

Off-Piste: Integrating an Agent-Based Model with a Multiregional Input–Output Framework to Link Climate, Tourism, and the Economy in the Pyrenees

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Snow tourism is one of the main economic drivers of the Pyrenees. Its effects extend well beyond ski resorts, generating employment and value added in hospitality, transport, retail, and a wide range of local services. However, its strong dependence on snow availability makes it particularly vulnerable to climate change, which is expected to reduce both the length and reliability of ski seasons. In this context, it is essential not only to estimate potential losses in ski days or visitors, but also to understand their territorial distribution and broader economic implications.

This paper proposes an integrated methodological framework that combines an Agent-Based Model (ABM) with a multiregional Input–Output (MRIO) model disaggregated at the municipal level. The objective is to connect climate-driven changes and skier behavior with their direct, indirect, and induced economic effects across the territory.

The first component is an agent-based model, which simulates interactions between skiers and ski resorts under changing climatic conditions. The agents are individual skiers, characterized by their place of residence, reference ski resort, and adaptation strategy in the event of closure (either substituting with another resort or abandoning the activity). Ski resorts are modeled as fixed entities defined by attributes such as location, maximum capacity, season length, and an attractiveness index constructed from physical and socioeconomic variables (e.g., slope length, prices, services, and accessibility).

The model incorporates climate projections affecting both natural and artificial snow cover in order to estimate season length under different scenarios. Based on these projections, it simulates the spatial redistribution of demand and calculates changes in the number of skiers at each resort using a gravity model in which the ski resort attractiveness index is placed in the numerator and the distance to the reference resort in the denominator. By capturing individual decision-making and adaptive behavior, the ABM generates a spatially detailed estimate of the tourism shock across municipalities.

The second step consists of translating these changes in visitor numbers into a direct economic impact. To do so, average expenditure per skier per day is estimated and allocated across key sectors linked to snow tourism, including accommodation, restaurants, transport, lift passes, equipment, and other services. Expenditure estimates are derived from official statistics and regional case studies for the Pyrenees, harmonized to ensure internal consistency and territorial representativeness. By multiplying average daily expenditure by the projected variation in skier numbers and season length, a sector-specific consumption shock is calculated for each municipality. This demand shock serves as the input for the multiregional Input–Output model. The starting point is an existing multiregional table for the Ebro River basin, previously disaggregated to the municipal level, with particular detail for Aragón and its network of snow-tourism municipalities. The model allows us to assess how reductions in tourism-related consumption affect not only directly linked sectors, but also the wider economy through intersectoral production linkages.

From the variation in final demand associated with snow tourism, the MRIO framework estimates the resulting changes in output, value added, and employment in each municipality and region. It distinguishes between direct effects (on sectors immediately related to tourism), indirect effects (through supply chains), and induced effects (stemming from changes in household income and

consumption). The multiregional structure further captures interterritorial spillovers, identifying the extent to which economic losses are concentrated in mountain municipalities or transmitted to other regions through production networks.

The main contribution of this research lies in the coherent integration of both approaches. While the ABM provides a micro-founded, spatially explicit estimation of visitor changes under alternative climate scenarios, the MRIO model translates these changes into a structural assessment of economic impacts. Together, they offer a robust framework for evaluating the vulnerability of snow-based development models and for informing sustainable territorial adaptation strategies in the face of climate change.

Although the full input–output results are not yet available, preliminary estimates of the direct demand effects already reveal a marked territorial asymmetry in the economic impacts derived from changes in skiability and skier redistribution. Under the more adverse scenarios, Aragón and Catalunya experience substantial losses, particularly in retail trade (CNAE 47), accommodation (CNAE 55) and food and beverage services (CNAE 56), while Andorra records significant gains, exceeding â,–100 million in retail and more than â,–60 million in accommodation