11th Scientific Meeting of the SIS Group
"Statistics for the Evaluation and Quality in Services"

BOOK OF SHORT PAPERS

Editors
Andrea Bucci
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Andrea Marletta

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STATISTICAL METHODS FOR EVALUATION AND QUALITY:

TECHNIQUES, TECHNOLOGIES AND TRENDS (T^3)

EDIZIONI Il Viandante

IES 2023 - Statistical Methods for Evaluation and Quality: Techniques, Technologies and Trends (T^3)

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Book of Short papers
11th International Conference **IES 2023**
Statistical Methods for Evaluation and Quality: Techniques, Technologies and Trends (T^3)

University 'G. d'Annunzio' of Chieti-Pescara

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Preface

Statistical thinking, design and analysis play a crucial role in social life and are useful to society at large. Besides, promoting advanced methodological research is useful to facilitate the dissemination of ideas related to various fields of interest. For this purpose, experts in statistics, data analysis, data mining, statistical methods for decision making, machine learning and related methods come together to understand and analyse phenomena through data.

In line with this objective, the Statistics Group for the Evaluation and Quality of Services (SVQS; `www.svqs.it`) of the Italian Statistical Society (SIS) has been organizing the Innovation and Society (IeS) conference biennially since 2009, focusing on new developments and ideas in statistics applied to the evaluation and quality of public and private services, attracting national and international statisticians and data scientists. The meeting contributes to spot light on the main statistical approaches and methodologies for the evaluation of public services currently in use in different contexts, as well as to facilitate discussion on the impact of innovative statistical evaluation systems for these services, involving various economic and social policy actors.

The conference "Statistical Methods for Evaluation and Quality: Techniques, Technologies and Trends (T^3)" recorded valuable contributions that are reported in this volume. The papers underscore how the growing availability of data has tasked social and economic actors, organizations, and researchers with the management and analysis of large volumes of unstructured and heterogeneous data. In recent years, many tools for both qualitative and quantitative models have been developed to better describe and understand complex systems and their underlying behaviors, and the papers reported in this volume bear witness to this.

Techniques, technologies and trends: the study of data complexity presents the potential to provide analyses with increased frequency and timeliness, accuracy and objectivity, and to define sustainable models. Traditional quantitative methods for capturing socioeconomic data have often shown limitations in their ability to examine underlying systems, and with the three 'T' just mentioned, the outlines of future developments are starting to emerge.

The volume reports 127 contributions in the following areas:

- Advanced statistical methods for pattern recognition
- Advances in statistical learning from high-dimensional data
- Data analysis for web sources
- Distance and depth-based statistical learning methods for robust data analysis

- Economics and environment
- Education and labour
- Inequalities in the labour market
- Innovations and challenges in official statistics
- Labour market: trends, perspectives and new challenges
- Methodological and applicative contributions for evaluating sustainable development
- Methodological developments and applications for the assessment of student competencies
- Networks data analysis: new perspectives and applications
- New advanced statistical methods for data science
- Recent advances in statistical learning and data analysis
- Statistical analysis and modeling of environmental pollution data
- Statistical methods and complexity for evaluation in finance
- Statistical methods and composite indicators for healthcare
- Statistical methods and models for land monitoring with spatio-temporal data
- Statistical methods for environmental monitoring and sustainability
- Statistical methods for the analysis of university student choices and academic performance
- Statistical methods for the assessment of transport services and sustainable emissions
- Statistical methods for education and educational services
- Statistics in sports
- Tourism and territory.

The Conference event attracted many contributions as well as numerous Authors, not just from Italy but also from abroad. Over the three-day meeting, the Community has the opportunity to witness some of the state-of-the arts, new trajectories, and methodological challenges in 24 solicited sessions, 7 sessions of free contributes, two round tables - organized by Maurizio Vichi and Matilde Bini respectively - and three keynotes sessions with Ron S. Kennet of Samuel Neaman Institute of Israel, Luigi D'Ambra of Federico II University of Naples, and the former Minister Enrico Giovannini from University of Tor Vergata.

