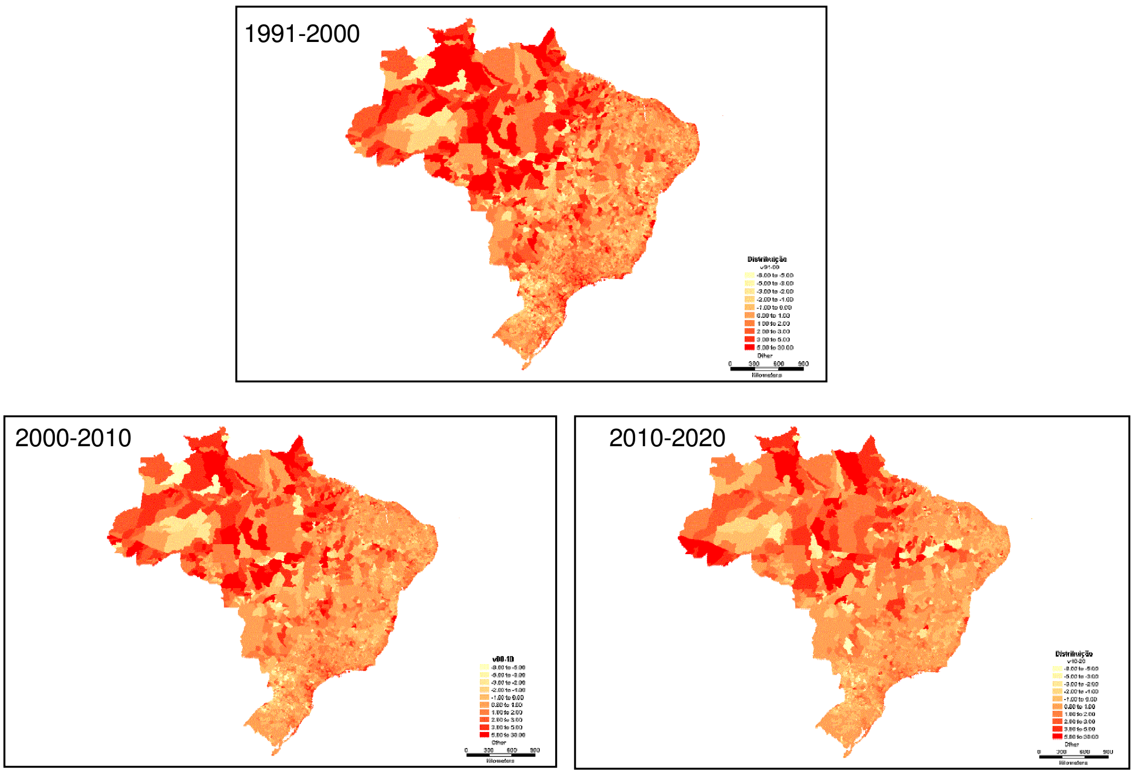
This metodology have been applied in different contexts in Brazil, at very small and larger scales, local or national aplications. In Jannuzzi & Jannuzzi (2002) the model was applied to produce population projections through 2005-2010 for the 96 districts of the 10-million city of São Paulo. Series on vital statistics and 1980-2000 Census data were used to estimate the basic parametes of the model. Specialists were invited to partipate on a Delphi inquiry on the demographic and economic scenarios of São Paulo and also on the trends of its districts for the next years. These inputs were used to model past growth rates and produce demographic projections as can be seen in the graphs below.

Surface maps representing annual growth rates of district population
São Paulo 1980-2010



Another application of the methodology was to produce population projections for the 5.661 brazilian cities e towns from 2005 through 2020, as requested for the research team contracted by federal government to develop the inputs and scenarios for the 2004-2007 Medium Range National Plan. This Plan deals with public investment and social expenditures, and for its efectiveness it is necessary to know where the demographic demand is growing and how it is been changing, as a quide to build elementary, high and technical schools, hospitals, roads, urban infrastructure at the right places, at the right pace. Is this application the unit "small aea"used were the 504 brazilian micro-regions, as a way to gain more confidence trends on vital statistics. After producing micro-regional population figures an apporttional method (Smith et al. 2001) was used to get local population projections. As described in São Paulo application, regional economy specialists' opinion were used to introduce future trends on population projections. As it can be seen in the carthograms, the demographic growth rates have been (and will continue) slowing down in the whole country (as maps gets less and less red), but at different pace in North and South of the country.

Carthograms representing annual growth rates of cities and towns' population
Brasil 1991-2020



4.Final remarks

The method presented in this paper for small area population projections is not a simple mathematical extrapolation model. It is a true demographic-type model. It is based on the cohort-component method and on a system of differential equations that discriminates, for each small area, the contribution of the natural growth and of the migratory balance.

Although it can be applied – in thesis - in any situation one wants estimate the population of small areas inside a larger one, the use of the method seems more reasonable in situations of demographic projection - with planning horizon of 5 to 10 years ahead - for neighborhoods in a same municipal district or municipal districts in metropolitan areas - whose environmental, infrastructure and economic resources (water, transport, houses, jobs, etc) are more and more scarce and disputed by resident populations. It seems also to be useful in situations that the recent demographic dynamics of the small areas dissuades the mere mathematical extrapolation of the recent tendencies and situations one can not count on other administrative data other than vital statistics.

Of course, the success in using this integrated model depends on the quality of implicit hypotheses in the projection components for the larger area and in the specifications of future values of the parameters $\mathbf{a}_i$ (natural growth) and $\mathbf{b}_i$ (migratory attractiveness) for small areas. When the vital statistics are good, the analysis of the historical series of the birth rate , mortality and of the migratory balances may suggest future tendencies for the parameters of the model. One can not forget, however, that the specification of the degree of migratory attractiveness of the small areas should be based in some prospective analysis concerning the future trends of macro-regional factors - such as level of jobs, wages level, occupational profile in the region – and the evolution of urban constraints- such as land use legislation, urban plans, road construction, residential mobility, among other aspects.

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