SPATIAL INFORMATION COMPREHENSIVE WELL-BEING COMPOSITE INDICATORS: AN ILLUSTRATION ON ITALIAN VARESE PROVINCE[1]

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1. Introduction

In recent years, the concept of well-being and its measurement has been at the forefront of the European research topic debates (Stiglitz *et al*., 2009). However, despite some great advancements, a unique definition of well-being has not been provided yet (Fiorillo *et al*., 2017). The well-being is thought as a multidimensional phenomenon that mirrors the values and preferences of a society and its citizens. Hence, its effective and faithful description requires relying on a set (or dashboard) of relevant indicators (Hall *et al.*, 2010). On the other hand, to enhance practicability, the complex information enclosed in such a dashboard of indicators must be synthesized through the construction of composite indicators (European Commission, 2008).

Within the Italian framework, the first project contextualized to this debate is the "Equitable and Sustainable Well-being (Bes)", jointly proposed in March 2013 by the National Council for Economics and Labor (Cnel) and the Italian National Institute of Statistic (Istat, 2018). In 2016, to complement this project with one more focused on the local level (NUTS3), a new project was started on "Well-being and planning measure at the municipal level (*"Misure di benessere e programmazione a livello comunale"*), coordinated by Istat, National Association of Italian municipalities (ANCI) and Union of Italian Provinces. The project aims to provide an integrated and harmonized data-set and information systems with a high local detail and to support local authorities in policymaking. The resulting dataset "*A Misura di Comune*" comes from an integration of different data sources, such as administrative archives or statistical surveys, which share the characteristic of being total and not sample sources.

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The main differential aspect of this data-set with respect to the others elaborated by Istat - "Bes" and "UrBes"- is the presence of particularly meaningful well-being domains, such as "Population and family" and "Mobility and Infrastructure", for the use of their indicators in the "Single Programming document of local authorities".

This paper exploits the "A Misura di Comune" dataset[2] for assessing the well-being of the Varese province by constructing composite indicators that synthesize, on a statistical basis, the atomic indicators information. We implement Bayesian factor analysis for spatially correlated data. Factor analysis for constructing composite indicators on BES dataset has already been proposed, for example in Chelli *et al.* (2015) and Ciommi *et al.* (2017). However, to the best of our knowledge, this is the first attempt to construct well-being composites indicators inclusive of spatial information in the underlying statistical model.

2. Methodology

The "A Misura di Comune" dataset is constituted by 50 atomic indicators, which are grouped into 10 macro-domains. Data are collected for four years, from 2014 to 2017, in all Italian municipalities.

The state of the art of aggregation methods entails a broad list of different approaches, form the simpler linear aggregation to more constructed ones. Constructed empirical indices, such as AMPI or GAMPI, are built on non-substitutable and non-compensatory indicators and allow for comparison across space (Mazziotta and Pareto, 2013). Nonetheless, they are based on several structural assumptions (Ciommi *et al*., 2017). For example, no adjustment is made for differential precision of the atomic indicators across local units that may have different population sizes. Moreover, it is usually assumed that for a specific area, information about well-being depends exclusively on variables from that area, and not on variables from neighboring areas. And finally, the traditional indices lack a posterior measure of uncertainty. This last feature can be problematic, for example, if decisions about policies or resource allocation are based on cutoff values or percentile of the index.

Hence, we try to move forward these shortcomings exploiting the methodology introduced in Hogan *et al*. (2004). We treat the "A Misura di Comune" atomic indicators as manifest variables while the well-being is the underlying latent factor. Hence, the well-being is defined as the posterior expectation of the latent factor given the manifest variables and the model parameters. Therefore, under the assumption

[2] The dataset is available at http://amisuradicomune.istat.it/aMisuraDiComune/

that adjacent areas have similar socioeconomic characteristics, we introduce spatial dependencies among the latent well-being variable of each municipality.

Given the presence of missing values, we have restricted our analysis to two years, 2014 and 2015. Moreover, we excluded from the analysis the indicators related to the domain "Population and family", since they are not strictly related to well-being. Our analysis hence is based on 32 atomic indicators and focuses on the 139 Varese province municipalities.

