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Explaining and predicting tourists' circular behaviour: A PLS-SEM and machine learning study of hotels in Mallorca

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Abstract

Understanding tourists' circular behaviour has become a critical issue for advancing sustainability in the hospitality sector. Partial Least Squares Structural Equation Modelling (PLS-SEM) is widely used to test theory-driven causal relationships among latent constructs, its reliance on linear and additive relationships. This study proposes an integrated analytical framework that combines PLS-SEM with selected machine learning (ML) techniques to jointly leverage causal explanation and predictive modelling.

PLS-SEM analysis is first employed to estimate and validated a confirmatory model. Latent variable scores derived from the PLS-SEM model are subsequently used as input for machine learning algorithms to explore alternative structural dependencies, potential mediating effects, and non-linear relationships.

The results confirm the robustness of the theory-driven relationships while revealing additional data-driven patterns that enhance predictive accuracy and provide complementary insights into tourists' decision-making processes.

Keywords: *PLS-SEM; Machine Learning; Circular Economy; Tourism; Bayesian Networks; Predictive Analytics*

1. Introduction

Partial least squares structural equation modeling (PLS-SEM) is widely recognized as a causal–predictive technique for examining relationships between latent constructs while enabling out-

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of-sample prediction (Jöreskog & Wold, 1982). Its adoption has increased substantially in recent years, driven by the growing demand for analytical approaches that integrate theory-driven explanation with predictive performance (e.g., Richter et al., 2016a; Richter et al., 2016b; Sarstedt et al., 2022a). By allowing the estimation of conceptually grounded models and providing a comprehensive set of established evaluation criteria, PLS-SEM supports the assessment of both explanatory strength and predictive accuracy (e.g., Guenther et al., 2023; Hair et al., 2022; Ringle et al., 2023).

Despite the strengths of PLS-SEM as a theory-driven and causal–predictive approach, its estimation framework relies primarily on linear and additive relationships, which may limit its ability to capture complex patterns commonly observed in human behaviour. Tourist decision-making related to circular economy practices is inherently multifaceted, involving non-linear effects, interaction mechanisms, and threshold-based responses that may remain undetected within conventional structural models. In this context, combining SEM with different machine learning (ML) algorithms provides a complementary data-driven perspective by enhancing predictive accuracy, uncovering hidden structures, and identifying non-linear relationships among latent constructs. Rather than replacing theory-based modeling, machine learning methods serve as an exploratory and predictive extension that supports the refinement of model specifications and the validation of alternative causal structures. Consequently, integrating PLS-SEM with machine learning enables a more comprehensive understanding of tourists' circular behaviour, combining explanatory rigor with enhanced predictive performance.

In PLS-SEM, researchers specify models that integrate latent constructs with their corresponding indicators (observable variables), enabling the simultaneous testing of theoretical relationships and the generation of predictions. Predictive assessments may focus either on the indicators, by forecasting the scores of indicators associated with endogenous constructs (Shmueli et al., 2016), or on the constructs themselves, through the prediction of endogenous construct scores. A key strength of PLS-SEM lies in the standardization of its estimation algorithms and evaluation procedures, which supports transparent interpretation of results and facilitates the comparison and selection of alternative structural models. In contrast, machine learning relies on a wide array of algorithmic approaches primarily designed to optimize predictive accuracy, often without imposing strict assumptions about the underlying functional form of the relationships.

Building on these complementary strengths, this study proposes an integrated analytical routine that combines PLS-SEM with selected machine learning algorithms to jointly leverage theory-driven causal explanation and data-driven predictive modeling. Specifically, the machine learning techniques are employed to enhance out of sample predictive accuracy, capture potential non-linear relationships, and explore alternative structural patterns, thereby extending the evaluation of tourists' circular behaviour in a sample of hotels in Mallorca.

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2. Methodology

2.1. Statistical Analysis

In our research, we adopt the analytical framework proposed by Richter and Tudoran (2024): The proposed relationships are first tested using Partial Least Squares Structural Equation Modeling (PLS-SEM), following standard model evaluation procedures (Hair et al., 2010). Next, the exogenous constructs are utilized as inputs for a subsequent ML approach. Finally, a sensitivity analysis is conducted to assess the contribution of each exogenous construct to the outcome development.

Figure 1 shows the steps proposed to combine PLS-SEM and selected ML algorithms.

1. PLS-SEM Analysis: Evaluate measurement and structural model quality considering the threshold values (Hair et al., 2022) and generate latent variable scores.