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Plenary Session

1. *Befitting Cross Validation with Three Case Studies* (Kenett R.S.)

A Predictive Functional Principal Component Analysis of Well-Being Data

Una Analisi Predittiva delle Componenti Principali Funzionali dei Dati sul Benessere

Laura Marcis, Maria Chiara Pagliarella and Renato Salvatore

Abstract We consider the case of the principal components of a multivariate random vector that obeys a linear mixed model. The random vector itself then lies in a lower dimensional subspace. This situation suggests that this subspace can be modeled by the probabilistic (random-effects) principal components. We employ a linear predictor adjusted by the residual part of the probabilistic principal components, that results not explained by the longitudinal time-varying linear model. A new predictor is given, employing the vector of scores that comes from that principal components, and the resulting scores approximated by spline curves as functionals. The application to the official Italian well-being data shows some of the features of the method.
Abstract *In questo articolo, consideriamo il caso delle componenti principali di un vettore casuale multivariato che segue un modello misto lineare. Il vettore casuale stesso risiede, quindi, in un sottospazio di dimensione inferiore. Questo sottospazio può essere modellato dalle componenti principali probabilistiche (ad effetti casuali). Facciamo uso di un predittore lineare corretto dalla parte residuale dei componenti principali probabilistici, che risulta non spiegato dal modello longitudinale lineare time-varying. Viene dato un nuovo predittore, utilizzando il vettore dei punteggi che proviene da quei componenti principali, e i punteggi risultanti approssimati da curve spline. L'applicazione ai dati ufficiali italiani sul benessere mostra alcune delle caratteristiche del metodo.*

Key words: multivariate random vector, probabilistic principal components, functional principal components, linear mixed model, well-being

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1 Introduction

Principal component analysis (PCA) is recognized as one of the most employed methods to reduce dimensionality, by means of projection of a set of variables in a subspace of them. By summarizing and allowing to visualize data, and, at the same time, minimizing the loss of information in the lower dimensional space, in many cases principal components (PCs) lead to a better assessment of the bundled statistical information, seized by the original variables [2]. In the case of studying data with measurements over time of a multivariate random vector, the goal is to assume that the principal components are curves considered as functionals [4]. These functionals change with a continue variable, that is time. Then, functional principal component analysis is a standard PCA performed by sampling units curves at each time instant. The evaluation of the functionals are related to smoothing time PC points, and the resulting curves considered as the principal sources of variability. This method involves an integral transform, which reflects the functional nature of the data, whose analytic solutions cannot, in general, be determined.

Another important and recurrent way of approaching redundancy and, in general, the recursive informative content of multivariate sample data, is given by considering a common subset of covariates which the population obeys. Two main cases in the literature are deemed representative of the joint dependence on a multivariate vector, the PCs "with covariates" or Partial PCA, and the redundancy analysis. Although these last represent a very useful tool in some cases, the deployment of linear models to explain part of the sample variability has had a remarkable development in the last years. One of these studies brings into play the role of prediction by linear statistical models.

Tipping and Bishop [7] had already introduced the notion of prediction for the PCs. They called "Probabilistic PCA" (PPCA) the model behind the PCA, which parameters are estimated with the Expectation-Maximization algorithm. Instead of a "fixed effects PCs", as the traditional linear regression PCA model, the PPC are random variables. This condition suggests, on the one hand, the Bayesian approach to handle the estimates for the PPC linear model and, on the other hand, to predict PCs under its meaning within random linear models theory [5]. Given normality of the error $\varepsilon \sim N(0, \sigma^2 I)$, for a linear model $\tau = B\lambda + \varepsilon$ - in case of the vector λ random - the likelihood is based on the conditional distribution $\lambda|\tau \sim N[E(\lambda|\tau), var(\lambda|\tau)]$. Moreover, it is known [6] that $E(\lambda|\tau) = \widetilde{\lambda}$ is the "Best Prediction" (BP) estimate, with $var(\widetilde{\lambda} - \lambda) = E_\tau[var(\lambda|\tau)]$. Therefore, given a linear mixed model (LMM, [1]) for τ, with $E(\tau|\lambda) = \lambda$, the model parameters are the realizations of random variables. Thus, given the BP estimates of the PPCs λ, $\widetilde{\lambda} = E(\lambda|\tau)$, the vector $\widetilde{\tau} = B\widetilde{\lambda}$ represents the BP of the p-variate vector.