Our prior hypothesis is that neighboring municipalities share information on socio-economic development levels. Hence, accounting for their spatial information should increase the accuracy of our estimates. Therefore, before constructing the statistical model, we tested for spatial autocorrelation in the atomic indicators through the Global Moran I test (Moran, 1950), which provided significant results for almost all the indicators.

For municipality i, with $i = 1, \dots, N$ and $N = 139$, let Y_{id} denotes the atomic indicator d in municipality i, where $d = 1, \dots, D,$ and $D = 32$. Hence $Y_i = (Y_{i1}, \dots, Y_{iD})^T$ is the well-being profile of municipality i. The general latent factor model assumes for each area a L dimensional $(L < D)$ latent variable $\delta_i = (\delta_{i1}, \dots, \delta_{iL})^T$, that fully characterizes socio-economic characteristics, which in turn manifest themselves through Y_i. We assume $L = 1$, hence reducing the model to one latent factor for each municipality and we represent the model in a hierarchical form.

At the first level we have:

$$\mathrm{Y_i} \mid \mu_i, \delta_i, \Sigma \sim \text{Multivariate-Normal}(\mu_i + \lambda\delta_i, \Sigma),$$

where μ_i is $a\ D\ \times 1$ mean vector, λ is a $D\ \times 1$ vector of factor loading's and $\Sigma = \mathrm{diag}(\sigma_1^2, \dots, \sigma_D^2)$ is a diagonal matrix measuring residual variation in Y_i. Assuming Σ diagonal implies independence among the elements of Y_i conditionally on δ_i.

Spatial autocorrelation is introduced at a second level. Let $\delta = (\delta_1, \dots, \delta_N)^T$ the municipalities' latent indexes vector. Thus, it is assumed:

$$\delta \sim \text{Multivariate-Normal}(0_N, \Psi),$$

where Ψ is a $N \times N$ spatial variance-covariance matrix having 1's on the diagonal and $\psi_{ij} = corr(\delta_i, \delta_j)$ on the off-diagonal. When $\Psi = I_N$ the model assumes spatial independence. The well-being composite index for municipality i is summarized by the conditional distribution of the latent factor δ_i given Y and μ, λ, Σ. Hence the posterior distribution of vector δ is a Multivariate normal distribution:

$$(\delta \mid Y, \mu, \lambda, \Sigma) \sim \text{Multivariate-Normal}(d, D),$$

$$\text{where } D = \{\Psi + \Lambda^T \Sigma^{-1} \Lambda\}^{-1} \text{ and } d = D\Lambda^T \Sigma^{-1}(Y - \mu).$$

We have chosen a conditional parametrization of the spatial variance-covariance matrix Ψ, through conditional auto-regressive specifications of spatial dependency. The more general structures are the Gaussian CAR models (Besag J.,1974; Sun *et al.*, 1999). Generally, these models require to construct a set $\mathcal{R}_i$,denoting the set of indices δ_j for areas that are neighbors of the area i. Then, they assume that:

$$\delta_i \mid \{\delta_j : j \in \mathcal{R}_i\} \sim N\left(\sum_{j \in \mathcal{R}_i} \beta_{ij} \delta_j , \frac{\nu}{\alpha_i}\right),$$

so that

$$(\delta_1, \dots, \delta_N)^T \sim \text{Multivariate-Normal}(0_N, \nu B^{-1}),$$

where B is $N \times N$ matrix with $\{\alpha_1, \dots, \alpha_N\}$ along the diagonal and $-\alpha_i \beta_{ij}$ on the off-diagonal, provided that B is symmetric and positive definite (Sun *et al.*, 1999). In order to ensure these conditions to hold one must constrain one or more parameters, but the constraints are model specific.

