ADOPTION OF 4.0 TECHNOLOGIES AND RELATED OBSTACLES. APPLICATION OF A MULTIVARIATE NONPARAMETRIC TEST FOR CATEGORICAL VARIABLES

Stefano Bonnini[1] and Michela Borghesi[1]

[1] Department of Economics and Management, University of Ferrara,
(e-mail: stefano.bonnini@unife.it, michela.borghesi@unife.it)

ABSTRACT: The goal of this work is to investigate the relationship between the adoption of Industry 4.0 technologies and organizational, economic and financial obstacles. A combined permutation test for ordinal categorical variables was applied to an original dataset from a survey carried out in Italy.

KEYWORDS: nonparametric test, Anderson-Darling, categorical variables, industry 4.0.

1 Introduction

The case study of this work concerns the adoption of Industry 4.0 technologies by Italian small and medium-sized enterprises (SMEs). Initially, Industry 4.0 was basically considered the fourth revolution in the manufacturing industry. For this reason, in recent years, this topic has been much debated (Ghobakhloo, 2020). Besides the technical implementation, aspects such as lacking trust, unclear benefits for suppliers and different perceptions of Industry 4.0 hamper digital information sharing, especially by SMEs (Müller et al., 2020).

In the literature, there are several works dedicated to Industry 4.0 and related technologies, as well as to the relationship between implementation of these new technologies and policy incentives (Oztemel, 2020). Our interest concerns the degree of relevance of the obstacles to the adoption of 4.0 technologies in the two-year period 2018-2019 by Italian manufacturing SMEs. From a methodological point of view, we applied a multivariate permutation test for ordinal categorical responses (Pesarin and Salmaso, 2010).

This work represents a contribution in the empirical literature on the adoption of 4.0 technologies by SMEs and related obstacles. Section 2 focuses on the methodological approach. Section 3 is dedicated to the application and section 4 includes the final conclusions.

2 Methodological approach

Let us consider the multivariate two-sample problem for ordered categorical variables with a one-sided alternative hypothesis of stochastic dominance. Such a complex problem has not an easy parametric solution (Cohen & Sackrowitz, 1998) and the asymptotic distribution of the test statistic of such solution under the null hypothesis depends on unknown parameters.

Let A_h^v be the h-th category for the v-th variable with $h = 1, \dots, c_v$ and $v = 1, \dots, k$. The null hypothesis in terms of CDFs (cumulative distribution functions) is

$$H_0: F_1^v(A_h^v) = F_2^v(A_h^v)\ \forall h, v,$$

where $F_i^v(x)$ is the CDF of the i-th population, with $i = 1,2$. The alternative hypothesis of stochastic dominance can be formalized as

$$H_1: F_1^v(A_h^v) \leq F_2^v(A_h^v)\ \forall h, v \text{ and } \exists h, v: F_1^v(A_h^v) < F_2^v(A_h^v).$$

A suitable test statistic for the partial hypothesis concerning the v-th variable might be that of Anderson-Darling:

$$T_v = \sum_{h=1}^{c_v - 1} \left[\hat{F}_2^v(A_h^v) - \hat{F}_1^v(A_h^v)\right] \left[\hat{F}_{\cdot}^v(A_h^v)\left(1 - \hat{F}_{\cdot}^v(A_h^v)\right)\right]^{-1/2},$$

where $\hat{F}_i^v(x)$, for $i = 1,2$, is the empirical cumulative distribution function of sample i and $\hat{F}_{\cdot}^v(x)$ is the marginal empirical distribution function for the v-th variable (Bonnini et al., 2014).

H_0 must be rejected in favor of the alternative hypothesis for large values of the test statistics. A test statistic for the multivariate problem can be obtained by combining the p-values of the univariate tests according to the Fisher combining function $T_{mul} = -\sum_v \log \lambda_v$, where λ_v is the p-value of the v-th partial test. The p-value of such a test is computed as

$$\lambda_v = P[T_v \geq t_v | H_0] = [\#(T_v \geq t_v) + 0.5]/(B + 1),$$

where t_v is a generic value taken by T_v, $\#(T_v \geq t_v)$ is the number of times T_v is greater than or equal to t_v according to the permutation distribution and B is the number of permutations.

3 Application

The permutation test for categorical data presented in the previous section was applied to original data collected in a sample survey carried out in January 2022. The survey was conducted in the northern regions of Italy by the Department of Economics and

Management of the University of Ferrara. It was aimed at manufacturing enterprises of the North Italy. The total number of interviewed companies is 3924. For the selection of the companies, a stratified random sampling was applied.

