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Italian Deprivation Index and Dental Caries in 12-Year-Old Children: A Multilevel Bayesian Analysis

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12-year-old children · Bayesian models · Caries · Deprivation index · Multilevel analysis

Abstract
Evidence from the literature has shown that people with a lower socioeconomic status enjoy less good health than people with a higher socioeconomic status. The Italian deprivation index (DI) was used with the aim to evaluate the association between the DMFT index and risk factors for dental caries, including city population and DI. The study included 4,305 12-year-old children living in 38 cities classified by demographic size as small, midsize and large. Zero-inflated negative binomial multilevel regression models were used to assess risk factors for DMFT and to address excess of zero DMFT and overdispersion through a Bayesian approach. The difference in the average level of DMFT among children living in cities with different DI quintile was not statistically significant (p = 0.578). The DI and ln(population), included as city-level fixed effects in the two-level variance components model, were not statistically significant. Consuming sweet drinks on average increased the mean DMFT of a susceptible child, while having a highly educated mother reduced it. Unobserved heterogeneity among cities was detected for the probability to be non-susceptible to caries (city-level variance = 0.26 with 95% credibility interval 0.09–0.57), while no territorial effect was found for the mean DMFT of the susceptible children. Our results suggest that the DI and city population did not play a role in explaining between-city variability. Interventions against social deprivation can be influential on the perception of oral health in Italian 12-year-old children to the extent that they can also affect individual level factors.

Ill health and deprivation have been explored since the mid-19th century [Wagstaff et al., 1991; Mackenbach and Kunst, 1997] and nowadays are well documented [Marmot et al., 2010]. An important principle to reduce health inequalities is highlighted by the final report of the Commission on Social Determinants of Health set up by the World Health Organization [Marmot et al., 2008], the major goal of the WHO being to eliminate the extensive, preventable and unjust health inequalities which persist within and between countries.

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Despite overall reductions in caries levels, there are still persistent inequalities among social classes. Evidence has shown that, within one country, people with a lower socioeconomic status (SES) enjoy less good health than people with a higher SES [Marmot et al., 1995; Reisine and Psoter, 2001]. Usually, SES is measured by indicators such as income or occupational status [Bertoldi et al., 2013]. Recently, new measures of SES have been proposed as alternatives to these conventional indicators [Blair et al., 2013]. Deprivation indexes (DIs) have given new impetus to measure health disparities in several groups defined by a variety of socioeconomic categorizations. Usually, DIs are used to synthesize, albeit indirectly, the ownership of resources, both material and social, at individual, family and geographical area levels [Morris and Carstairs, 1991]. The use of census data on small areas has the advantage of classifying individuals in terms of the level of material deprivation in their neighborhood. The small area approach can help to show the characteristics of a population which are relevant to health planning, such as demography, social circumstances, mortality and morbidity.

Enquiries examining the association between socioeconomic area characteristics and health events have, in the main, made use of the postcode sector (in Scotland) or ward (in England) as the area base [Jarman, 1983; Townsend et al., 1988; Carstairs and Morris, 1991]. Many studies have focused on using a measure of 'deprivation', i.e. a score composed of a number of social variables from the census. A deprivation score of this kind, producing a continuous variable (albeit artificial), has the benefit of offering opportunities for statistical analysis.

Also in Italy, a nationwide DI at municipality and census block level was developed using data drawn from the 2001 General Census of Population and Housing [Caranci and Costa, 2009]. To represent the multidimensionality of the social and material deprivation concept, variables measuring low level of education, unemployment, home non-ownership, one-parent family and house overcrowding have been considered. Over the past few decades, in most industrialized countries the prevalence of dental caries has varied [Petersen, 2003; Marthaler, 2004]. Studies on the etiology of dental caries have shown that small population groups maintain a high prevalence of this disease [Ueda et al., 2004; Masood et al., 2012], and others reported that the disparity of disease may be related to a more intense exposure to risk factors (gender, educational level of mothers, SES, oral hygiene habits, fluoride history, dental fluorosis, access to oral health services, sugar consumption, diet habits, area of residence) and to social deprivation [Patrick et al., 2006; Sabbah et al., 2009].

In Italy, the national epidemiological data show a low DMFT index in healthy subjects varying from a value of 6.9 in 13-year-old [Vogel et al., 1979] to 1.44 with a caries-free percentage of 56.9% in 12-year-old healthy subjects. From an explanatory point of view of disparities related to dental caries, it becomes interesting to explore the variability of dental caries distribution taking into account the hierarchy of interactions between the individual and environment at different levels [Locker and Ford, 1994].

