UNPACKING DETERMINANTS OF WATER CONSERVATION BEHAVIOUR AND SPATIAL HETEROGENEITY IN THEIR COEFFICIENTS

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Abstract. Water scarcity issues around the world require a thorough understanding of the factors that influence water consumption and conservation behaviour to address the problems on the demand side. This study investigates the determinants of water conservation behaviour through a comprehensive empirical analysis and explores spatial heterogeneity in their coefficients at a regional unit scale with a specific focus on Italy. Ordinal logistic regression with sequential analysis provides that various socio-demographic, behavioural, and social factors including trust in public institutions have a significant impact on water conservation. Furthermore, the findings of the geographically weighted regression reveal statistically significant spatial variations in the relationship between water saving and its four factors including gender, household size, energy saving, and trust in public institutions. The study concludes that targeted interventions tailored to specific regions are essential for effective water-saving interventions which have important implications for policymakers in promoting this type of conservation behaviour.

1. Introduction

Insufficient access to clean water is a prevalent and persistent issue that affects populations worldwide, and these problems are expected to deteriorate further in the forthcoming decades as water scarcity becomes increasingly widespread due to population growth, water pollution, climate change, and the overexploitation of natural resources (Gregory & Di Leo, 2003).

Prior research has found that water consumption or conservation is affected by multiple parameters, such as socio-demographic characteristics including income (Fielding et al., 2012), age (Aprile & Fiorillo, 2017), household size (Russell & Knoeri, 2012), and education (Gregory & Di Leo, 2003). Psychosocial factors, such as habits (Straus et al., 2016), subjective norms (Russell & Knoeri, 2020), and pro-environmental behaviour (Dolnicar et al., 2012), influence residential water use and saving as well. Furthermore, the altitude of the geographic location (Romano et al., 2016), ownership structure (Kontokosta & Jain, 2015), and water prices (Romano et al., 2016) are also significant in determining this behaviour. A major limitation of previous research is the limited number of potential determinants included in the models and the reliance on small sample sizes (Dolnicar et al., 2012). Additionally, the impact of socio-demographic variables on water consumption behaviour differs significantly across different geographic regions. Therefore, it is crucial to conduct determinant analysis using localized data to evaluate the relevance of the results of previous studies to the local conditions of target region (Kontokosta & Jain, 2015).

The present study aims to address the limitations in two steps. First, it investigates the factors of water conservation using a large sample from Italy. Then, it explores spatial heterogeneity at a regional unit scale in the relationship between water-saving behaviour and its determinants. In addition to exploring the impact of previously known factors, the effects of two domains of subjective well-being, charitable donations, trust in others and trust in public institutions are tested to go beyond the existing empirical research and determine new implications for policy measures.

2. Materials and Methods

The present research utilizes data from the Aspects of Daily Life (AVQ) survey, which is an annual, multipurpose survey conducted by the Italian National Institute of Statistics (ISTAT) since 1993. This survey gathers information from approximately 50,000 individuals residing in 20,000 households about their daily activities, behaviours, and difficulties. I use the 2021 wave and focus solely on respondents aged 16 and above as well as exclude the rows with non-available information in education, civil status, region of residency, and the judgment of the cost of the water variables. Furthermore, as the models include both individual and household level variables, only the first individual from each household in the dataset is retained, resulting in a sample size of 18,633 observations. In order to address the presence of missing data, comprising approximately 1.21% of the entire dataset, the k-nearest neighbours (kNN) imputation technique is performed as the results of Little’s test indicate that there is no significant evidence that the data is not missing completely at random (MCAR).

To evaluate water conservation behaviour, a survey question, that asks participants about the frequency with which they attempt to avoid wasting water, is exploited. Responses are provided on a 4-point frequency scale, which is reordered for this study. A score of 1 indicates “never,” a score of 2 indicates “sometimes,” a score of 3 indicates “habitually,” and a score of 4 indicates “always.” Table 1 presents some descriptive statistics of the selected variables.

