

# Sustainability in tourism determined by an asymmetric game with mobility

Manuel Chica<sup>a,b,\*</sup>, Juan M. Hernández<sup>c</sup>, Matjaž Perc<sup>d,e,f,g</sup>

<sup>a</sup> Andalusian Research Institute DaSCI "Data Science and Computational Intelligence", University of Granada, 18071 Granada, Spain

<sup>b</sup> School of Electrical Engineering and Computing, The University of Newcastle, Callaghan, NSW 2308, Australia

<sup>c</sup> Department of Quantitative Methods in Economics and Management, University Institute of Tourism and Sustainable Economic Development (TIDES), University of Las Palmas de Gran Canaria, 35017 Las Palmas, Spain

<sup>d</sup> Faculty of Natural Sciences and Mathematics, University of Maribor, Koroška cesta 160, 2000 Maribor, Slovenia

<sup>e</sup> Department of Medical Research, China Medical University Hospital, China Medical University, Taichung, Taiwan

<sup>f</sup> Alma Mater Europaea, Slovenska ulica 17, 2000 Maribor, Slovenia

<sup>g</sup> Complexity Science Hub Vienna, Josefstädterstraße 39, 1080 Vienna, Austria

## ARTICLE INFO

Handling Editor: Zhifu Mi

### Keywords:

Asymmetric game  
Spatial structure  
Migration  
Evolutionary game theory  
Sustainable tourism  
Over-tourism

## ABSTRACT

Many countries worldwide rely on tourism for their economic well-being and development. But with issues such as over-tourism and environmental degradation looming large, there is a pressing need to determine a way forward in a sustainable and mutually rewarding manner. With this motivation, we here propose an asymmetric evolutionary game with mobility where local stakeholders and tourists can either cooperate or defect in a spatially structured setting. Our study reflects that sustainable tourism is primarily determined by an optimal trade-off between economic benefits of the stakeholders and their costs related to the application of sustainability policies. In contrast, the specific benefits and costs of the tourists are comparatively less relevant. The reader can also observe that allowing for greater tourist mobility decreases cooperation and leads to faster polarization among local stakeholders. In agreement with observations worldwide, we identify decreasing population densities in tourist areas in terms of both, stakeholders and tourists, to be a key aid to greater cooperation and overall sustainability of tourism. These results are rooted in spatial formations and complex alliances that manifest spontaneously through the evolutionary dynamics in a structured population.

## 1. Introduction

Tourism is a human activity that implies interaction among two populations, tourists and stakeholders (i.e., local business, service providers, and residents). Continuous and non-virtuous relationships between these actors can generate over-tourism, which is a type of unsustainable tourism development characterized by a change of the local lifestyle and socio-cultural identity, loss of amenities, and local businesses. Over-tourism is then revealed as a physical "touristification" or domination of tourism business in the city centers (Cheung and Li, 2019; Koens et al., 2018; Mihalic, 2020; Milano et al., 2019). This is not a new phenomenon but there was a growing concern of unsustainable tourism development in the last decade, mostly arising in cities. Although the causes for over-tourism are complex and multidimensional, the most relevant ones are the high increase of accommodation units for tourism since the irruption of platforms such as Airbnb, excessive affluence of visitors, the deterioration of environmental conditions, food waste, and inappropriate behavior of tourist and local stakeholder (Cheung and Li, 2019; Koens et al., 2018; Milano et al., 2019; Wang et al., 2021a; Seraphin et al., 2018).

Several measures to avoid over-tourism and favor sustainability have been implemented in recent years. Some of them are oriented to restrict the activity to local stakeholders. For example, the city of Barcelona has applied limits to accommodation growth by imitating similar solutions implemented in coastal destination two decades before (Dodds, 2007; Weaver, 2012). Local government from Amsterdam has opted by restricting tourism-related commercial activities in the city center (Goodwin, 2019). Other policies have been focused on regulating some specific touristic activities such as banning visits to certain areas (e.g., the Maya Beach in Thailand BBC (2018)), imposing higher fees or taxes to visit certain cities (e.g., Venice Berlinghieri (2021)), setting strict regulations for tourists' behavior (e.g., Rome and Barcelona Goodwin (2019)), and avoiding the advertising of some star attractions (e.g., the Taj Mahal monument in India Khalil, 2017).

Understanding the ruling forces of over-tourism and the dynamics of the different tourism players are necessary to select the most appropriate policy to handle this phenomenon and move towards a more sustainable tourism development. This is the main goal of this work,

\* Corresponding author at: Andalusian Research Institute DaSCI "Data Science and Computational Intelligence", University of Granada, 18071 Granada, Spain.  
E-mail addresses: [manuelchica@ugr.es](mailto:manuelchica@ugr.es) (M. Chica), [juan.hernandez@ulpgc.es](mailto:juan.hernandez@ulpgc.es) (J.M. Hernández), [matjaz.perc@gmail.com](mailto:matjaz.perc@gmail.com) (M. Perc).

<https://doi.org/10.1016/j.jclepro.2022.131662>

Received 10 December 2021; Received in revised form 10 March 2022; Accepted 2 April 2022

Available online 9 April 2022

0959-6526/© 2022 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

where we propose and analyze an evolutionary game model to represent the phenomenon of over-tourism. We focus on understanding the dynamics and social interactions driving to unsustainable or sustainable tourism, the role of the agents' behavior, and how over-tourism can appear in a social network from the dynamic interrelationship among tourists and local tourism businesses (we call them stakeholders, from now on).