The challenges of estimating the prevalence of dental caries and other features of the distribution of the DMFT index have received some attention from a statistical point of view. Methodological approaches have been proposed to understand caries risk factors and to counteract their development, consisting of modeling the DMFT index through zero-inflated models [Böhning et al., 1999; Solinas et al., 2009; Javali and Pandit, 2010; Lesaffre and Lawson, 2012; Matranga et al., 2013a], although recommendations are provided to enhance the use of these models [Preisser et al., 2012]. The topic of simultaneous occurrence of zero inflation and correlation has been thoroughly tackled by various studies for the analysis of hierarchical data for either study design or data collection procedures [Burnside et al., 2007; Moghimbeigi et al., 2008]. Furthermore, models for correlated zero-inflated data have been developed within a Bayesian framework as an alternative to the classical, frequentist approach [Dunson, 2001; Greenland, 2006]. These include zero-inflated models for correlated territorial data [Gschlößl and Gzado, 2008] and hurdle, zero-inflated and zero-altered models for longitudinal data [Neelon et al., 2010]. As shown elsewhere in detail, Bayesian estimation for zero-inflated dental caries modeling offers many computational advantages and the possibility of expressing statistical inference about parameters in terms of credibility intervals (CrIs) [Matranga et al., 2013b].

Considering these precepts, the aim of this study was to evaluate the association between the DMFT index and risk factors for dental caries, including two city-level factors, DI and city population. Data for this analysis were collected through the Italian Pathfinder survey [Campus et al., 2007] and were hierarchically structured as children within cities, within territorial macro-areas. The information at both individual and territorial levels was integrated through multilevel Bayesian zero-inflated models.

Materials and Methods

Data Source

Data from the Italian Pathfinder survey carried out from March 2004 to April 2005 were used as the source of the oral health out-

Table 1. Distribution of DMFT and contextual factors by cities and by demographic size

Cities	Children	DMFT = 0	DMFT (mean ± SD)	DI z score	DI categories	Population
Ancona	164	133 (5.37%)	0.34±0.80	–0.405	2	90,565
Arezzo	107	48 (1.94%)	1.58±2.03	–0.922	1	91,589
Bari	368	191 (7.71%)	1.22±1.77	4.104	5	316,532
Bergamo	44	30 (1.21%)	0.68±1.29	–0.187	2	113,143
Camucia	41	20 (0.81%)	1.41±2.55	–1.655	1	22,048
Casciavola	36	23 (0.93%)	1.06±1.67	–0.569	2	38,359
Como	37	27 (1.09%)	0.46±0.90	0.818	3	78,680
Cremona	30	20 (0.81%)	0.70±1.21	1.066	3	70,887
Crotone	145	41 (1.66%)	2.44±2.31	5.258	5	60,010
Firenze	180	90 (3.63%)	1.37±1.78	0.332	3	356,118
Fiuggi	205	104 (4.20%)	1.29±1.73	0.776	3	8,763
Follonica	30	18 (0.73%)	1.00±1.64	–0.335	2	21,091
Grosseto	53	38 (1.53%)	0.66±1.34	–0.422	2	71,263
Latisana	44	36 (1.45%)	0.39±0.95	–0.011	2	11,896
Lecco	30	14 (0.57%)	1.20±1.37	0.755	3	45,501
Livorno	77	43 (1.74%)	0.87±1.35	2.019	4	156,274
Lodi	130	69 (2.79%)	1.02±1.50	0.642	3	40,805
Lucca	38	18 (0.73%)	1.42±1.65	–0.880	1	81,862
Mantova	33	20 (0.81%)	0.73±1.10	1.380	4	47,790
Milano	257	168 (6.79%)	0.88±1.68	0.645	3	1,300,000
Napoli	119	58 (2.34%)	1.37±1.77	11.309	5	1,000,000
Palermo	337	204 (8.2%)	0.91±1.50	6.535	5	686,722
Parma	124	74 (2.99%)	0.77±1.20	–0.488	2	163,457
Pavia	39	25 (1.01%)	0.62±0.99	0.511	3	71,214
Perugia	213	140 (5.65%)	0.78±1.37	–1.135	1	149,125
Pisa	166	108 (4.36%)	0.90±1.64	0.130	2	89,694
Pistoia	106	46 (1.86%)	1.73±2.11	–0.413	2	84,274
Poggibonsi (SI)	34	8 (0.32%)	2.09±1.90	0.470	3	27,420
Prato	89	41 (1.66%)	1.69±2.13	0.102	2	172,499
Roma	195	128 (5.17%)	0.76±1.31	2.690	4	2,500,000
San Miniato (PI)	37	15 (0.61%)	1.49±1.61	–1.044	1	89,694
Sassari	268	171 (6.91%)	0.83±1.45	3.065	5	120,729
Siena	40	35 (1.41%)	0.25±0.81	–1.240	1	52,625
Sondrio	41	17 (0.69%)	1.66±2.23	2.115	4	21,642
Tolmezzo (UD)	92	53 (2.14%)	0.93±1.38	0.625	3	10,611
Val Camonica	44	21 (0.85%)	1.50±1.76	0.716	3	120,289
Varese	31	19 (0.77%)	1.16±1.70	0.934	3	80,511
Verona	281	163 (6.58%)	1.00±1.70	1.011	3	253,208
Demographic size[1]						
Small (<75,000)	1,023	541 (52.9%)	1.24±1.80	1.09±1.86	3.04±1.06	34,963±22,500 (38,359)
Midsize (75,000–350,000)	2,194	1,288 (58.7%)	1.02±1.64	1.05±1.85	2.94±1.49	168,638±84,046 (149,125)
Large (>350,000)	1,088	648 (59.6%)	1.00±1.61	3.95±3.61	4.02±0.91	1,100,000±725,025 (1,000,000)
Total sample	4,305	2,477 (57.5%)	1.07±1.67	1.79±2.73	3.20±1.34	381,021±575,779 (149,125)