Table 1 – *Descriptive Statistics.*

Variable	Category or Description	% *or* mean
Age	16 – 34	4.6%
	35 - 44	11.4%
	45 - 54	19.3%
	55 - 64	21.0%
	65 and more	43.7%
Gender	1 = Female	37.7%
Civil status	1 = Married	49.8%
Education	1 = Higher education (bachelor’s degree and above)	15.6%
Income (judgement)	Insufficient (Scarce)	30.1%
	Adequate	68.2%
	Excellent	1.6%
Household size	Number of household members	2.29
Health Status	5-point scale: 1 = "very bad"; 5 = "very good"	3.60
Satisfaction with Life	0-10 scale: 0 = "not at all"; 10 = "very satisfied"	7.18
Sat. with Environment	4-point scale: 1 = "not at all"; 4 = "very satisfied"	2.84
Sat. with Water Services	4-point scale: 1 = "not at all"; 4 = "very satisfied"	3.06
Drinking tap water	1 = Yes	43.4%
Cost of Water (judgement)	Low	1.9%
	Adequate	57.9%
	High	40.2%
Ownership structure	1 = Rent	13.6%
Reading labels	4-point scale: 1 = “never”; 4 = “always”	2.87
Organic food	4-point scale: 1 = “never”; 4 = “always”	2.46
Local food	4-point scale: 1 = “never”; 4 = “always”	2.87
Energy Saving	4-point scale: 1 = “never”; 4 = “always”	3.63
More sustainable transports	4-point scale: 1 = “never”; 4 = “always”	2.05
Churchgoing	1 = Regularly (at least once in a month)	31.6%
Waster Sorting[1]	3-point scale: 1 = “never”; 3 = “always”	2.91
Volunteering	1 = Yes	8.4%
Trust in others	1 = “most people are trustworthy”	26.8%
Trust in public institutions[2]	10-point scale: 0 = “not at all”; 10 = “totally trust”	5.88

To allow for addressing the questions raised in Section 1, this paper estimates the determinants of water conservation behaviour in Italy using two different modelling approaches. The first approach involves sequential analysis using ordinal logistic regression to identify significant factors, while the second approach utilizes geographically weighted regression (GWR) to investigate the spatially heterogeneous effects of each independent variable at a regional unit scale of Italy.

[1] It is a composite indicator constructed as an as an arithmetic mean of the four same scale variables which are sorting habits for paper, glass, plastic, and organic. Cronbach’s alpha is 0.85.

[2] It is a composite indicator constructed as an as an arithmetic mean of the seven same scale variables which represent trust in Italian Parliament, European Parliament, regional government, municipalities, political parties, justice system and law enforcement. Cronbach’s alpha is 0.91.

In the first approach, the proportional odds model for Ordinal Logistic Regression, as described by McCullagh (1980) is exploited:

$$logit\big(P(Y \leq i)\big) = \log\ (\frac{P(Y\leq i)}{P>i}) = \beta_{i_0} + \beta_{i_1}x_1 + \cdots + \beta_{i_{n-1}}x_{n-1} + \beta_{i_n}x_n \quad (1)$$

where Y is an outcome variable with I categories, so that, $P(Y \leq I) = 1$; i is a specific category of Y; $\beta_{i_o}, \beta_{i_o}, \beta_{i_1}, \dots \beta_{i_{n-1}}, \beta_{i_n}$ are model coefficient parameters with n predictors. The odds of being less than or equal a $i - th$ category is $\frac{P(Y\leq i)}{P>i}$.

Before constructing GWR model, variable importance and feature selection methods using Bayesian Networks and Random Forest algorithms are implemented both for robustness check and for reducing the dimensionality of the data and improving the model's performance by eliminating irrelevant features.

In the final stage, a geographically weighted regression (GWR) model is employed to examine the association between water conservation behaviour and predictor variables across various geographic regions in Italy. GWR is a method that expands the traditional regression framework by allowing for local variations in the coefficients. It accounts for the geographic location of each observation by assigning a diagonal matrix of locally weighted regression coefficients, in which each diagonal element is a function of the location of the observation, enabling a diverse relationship between the dependent variable and predictors across different spatial units (Fotheringham & Charlton, 1998):

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{p} \beta_{ik}(u_i, v_i)x_{ik} + \varepsilon_i \quad (2)$$

where β_i is the value of the kth parameter at location i, and (u_i, v_i) are the geographical coordinates of that location. Diagonal elements of a weight matrix are determined using a Gaussian weighting function as a kernel density function:

$$w_j(i) = \exp\left[-\left(\frac{d_{ij}}{b}\right)^2\right], j = 1,2, \dots, n \quad (3)$$

where d_{ij} is the distance between regression point i and data point j and b is bandwidth.