Our proposed model is an evolutionary asymmetric game which introduces two time-invariant roles for the populations' players: tourists and stakeholders. Although evolutionary game theory has been traditionally used to explain stable cooperative interactions among biological species (Hofbauer and Sigmund, 2003), the range of application has widened in the last decade. New evolutionary models have been recently built to analyze the conditions for cooperation among agents involved in diverse contemporary socioeconomic problems, such as actions against climate change (Pacheco et al., 2014) and reopening policies after COVID-19 pandemic (Chica et al., 2021).

More specifically, both playing roles of the proposed model can choose to either cooperate (being sustainable) or defect (being unsustainable). This sustainability can be understood from an environmental point of view (e.g., decreasing amount of waste, adopting low carbon emission policies, or having a proper use of water), or from a social point of view (e.g., by supporting local culture and business, reducing tensions with residents, or offering authentic local and eco-friendly products and experiences by the stakeholders). The combined actions of the players in the spatial ecosystem produce a payoff for each player when it interacts with players of an opposing role. Therefore, the model is an asymmetric game with two species (tourist and stakeholders) and two strategies (these models are called bi-matrix games Hofbauer and Sigmund, 2003). In general, asymmetric games include interaction among any individual belonging to the same role or not. But in our case, interactions are only possible for individuals belonging to different species (i.e., opposing roles).

The players of the game occupy nodes in a structured network of interactions and accumulates its payoffs from pair-wise interactions with neighbors having opposing role. The asymptotic stable strategies in asymmetric games have been long analyzed in infinite populations using replicator equation (Cressman and Tao, 2014; Hauert et al., 2019; McAvoy and Hauert, 2015) and for finite populations using Markov processes (Ohtsuki, 2010). However, when including structured populations, the dynamic evolution of asymmetric models is increased in complexity and results from well-mixed populations do not apply in this context (Szabó and Fátih, 2007). Some general results for this kind of asymmetric games have been found (McAvoy and Hauert, 2015), but assuming restrictive conditions over the strategy update at every time step. In other cases, as in our model, simulations are a useful tool to study the evolutionary dynamics of such game (Guo et al., 2020; Szolnoki and Perc, 2018; Wang et al., 2021c), and this is why we employ agent-based simulations for computing the outcomes of the model (Macal and North, 2005; Adami et al., 2016).

Additionally, the model incorporates a migration process. But, to be closer to reality, this migration process is only performed by tourists, one of the two roles in the asymmetric game, which are the dynamic players while stakeholders have a more static nature. Tourists can then migrate to empty nodes at every time step when a neighboring position of the network is vacant. This migration process produces new interactions with tourist stakeholders. The effect of migration in spatial evolution of evolutionary games has also been analyzed, favoring final cooperation (Wang et al., 2021c; Zhang et al., 2021), but has not been applied to a single role in an asymmetric game.

Our foremost aim is to explore the conditions for facilitating a cooperative behavior of the population to avoid over-tourism and help tourism sustainability. We also present here the first evolutionary model to explain how over-tourism can unintentionally appear in a tourist area from the collective interactions between tourists and stakeholders. Thus, the experimentation and the results of this work

will consist of: (a) exploring the outcome of the asymmetric model and main dynamics of the game and its parameters, (b) finding the best conditions for avoiding the defective behavior of both roles of players, (c) showing the impact of introducing migration for tourists and (d), observing the spatial formation of the structured population at the end of the simulation.

## 2. Theoretical framework and related work

The term sustainable tourism began to be used by academic researchers at the beginning of the 90s, as an application to the case of tourism of the general concept of sustainable development, popularized by the Brundtland report (WCED, 1987). The conceptualization and practice of sustainable tourism has been long debated throughout these last three decades, but the definition given by the World Tourism Organization (UNWTO) has achieved an extended consensus (Mihalic, 2020). According to UNWTO, sustainable tourism is a "tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities" (UNWTO, 2022). Then, sustainable tourism refers to these three principles, the economic, environmental and socio-cultural, and a suitable balance among them to guarantee long-term sustainability (UNWTO, 2004).

In this paper we deal with over-tourism, a relatively recent term aimed by its diffusion in social media and social contest. Over-tourism can be described as "destination where hosts or guests, local or visitors, feel that there are too many visitors and the quality of life in the area or the quality of the experience has deteriorated unacceptably" (Goodwin, 2017). Therefore, over-tourism is a form of unsustainable tourism that focuses on the socio-psychological and socio-political dimensions of sustainability (Mihalic, 2020). Its antithesis is responsible tourism, a kind of tourism based on the respect of the local culture (Goodwin, 2017). Responsible tourism is therefore a sustainable tourism in action, or in other words, a tourism where visitors and stakeholders behave in a sustainable manner (Mihalic, 2016).

The role of tourist behavior and encounters with stakeholders as a cause of over-tourism has been also stressed in other exploratory studies (Koens et al., 2018). Other contributions relate over-tourism to residents' negative attitudes on tourism, maintained over time although the visitors change behavior (Cheung and Li, 2019). Then, over-tourism and responsible tourism lean on the role of actors' behavior to direct or promote sustainability, in line with the recent interest in the studies of sustainable tourism (Bramwell et al., 2017).

The model presented in this paper connects with this behavioral aspect of sustainability by proposing an evolutionary game model to show how over-tourism can naturally appear from the interrelationship among tourists and local stakeholders. Fig. 1 shows the framing of our work with respect to the critical variable of study. Evolutionary game models have been previously used to represent the adoption of sustainable practices in tourism by mean of green incentives (He et al., 2018; Antoci et al., 2013) and also for the promotion of eco-tourism activities and its implications in a cleaner production (Wang et al., 2021b). In these contributions, the authors study the dynamics of tourist stakeholders, residents, and governments in a multiplayer coordination evolutionary game. Unlike to previous studies, our model focuses on the relationships and synergies between tourists and local stakeholders, without assuming any incentive or external influence to orient the system to sustainability. By doing so, we analyze the inner forces in the tourist-stakeholder dyad that can lead to sustainable or unsustainable tourism. The details of the evolutionary model are given in the next Section 3.