[1] With regards to demographic size analysis, mean ± SD is given for DI z score and DI categories; mean ± SD and median, in parentheses, are given for population.

comes and individual level covariates for the present paper. An original sample of 5,342 12-year-old children, randomly chosen in a multistage sampling frame extracted from twenty Italian regions, were enrolled and then examined. A detailed description of sampling techniques is reported in a separate paper [Campus et al., 2007]. Children were examined by calibrated operators according to the WHO guidelines [World Health Organization, 1997], and training and inter-examiner reliability were assessed before the start of the study [Castiglia et al., 2007].

The study design also included an ad hoc questionnaire with closed questions which focused on sociodemographic background, oral hygiene behavior and other information related to caries risk. Seven individual level variables were considered, with categories shown in parentheses and the first one as reference: gender (male, female), mother and father education (low, high), intake of fluoride (no, yes), sweet drinking, such as milk or sugar water, before sleeping (no, yes), intake of sweet foods (never/sometimes, often), and type of water (spring, tap, mineral). Low education was defined as people with no, pre-primary or primary education.

Table 2. Relationship between five DI categories and DMFT, by demographic size

DI categories	Demographic size, mean ± SD					
	small		midsize		large	
	DMFT	DI z score	DMFT	DI z score	DMFT	DI z score
1st quintile (least deprived)	0.84±1.98	–1.45±0.21	1.12±1.66	–1.04±0.11	–	–
2nd quintile (2nd least deprived)	0.74±1.40	–0.33±0.21	0.96±1.63	–0.21±0.26	–	–
3rd quintile (3rd most deprived)	1.13±1.58	0.69±0.13	1.02±1.66	0.95±0.10	1.08±1.73	0.52±0.15
4th quintile (2nd most deprived)	1.24±1.86	1.79±0.37	0.87±1.35	2.02±0[a]	0.76±1.31	2.69±0[a]
5th quintile (most deprived)	2.44±2.31	5.53±0[a]	1.06±1.66	3.67±0.51	1.03±1.58	7.78±2.10

[a] Only one city in this class.

To make sure to get accurate estimates, municipalities with less than 30 sampled children were excluded from the original sample. The current study included 4,305 12-year-old children, living in cities classified by demographic size as small (<75,000 inhabitants), midsize (between 75,000 and 350,000 inhabitants) and large (>350,000 inhabitants). Apart from population data, the Italian DI was considered at city level, calculated as the sum of standardized indicators of low education, unemployment, rented housing, one-parent family and high density in housing [Caranci and Costa, 2009]. This index was considered as a proxy of the socioeconomic level of each city. The relationship between DMFT and deprivation area was evaluated by the quintiles of DI ranked from the least deprived to the most deprived.

Statistical Analysis

To assess risk factors for DMFT data and to address excess of zero DMFT and overdispersion, a zero-inflated negative binomial (ZINB) regression model was considered, as it appeared to be the best-fitting model for this dataset [Campus et al., 2007]. The ZINB model constitutes a mixture of the NB distribution (NB component), from which all of the non-zero and a few of the zero values are observed to represent the 'susceptible' subpopulation of children, and the zero distribution (inflation component), from which only zero values are observed (structural zeros) to represent the subpopulation of 'non-susceptible' children who are considered to be not at risk [Preisser et al., 2012]. Sampled children (first level) were nested into 38 cities (second level) which, in turn, were grouped into North-East, North-West, Center, South and Islands macro-areas (third level).

A ZINB three-level model was initially considered, with random intercepts and slopes for DI and (ln-transformed) city population at second level and variance components at third level. The simplest and parsimonious ZINB variance components model was definitively fitted. The data augmentation procedure for Bayesian estimation was applied [Ghosh et al., 1999, 2006]. The deviance, defined as –2 times the log likelihood, was used to assess goodness of fit. The lower the deviance, the better the fit. Results were expressed as medians and 95% CrIs of the posterior distribution of the model parameters. The full specification of the statistical model and the WinBUGS code [Spiegelhalter et al., 2003] used to fit the models are given as online supplementary material (www.karger.com/doi/10.1159/000358810).