2. ML Analysis: Bayesian Network (BN) was used to explore nonlinearities or to validate their PLS-SEM findings. BN based causal discovery approach was implemented to support the assessment of the model's underlying causal structure. Specifically, latent variable scores obtained from the PLS-SEM analysis were used as input data to explore potential causal dependencies among constructs, including the identification of previously unmodeled direct and indirect (mediating) relationships.

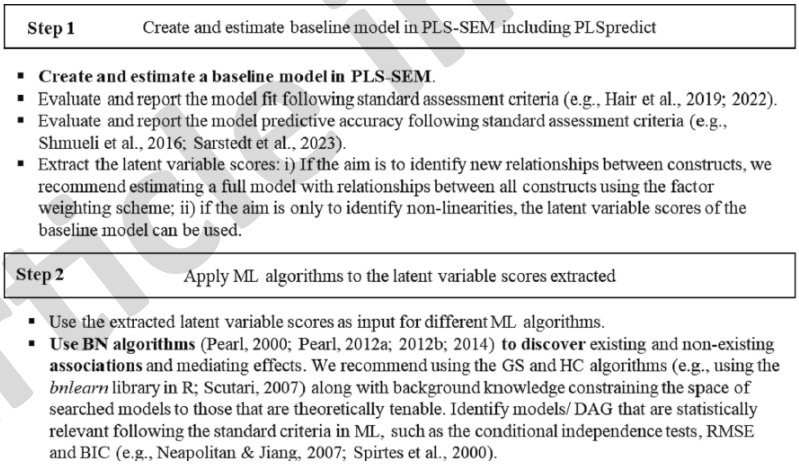


Figure 1. Two first step guidelines. Source Ritcher and Tudorán, (2024)

2.2. Conceptual Model

This study builds on the Theory of Planned Behaviour (TPB) (Ajzen, 1991), a well-established theoretical framework for explaining human behaviour through three key determinants:

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attitudes, subjective norms, and perceived behavioural control. TPB has been widely applied in tourism and sustainability research to explain pro-environmental and responsible consumption behaviours.

In the context of this study, TPB is extended to analyse tourists' circular economy (CE) behaviour in hotels. Circular economy practices in tourism refer to actions aimed at reducing waste, reusing resources, and promoting sustainable consumption patterns within hospitality services. Given the increasing relevance of sustainability in tourism decision-making, understanding the drivers of circular behaviour is essential.

The conceptual model incorporates the core TPB constructs, together with an additional cognitive belief: the perceived effectiveness of circular economy implementation (PECE). This construct captures the extent to which tourists believe that circular practices implemented by hotels are effective in achieving environmental sustainability outcomes. Specifically, the model includes the following latent constructs:

- Perceived Effectiveness of Circular Economy implementation (PECE), measured through items 13.1–13.4, reflects tourists' beliefs about the actual impact and usefulness of CE practices adopted by hotels.

- Subjective Norms (SN), measured using items 10.3–10.6, reflect the perceived social pressure from significant others (e.g., family, friends, or society) to engage in circular or sustainable behaviours during hotel stays.

- Attitudes towards Circular-Innovative Hotels (ACIH), measured using items P10.1–P10.2, capture the overall positive or negative evaluation of hotels implementing circular economy practices.

- Perceived Behavioural Control in the context of CE (PBC-CE), measured using items P12.1–P12.7, reflects tourists' perceived ability, resources, and opportunities to engage in circular behaviours during their stay.

- Circular Behaviour at Hotel (CBH), represents the actual or intended behaviour of tourists related to circular practices, such as resource-saving actions, recycling, or participation in sustainability initiatives.

Following this extended TPB framework, PECE is introduced as an antecedent that complements traditional attitudinal and control-related determinants. It is expected to influence both attitudes and perceived behavioural control. All constructs were operationalised using multi-item scales derived from the survey instrument.

2.3. *Research hypothesis*

The following hypotheses concerning this research were established, based on the theoretical foundations.

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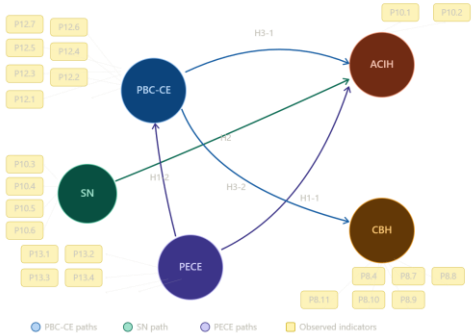


Figure 2. Conceptual model (Source: author's own).