## 3. Model

The evolutionary game is asymmetric since consists of a finite set of  $Z$  agents having two different and time invariant roles: being a tourist

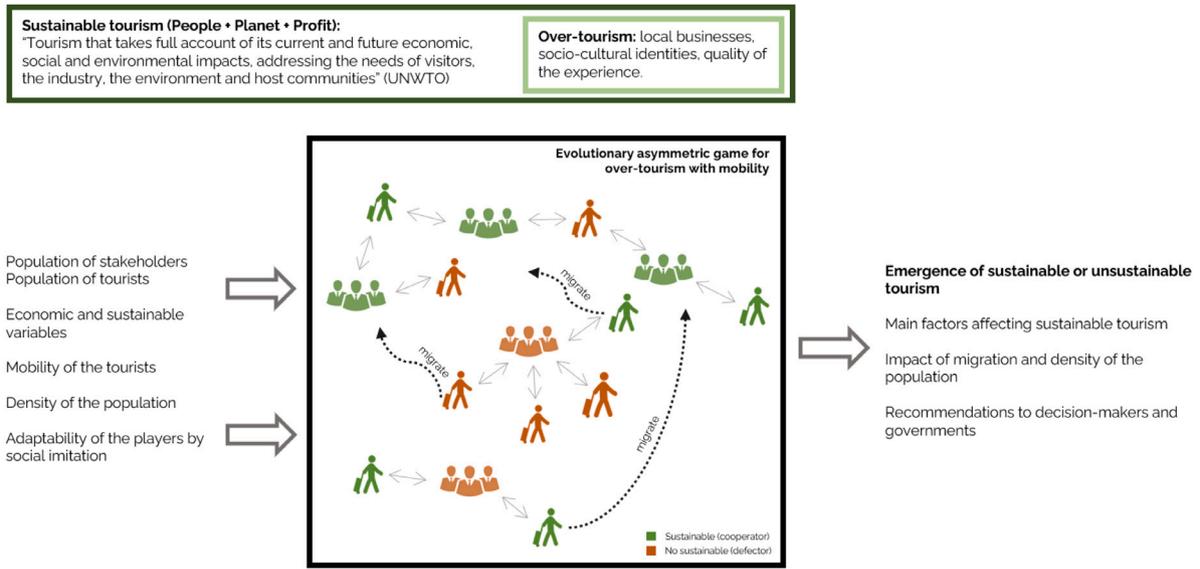


Fig. 1. Theoretical framework and outline of our proposed evolutionary model for sustainable tourism.

( $T$ ) or a stakeholder ( $S$ ). The model satisfies that  $Z = Z_T + Z_S$  with  $Z_T$  being the number of tourists and  $Z_S$  the number of stakeholders. All the players are distributed on the nodes of a social network. Specifically, we consider a regular lattice, given its simplicity with respect to other interaction networks such as scale-free networks but still ensuring the fundamental property of a limited players interaction range. Thanks to this limitation in the interaction range provided by the square lattice, we provide sufficient conditions to observe all possible results that are due to pattern formation in the studied system. The regular lattice has size  $L \times L$ , being  $Z \leq L \times L$  so the lattice can have vacant cells. We call  $\rho = \frac{Z}{L \times L}$  to the time invariant population density of the lattice and  $\rho_T = 1 - \frac{Z_S}{Z}$  to the tourism pressure.

Independently from its role, an agent  $i$  from both populations can adopt two strategies: cooperation  $C$  or defection  $D$ . Tourist cooperators are noted by  $TC$  while tourist defectors are noted by  $TD$ . We use the same notations for stakeholders, being  $SC$  and  $SD$  the stakeholder cooperators and stakeholder defectors, respectively. In our model, cooperation means to be sustainable while defection is understood as a tourist option that does not consider sustainability in the tourism transaction.

### 3.1. Payoffs matrix

We define here the pair-wise interaction between two players in the game having opposing roles. In the model, a cooperative behavior towards sustainability can be seen as obtaining an added value to the tourism experience and some revenue for stakeholders while both of them pay a cost in a short-term horizon. Table 1 shows the payoff matrix for the asymmetric game and their interactions of these two types of roles and both cooperating and defecting strategies.

In the defined payoffs matrix, every cooperating tourism stakeholder  $SC$  offers a sustainable product or service to a tourist. A tourist pays then an additional cost  $\epsilon \in [1, 2]$  for this sustainable transaction but obtains an added value  $v$  (we set  $v = 1$  for simplicity in the rest of the paper). This additional cost is also referred as the willingness to pay value for a consumer when having sustainable products or services to be chosen in their decision process (Zhao et al., 2018). On the other hand, the revenue obtained by the stakeholder from the sustainable transaction is equal to the additional cost  $\epsilon$  paid by the tourist.

If a tourist player defects ( $TD$ ) and is not sustainable when the stakeholder offers a sustainable asset, the cooperator stakeholder  $SC$  reduces her/his profit by an additional cost  $\gamma \in [0, 1]$ . Tourists, both

Table 1

Payoffs matrix for each player in the asymmetric game for sustainable tourism.