As preliminary analysis, after computing the summary statistics at city level, the ANOVA test was used to test the null hypothesis of equality of DMFT index and equality of DI by demographic size, and to test the null hypothesis of equality of DMFT index by quintiles of DI. In order to overcome the positive within-city correlation, one-way ANOVA was applied to the city-specific proportions to compare the occurrence of zero DMFT and the distribution of individual factors by demographic size. When ANOVA test showed statistical significance, the Scheffé test for multiple comparison was used to assess statistical significance of post-hoc paired comparisons. The χ^2 test was used to assess statistical significance of the distribution of individual factors at city level.

Results

Of the 4,305 individuals of the sample, 1,023 (23.8%) were living in small cities, 2,194 (50.9%) in midsize cities and 1,088 (25.3%) in large cities. The total mean of DMFT was 1.07 ± 1.67 and, in detail, 1.24 ± 1.80 in small cities, 1.02 ± 1.64 in midsize cities and 1.00 ± 1.61 in large cities. However, the difference in the average level of DMFT among children living in cities with different demographic size was not significantly different (p = 0.210). The percentage of children with zero DMFT was 57.5% in the whole sample. It was maximum in larger towns (59.6%) and decreased with decreasing demographic size (58.7% and 52.9% in midsize and small towns, respectively), but the decreasing trend was not statistically significant (p = 0.979). On average, the DI was higher in the largest cities (3.95 ± 3.61) than in midsize (1.05 ± 1.85) (p = 0.004) and in small ones (1.09 ± 1.86) (p = 0.006) (table 1).

The relationship between five DI quintiles and DMFT, by demographic size of cities, is shown in table 2. The difference in the average level of DMFT among children living in cities with different DI quintiles was not statistically significant (p = 0.578).

Table 3. Distribution of individual factors at city level, n (%)