In the present paper we introduce a model of PPCs combined with a multivariate longitudinal linear predictor, considering then the random vector effectively represented by the subspace of the resulting "shifted" PPCs (SPCs). The new smoothed SPCs can be considered as time-varying functional principal components, because they combine the linear model and the PPC's, and carry out simultaneously the linear predictor and the contribution given by the PPCs not "explained" by the linear predictor itself.

An application to the official Well-being Italian indicators shows some of the features of the method.

2 Theory

In the sequel we report the following symbols, giving the model specification. We consider n as the number of subjects in the longitudinal LMM $(i = 1,...,n)$, $N = n \times T$ as the total number of observations considered, with $t = 1,...,T$ the time instants. Then p $(j = 1,...,p)$ is the number of the response dependent variables, l the number of the linear model covariates, and s is the dimension of the effective PC subspace. Consider Θ as the $N \times p$ sample matrix of the p-variate $p \times 1$ random vector θ, with N as the total number of the units given by the sample. Moreover, consider that the vector θ obeys the linear model:

$$\theta = \beta' x + u', \tag{1}$$

where x the $l \times 1$ vector of covariates, β the $l \times p$ matrix of the regression effects, u is the vector of the p-variate random effect, with $u \sim N(0, \Sigma_u)$, $\Sigma_u = cov(u)$. Furthermore, we consider at the same time that the multivariate random vector θ obeys the following linear model:

$$\theta = Ab + \varepsilon, \tag{2}$$

in which A is $p \times s$ a loading matrix of eigenvectors, b is the random vector of PPCs, and ε is a vector of isotropic error, with $\theta \sim N(\mu, A\Psi A' + \sigma_\varepsilon^2 I)$, $b \sim N(0, \Psi)$, $\Psi = diag(\psi_1, ..., \psi_s)$, $s < p$, and $\varepsilon \sim N(0, \sigma_\varepsilon^2 I)$. When a sample of N observations is given, an $N \times p$ matrix Y of observations from the random vector θ is simply modeled as $Y = \Theta + E$, with the "sampling error" $Np \times Np$ covariance matrix $cov(vec(E)) = (\Sigma_e) \otimes I_N$ ($\otimes$ is the Kronecker product), $e \sim N(0, \Sigma_e)$, $\Sigma_e = var(e)$. Thus, models 1 and 2 are rewritten as $Y = \Theta + E = X\beta + ZU + E$, with the 1 that becomes $\theta = \beta' x + u' + e'$, and $Y = \Theta + E = BA' + \Xi + E = BA' + \Gamma$, with the 2 that is $\theta = Ab + \varepsilon + e = Ab + \gamma$, respectively. The model errors u, ε, and e, are mutually independent. The matrix Z represents the $N \times n$ design matrix of random effects and E is the $N \times p$ matrix of the residual errors of the multivariate LMM, B is the $N \times s$ matrix of the PPCs that lie in the s-dimensional subspace, Ξ is the $N \times p$ matrix of the isotropic errors of the model 2. The models 1 and 2 have the following conditional expectations and variances:

$$\begin{aligned} E(\theta|y) &= \widetilde{\theta}_y = y - E(e|y) = y - cov(e,y)var(y)^{-1}y = y - var(e)Py, \\ var(\theta|y) &= var(\theta) - cov(\theta,y)var(y)^{-1}cov(y,\theta) = var(e) - var(e)Pvar(e), \end{aligned}$$