	Tourism stakeholder ( $S$ )	
	$C$	$D$
Tourist ( $T$ )		
$C$	$v - \epsilon, \epsilon$	$-1 - \tau, 1$
$D$	$v - \epsilon, \epsilon - \gamma$	$-1, 1$

Notes:  $\epsilon$  is the cost for the tourist when choosing sustainable tourism (the revenue for the stakeholder);  $v$  is the added sustainability value for the tourist;  $\gamma$  is the additional cost to stakeholder for attending a tourist defector; and  $\tau$  is the tourist discomfort when the provided offer is not fulfilling their expectations.

cooperators  $TC$  and defectors  $TD$ , obtain the added value from the sustainable service  $v$  minus its additional cost  $\epsilon$  from the transaction with cooperating stakeholders. When a stakeholder adopts a defecting strategy  $SD$ , its payoff is a normalized value of 1 independently from the strategy followed by tourists. Cooperating tourists  $TC$  also pay a cost when stakeholders do not provide a sustainable asset, modeled by a discomfort parameter  $\tau \in [0, 1]$ . In this way, tourists obtain a lower payoff of  $-1 - \tau$  if they adopt a sustainable or cooperation strategy  $C$  and they do not obtain the expected venue.

### 3.2. Payoffs accumulation and players' strategy update

Players of both roles interact with their direct neighbors in a pair-wise interaction in the lattice. A focal player  $i$  only plays with those having opposing roles and accumulates its payoff in  $\Pi_i$  from all its interactions if at least there is one possible interaction; being four the maximum number of possible interactions if all the neighboring cells are occupied by agents of opposing roles.

The dynamics of the game includes an imitation process of the neighboring agents in the spatial lattice and a mutation to randomly change the strategies of the players at every time step  $t$ . A player  $i$  changes its strategy at random with a mutation probability  $\mu$  and imitates the strategy of a local neighbor with probability  $1 - \mu$ . As players will keep their role for the whole simulation, they can only imitate other players in the lattice having the same role in the game. After playing the pairwise interactions in the lattice and accumulating its payoffs in  $\Pi_i$ , a player  $i$  has the opportunity of updating its strategy according to this payoff value in previous time step  $t - 1$  and the ones from their neighbors.

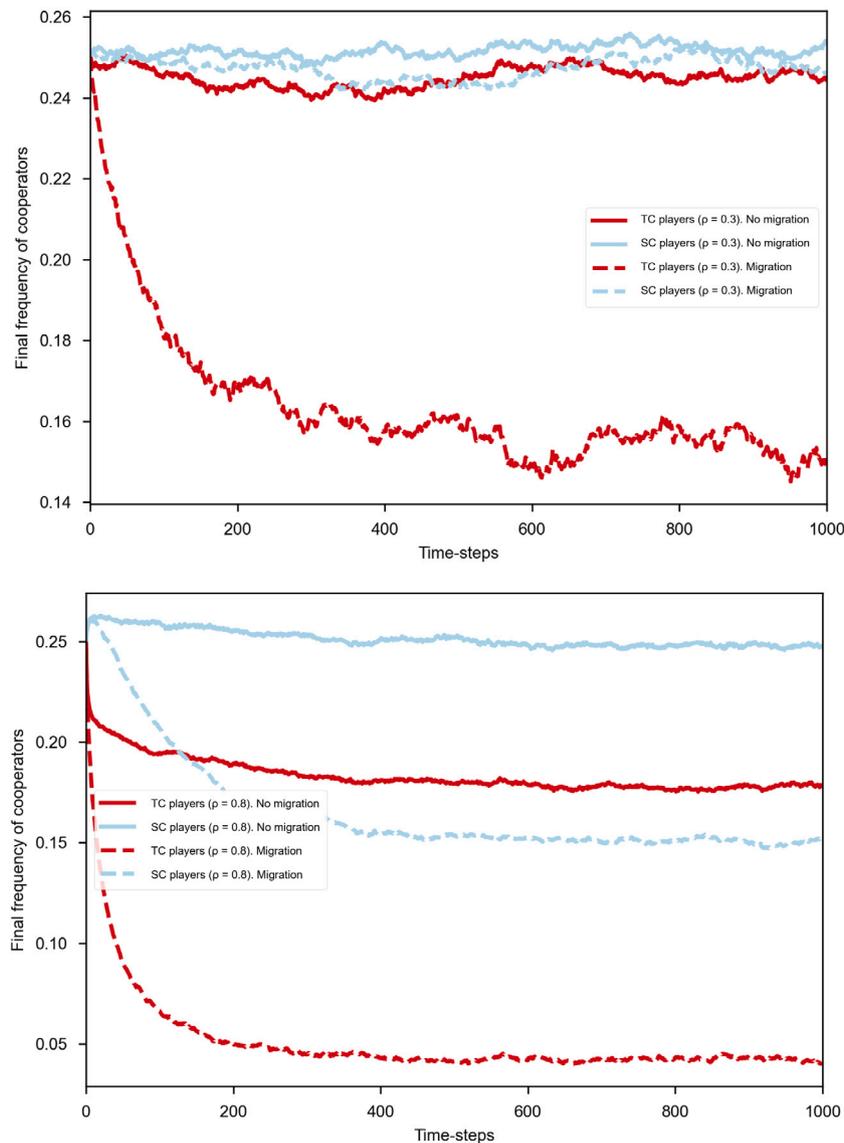


Fig. 2. We observe from the simulation results how the system easily achieves a stationary state for two different densities  $\rho \in \{0.3, 0.8\}$ , with and without migration. The rest of parameters are  $\epsilon = 2.0$ ,  $\gamma = 1.0$ ,  $\tau = 0.5$  with equal initial frequency of strategies.