Cities	Gender = female	Mother education = high	Father education = high	Fluoride intake = yes	Sweet beverage before sleeping = yes	Sweet foods intake = often	Type of water = mineral or tap
Ancona	71 (43.3)	133 (81.1)	132 (80.5)	89 (54.3)	13 (7.9)	112 (69.3)	163 (99.4)
Arezzo	53 (49.5)	53 (49.5)	48 (44.9)	79 (73.8)	8 (7.5)	59 (55.1)	99 (92.5)
Bari	190 (51.6)	221 (60.1)	230 (62.5)	167 (45.4)	42 (11.4)	210 (57.1)	343 (93.2)
Bergamo	20 (45.5)	27 (61.4)	31 (70.5)	34 (77.3)	1 (2.3)	31 (70.5)	43 (97.7)
Camucia	12 (29.3)	28 (68.3)	27 (65.9)	27 (65.9)	2 (4.9)	23 (56.1)	33 (80.5)
Casciavola	18 (50.0)	22 (61.1)	19 (52.8)	18 (50.0)	4 (11.1)	22 (61.1)	34 (94.4)
Como	12 (32.4)	22 (59.5)	22 (59.5)	32 (86.5)	3 (8.1)	25 (67.6)	36 (97.3)
Cremona	15 (50.0)	17 (56.7)	16 (53.3)	24 (80.0)	5 (16.7)	22 (73.3)	29 (96.7)
Crotone	77 (53.1)	66 (45.5)	70 (48.3)	33 (22.8)	26 (17.9)	93 (64.1)	126 (86.9)
Firenze	94 (52.2)	108 (60.0)	95 (52.8)	112 (62.2)	14 (7.8)	114 (63.3)	171 (95.0)
Fiuggi	109 (53.2)	110 (53.7)	112 (54.6)	116 (56.6)	29 (14.2)	127 (62.0)	160 (78.1)
Follonica	16 (53.3)	12 (40.0)	12 (40.0)	20 (66.7)	3 (10.0)	20 (66.7)	24 (80.0)
Grosseto	26 (49.1)	27 (50.9)	29 (54.7)	43 (81.1)	4 (7.6)	31 (58.5)	46 (86.8)
Latisana	23 (52.3)	19 (43.2)	21 (47.7)	28 (63.6)	5 (11.4)	28 (63.6)	42 (95.5)
Lecco	8 (26.7)	12 (40.0)	15 (50.0)	25 (83.3)	4 (13.3)	19 (63.3)	30 (100.0)
Livorno	41 (53.3)	39 (50.7)	38 (49.4)	43 (55.8)	5 (6.5)	51 (66.2)	76 (98.7)
Lodi	64 (49.2)	71 (54.6)	69 (53.1)	85 (65.4)	10 (7.7)	102 (78.5)	126 (96.9)
Lucca	22 (57.9)	26 (68.4)	24 (63.2)	20 (52.6)	1 (2.6)	24 (63.2)	21 (55.3)
Mantova	16 (48.5)	21 (63.6)	17 (51.5)	24 (72.7)	1 (3.0)	20 (60.6)	32 (97.0)
Milano	134 (52.1)	176 (68.5)	174 (67.7)	181 (70.4)	29 (11.3)	174 (67.7)	244 (94.9)
Napoli	53 (44.5)	61 (51.3)	62 (52.1)	31 (26.1)	17 (14.3)	67 (56.3)	105 (88.2)
Palermo	141 (42.0)	226 (67.3)	232 (69.1)	162 (48.2)	18 (5.4)	175 (51.9)	305 (90.8)
Parma	66 (53.2)	108 (87.1)	97 (78.2)	69 (55.7)	12 (9.7)	76 (61.3)	121 (97.6)
Pavia	21 (53.9)	19 (48.7)	17 (43.6)	26 (66.7)	1 (2.6)	30 (76.9)	37 (94.9)
Perugia	113 (53.1)	144 (67.6)	136 (63.9)	91 (42.7)	23 (10.8)	128 (60.1)	205 (96.2)
Pisa	89 (53.6)	137 (82.5)	134 (80.7)	87 (52.4)	13 (7.8)	111 (66.9)	157 (94.6)
Pistoia	61 (57.6)	60 (56.6)	48 (45.3)	62 (58.5)	5 (4.7)	63 (59.4)	95 (89.6)
Poggibonsi (SI)	14 (41.2)	17 (50.0)	12 (35.3)	19 (55.9)	3 (8.8)	19 (55.9)	33 (97.1)
Prato	57 (64.0)	44 (49.4)	31 (34.8)	38 (42.7)	7 (7.9)	55 (61.8)	81 (91.0)
Roma	102 (52.3)	120 (61.5)	116 (59.5)	86 (44.1)	20 (10.3)	102 (52.3)	172 (88.2)
San Miniato (PI)	20 (54.1)	21 (56.8)	12 (32.4)	21 (56.8)	1 (2.7)	25 (67.6)	35 (94.6)
Sassari	150 (56.0)	157 (58.6)	156 (58.2)	230 (85.8)	16 (6.0)	152 (56.7)	212 (79.1)
Siena	18 (45.0)	34 (85.0)	29 (72.5)	27 (67.5)	2 (5.0)	25 (62.5)	35 (87.5)
Sondrio	19 (46.3)	23 (56.1)	16 (39.0)	27 (65.9)	9 (22.0)	33 (80.5)	37 (90.2)
Tolmezzo (UD)	54 (58.7)	46 (50.0)	50 (54.4)	81 (88.0)	9 (9.8)	63 (68.5)	78 (84.8)
Val Camonica	25 (56.8)	9 (20.5)	14 (31.8)	35 (79.6)	7 (15.9)	32 (72.7)	41 (93.2)
Varese	14 (45.2)	20 (64.5)	17 (54.8)	25 (80.7)	3 (9.7)	27 (87.1)	29 (93.6)
Verona	141 (50.2)	196 (69.8)	197 (70.1)	219 (77.9)	24 (8.5)	183 (65.1)	271 (96.4)
p value	0.019	<0.001	<0.001	<0.001	0.002	<0.001	<0.001

The distribution of individual factors was statistically significant at city level (table 3), but not by demographic size (table 4). The DI was significantly lower on average for high (1.70 ± 2.68) than for low mother's education level (1.95 ± 2.80) (p = 0.003). Differently, the DI was not significantly different on average between high (1.80 ± 2.71) and low father's education level (1.80 ± 2.75) (p = 0.879) (data not in tables).

The ZINB three-level model was initially considered, but unobserved heterogeneity at macro-area level was negligible for both the probability to be an excess zero (macro-area level variance = 0.04 with 95% CrI 0.00–0.27) and the mean DMFT level (macro-area level variance = 0.04 with 95% CrI 0.00–0.25). The ZINB two-level model with random slopes for DI and ln(population) at city level was applied, but random slopes were not significantly

Table 4. Distribution of individual factors by demographic size, n (%)

Individual factors	Demographic size			Total	p value
	small	midsize	large		
Females	510 (49.9)	1,145 (52.2)	525 (48.3)	2,180 (50.6)	0.303
High mother education	544 (53.2)	1,417 (64.6)	692 (63.6)	2,653 (61.6)	0.251
High father education	531 (51.9)	1,637 (62.3)	680 (62.5)	2,578 (59.9)	0.223
Intake of fluoride (yes)	623 (60.9)	1,341 (61.1)	572 (52.6)	2,536 (58.9)	0.161
Sweet beverage before sleeping (yes)	117 (11.4)	184 (8.4)	98 (9.0)	399 (9.3)	0.138
Sweet foods intake (often)	677 (66.2)	1,364 (62.2)	632 (58.1)	2,673 (62.1)	0.212
Type of water (mineral or tap)	902 (88.2)	2,028 (92.4)	997 (91.7)	3,927 (91.2)	0.904