for the model in 1, where $P = \Sigma_y^{-1}(I - P_X)$, $\Sigma_y = var(y)$, and P_X is the projection matrix. For the model in 2:

$$\begin{aligned} E(b|\theta) &= E(b) + cov(b,\theta)var(\theta)^{-1}(\theta-\mu) \\ &= cov(b,\mu+Ab+\varepsilon)C^{-1}(\theta-\mu) = \Psi A'C^{-1}(\theta-\mu), \\ var(b|\theta) &= var(b) - cov(b,\theta)var(\theta)^{-1}[cov(b,\theta)]' \\ &= \Psi - \Psi A'C^{-1}A\Psi, \quad C = A\Psi A' + \sigma_\varepsilon^2 I. \end{aligned}$$

Based on some results on linear projections, i.e., given the random variable y, and the $1 \times j, 1 \times k$ random vectors x, z, with positive definite covariance matrix of $(y,x,z)'$, then we get for the linear projection $L(y|x,z) = L(y|x) + [z - L(z|x)]\gamma$, where $\gamma = var(z|x)^{-1}[cov(y,z|x)]'$. We have the following:

Proposition 1. *Given the model 2 for the p-dimensional random vector θ, with $b = \overline{F}'(\theta-\varepsilon)$, and under the models in 1 and 2, the multivariate Best Predictor based on (y,b), $E(\theta|y,b)$, is:*

$$E(\theta|y,b) = \widetilde{\theta}_{y,b} = E(\theta|y) + cov(\theta,b|y)var(b|y)^{-1}\left\{\widetilde{b} - E(b|y)\right\}, \tag{3}$$

with $\widetilde{b} = E(b|\theta)$, $\overline{F}$ the $sN \times pN$ matrix $(\overline{A}'\overline{A})^{-1}\overline{A}$, and $\overline{A}$ is the $pN \times sN$ matrix $A \otimes I_N$. Then, $var(\theta|y,b) = var(\theta|y) - cov(\theta,b|y)var(b|y)^{-1}[cov(\theta,b|y)]'$.

The predictor $\widetilde{\theta}_{y,b}$ in 3 gives the Best Linear Unbiased Predictor $E(\theta|y)$, "embedding" the PPCs through an adjoint component. The last due to knowing that the random vector θ lies in the s-dimensional subspace of the PPCs. In particular, the difference $\widetilde{b} - E(b|y)$ gives the multivariate vector of the PPCs "not explained" by the estimation of the linear model $E(\theta|y)$. The matrix $var(\theta|y,b)$ has rank s, and, consequently, there are $(p-s)$ linear combinations of θ for which their respective variances do not depend on the PPCs.

Proposition 2. *Given the p-dimensional random vector θ,and under the models in (1) and (2), and the Best Predictor $E(\theta|y,b)$ in 3, we get:*

$$\widetilde{b}^* = \overline{F}E(\theta|y) + \overline{F}cov(\theta,b|y)var(b|y)^{-1}\left\{\widetilde{b} - E(b|y)\right\}, \tag{4}$$

where $\widetilde{b}^* = \overline{F}E(\theta|y,b) = \overline{F}\widetilde{\theta}_{y,b}$ is the s-dimensional vector of the PPCs "shifted" (SPCs) by the linear predictor $E(\theta|y)$. As a particular case, when $\sigma_\varepsilon^2 \longrightarrow 0$, $var(\varepsilon) \longrightarrow 0$, $var(\gamma) \longrightarrow var(e)$, and $\widetilde{b} \longrightarrow \overline{b}$. Therefore, $\overline{F}\widetilde{\theta}_{y,b} = \widetilde{b}^* \longrightarrow \overline{b}$, with $\overline{B} = vec^{-1}(\overline{b}) = ((vecI_s)' \otimes I_N)(I_s \otimes \overline{b})$ the matrix of the PC scores by sample PCs $\overline{b} = A'\theta$. The matrix $\widetilde{B}^* = vec^{-1}(\widetilde{b}^*) = ((vecI_s)' \otimes I_N)(I_s \otimes \widetilde{b}^*)$ can be written as $\underset{1 \le i \le n}{col}(\widetilde{b}_i^*(t))$, with $\widetilde{b}_i^*(t) = \underset{1 \le t \le T}{col}(\widetilde{b}_{it}^*)$. Thus, the SBCs are the PPCs with the scores predicted by the linear model (1), with subjects as time repeated observations, and $\widetilde{b}_s^*(t)$ expressed in terms of spline basis.

