



C LADAG 2023



BOOK OF ABSTRACTS AND SHORT PAPERS
14th Scientific Meeting of the Classification and Data Analysis Group
Salerno, September 11-13, 2023

edited by

Pietro Coretto
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edited by Carla Rampichini, Michele La Rocca, Pietro Coretto, Giuseppe Giordano, Maria Lucia Parrella

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Preface

This book collects the abstracts and short papers presented at CLADAG 2023, the 14th Scientific Meeting of the Classification and Data Analysis Group (CLADAG) of the Italian Statistical Society (SIS). The meeting has been organized by the Department of Economics and Statistics of the University of Salerno, under the auspices of the University of Salerno, the SIS and the International Federation of Classification Societies (IFCS).

CLADAG is a member of the IFCS, a federation of national, regional, and linguistically-based classification societies. It is a non-profit, non-political scientific organization, whose aims are to further classification research. Every two years, CLADAG organizes a scientific meeting, devoted to the presentation of theoretical and applied papers on classification and related methods of data analysis in the broad sense. This includes advanced methodological research in multivariate statistics, mathematical and statistical investigations, survey papers on the state of the art, real case studies, papers on numerical and algorithmic aspects, applications in special fields of interest, and the interface between classification and data science. The conference aims at encouraging the interchange of ideas in the above-mentioned fields of research, as well as the dissemination of new findings. CLADAG conferences, initiated in 1997 in Pescara (Italy), were soon considered as an attractive information exchange market and became an important meeting point for people interested in classification and data analysis. A selection of the presented papers is regularly published in (post-conference) proceedings, typically by Springer Verlag.

The Scientific Committee of CLADAG 2023 conceived the Keynote Sessions to provide a fresh perspective on the state of the art of knowledge and research in the field. The scientific program of CLADAG 2023 is particularly rich. All in all, it comprises 5 Keynote Lectures, 31 Invited Sessions promoted by the members of the Scientific Program Committee, and 27 Contributed Sessions. We thank all the session organizers for inviting renowned speakers, coming from many different countries. We are greatly indebted to the referees, for the time spent in a careful review of the abstracts and short papers collected in this book. Special thanks are finally due to the members of the Local Organizing Committee and all the people who collaborated for CLADAG 2023. Last but not least, we thank all the authors and participants, without whom the conference would not have been possible.

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CIRCULAR REGRESSION WITH MEASUREMENT ERRORS

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ABSTRACT: We propose techniques for estimating a regression function when the predictor is circular. A case study on Carbon monoxide pollution is presented.

KEYWORDS: Characteristic function, deconvolution kernels, measurement errors.

1 Introduction

We propose a nonparametric regression estimator that is consistent in the presence of measurement error when predictor data are circular. Following the approach of Carroll & Hall, 1988 and Carroll *et al.*, 1995, we introduce a deconvolution-type estimator.

Some facts on the characteristic functions are worth to be recalled. The characteristic function of a circular random variable Θ , denoted as $\varphi_{\Theta}(\ell) = \alpha_{\ell} + i\beta_{\ell}$ satisfies $\varphi_{\Theta}(\ell) = \varphi_{\Theta+2\pi}(\ell)$, $\ell \in \mathbb{Z}$, being zero elsewhere. Moreover, $\alpha_{\ell} = E[\cos(\ell\Theta)]$ and $\beta_{\ell} = E[\sin(\ell\Theta)]$, both are the coefficients in the Fourier series representation of f_{Θ} , and correspond to the ℓ th *trigonometric moment* of Θ . Finally, $\beta_{\ell} = 0$ when f_{Θ} is symmetric. If f_{Θ} is square integrable on $[0, 2\pi)$, one can represent $f_{\Theta}(\theta)$, $\theta \in [0, 2\pi)$, as

$$\frac{1}{2\pi} \sum_{\ell=-\infty}^{\infty} \varphi_{\Theta}(\ell) \exp(-i\ell\theta) = \frac{1}{2\pi} \left\{ 1 + 2 \sum_{\ell=1}^{\infty} (\alpha_{\ell} \cos(\ell\theta) + \beta_{\ell} \sin(\ell\theta)) \right\}. \quad (1)$$

Our estimator is described in Section 2. In Section 3, we model the carbon monoxide propagation due to wind direction in a region near Huston (Texas).

