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Giovanni C. Porzio
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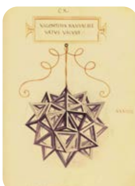

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Contributed Papers

ALI-MIKHAIL-HAQ COPULA TO DETECT LOW CORRELATIONS IN HIERARCHICAL CLUSTERING

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ABSTRACT: In this work we introduce a new dissimilarity measure based on the Ali-Mikhail-Haq copula, motivated by the empirical issue of detecting low correlations and discriminating variables with very similar rank correlation. This issue arises from the analysis of panel data concerning the district heating demand of the Italian city Bozen-Bolzano. In the hierarchical clustering framework, we empirically investigate the features of the proposed measure and compare it with a classical dissimilarity measure based on Kendall's rank correlation.

KEYWORDS: Ali-Mikhail-Haq copula; cluster analysis; dissimilarity measure; low correlation.

1 Introduction

Copula-based measures of association have been employed in clustering procedures in a variety of applied contexts, since they allow to describe complex multivariate dependence structures and address specific features of the joint distribution of random variables, such as asymmetries and tail dependence (Durante & Sempi, 2015). For instance, the copula approach made it possible to define pairwise dissimilarities in terms of concordance or tail dependence measures (see, e.g., Fuchs *et al.*, 2021, and the references therein).

While many contributions in this context have focused on detecting high association between extremely low/high values, in this paper we focus on modeling weak correlation and the ability to discriminate objects with low and very similar degree of dependence. This issue comes from the features of the district heating (DH hereafter) demand from residential users of the Italian city of Bozen-Bolzano. We thus propose a new dissimilarity measure based on the

Ali-Mikhail-Haq (AMH hereafter) copula, and empirically compare it with a classical dissimilarity measure based on Kendall's τ coefficient.

The contribution is organized as follows. First, we introduce the copula-based dissimilarity measures (Sect. 2). Second, we present the cluster analysis performed to compare the proposed AMH-based dissimilarity with the one based on Kendall's τ (Sect. 3). Finally, Sect. 4 summarizes the main findings.

2 Kendall's τ- and AMH-based dissimilarity

Here, we want to perform an agglomerative hierarchical clustering (AHC hereafter) of m continuous random variables $(X_1,\ldots,X_m)$ defined on the same probability space by taking into account their stochastic dependence. A typical dissimilarity measure used in the AHC algorithm can be defined in terms of Kendall's τ coefficient as follows

$$d^{\tau}_{jj'} = \sqrt{2(1-\tau_{jj'})} \in [0,2] \tag{1}$$

where $\tau_{jj'},\ j,j' \in \{1,\ldots,m\}$, is computed from n observations of the pair $(X_j,X_{j'})$. From a different perspective, one can assume a specific copula function, motivated by its ability to capture some features of the joint behaviour observed from the data. Here we focus on the AMH copula function $C(u_1,u_2) = (u_1u_2)/(1-\theta(1-u_1)(1-u_2))$, where $\theta \in [-1,1]$. The AMH copula is very suitable for modeling low degree of association since the corresponding range for τ is $[-0.1817, 0.3333]$. Hence, we introduce a new dissimilarity measure

$$d^{\text{AMH}}_{jj'} = \sqrt{2(1-\theta_{jj'})} \in [0,2] \tag{2}$$

where $\theta_{jj'}$ is the dependence parameter of the AMH copula that can be estimated via one of the methods in the literature (see, e.g., Gunky *et al.*, 2007).

3 Application to district heating demand

We analyse time series data concerning the heat demand (in kWh) of $m = 41$ residential users connected to the DH of Bozen-Bolzano, which has been identified as a key technology for the development of sustainable cities. We consider $n = 150$ hourly observations in the period Jan 1–Jan 14, 2016. We first tackle serial dependence in the original time series by adopting a dynamic panel regression model (Wooldridge, 2002), that takes into account the relationships between DH demand and meteorological variables, such as temperature and solar radiation. Then, the residual time series are used to estimate the 41×41 dissimilarity matrices based on Eqs. (1) and (2) to use in the AHC algorithm. The crucial point is that all pairs of users have a quite low Kendall's τ (the minimum is -0.2, the highest value is 0.39). Thus, in principle, d^{AMH} should be able to better distinguish objects with low and very similar degree of association. On the basis of both the informativeness of the final clusters and the separation index by Akhanli & Hennig, 2020, we decide to adopt the complete linkage method and cut the dendrogram at $k = 3$ for both the dissimilarities.