Table 5. ZINB two-level variance components model: medians and 95% CrIs of posterior distribution of coefficients in a sample of 4,305 Italian 12-year-old children

	Inflation component	NB component
Fixed effects		
Child level		
Female vs. male	–0.30 (–0.50; –0.09)	0.12 (0.02; 0.22)
Mother education (high vs. low)	0.21 (–0.03; 0.45)	–0.27 (–0.39; –0.16)
Father education (high vs. low)	0.48 (0.26; 0.73)	–0.03 (–0.13; 0.08)
Sweet beverage (yes vs. no)	–0.37 (–0.74; –0.03)	0.18 (0.04; 0.33)
Fluoride intake (yes vs. no)	0.08 (–0.13; 0.29)	–0.08 (–0.18; 0.01)
Water intake (tap vs. spring)	0.56 (0.08; 1.09)	–0.01 (–0.22; 0.21)
Water intake (mineral vs. spring)	0.53 (0.15; 1.01)	–0.01 (–0.16; 0.16)
Sweets intake (often vs. never/sometimes)	–0.15 (–0.36; 0.06)	0.07 (–0.03; 0.17)
City level		
DI	–0.07 (–0.16; 0.02)	0.01 (–0.03; 0.05)
ln(population)	0.10 (–0.09; 0.30)	–0.01 (–0.09; 0.06)
Random effects		
Intercept variance	0.26 (0.09; 0.57)	0.04 (0.02; 0.10)
Overdispersion rate	2.63 (1.95; 3.56)	
Deviance	8,837 (8,473; 9,243)	
Estimated % of zeros	57.4 (55.9; 58.8)	

different from each other (fig. 1). The ZINB two-level variance components model was definitively considered and DI and ln(population), included as city-level fixed effects, were not statistically significant (table 5). Females and children consuming sweet drinks, respectively, had exp(–0.30) = 0.74 (95% CrI 0.61–0.91) and exp(–0.37) = 0.70 (95% CrI 0.48–0.97) times lower odds of being an extra zero, compared to males and children not consuming. By contrast, children drinking tap water or mineral water had higher odds to be an extra zero compared to children drinking spring water. Furthermore, children with high-educated father had exp(0.48) = 1.62 (95% CrI 1.30–2.08) times higher odds of being an extra zero than children with a lower-educated father. With regards to the NB part of the ZINB model, on average, females had exp(0.12) = 1.13 (95% CrI 1.02–1.25) times higher DMFT than males in the susceptible population. Analogously, consuming sweet drinks on average increased the mean DMFT of a susceptible child, while having a highly educated mother reduced it. Unobserved heterogeneity was significant for the probability of being a structural zero DMFT (city-level variance = 0.26 with 95% CrI 0.09–0.57), but not for the mean DMFT level of the susceptible population.