According to how we have defined the $\mathcal{R}_i$ and β_{ij}, different CAR models are specified. For this analysis we have defined: $R_{ij} = I(j \in \mathcal{R}_i)$, which is the indicator function that area j is a neighbor of area i, $\beta_{ij} = \omega R_{ij}$, $\alpha_i = 1$ and $\nu = 1$; then $B = I_N - \omega R$, where R is an adjacency (weight) matrix with $R_{ii} = 0$ and indicators $R_{ij} = R_{ji}$. One necessary condition for B to be positive definite is that the ordered eigenvalues $\xi_1, \dots, \xi_N$ of R have to satisfy: $\xi_1^{-1} < \omega < \xi_N^{-1}$.

Finally, a characteristic of the Bayesian framework is the introduction of prior distributions on all the model's parameters. In our model we have set: $\lambda_j \sim \text{Normal}(g, G) I(\lambda_1 > 0)$; $\sigma_j^2 \sim \text{Inverse-Gamma}(\alpha/2, \beta/2)$; $\mu_j \sim \text{Normal}(0, V_\mu)$.

The scope of prior distributions is to include subjective opinions on the parameters of interest. However, we let the data "speak for them-self" and choose uninformative priors with $g = 0$, $G = 10000$, $\alpha = 1/1000$, $\beta = 1/1000$, $V_\mu = 1000$.

The model is estimated through a Gibbs sampling that includes Metropolis Hasting steps for the spatial parameter ω.[3]

[3] We have written the sampling algorithm in the R software and made it available in GitHub through the link https://github.com/CarlottaMnt/Bayesian-factor-analysis-sampler.

3. Results

Following this methodology, we have first computed a uni-dimensional overall well-being composite indicator which synthesizes, for each municipality, the 32 "A Misura di Comune" atomic indicators.

In Table 1 we report the factor loadings' distributions, which represent the covariances among the "A Misura di Comune" atomic indicators and the composite indicator (latent variable). Factor loadings with negative sign impact negatively the latent well-being, such that an increase in the corresponding atomic indicator leads to a decrease in the overall well-being. On the other hand, factor loadings with a positive sign would raise the value of the overall well-being. When the estimated factor loading is around zero all along its distribution, we consider the associated indicator meaningless for the well-being.

The main contributor with a positive impact on the composite indicator is the "Gross Income per capita" while the one with the greater negative impact is "Household with gross income less than the social allowance benefit". Having zero impact are the "Self-containment index"[4] and the "Leakage of drinking water".

Figure 1 illustrates the estimate of the well-being composite indicator for the Varese municipalities in 2014 and 2015. For each municipality, the graph reports the mean value of the composite indicator and its posterior 95% credibility intervals. We have highlighted in red the most populated municipalities, i.e. Varese, Gallarate, Busto Arsizio and Saronno. Among the two years considered, the municipalities' rank in term of composite indicator slightly changes, while the polarization among municipalities does not change significantly.

Finally, the maps in Figure 2 report the spatial distribution of the composite indicator's mean across the Varese municipalities. The above-average values are in green while below-average values are in red. We notice clusterization in the well-being phenomenon, which is discriminated among northern and southern municipalities, whereas the first appreciate the lowest level of well-being and the latter are better off. This result is maintained throughout the two years considered.

Next, we proceed with our well-being assessment by constructing a composite indicator for each of the three, non-fungible, sustainable development domains: social well-being, economic well-being and environmental well-being (Ciommi et al., 2020). This will clarify the contribution each domain provides on the overall well-being and the relative importance of the atomic indicators with respect to the specific well-being composite indicator they interact with. It may be that, when the number of atomic indicators in each domain is too little, the uncertainty of the composite indicator as well in the factor loading's estimates increases.

[4] It represents the ratio among the monetary flows from those who work within the municipal boundaries and the overall monetary flows generated overall in the municipality.