The SPCs $\widetilde{b}^*$ are then the PPCs "adjusted" by the Linear BP $E(\theta|y)$, and $\widetilde{b}^*$ is then the vector obtained by stacking columns of the matrix $\widetilde{B}^*$ of the SPC scores. Given $\sigma_\varepsilon^2 = 0$, the vector θ in the model 2 lies in the s-dimensional subspace of the standard sample PCs $\overline{b}$. In fact, in this case $\widetilde{b} \equiv \overline{b}$, $cov(\theta, b|y) = var(\theta|y)\overline{F}'$, $var(b|y) = \overline{F} var(\theta|y)\overline{F}'$, $E(b|y) = \overline{F} E(\theta|y)$, and then $\overline{F} E(\theta|y, b) = \overline{b}$.

3 Application and Discussion

The data for the application are the Equitable and Sustainable Well-being indicators (in Italian, BES) - annually provided by the Italian Statistical Institute ([3], 2017). In order to highlight the result of the proposed method we use 12 BES indicators relating to the years 2013-2016, collected at NUTS-2 (Nomenclature of Territorial Units for Statistics -2) level. Please, refer to Table 1 for the description and acronyms used for the variables. We use LBE1 as a unique covariate in the LMM model, while the remaining 11 variables are dependent variables. The application uses the REML estimation, a Sas/IML code together with a sequence of Sas-HPMixed procedures. We propose to estimate the model under a uniform correlation structure among the multivariate components of the random effects, and an AR(1) within-subject errors. The uniform correlation between the multivariate components of the random effects is equivalent to compound-symmetry covariance, with a better numerical property in terms of optimization. Further, some studies highlight that using uniform correlation matrices reduces the estimation noise. The slope parameter estimates from the multivariate regression are all significant. The MANOVA multivariate test statistics (Wilks Lambda, Pillai's Trace, Hotelling-Lawley Trace, Roy's Largest Root), based on the characteristic roots are all significant. Figure 1 shows the application of the model described in (3) and (4). The plots represent the spline curves of PPCs and SPCs, for each of the subjects (the 20 Italian administrative Regions). The PPC1 is mainly related with the variables INN1, BS3, AMB9, POL5, S8, while the PPC2 is related with REL4, Q2, L12. The smoothing operated by the linear model part of the SPCs is highlighted especially comparing PPC2 and SPC2, for which the SPC2 shows a less confusing behavior when varying the year. The resulting splines indicate that the prediction stabilizes a lot the scores of the principal components. This is because the SPCs use PPCs, retaining all the main features of the principal components analysis approach, and utilizing at the same time all the capabilities of a linear predictor.

The SPCs in 4 can be viewed from two different perspectives. An "adjusted" linear predictor by the PPCs, by relation (3), as the shifted PCs (SPCs) that modify the probabilistic PCs (PPCs) to accommodate the mixed model regression predicted values. The present work considers then the probabilistic principal components as a "constraint" model, that links together the components of the multivariate random vector in a lower dimensional subspace.

The SPCs are generated considering the multivariate linear predictor 1, by adjusting its standard formulation through the sample parameter vector scores in a convenient subspace. The main advantage of the method proposed is that allows using all the features that a linear model can contribute to improving the principal component data analysis.