In this imitation process, a player  $i$  imitates a player  $j$  having the same role as  $i$  with a probability  $p_{i \rightarrow j}$  that increases with their payoff difference  $(\Pi_j - \Pi_i)$ , being  $\Pi_i$  and  $\Pi_j$  the payoffs of  $i$  and  $j$  in  $t - 1$ , respectively), as done in (Traulsen et al., 2006):

$$p_{i \rightarrow j} = \frac{1}{1 + e^{-(\Pi_j - \Pi_i)/\kappa}}, \tag{1}$$

where the amplitude of noise  $\kappa$  equals to 0.1 as done in Wang et al. (2021c) and Zhang et al. (2021). It is important to notice that a player  $j$  cannot be imitated if it did not interact with any other player and did not accumulate any payoff in previous time step  $t - 1$ . This can happen if, for instance, a player is isolated in the lattice or all the neighboring players have the same role.

### 3.3. The migration process

The model also considers a migration process for players having a tourist role. Tourist players move through the lattice at each time step  $t$  to a vacant neighboring cell independently from their strategy. In case there are more than one neighboring vacant positions, the agent picks one vacant position at random for the migration movement. Stakeholder players cannot move and keep the same position of the

spatial cell during the simulation. If population density  $\rho = 1$ , the spatial lattice has no vacant positions and therefore, no migration is allowed.

### 3.4. Agent-based computer simulations

We use Monte-Carlo (MC) agent-based simulations (Macal and North, 2005; Adami et al., 2016), performed in computing clusters and resorting to parallel computing architectures. Evolution proceeds in discrete steps involving the payoffs accumulation, update rules, and migration processes in line with the dynamics described above. The mutation (or exploration) probability ( $\mu$ ) equals  $\frac{1}{Z}$  in all experiments.

For the agent-based simulations, the size of the population is  $Z = 4.9 \times 10^3$  in a squared regular lattice of  $70 \times 70$  with periodic boundary conditions and Von Neumann neighborhood. Each node of the lattice is either vacant or occupied by one player. The vacant positions are given by density  $\rho$ . We run the model for 30 independent MC realizations and a maximum number of  $10^3$  synchronous time steps, where all the realizations reach a stationary stable state and deviation from the MC realizations is low. Finally, all the simulation results were obtained by averaging the last 25% of the simulation time steps in the independent MC realizations.

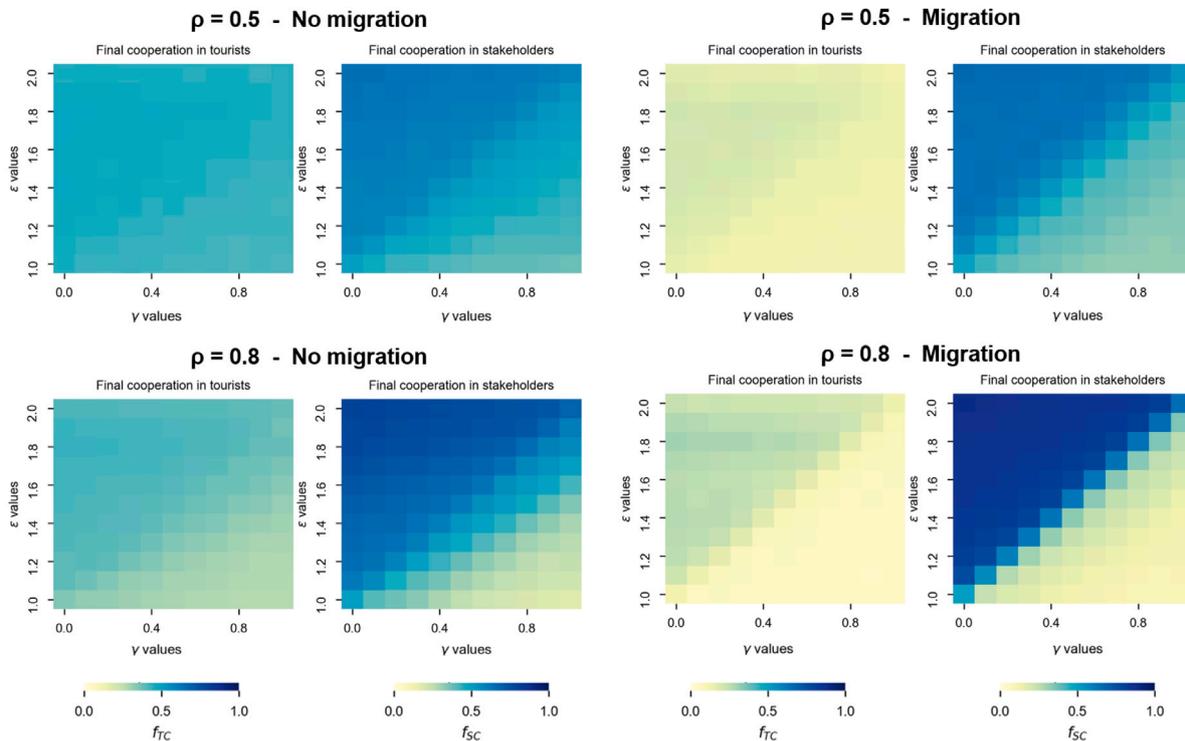


Fig. 3. Final frequency of  $TC$  and  $SC$  for a sensitivity analysis on  $\gamma$  and  $\epsilon$  parameters ( $\tau = 0.5$ ). We see how migration reduces cooperation for tourists and generates two clear different regions with global cooperating and defecting strategies (polarization of the population). Higher densities also help to achieve this polarization.

#### 4. Results

We first analyze the general dynamics of the asymmetric model. Later, we evaluate the implications of the main parameters for both sub-populations and how population density and migration affect the outcome of the model. Finally, we present the spatial formations obtained in the lattice.