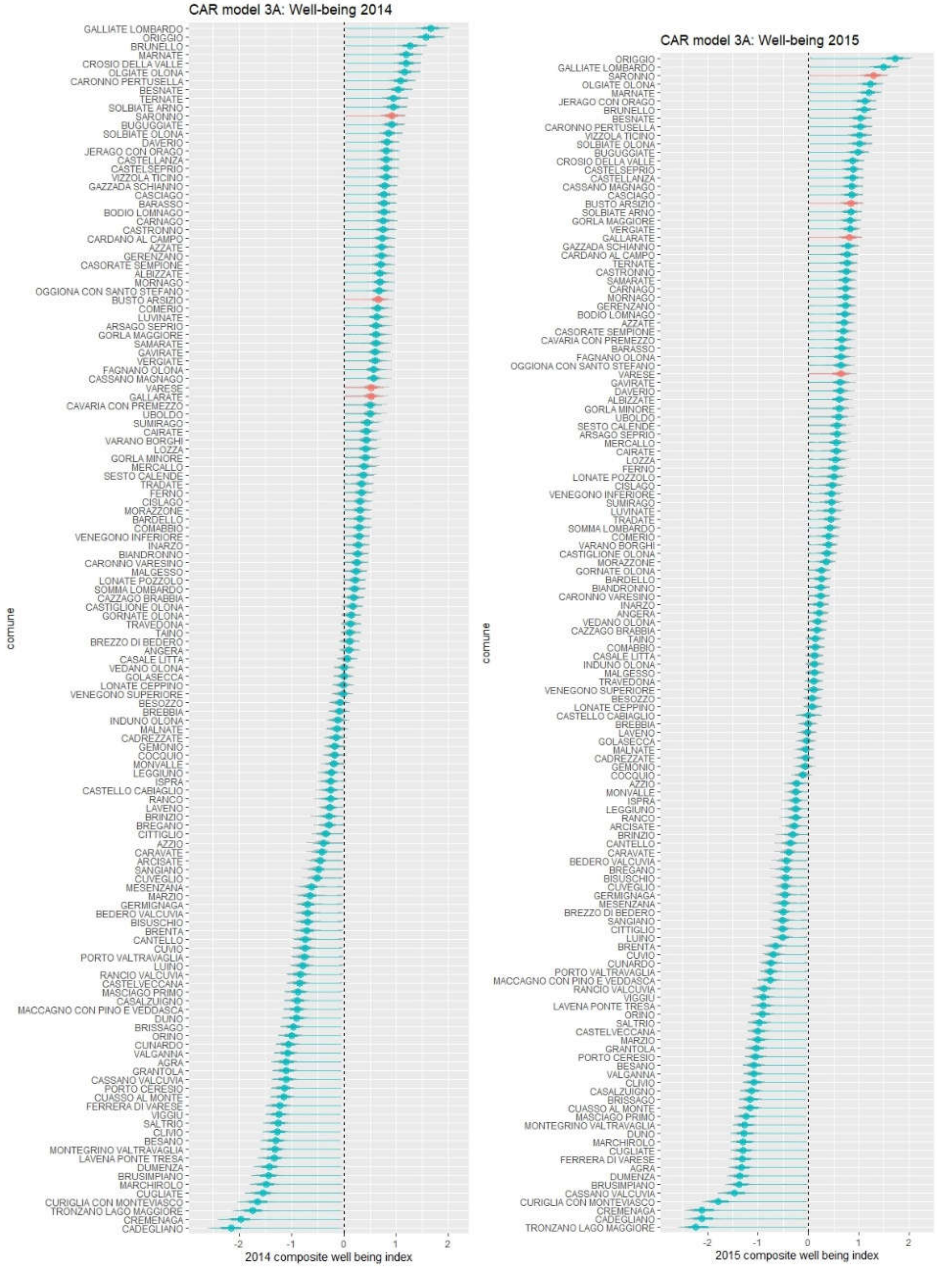
As a first result, Table 2 to Table 4 report the factor loading's distribution in the four domains.