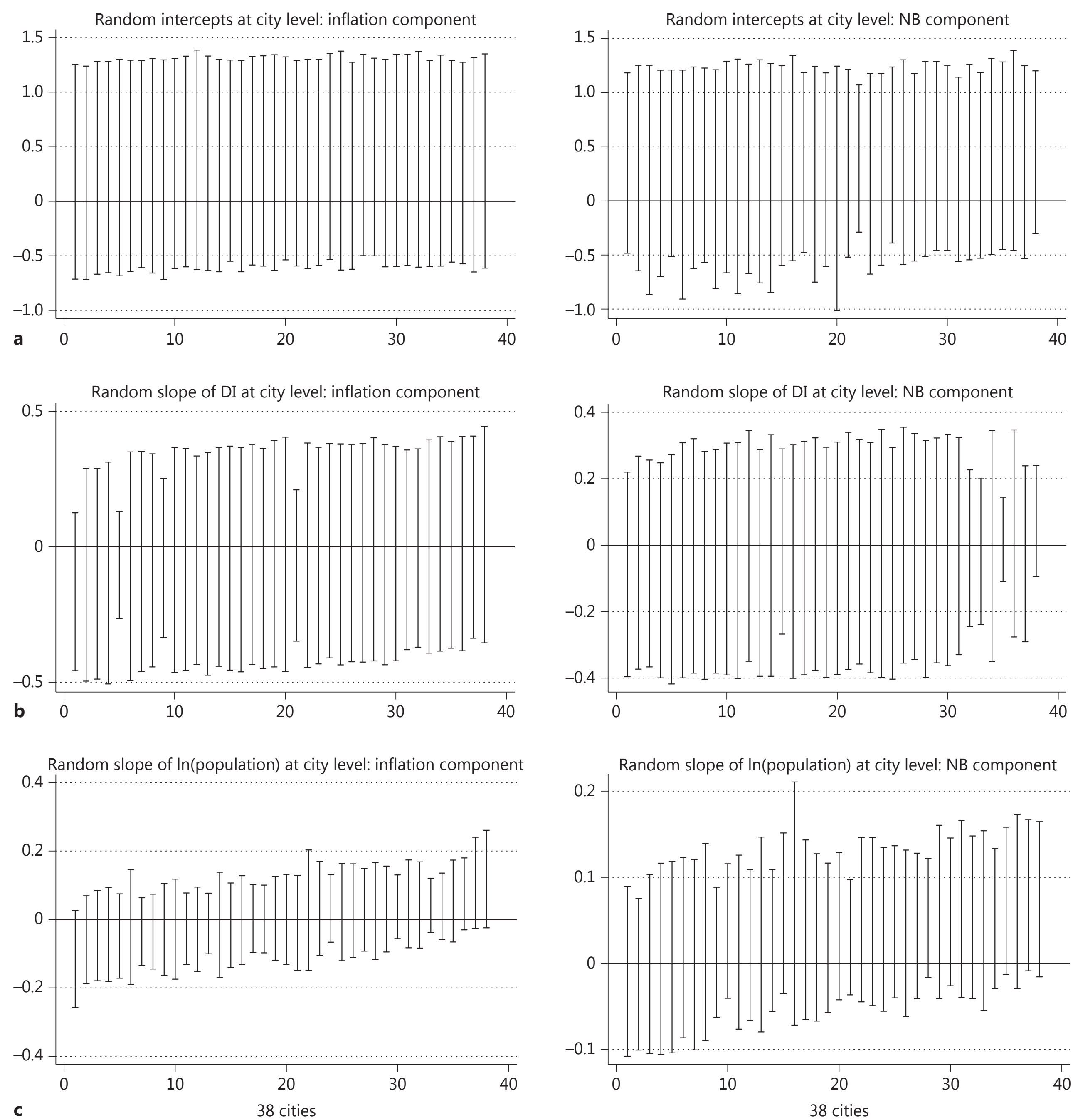

Fig. 1. ZINB random slopes model: random intercepts (**a**), random slopes of DI (**b**) and ln(population) (**c**) for the inflation (left) and the NB (right) components.

Discussion

The aim of this study was to investigate the association between dental caries, as measured by the DMFT index, and dental risk factors, including a DI and (ln-transformed) city population. For this purpose a ZINB regression model was applied to data on 4,305 12-year-old children extracted from the Italian Pathfinder study and multilevel Bayesian modeling was used for parameter estimation. In Bayesian analysis, all forms of uncertainty are expressed in terms of probability. The approach starts with the formulation of a model with which we hope to describe the situation of interest. We then assume a prior distribution over the unknown parameters of the model, which is meant to capture our beliefs about the situation before observing the data. After observing some data, we apply Bayes' rule to obtain a posterior distribution for these unknowns, which takes account of both the prior and the data. Prior elicitation plays an important role in Bayesian inference. As Kadane and Wolfson [1998] pointed out, the experimenters' knowledge or experience can be essential information, which makes the Bayesian inference more plausible. When no prior information is available, a non-informative or vague prior is chosen that will not influence the posterior distribution. If prior information is available, it should be appropriately summarized by the prior distribution.

In dental caries epidemiology, the use of prior information about the DMFT parameter in Bayesian modeling can be very attractive, especially in observational studies, where neither random sampling nor randomization is performed and uncontrolled sources of bias, such as confounding, selection bias and measurement error, can be present [Dunson, 2001; Greenland, 2006]. Alternatively, as the data considered in this paper were randomly chosen in a multistage random sampling frame, the advantages of the Bayesian framework have to be ascribed to the computational flexibility and the ease of estimation of zero-inflated modeling. In classical methods such as maximum likelihood, parameter estimates are found through numerical optimization, which can be computationally intensive in the presence of many unknown parameter values. Alternatively, Bayesian parameter estimates are found by drawing realizations from the posterior distribution [Greenland, 2006].

To the best of our knowledge, this paper is the first to have considered the role of deprivation and municipality in dental caries epidemiology in Italy.

There is consistent evidence throughout Europe that people at a socioeconomic disadvantage suffer a heavier burden of oral health problems than their better-off counterparts [Petersen, 2003]. The reasons of disparities in oral health are complex.

Various studies confirmed that socioeconomic indexes are sensitive to variations in oral health and oral health behaviors and can be used to identify small areas with high levels of need for dental treatment and oral health promotion services [Locker, 1993; Pine et al., 2004].