##### 4.1. Temporal evolution of the model and stationary state

As stated in Section 3.4, the model needs to be analyzed through simulations since general results for asymmetric games do not apply in the context of a game in structured network allowing migration. Nevertheless, we can first analyze the asymptotic trend of the model in a simpler case, well-mixed and infinite population, by using the replicator equation. Calculation details can be found in Appendix. Under these conditions, the asymptotic stable strategy depends on the relative values between the stakeholders' benefit margin when being sustainable and attending a cooperator tourist ( $\epsilon - 1$ ) and the cost for attending a defector tourist ( $\gamma$ ). The final strategy is pure defection in both populations when  $\gamma > \epsilon - 1$  and pure cooperation only for stakeholders when  $\gamma \leq \epsilon - 1$ . The specific asymptotic stable strategy for tourists in the latter case ranges between pure cooperation and pure defection, depending on the initial cooperation levels in both populations.

The latter observation helps to foresee the outcomes for the general model. First, we study whether the simulations converge to stable strategies for different values of the parameters. Fig. 2 presents the temporal evolution of the strategies adopted by tourist and stakeholder players under different population densities  $\rho$  and migration settings. The results confirm that the strategy stabilizes after 400 time steps for most of the cases. The highest variability in the final frequency of strategies are when having low population densities ( $\rho = 0.3$ ) with migration. Nevertheless, these figures confirm the stability of the cooperation levels in the long term for different conditions of the game. Additionally, no significant changes were observed when modifying the

initial frequency of strategies for both roles of players. Therefore, we will set an equal initial frequency of strategies to have the same number of players with  $TC$ ,  $TD$ ,  $SC$ , and  $SD$  in the rest of the experiments.

##### 4.2. Migration and population densities effects

In this section we run different sensitivity analysis on the main parameters of the model to understand the dynamics of the game when having migration under different densities of the population. First, Fig. 3 shows a sensitivity analysis on tourists' cost ( $\epsilon$ ) and stakeholders' cost ( $\gamma$ ) when having different population densities ( $\rho$ ), by also comparing the dynamics with and without migration. Values of the heatmaps show the final frequency of tourists cooperators  $f_{TC}$  and stakeholders cooperators  $f_{SC}$ .

From Fig. 3 we can observe how the results for high density values ( $\rho = 0.8$ ) are similar to the analytical outcome of the well-mixed and infinite population shown in Appendix. When  $\gamma > \epsilon - 1$ , pure defection is the expected stable strategy for both types of players  $TC$  and  $SC$ . When  $\gamma \leq \epsilon - 1$ , stakeholders show high levels of cooperation in the population. In the latter case, the stable strategy for tourists depends on the specific initial conditions.

When migration is introduced, we are favoring more interactions among tourist and stakeholders by consequently relaxing the effect of the fixed lattice. This generates two clear regions with global cooperating and defecting strategies for stakeholders, above and below the line  $\gamma = \epsilon - 1$ . Some combinations of parameters generate a full cooperation in the sub-population of stakeholders ( $f_{SC}$  is 1). In contrast, migration is clearly decreasing cooperation for tourists for different density values. Therefore, when migration is not induced, the boundary between having either cooperating or defecting populations is smoother for stakeholders while final frequency of  $TC$  is almost independent from the parameters of the model and higher than when having migration.

In order to further study the effects of the parameters in the model, Fig. 4 shows the final frequency of cooperators  $f_{TC}$  and  $f_{SC}$  for a sensitivity analysis on stakeholders' costs ( $\gamma$ ) and tourist discomfort ( $\tau$ ).

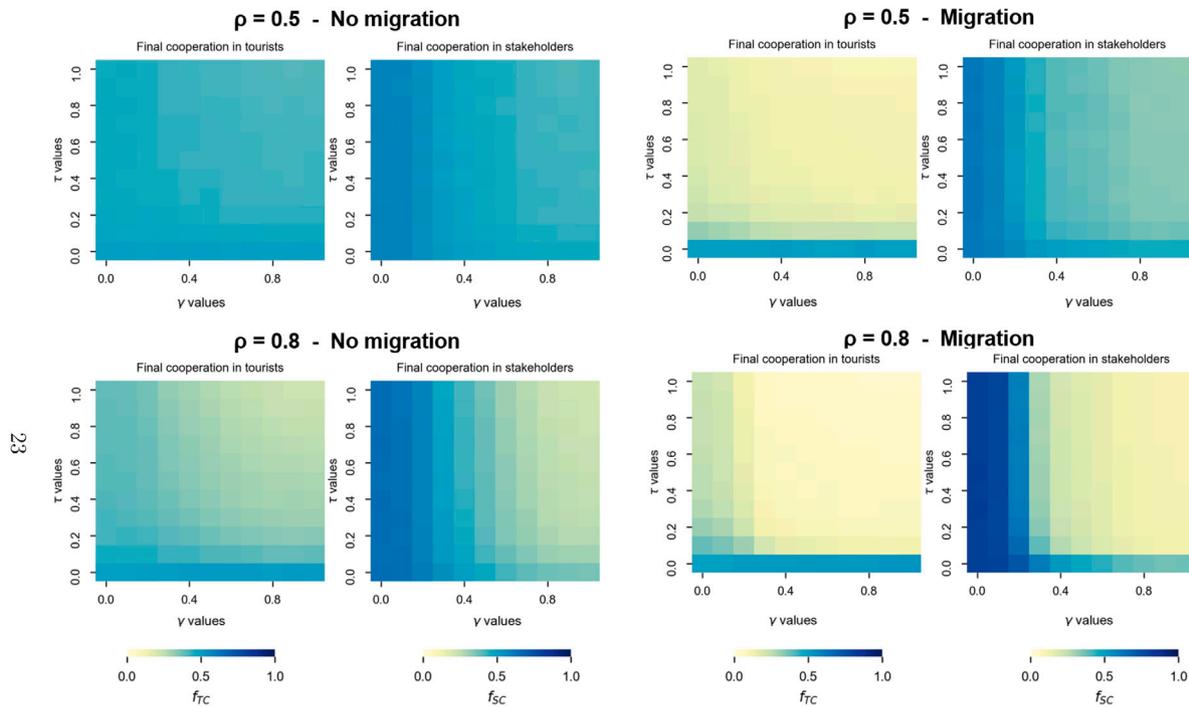


Fig. 4. Final frequency of  $TC$  and  $SC$  for a sensitivity analysis on  $\gamma$  and  $\tau$  parameters ( $\epsilon = 1.2$ ). We show that low densities increase cooperation in tourists as well as reduces polarization in the results. The inclusion of migration favors the opposite: higher polarization in the results and a lower tourists' cooperation level.