2 Model and estimator

We consider the case of a circular predictor and linear response. Given the random sample $(\Psi_1, Y_1), \dots, (\Psi_n, Y_n)$, assume the regression model $Y_i = m(\Psi_i) +$

$\sigma(\Psi_i)e_i$, but it is available the sample $(\Phi_1, Y_1), \dots, (\Phi_n, Y_n)$, modelled according $\Phi = (\Psi + \varepsilon) \bmod(2\pi)$. Here we have that

- the e_i s are i.i.d. real-random variables with zero mean and unit variance, and $\sigma^2(\cdot)$ is the conditional variance of Y ;
- the Ψ_i s are independent copies of the circular latent variable Ψ with density function f_Ψ ;
- the ε_i s are i.i.d. circular random variables independent of the (Ψ_i, e_i) 's, with a known density function f_ε which is symmetric around zero.

We assume that f_ε , f_Ψ and f_Φ are square integrable, and f_ε is a circular density allowing an absolutely convergent Fourier series representation.

A local estimator for m at $\psi \in [0, 2\pi)$, denoted by $\tilde{m}(\psi; \kappa)$, can be obtained by employing a *circular* deconvolution kernel. Using the inversion formula (1), and considering that for a symmetric function $\beta_\ell = 0$ for any ℓ , we have

$$\tilde{K}_\kappa(\phi) = \frac{1}{2\pi} \left\{ 1 + 2 \sum_{\ell=1}^{\infty} \frac{\gamma_\ell(\kappa)}{\lambda_\ell(\kappa_\varepsilon)} \cos(\ell\phi) \right\}, \quad (2)$$

with smoothing parameter $\kappa > 0$, where $\gamma_\ell(\kappa)$ and $\lambda_\ell(\kappa_\varepsilon)$, for $\ell \in \mathbb{Z}$, respectively are the ℓ th Fourier coefficient of the periodic weight function K_κ and the error density f_ε whose concentration is κ_ε . The estimator is well defined when the error density has nonvanishing Fourier coefficients, $\gamma_\ell(\kappa)$ is not identically zero and $\sum_{\ell=1}^{\infty} |\gamma_\ell(\kappa)/\lambda_\ell(\kappa_\varepsilon)| < \infty$ for all $(\kappa, \kappa_\varepsilon) \in \mathbb{R}_+^2$, which, in turn, imply that both K_κ and \tilde{K}_κ are square integrable functions.

The local constant estimator for m is defined by

$$\tilde{m}(\psi; \kappa) = \frac{\sum_{i=1}^n \tilde{K}_\kappa(\Phi_i - \psi) Y_i}{\sum_{i=1}^n \tilde{K}_\kappa(\Phi_i - \psi)}, \quad (3)$$

where \tilde{K}_κ is a circular deconvolution kernel.

Theorem 1. *Given the $[0, 2\pi) \times \mathbb{R}$ -valued random sample $(\Psi_1, Y_1), \dots, (\Psi_n, Y_n)$, consider the local constant estimator. If*

- K_κ is a second sin-order kernel admitting a convergent Fourier series representation $1/(2\pi) \{1 + 2 \sum_{\ell=1}^{\infty} \gamma_\ell(\kappa) \cos(\ell\theta)\}$, with κ increasing with n in such a way that, for $\ell \in \mathbb{Z}^+$,

$$\lim_{n \rightarrow \infty} \frac{1 - \gamma_\ell(\kappa)}{1 - \gamma_2(\kappa)} = \frac{\ell^2}{4},$$

$$\lim_{n \rightarrow \infty} \gamma_\ell(\kappa) = 1 \quad \text{and} \quad \lim_{n \rightarrow \infty} \frac{1}{n} \sum_{\ell=1}^{\infty} \gamma_\ell^2(\kappa) = 0,$$