3. Results

Prior to conducting the analysis, the presence of multicollinearity among the independent variables is assessed using the Variance Inflation Factor (VIF). The VIF for civil status variable is the highest at 1.995, indicating a moderate level of collinearity with the other independent variables. However, it is below the recommended threshold of 5, which means that collinearity is not substantial enough to significantly affect the analysis.

Sequential analyses with OLR are performed to explore the determinants of water conservation behaviour. Three models are constructed. In the first step, only socio-demographic characteristics, various domains of well-being, and water-related variables are included (Model 1). The pro-environmental behaviour variables are entered into the regression in the second step (Model 2). Finally, Model 3 which also includes the social capital variables is performed. Table 2 presents the results of the ordinal logistic regression analysis with the dependent variable being ordered categorical. The coefficients indicate the log odds ratio of the odds of a higher category of water conservation, given a one-unit increase in an explanatory variable.

At the first step of the regression, demographic, well-being and water-related variables do not account for a significant amount of variance in water conservation behaviour. The inclusion of pro-environmental behaviours leads to a significant increase in the explanatory power of the model, with 50% of the variance in self-reported frequency of water-saving behaviour explained ($Nagelkerke\ R^2 = 0.4969$).

In the realm of socio-demographic characteristics, age and gender significantly contribute to explaining water conservation behaviour. The variable of age exhibits a positive correlation ($p<0.001$) with water conservation efforts, indicating that older individuals tend to be more inclined towards minimizing water wastage compared to their younger counterparts. This finding aligns with previous studies conducted by Aprile and Fiorillo (2017), and Gregory and Di Leo (2003), while standing in contrast to the results obtained by Fielding et al. (2012) and Russell and Knoeri (2020). Similarly, the marginal effect of being female presents a positive sign and is statistically significant at the 1% level, indicating that females save water more than males. This finding is consistent with previous research (Aprile & Fiorillo, 2017). However, contrary to the various prior findings, education, income, household size, ownership structure and perceived health have not significant effect on water saving. Considering the well-being variables, those who report higher satisfaction with life are also more likely to report a higher frequency of water conservation ($p<0.01$).

Even though in Model 1, as the judgment on the cost of water ($p<0.01$) increases from lower to adequate, and from adequate to higher ($p<0.001$), individuals are more likely to conserve water, which is in line with expectations and supported by previous research (Romano et al., 2016), their marginal effect reduces to statistical insignificance in Model 2. Drinking tap water is also has a non-significant effect.

With regard to pro-environmental behaviour (PEB), all domains of PEB except consuming organic food and waste sorting habits, have a statistically significant positive effect on water-saving habits, which is in align with the prior findings (Dolnicar et al., 2012). The statistically insignificant effect of organic food could be the result of the motivation behind consuming naturally, as a study by Idda et al.

(2008) shows that the primary motivations for organic food in Italy are food safety and taste rather than environmental safeguard.

Table 2 – *Determinants of Water Conservation Behaviour*.

Variables	Model 1		Model 2		Model 3	
	Odds Ratio	S.E.	Odds Ratio	S.E.	Odds Ratio	S.E.
Age	0.055***	0.010	0.047***	0.012	0.045***	0.012
Gender: female	0.298***	0.039	0.147**	0.046	0.142**	0.047
Civil status: married	0.153***	0.046	0.093	0.053	0.092	0.053
Education: higher	0.059	0.047	-0.046	0.055	-0.042	0.056
Household size	-0.063***	0.018	-0.024	0.021	-0.027	0.021
Income	-0.150***	0.032	-0.062	0.037	-0.060	0.038
Ownership structure: rent	-0.063	0.049	-0.007	0.057	-0.019	0.058
Health Status (perceived)	0.080***	0.023	0.016	0.027	0.016	0.027
Satisfaction with life	0.122***	0.011	0.036**	0.013	0.028*	0.013
Satisfaction with environment	0.034	0.023	0.032	0.028	0.029	0.028
Satisfaction with water services	0.030	0.027	0.003	0.031	-0.013	0.031
Drinking tap water	0.062	0.034	0.019	0.040	0.032	0.040
Cost of water: Adequate	0.315**	0.110	0.176	0.133	0.129	0.134
Cost of water: High	0.409***	0.111	0.172	0.134	0.132	0.136
Reading labels			0.136***	0.022	0.134***	0.022
Organic food			0.003	0.026	0.009	0.026
Local food			0.118***	0.024	0.118***	0.024
Energy Saving			2.254***	0.029	2.257***	0.029
More sustainable transportation			0.116***	0.019	0.119***	0.019
Waste sorting			0.095	0.053	0.089	0.053
Churchgoing: regularly					-0.013	0.043
Charitable giving					-0.104	0.060
Volunteering activities					0.016	0.077
Trust: most people are reliable					0.004	0.046
Trust in public institutions					0.028**	0.010
AIC	*30,884*		*21,569*		*21529*	
Pseudo R^2 (Nagelkerke R^2)	*0.02*		*0.4969*		*0.4976*	