Table 1 - *Summary of the factor loadings' distribution for each "A misura di comune" indicators, year 2014.*

Indicator	**Mean**	5%	50%	95%
Circulating polluting vehicles	-2.70	-7.46	-0.67	-0.51
Children in municipal childcare services	0.83	0.05	0.21	2.27
Household low labour intensity	-4.23	-12.28	-1.03	-0.85
Soil consumption	3.53	0.67	0.84	11.65
IRPEF taxpayers with total income < 10.000	-4.38	-11.52	-1.00	-0.83
Local units' density	3.25	0.59	0.75	9.86
High school graduates (25-64)	2.47	0.48	0.63	6.98
Leakage of drinking water	0.40	-0.06	0.09	0.67
Gross income differences	4.41	0.83	1.00	12.74
Women and political representation - City Council	-0.20	-0.20	0.01	0.20
Women and decision-making - Municipal council	0.92	0.07	0.22	1.99
Mean age local administrator	-0.84	-2.17	-0.19	-0.04
Mean age municipal councillors	-0.49	-0.73	-0.09	0.07
Household with gross income less then social allowance benefit	-4.39	-12.96	-1.01	-0.84
Single-income households with children (age < 6)	-2.56	-7.20	-0.58	-0.43
Neet	-4.08	-12.42	-0.99	-0.81
Attraction Index	2.25	0.37	0.52	6.18
Self-containment index	0.12	-0.18	0.02	0.21
Harmfulness of road accidents	-1.26	-3.31	-0.30	-0.15
Mortality index of road accidents	0.29	-0.01	0.15	0.95
Employed (20-64)	4.58	0.85	1.02	13.37
Not stable employed	-1.53	-3.27	-0.31	-0.16
Graduates (30-34)	2.36	0.40	0.56	6.66
Museum, galleries, monuments	-1.50	-4.28	-0.39	-0.23
Electoral participation	2.73	0.48	0.63	8.00
Separate collection of municipal waste	1.06	0.17	0.33	3.76
Gross per capita income	4.33	0.84	1.02	13.02
Production specialization in high-tech sectors	1.95	0.34	0.49	5.96
Rate of entrepreneurship	2.86	0.56	0.73	8.73
Number of road accidents	0.78	0.02	0.18	1.68
Jobs' transformation from not stable to stable	1.09	0.10	0.26	2.81
Visitors to museum, galleries, monuments	-0.62	-1.65	-0.14	0.01

Source: our elaboration on "A misura di comune" data.

Figure 1 – *Overall well-being indicator estimate and its 95% credibility interval for 2014 and 2015***.**



Source: our elaboration on "A Misura di Comune" data.

Table 2 – *Social well-being: factor loadings' distribution, year 2014.*

Indicator	Mean	5%	50%	95%
Children in municipal childcare services	-0.31	-0.22	-0.07	-0.01
High school graduates (25-64)	0.85	0.45	0.64	0.85
Women and political representation - City Council	0.55	0.10	0.29	0.50
Women decision-making - Municipal council	0.57	0.15	0.33	0.52
Mean age local administrator	-0.60	-0.67	-0.45	-0.24
Mean age municipal councillors	-0.26	-1.09	-0.26	0.53
Neet	-0.56	-0.65	-0.45	-0.25
Harmfulness of road accidents	-0.33	-0.45	-0.26	-0.08
Mortality index of road accidents	-0.37	-0.32	-0.12	0.06
Graduates (30-34)	0.85	0.48	0.65	0.86
Museum, galleries and monuments	0.12	-0.25	-0.04	0.17
Number of road accidents	-0.56	-0.33	-0.13	0.05
Visitors to museum, galleries and monuments	0.26	-0.17	0.01	0.21