We test different density values  $\rho$  as done before, with and without inducing migration for tourists. The results confirm that the effect of the tourist discomfort is less significant than the other parameters, as shown in the analytical study for the well-mixed population in Appendix.

More importantly, we observe the same insights with respect to the effects of densities and migration in the final frequency of cooperators for both sub-populations. We can summarize the main observations below:

- When allowing migration, results are more polarized than when migration is not allowed and higher levels of cooperation are achieved for stakeholders. However, cooperation in the tourists sub-population ( $f_{TC}$ ) is decreased with respect to no migration. This phenomenon was also observed in Fig. 3.
- Decreasing the population density reduces results' polarization as well as increases homogeneity in the results. Stakeholders are the players having the highest sensitivity with respect to the parameters' values and the final cooperation. For instance, when  $\rho = 0.8$  and migration is induced, there is a steep and rapid transition from  $f_{SC} = 1$  to  $f_{SC} = 0$ .
- Tourists obtain higher level of cooperation when population densities are low. The final stable strategy depends on the specific initial conditions. Therefore, crowded populations increase the chances of having defecting tourists, apart from rapidly moving from defecting to cooperating states in the sub-population of stakeholders.

#### 4.3. Spatial formation

Fig. 5 shows the lattices at time steps  $t = 0$  and  $t = 900$  for the population of players without migration and full density. In addition, Fig. 6 shows the lattices for the same time steps  $t = 0$  and  $t = 900$  when having migration and  $\rho = \{0.3, 0.8\}$ . Tourists are represented by red cells (light red for  $TC$  and intense red for  $TD$ ) while stakeholders are blue cells (light blue for  $SC$  and intense blue for  $SD$ ). When the density of the population is not full, white cells are vacant cells.

For all the cases we can see how, when showing the stationary state at  $t = 900$ , there are clear spatial formations of cooperators and defectors of opposing roles. Cooperators in the two sub-populations are joined in isolated or weakly interconnected clusters. The same spatial disposition occurs for defectors in the two populations. When including migration, the cooperators clusters are smaller and more isolated, whereas the defective strategy predominates.

### 5. Discussion

We present in this section the theoretical implications of our study in Section 5.1, the practical insights obtained from the model in Section 5.2, and the limitations of our work in Section 5.3.

#### 5.1. Theoretical implications

The evolutionary game model presented in this paper explains how the players' behavior in the tourism system (tourist and stakeholder) determines over-tourism in a tourist area. Previous analyses have described multiple causes of over-tourism, such as the irruption of Airbnb, low-cost trips and unsustainable behavior (Koens et al., 2018; Goodwin, 2017). However, the mechanism from which the destination slides into over-tourism has not been addressed in the scientific literature yet. In this regard, this paper attempts to represent this mechanism by using a dynamic model where tourist and stakeholder interact in a spatial structure.

Previous applications of evolutionary games that analyze the adoption of sustainable practices in tourism assume the existence of an exogenous incentive to favor sustainable practices. For example, subsidies and penalties to stakeholder (He et al., 2018; Wang et al., 2021b) or environmental bonus to tourist (Antoci et al., 2013). This kind of incentives are absent in our model. Instead, the model describes how sustainable or unsustainable tourism can arise from the economic and psychological conditions of the players, without any external intervention.

Then, the model and its results present an innovative focus to the question of sustainability, showing the factors that help or hinder

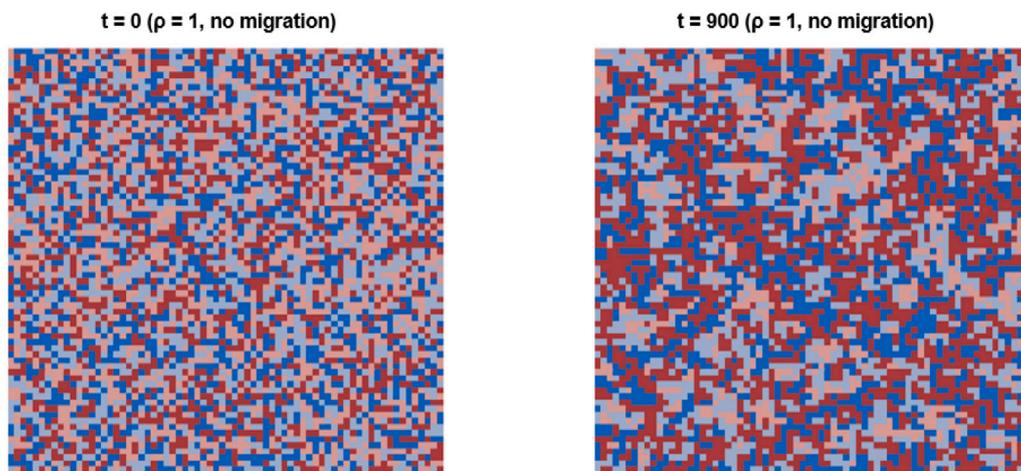


Fig. 5. Lattices showing spatial formations with players of similar strategies from  $t = 0$  (left plot) to  $t = 900$  (right plot) when having full density  $\rho = 1$  and without migration. Colors mean: red ( $TD$ ); light red ( $TC$ ); Blue ( $SD$ ), light blue ( $SC$ ). The rest of parameters are  $\mu =$ ,  $\epsilon = 1.2$ ,  $\gamma = 0.3$ ,  $\tau = 0.5$ .