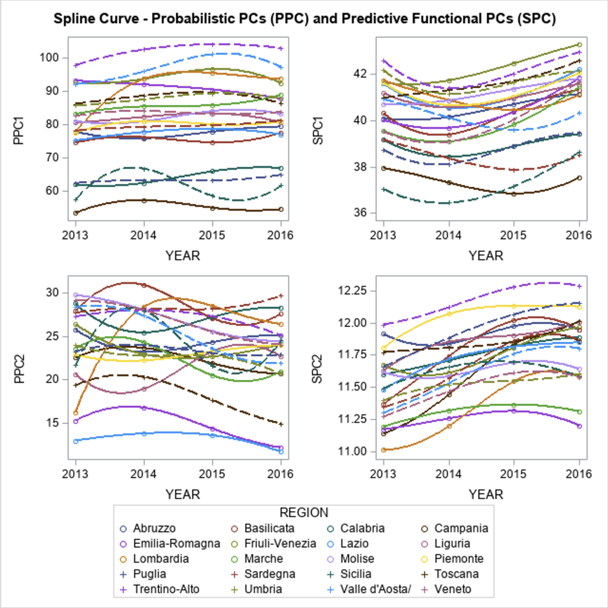

Fig. 1 Joint spline curves of the first two PPCs and SPCs, for the four years (2013-2016) and the twenty Italian administrative Regions. The official Italian Well-Being data are reported and downloadable by the Italian National Statistical Institute web site.

Table 1 Description of the variables used for the application

Variables	Description
S8	Age-standardised mortality rate for dementia and nervous system diseases
IF3	People having completed tertiary education (30-34 years old)
L12	Share of employed persons who feel satisfied with their work
REL4	Social participation
POL5	Trust in other institutions like the police and the fire brigade
SIC1	Homicide rate
BS3	Positive judgment for future perspectives
PATR9	Presence of Historic Parks/Gardens and other Urban Parks recognised of significant public interest
AMB9	Satisfaction for the environment - air, water, noise
INN1	Percentage of R&D expenditure on GDP
Q2	Children who benefited of early childhood services
BE1	Per capita adjusted disposable income
LBE1	Logarithm of Per capita adjusted disposable income

References

1. Demidenko, E.: Mixed Models: Theory and Applications. Wiley, New York (2004)
2. Hardle, W. K., Simar, L.: Principal Components Analysis. In Hardle, W. K., Simar, L. (eds.) Applied Multivariate Statistical Analysis, 319-358. Springer (2015)
3. ISTAT: BES project www.istat.it/en/well-being-and-sustainability
4. Jolliffe Ian T., Cadima J.: Principal component analysis: a review and recent developments Phil. Trans. R. Soc. A. 374: 20150202.20150202 (2016)
5. Longford N.T.: Random Coefficient Models. In: Lovric M. (eds.) International Encyclopedia of Statistical Science. Springer, Heidelberg (2011)
6. Timm, N. H.: Applied Multivariate Analysis. Springer, New York (2002)
7. Tipping, M.E., Bishop C.M.: Probabilistic principal component analysis. J. R. Stat. Soc., Ser. B (Stat. Methodol.) 61(3), 611–622 (1999)

This book collects the papers presented at the 11th Scientific Meeting of the SIS Group "Statistics for the Evaluation and Quality in Services" *Statistical Methods for Evaluation and Quality: Techniques, Technologies and Trends (T^3)*, which took place at the University of Chieti-Pescara, on 30th August-1st September, 2023.
The papers, which had been selected through a refereeing process, contain topics on statistical approaches and methodologies for the evaluation of public services in different contexts, and cover the areas of digital transition, e-commerce and digital marketing, enterprises, environment and territory, healthcare and wellness, finance, bank and FinTech, justice system, labour market, official statistics, public administration, food and wine, school, education and training, social, sports, sustainability, tourism, transport, university and research, well-being and welfare.

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