Source: our elaboration on "A misura di comune" data

Table 3 – *Economic well-being: factor loadings' distribution, year 2014.*

Indicator	Mean	5%	50%	95%
Household low labour intensity	-6.84	-44.49	-1.05	-0.89
IRPEF taxpayers with total income < 10.000 euros	-6.72	-45.48	-1.03	-0.89
Local unit density	4.44	0.57	0.68	28.21
Gross income differences	6.51	0.84	0.99	44.25
Household with gross income < social allowance	-6.66	-44.62	-1.05	-0.89
Single-income households with children (age < 6)	-4.15	-27.65	-0.63	-0.51
Attraction Index	3.25	0.40	0.51	20.70
Self-containment index	-0.44	-1.53	-0.06	0.03
Employed (20-64)	6.78	0.89	1.04	45.30
Not stable employed	-2.21	-14.35	-0.35	-0.26
Electoral participation- municipal elections	3.99	0.54	0.65	28.30
Gross per capita income	6.40	0.84	0.99	42.29
Production specialization in high-tech sectors	3.27	0.40	0.50	22.16
Rate of entrepreneurship	0.63	0.47	0.63	0.79
Jobs transformation from not stable to stable	1.72	0.19	0.28	10.97

Source: our elaboration on "A misura di Comune" data

Table 4 – *Environmental well-being: factor loadings' distribution, year 2014.*

Indicator	Mean	5%	50%	95%
Circulating polluting vehicles	-0.90	-0.84	-0.66	-0.46
Soil consumption	0.98	0.49	0.65	0.83
Leakage of drinking water	0.10	0.04	0.21	0.40
Separate collection of municipal waste	0.05	0.05	0.26	0.44

Source: our elaboration on "A misura di Comune" data

The leading domain is "economic well-being" (Table 3), where all the factors' loadings, in absolute value, are far from being zero. In this domain, the indicators

driving the composite indicator to greater positive values are "Gross per capita income" and "Employed (20-64)". Table 2 reports the social well-being indicators' factor loadings. With greater positive impact on the social well-being, despite being small and near zero, are "High school graduates" and "Graduates (25-64)", revealing the importance of education in boosting the estimated well-being. Lastly, the environmental well-being (Table 4) is mainly explained by "Soil consumption", which is the ratio among the soil consumed and the overall municipal soil, and "Circulating vehicles with standard emissions lower than euro 4", that points out the negative role played by motor vehicles on air pollution.

Figure 2 – *Overall well-being indicator's spatial distribution in Varese province.*

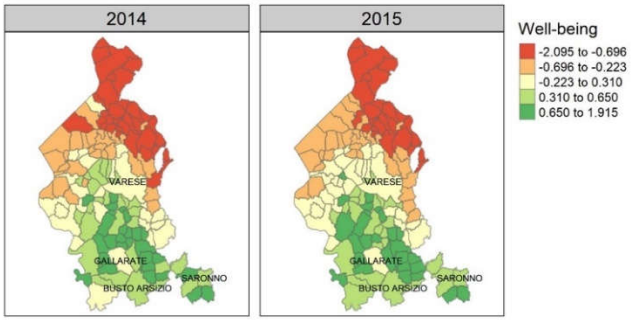
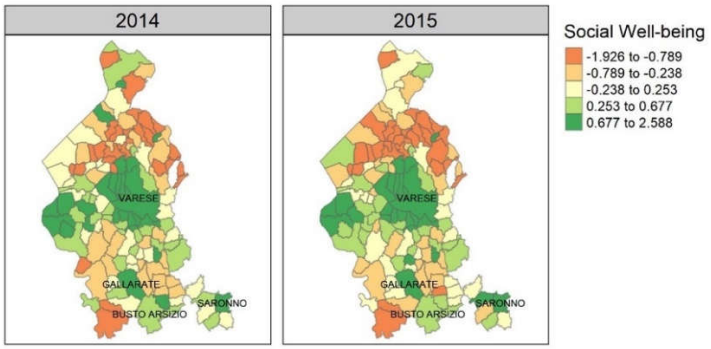


Figure 3 – *Social composite indicator's spatial distribution in Varese province.*



Finally, we move directly to the spatial distribution of the composite indicators across the Varese province. Figures from 3 to 5 map respectively the mean of the composite indicator distribution for social well-being, economic well-being and environmental well-being. The social well-being composite indicator interestingly shrinks from 2014 to 2015: the worse off municipalities, despite remaining below the average, increase their social well-being, indeed they become "clearer", while

the better off municipalities slightly reduce their social well-being. The spatial distribution for the economic well-being composite indicator detects the presence of three separated groups, from the Southern to the Northern municipalities, with high, medium and low economic well-being. This figure looks like Figure 1, corroborating the greater importance of economic well-being in driving the overall well-being.
Finally, the environmental well-being spatial distribution also highlights differences among municipalities in the North and in the South, with the latter performing better