Fig. 1 displays the mean daily pattern of each user (hourly heat demand over daily average heat demand (Menapace *et al.*, 2019)) by cluster, according to d^{τ} and d^{AMH}. As can be seen, a certain degree of internal homogeneity is obtained in both cases, denoting an overall good quality of the results. However, by using static features of the buildings, such as heating surface (in m^2), age class (in years), and energy class (in yearly kWh/m^2), we can highlight the diversity between the obtained partitions. The clusters based on d^{τ} are quite similar in terms of heating surface with median values in the range $(3656, 4076)$, and even though are better separated in terms of age class and energy class, they also present a source of variability. Indeed, the 75% of buildings in cluster 1 was built between 1961 and 1990, in cluster 2 almost the 70% of buildings is dated after 1981), while cluster 3 has a larger variability, and contains both recently-constructed and old energy-renovated buildings, with relatively low energy class (the third quartile is equal to 120). On the contrary, the d^{AMH} produces groups that are different in terms of heating surface (the medians are 3969, 5382, and 3102, respectively) and show within-homogeneity with respect to the energy and age class (e.g. buildings in cluster 3 are old, i.e. mostly dated before 1990, and non-efficient with first and third quartiles of energy class equal to 120 and 145, respectively).

4 Conclusions

We have introduced a new dissimilarity measure based on the Ali-Mikhail-Haq copula and empirically showed its ability to detect low correlations and discriminate among them. The application to district heating demand illustrates that the proposed measure seems to produce clusters that have a clear interpretation in terms of the relevant features, thus leading to a valuable tool to support the management and planning of a district heating system.

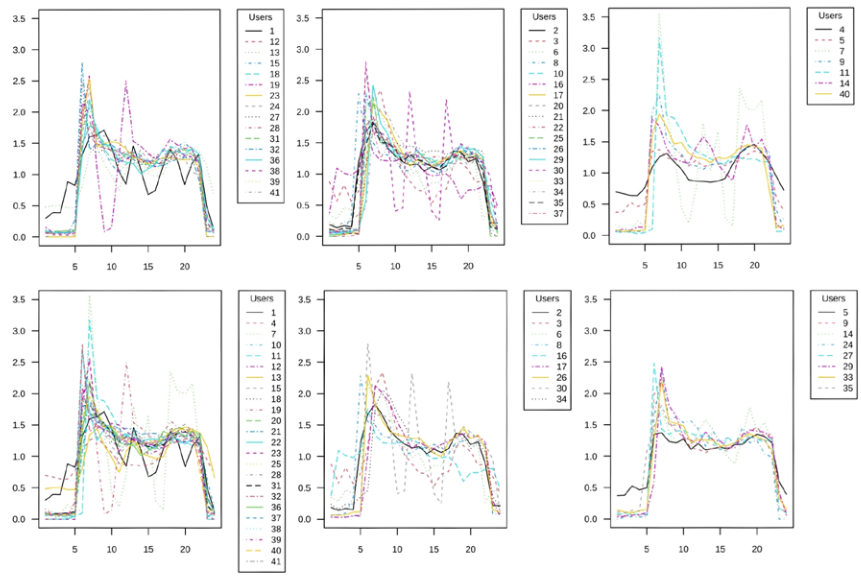

Figure 1. *Mean daily pattern (hours in x-axis) of DH users according to AHC based on* d^{τ} *and* d^{AMH} *(panels by rows) in cluster 1, 2, and 3 (panels by columns).*

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