****p < 0.001, **p < 0.01, *p < 0.05*

In the final step, the addition of social capital variables does not considerably increase the power of the model to explain variance in water saving behaviour ($Nagelkerke\ R^2 = 0.4972$). In comparison with Model 2, the signs and significance of the coefficients of all variables remain the same with modest variations in values.

Contrary to the findings by Aprile and Fiorillo (2017), regular church attendance is not statistically significantly correlated with more frequent water-saving behaviour. Similarly, charitable giving and volunteering activities in the last 12 months, and trust in others also have statistically insignificant coefficients which are somewhat unexpected as Brekke et al. (2011) argue that people who act more prosocially tend to make higher contributions to public goods, including the environment; and Tam and Chan (2018) demonstrate that an individual-level generalized trust in others can help elicit more pro-environmental behaviour. In contrast to trust in others, individuals become more likely to save water as their trust in public institutions increases ($p<0.01$), which is in line with previous findings on the relationship between pro-environmental behaviour in general and general trust.

Concerning feature selection (Table 3), following the robust approach suggested by Cugnata et al. (2016), the BN structures are estimated using eight algorithms, including constrained-based algorithm which utilizes conditional independence tests to assess edges in $\mathcal{G}$, a score-based algorithm which uses heuristic search algorithms to evaluate a goodness-of-fit based on AIC or BIC, and hybrid approaches, provided by Scutari (2016). For direct connections, a weight of 1 is assigned to the arcs linking pairs of nodes, 0.5 for indirect connections, and 0 for unlinked arcs. Then weights for each arc through the eight algorithms are summed up. For the purposes of this paper, a robust BN is defined as the one containing the largest set of arcs scoring 4 or more, corresponding to an arc found in half or more of the algorithms considered. Finally, a Markov blanket of water conservation behaviour, as well as any variable on the path leading to this behaviour through directed or undirected arcs in the robust network are selected. As for feature selection with Random Forest, variable importance techniques with Mean Decrease Accuracy (MDA) and Mean Decrease Gini (MDG) are employed. Later, the scores in decreasing order for both MDA and MDG are ranked, and the variables which have higher importance score than the average scores of all variables are selected.

Table 3 – *Robust Variable Selection.*

Variable	OLR	BN	MDA	MDG	Total
Age	1	0	1	1	3
Gender	1	1	1	0	3
Civil status	0	0	0	0	0
Household size	0	0	1	1	2
Health Status (perceived)	0	0	1	1	2
Satisfaction with life	1	0	1	1	3
Satisfaction with environment	0	0	0	1	1
Satisfaction with water services	0	0	0	1	1
Reading labels	1	1	1	0	3
Organic food	0	1	1	1	3
Local food	1	1	1	1	4
Energy Saving	1	1	1	1	4
More sustainable transportation means	1	1	1	1	4
Trust in public institutions	1	0	0	1	2

Finally, the study utilizes a scoring system in which a score of 1 is assigned to variables that are selected by Bayesian Network, and Random Forest (both MDF and MDA) techniques, as well as to the explanatory variables which has a statistically significant coefficient in the third OLR model, while a score of 0 is assigned to the remaining variables. Then, the scores are summed up and 11 variables with a total score of 2 or more are selected for inclusion in the GWR model.

Table 4 presents the output of the GWR model along with the results of global OLR model with the selected variables. F2 test, which examines the SSR improvement of GWR over OLS through the difference between their residual sums of squares (Leung et al., 2000), provides that GWR demonstrates significant improvement in explanatory power over the OLS, while it underperforms the OLR model based on the comparison with their AIC values.