Figure 4 – *Economic composite indicator's spatial distribution in Varese province.*

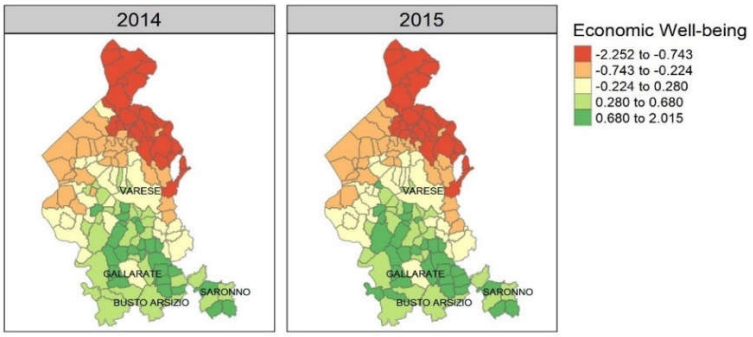
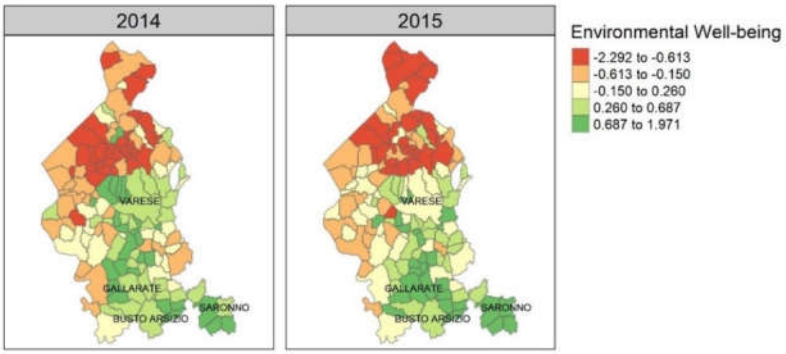


Figure 5 – *Environmental composite indicator's spatial distribution in Varese province.*



4. Concluding remarks

We have constructed well-being composite indicators by adopting a Bayesian latent variable approach which includes spatial information. From the overall well-being assessment on the Varese province, we have estimated heterogeneous well-being levels across the province's municipalities. Notably, when considering all the "A Misura di Comune" atomic indicators, the resulting composite indicator is

clustered among Northern and Southern municipalities, where the former enjoys, on average, a lower well-being level with respect to the latter.

Next, we have analyzed the well-being within each of the three sustainable development domains. We have highlighted the greater importance of economic well-being in driving the overall municipalities' well-being. Within this domain, the leading indicators are related to income and occupational levels.

Given the severe presence of missing values, our analysis focuses only on two years, 2014 and 2015. However, as soon as updated data becomes available, future research will consider the inclusion of temporal information within the model.

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SUMMARY
Spatial information comprehensive well-being composite indicators: an illustration on Italian Varese province

This analysis bears upon the European "Beyond GDP initiative", which promotes multi-dimensional approaches going beyond the traditional and uni-dimensional GDP macroeconomic indicator to monitor the living condition and the well-being of a territory. We assess the well-being within the Varese province by applying factor analysis with integration of spatial information in a Bayesian framework. To summarize the large number of indicators within the 10 domains that constitutes "A misura di comune" dataset we construct four composite indicators for each Varese municipality. The first is comprehensive of all the "A misura di comune" indicators but not the one related to the Population and Family domain. The last three composite indicators assess the municipalities in term of their social, economic and environmental well-being. We highlight differentials across Northern and Southern municipalities in all the well-being domains, with the former performing usually better. We also identify in the economic domain the leading well-being domain, that drives the overall wealth to higher values.

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