- ii) the second derivative of the regression function m is continuous,
- iii) the conditional variance σ^2 is continuous, and the density f_Ψ is continuously differentiable,

then

$$E[\hat{m}(\psi; \kappa)] - m(\psi) = \frac{(1 - \gamma_2(\kappa))}{4} \left\{ m''(\psi) + \frac{2m'(\psi)f'_\Psi(\psi)}{f_\Psi(\psi)} \right\} + o(1 - \gamma_2(\kappa)),$$

$$\text{Var}[\hat{m}(\psi; \kappa)] = \frac{(1 + 2\sum_{\ell=1}^{\infty} \gamma_\ell^2(\kappa))}{2\pi n f_\Psi(\psi)} \sigma^2(\psi) + o\left(\frac{\sum_{\ell=1}^{\infty} \gamma_\ell^2(\kappa)}{n}\right).$$

We notice that, as in the Euclidean setting, the measurement error has no effect on the asymptotic bias of the estimator, which, when the predictor observed with error is circular (linear respectively), depends only on the second moment of the classical kernel K_κ (K_h resp.). The asymptotic variance, similarly to the Euclidean setting, depends on the Fourier coefficients (characteristic function resp.) of the error density appearing in roughness of the deconvolution kernel \tilde{K}_κ (\tilde{K}_h resp.).

3 Pollution and surface wind data

Usually, air pollution in a region strongly depends on wind direction. We consider data from the Texas Commission on Environmental Quality, where the response variable is the amount of carbon monoxide (CO) while the explanatory variable is the wind direction. We have selected a site near Houston (“North Loop”) in Harris County at Latitude: 29.81° North and Longitude: -95.39° West using data from 2018*. The data are collected hourly, but we have calculated the average daily wind direction (using the directional average), and the average daily CO (in parts per million). These daily averages were “thinned” to reduce serial correlation resulting in 183 observations from alternate days. We initially fit a parametric model in which CO (y) is related to wind direction (ϕ) using a sine-cosine model $Y_i = \beta_0 + \beta_1 \sin \Phi_i + \beta_2 \cos \Phi_i + e_i$. This gives fitted values $\hat{\beta}_0 = 0.568$, $\hat{\beta}_1 = -0.173$, $\hat{\beta}_2 = 0.074$. The CO pollution is highest when the wind is coming from the south (2.73 radians). Then, we fit a standard circular-linear nonparametric regression, in which the measurements are treated as error free. The smoothing parameter (chosen by leave-one-out

*<https://www.tceq.texas.gov/>

cross-validation) was selected as $\kappa = 7.77$ for a von Mises kernel. For this model, the maximum CO occurs at 2.11 radians.

Finally, in this circular-linear case, we use an error-in-variables model for the observed wind direction which can be approximated by a wrapped Normal error with zero mean and concentration equal to 0.9. The estimated CO is then given using equation (3), in which κ was found by leave-one-out cross-validation to be 3.35. The three curves, depicted in Figure 1, show that, in the last case, the curve appears to be somewhat less smooth than the error-free model estimate. The nonparametric errors-in-variables model has residual sum of squares equal to 1.91, whereas the parametric model is slightly larger (2.40) and the error-free model very similar (1.99). The maximum estimated CO occurs at $\phi = 2.17$ for the errors-in-variables model.

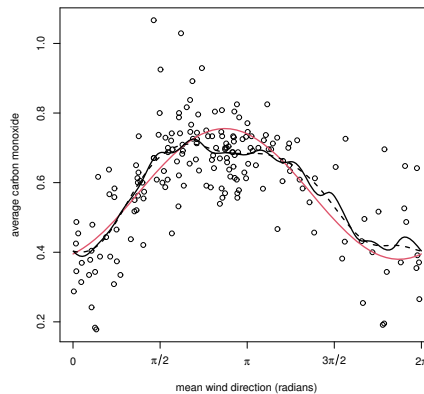


Figure 1. Carbon monoxide vs wind direction at Houston North Loop monitoring station — alternate daily averages for 2018. Parametric sin/cos model (red), fitted non-parametric errors in variables model (black) and standard circular-linear (no error model) kernel regression (dashed).

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