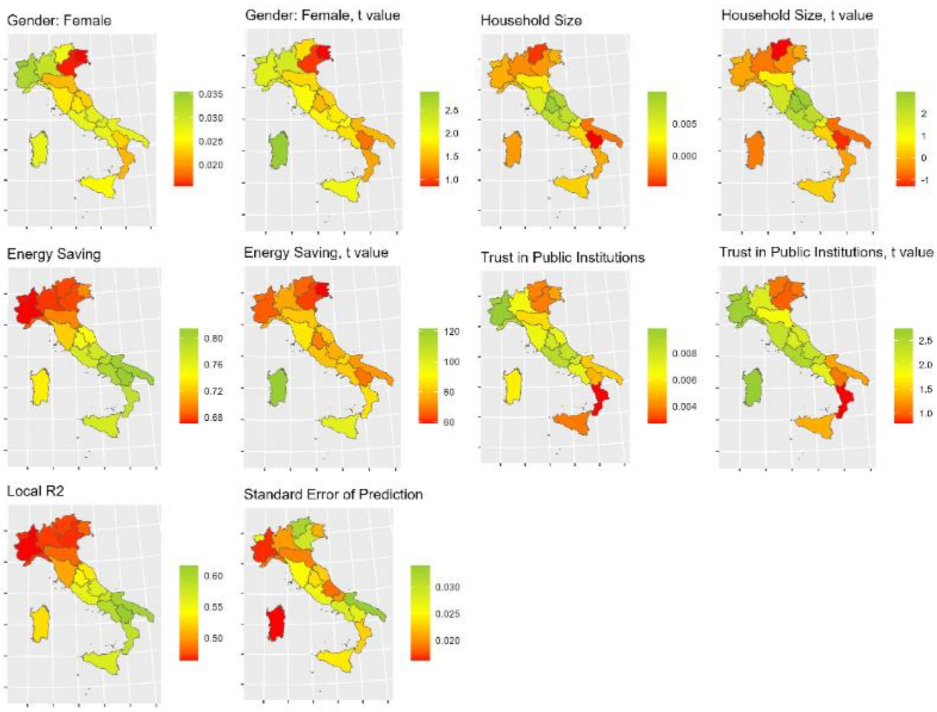
Table 4 – *Results of the geographically weighted regression (GWR) model.*

Variable	Min	Median	Mean	Max	F3 Test	Global (OLR)
Intercept	0.324	0.528	0.534	0.744	1.000	
Age	-0.001	0.007	0.006	0.012	1.000	0.049***
Gender: Female	0.015	0.028	0.026	0.035	0.000	0.112**
Household Size	-0.005	-0.000	0.001	0.010	0.000	-0.004
Health Status (perceived)	-0.023	0.003	-0.000	0.015	1.000	0.012
Satisfaction with life	-0.001	0.003	0.003	0.008	1.000	0.027*
Reading labels	0.004	0.038	0.034	0.045	0.770	0.132***
Organic food	-0.009	0.004	0.004	0.020	0.134	0.003
Local food	0.027	0.033	0.037	0.055	1.000	0.119***
Energy Saving	0.671	0.737	0.733	0.814	0.000	2.261***
More sustainable. trans.	0.017	0.024	0.024	0.033	1.000	0.116***
Trust in public institutions	0.003	0.007	0.006	0.010	0.000	0.026**
Local R^2	0.464	0.527	0.524	0.616		0.497
AIC	*31,163*					*21,516*
F2 test (Leung et al., 2000)	*2.807*	*p<0.001*				

****p < 0.001, **p < 0.01, *p < 0.05*

F3 statistics, which verifies the significance of the spatial heterogeneity in each GWR estimate (Leung et al., 2000), indicates that the coefficients of gender, household size, energy saving, and trust in public institutions vary significantly across space (Figure 1). The coefficients of three variables are consistently positively associated with water conservation, while, the estimate of household size takes both negative and positive values in different regions of Italy. In particular, it has a negative impact in most regions of North Italy including Trentino-Alto Adige, and Lombardy, as well as in Basilicata, Apulia, and Sardinia, however, these results are not significant. While it positively and significantly influences water saving in Central Italy. The highest positive effect is observed in Umbria.