- *H1-1: The extent to which consumers perceive CE practices as effective (PECE) is anticipated to shape their attitudes towards hotels embracing circular innovation (ACIH).*
- *H1-2: Consumers' perceived effectiveness of CE implementation (PECE) is posited to have a significant effect on their perceived behavioural control in circular economy contexts (PBC-CE).*
- *H2: The influence of social referents' opinions is hypothesised to play a determining role in shaping attitudes toward circular-innovative hotels (ACIH).*
- *H3-1: An individual's sense of perceived behavioural control within CE frameworks (PBC-CE) is proposed to exert a meaningful effect on their attitudes toward circular-innovative hotels (ACIH).*
- *H3-2: Perceived behavioural control in CE contexts (PBC-CE) is hypothesised to be a significant predictor of actual circular behaviour exhibited during hotel stays (CBH).*

3. Results

Data were collected from a sample of approximately 1,400 tourists staying in hotels in Mallorca through face-to-face surveys administered using a structured questionnaire. The adequacy of the sample size was assessed through an a priori power analysis conducted with G*Power 3.1 software (Faul et al., 2009), confirming that the sample size was sufficient to detect the expected effects.

3.1. PLS-SEM Results

Partial Least Squares Structural Equation Modelling (PLS-SEM) was first employed to assess both the measurement and structural models.

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The evaluation of the measurement model focused on reliability and validity. Indicator reliability was confirmed by outer loadings exceeding the recommended threshold of 0.70. Internal consistency reliability was established through Cronbach's alpha (α) and composite reliability (CR), both exceeding the recommended value of 0.70. Convergent validity was supported by average variance extracted (AVE) values above 0.50 (Fornell & Larcker, 1981; Henseler et al., 2015).

Discriminant validity was assessed using three complementary approaches: the Fornell–Larcker criterion, cross-loadings, and the heterotrait–monotrait ratio (HTMT). All criteria were satisfactorily met, confirming the adequacy of the measurement model. Bootstrapping results indicated that all outer loadings were statistically significant ($p < 0.05$).

The structural model was evaluated following Hair et al. (2010), considering collinearity (VIF < 5), significance of path coefficients ($p < 0.05$), coefficient of determination (R^2), predictive relevance ($Q^2 > 0$), and model fit indices (SRMR ≤ 0.08; RMStheta ≤ 0.12). The results indicate that the proposed model achieves acceptable explanatory power and predictive relevance.

3.2. Machine Learning Results: Bayesian Network Analysis

To complement the theory driven PLS-SEM results, a Bayesian Network (BN) analysis was conducted using the latent variable scores obtained from the PLS-SEM model as input data. The BN analysis aimed to explore potential non-linear relationships and alternative dependency structures among the constructs. The results largely confirm the relationships identified in the PLS-SEM model, indicating a high level of consistency between the theory-driven and data-driven approaches.

In particular, strong and stable dependencies were identified between:

- Perceived Effectiveness of Circular Economy implementation (PECE) and Perceived Behavioural Control (PBC-CE).

- Perceived Behavioural Control (PBC-CE) and Circular Behaviour at Hotel (CBH).

These relationships exhibited both directional consistency and high robustness across the BN structure.

Additionally, the BN analysis suggests complementary pathways involving Perceived Behavioural Control (PBC-CE), highlighting its central role not only in directly influencing behaviour but also in shaping attitudes towards circular-innovative hotels. However, no substantively new or contradictory relationships were identified beyond those specified in the original structural model.

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3.3. Comparative Interpretation

Overall, the results indicate that the machine learning analysis reinforces the validity of the PLS-SEM model rather than substantially extending it. The absence of strong additional relationships suggests that the theoretical model provides an adequate representation of tourists' circular behaviour in this context.

At the same time, the BN-approach contributes by confirming the robustness of the structural relationships and offering an alternative, data-driven perspective on the dependency structure among constructs.

4. Conclusions

This study contributes to the literature on methodological integration by applying a combined PLS-SEM and machine learning (ML) approach to analyse tourists' circular behaviour in hotels. The results show a high level of consistency between the theory-driven PLS-SEM model and the data-driven Bayesian Network analysis. While the ML approach did not reveal substantively new structural relationships, it confirmed the robustness and stability of the core paths specified a priori.

These findings highlight the complementary role of ML as a validation and structural exploration tool, reinforcing confidence in theory-based models and supporting the integration of explanatory and predictive approaches in behavioural research.

From a practical perspective, the results underline the relevance of key determinants of circular behaviour in tourism, providing useful insights for decision-making in sustainable hospitality management. Future research may extend this approach by incorporating alternative ML techniques or exploring non-linear relationships in different contexts.

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