In the EU Resolution on Reducing Health Inequalities (dated March 8, 2011), the European Parliament acknowledged that 'the EU faces a challenge arising from the wide disparities in physical and mental health which exist and are growing between and within EU Member States, noting that inequalities in health between people in higher and lower educational, occupational and income groups have been found in all Member States'. The European Parliament specifically recognized that substantial inequalities can be seen in the prevalence of most specific forms of disability and of most specific chronic non-communicable diseases, including oral diseases, and that health inequalities are linked to problems in accessing healthcare both for economic reasons for everyday treatment such as dental care and prevention and as a result of poor distribution of medical resources in certain areas of the European Union (http://www.oralhealthplatform.eu/eu-oral-health-policy).

In this paper, unobserved heterogeneity among cities was detected only for the probability to be non-susceptible to caries, while no territorial effect was found for the mean DMFT of the susceptible children. As the previous analysis of this dataset [Campus et al., 2007] had already shown, even if the level of dental caries recorded in Italian 12-year-olds is quite low and very close to the value fixed by the WHO, there are significant differences in the percentage of non-susceptible children among geographical sections, with the lowest percentage in the Southern Italy compared to the two Northern macro-areas.

The relationship between DMFT and DI was not statistically significant, despite the trend observed in small cities where mean DMFT increases with quintiles of DI. One possible reason can be related to the strong inverse relationship between dental caries and contact with primary dental care services [Tickle et al., 2000]. The inadequate supply of oral public healthcare services in small Italian centers makes the access to care more difficult for deprived people.

The first hypothesis to explain why the DI and the (ln-transformed) city population did not result in playing a different role variable from town to town concerns the DI used in this study. It cannot be excluded that the analysis of DI at the city level may miss an existing association of

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DI and DMFT at the census block level. However, considering this variable at this detail was not possible because of much missing or inaccurate information regarding the address of sampled children in the considered dataset. Furthermore, differently from other measures as the Townsend and the Jarman indexes, more often used in other literature on the same topic [Jarman, 1983; Townsend et al., 1988; Morgan and Treasure, 2001], the Italian DI included some aspects of social deprivation concerning education, unemployment, disadvantaged housing and familiar conditions, but excluded other important aspects related to vulnerable groups, including disadvantaged migrant groups and people belonging to ethnic minorities, children and adolescents, people with disabilities, with a special focus on mental illness, patients diagnosed with chronic diseases or conditions, older people, people living in poverty, and people affected by alcoholism and drug addiction. The limitations of statistical indexes to measure deprivation, especially in areas with pronounced regional income disparities, are well known [Kunst et al., 2005; Franzini and Giannoni, 2010]. To represent the multidimensionality of the social deprivation, a DI specific to the aims of dental epidemiology should be developed at small-area level, including statistics about dental services as, for example, dentists to population ratio.

The second hypothesis concerns characteristics of accessing oral healthcare in Italy, with poor distribution of public dental clinics and low propensity to dental visit attendance with slight variability throughout Italy [ISTAT, 2005]. In Italy, oral health education programs in schools are at an early stage and distributed as leopard spots, without significant differences along territory. Non-fluoridated tap water and fluoride-containing toothpastes are widespread throughout the nation [Pizzo et al., 2007], and this circumstance can explain why caries susceptibility in Italy does not vary from small to large and midsize cities, as it was demonstrated in some developing countries [Tagliaferro et al., 2004]. Some papers in the literature [Gratrix and Holloway, 1994; Ellwood and O'Mullane, 1995; McGrady et al., 2012] pointed out the association between social deprivation and dental caries through the combined effect of water fluoridation as means of caries prevention, while the Italian legislation establishes a maximum limit for the presence of fluoride in drinking water (http://www.camera.it/parlam/leggi/deleghe/01031dl.htm).

Another result of this study was the preeminent role of factors at individual level. Maternal education plays an important function in the oral health of children. To support early oral health education, there is new evidence that mothers of all socioeconomic levels are equally interested and engaged in their children's overall health [Lee, 2010]. However, mothers of higher social strata and income levels have minor barriers of access to educational information in a culturally sensitized matter.

Our results suggest that actions against social deprivation can be influential on the perception of oral health in Italian 12-year-old children to the extent that they can also affect individual-level factors, as oral health programs involving the mother's participation, and can be effective in improving dental health behavior and perceived self-efficacy in children.

Authors' Contributions

D.M. and G.S. conceived and designed the study; G.C., P.C. and L.S. performed the clinical examination; D.M. and G.S. analyzed and interpreted the data; D.M., G.C., P.C., L.S. and G.S. wrote the paper; D.M. and G.S. critically revised the manuscript. All authors read and approved the final manuscript.

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