Figure 1 – *Spatial Heterogeneity in the GWR coefficients vary significantly over the space.*



The correlation between being female and water conservation is the highest in the Northwest Italy, specifically in regions such as Valle d'Aosta, Piedmont, and Lombardy, while it is lowest in the central regions including Tuscany and Umbria, and Sicily, and not significant in the remaining areas. When it comes to energy-saving behaviour, it emerges as the strongest positive predictor of water conservation across the country, with the highest impact observed in south-eastern regions such as Apulia, and Basilicata, and the lowest impact observed in North Italy. Conversely, trust in public institution more are more likely to be a stronger predictor in some northern regions, namely, Piedmont, Valle d'Aosta, and Liguria, and slightly less strong or has not significant effect in southern and north-eastern regions.

Gutiérrez-Posada et al. (2017) suggest three possible scenarios when comparing the global and GWR estimates. The first is when the global model estimates are significant but the variation in parameters under GWR is not, indicating that the factor being studied does not have a spatially heterogeneous effect and the global model parameter is representative at local level. This scenario includes age, reading labels, local food and more sustainable transportation means. The second context is when the variation in GWR coefficients is significant, but the global model coefficient is not, indicating spatial variability leads to an average general effect near zero. Household size belongs to this group. The third scenario is when both the global estimator and the F3 statistic are significant, showing that the global estimates have failed to capture spatial non-stationarity. This scenario encompasses gender, energy saving, and trust in public institutions. In the second and third scenarios, GWR is necessary to understand the spatially heterogeneous processes and propose customized policy implications at the local level (Gutiérrez-Posada et al., 2017).

4. Discussion and Conclusion

The present study investigates the factors affecting water conservation behaviour and spatial heterogeneity in their estimates by utilizing the 2021 Aspects of Daily Life survey data from Italy. The findings from the ordinal logistic regression provide some support for the predictive ability of socio-demographic, behavioural, and social capital variables on explaining the frequency of paying attention to not wasting water. The profiles of water savers suggest that individuals who save water more often are female, and comparatively older, have higher subjective well-being, and engage in other sustainable behaviours as well. These results are consistent with past research. However, unlike previous findings, income, education, and household size are found to be non-significant predictors for water saving behaviour. Furthermore, the results of the geographically weighted regression confirm the existence of spatial heterogeneity in four determinants of water conservation behaviour, namely gender, household size, energy saving, and trust in public institutions.

From a theoretical standpoint, the current study contributes significantly by exploring a wide range of potential factors simultaneously and testing their roles in explaining water conservation behaviour. Furthermore, as described in Sections 1, the models investigated include additional potential explanatory variables that had not been previously examined. Regarding these variables, trust in public institutions and satisfaction with life, have positive coefficients, whereas trust in others, charitable donations and volunteering activities have a non-significant relationship with water conservation. Finally, by applying GWR and obtaining spatial heterogeneity in the coefficients at a regional unit scale, the study provides further empirical contributions to the debate on the determinants of water-saving behaviour.

The study's findings have important policy implications as well. In general, to change behaviour and habits, upstream and downstream interventions are suggested in which according to Martínez-Espiñeira and García-Valiñas (as cited in Russell & Knoeri, 2020), the latter including educational programs in schools is more effective in promoting desirable habits for water conservation. Furthermore, it is worthwhile to state that spatial non-stationarity across the regions of Italy in the estimates of four determinants requires flexibility in the implementation of national policies or the design of regionally heterogeneous or customized policies at local level. It is particularly important for the determinants encompassed in the second and third scenarios described by Gutiérrez-Posada et al. (2017) as discussed in Section 3.

One of the limitations of the present research is that the measurement of water conservation behaviour relies on self-reported data, which may be subject to social desirability bias. Although some studies find no evidence of this bias affecting the accuracy of the measurements of sustainable behaviour (Milfont, 2009), and others provide evidence that stronger self-reported water conservation habits are associated with lower water consumption (Straus et al., 2016), caution is still needed when interpreting the results. Second, while the study uses regions as spatial units for GWR, smaller units such as provincial or point unit scales may provide more insights into spatial disparities in the GWR estimates. Finally, the cross-sectional nature of the study may limit the ability to establish causality. Therefore, future research that addresses these limitations, such as using actual behaviour as a dependent variable to address social desirability bias (Dolnicar et al., 2012) or employing a longitudinal design to address reverse causality (Russell & Knoeri, 2020), is necessary.

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