The goal is to compare companies that have adopted at least one 4.0 technology with those that have not adopted any 4.0 technology, in terms of the degree of relevance of the obstacles to the adoption of such technologies in the two-year period 2018-2019. The hypothesis under test is that the relevance of obstacles is higher for the companies that didn't adopt 4.0 technologies. The significance level is $\alpha = 0.05$.

The technologies considered were: advanced manufacturing solutions (interconnected and programmable robots), additive manufacturing (3D printers connected to digital development software), augmented reality (to support production processes), simulation (between interconnected machines for process optimization), horizontal integration (integration of information along the production process stages), vertical integration (sharing of information along the value chain/supply chain with suppliers and customers), industrial internet (multidirectional communication between production processes and products), cloud computing (data management on open systems), cyber-security (during network operations on open systems) and big data/analytics (for the optimization of products and production processes).

On the other hand, the barriers to the adoption of the aforementioned technologies are:

- lack of internal economic resources,
- difficulty in obtaining credit,
- difficulty in accessing public funding (subsidies),
- high costs,
- lack of internal skills.

For each category of obstacles, the degree of relevance was expressed in a Likert scale from 1 to 4, where 1="not at all", 2="somewhat", 3="very" and 4="extremely".

The application of the permutation test presented in the previous section, leads to the overall p-value **0.006**. Hence, at the significance level $\alpha = 0.05$, we have empirical evidence in favor of the hypothesis that the relevance of obstacles is higher for the companies that didn't adopt 4.0 technologies.

Given the overall result, we can attribute the significance to one or more specific partial tests, after adjustment of the partial p-values to control the family-wise error (FWE) with the Bonferroni-Holm method (Westfall & Young, 1992).

Table 1: Table of adjusted p-values with Bonferroni-Holm method (significant in bold).

	Lack of resources	*Difficulty obtaining credit*	*Difficulty access subsidies*	*High costs*	*Lack of skills*
Partial p-values	**0.010**	**0.010**	**0.034**	0.961	**0.021**

According to Table 1, we can conclude that the most significant obstacles to the introduction to Industry 4.0 technologies are the lack of internal economic resources, the difficulty to obtain credit, the difficulty in accessing public funding and the lack of internal skills.

4 Conclusions

The nonparametric approach used in this work, based on the application of a combined permutation test, is a robust and flexible statistical solution for multivariate tests in the presence of categorical data. Its application to an original dataset concerning a survey about Italian enterprises leads to the conclusion that the main obstacles that determine the decision of adopting 4.0 technologies are the lack of internal economic resources, the difficulty to obtain credit, the difficulty in accessing public funding and furthermore the lack of internal skills.

Acknowledgments

Authors thank University of Ferrara that funded the project entitled "Public policies, 4.0 technologies and enterprise performance. Empirical analyses on a representative sample of manufacturing enterprises of northern Italy (Politiche pubbliche, tecnologie 4.0 e performance d'impresa. Analisi empiriche su un campione rappresentativo di imprese manifatturiere del Nord Italia)" for the period 2022-2024, with the Departmental Research Incentive Fund - FIRD 2022.

References

BONNINI, S., CORAIN, L., MAROZZI, M., & SALMASO, L. 2014. *Nonparametric Hypothesis Testing: Rank and Permutation Methods with Applications in R*. Chichester, UK: Wiley.

COHEN, A., & SACKROWITZ, H.B. 1998. Directional tests for one-sided alternatives in multivariate models. *Annals of Statistics*, **26**, 2321-2338.

GHOBAKHLOO, M. 2020. Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production*, **252**, 119869.

MÜLLER, J.M., VEILE, J.W.& VOIGT, K. 2020. Prerequisites and incentives for digital information sharing in Industry 4.0 - An international comparison across data types. *Computers & Industrial Engineering*, **148**, 106733.

OZTEMEL, E., & GURSEV, S. 2020. Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing*, **31**, 127-182.

PESARIN, F., & SALMASO, L. 2010. *Permutation tests for complex data. Theory, applications and software*. Chichester, UK: Wiley.

WESTFALL, P.H., & YOUNG, S.S. 1992. *Resampling-Based Multiple Testing: Examples and Methods for p-Value Adjustment*. New York, NY, USA: Wiley-Interscience.