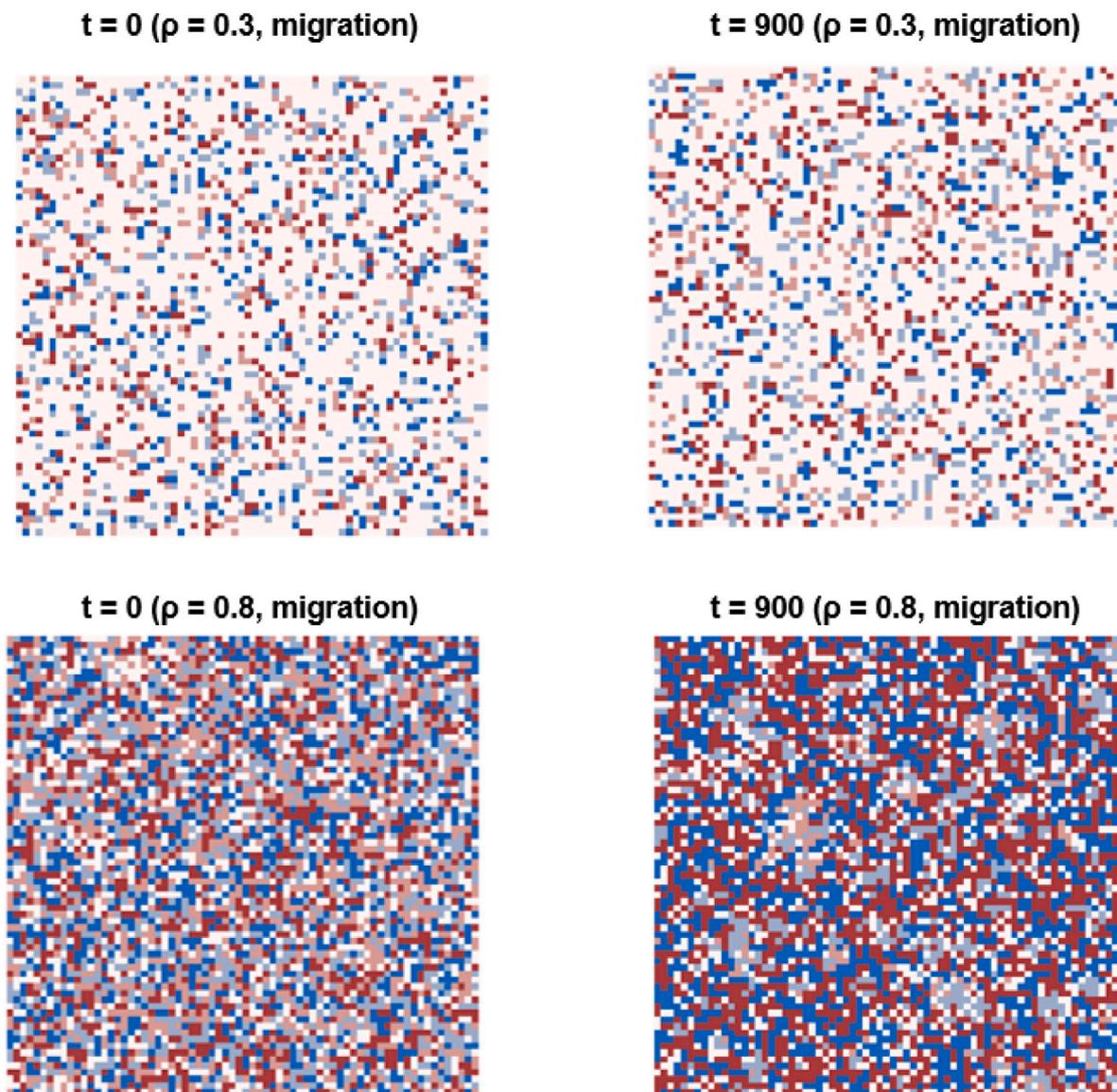


Fig. 6. Lattices showing spatial formations with players of similar strategies from  $t = 0$  (left column) to  $t = 900$  (right column) for  $\rho = \{0.3, 0.8\}$  when allowing migration. Colors mean: red ( $TD$ ); light red ( $TC$ ); Blue ( $SD$ ), light blue ( $SC$ ), and white cells are vacant cells. The rest of parameters are  $\mu =$ ,  $\epsilon = 1.2$ ,  $\gamma = 0.3$ ,  $\tau = 0.5$ .

agents (tourist and stakeholders) to adopt sustainable behavior. The findings provide useful information for researchers and practitioners about the inner forces that lead to (un)sustainable tourism. Specifically, two relevant findings can be extracted from the simulations of the model. First, we show that sustainable tourism primarily depends on the relative importance between revenue margin and costs to stakeholder when offering a sustainable product, whereas the tourist discomfort with unsustainable service does not play a major role. And second, we generally observe that reducing the density and migration of the population of tourists generates homogeneous outcome for diverse values of the model's parameters such as tourists and stakeholders costs or tourist discomfort. In other words, long-term over-tourism is more likely if the population density and tourist mobility in the destination is high.

Those previous findings determine a starting point to further analyze the factors influencing over-tourism in touristic areas by including new real-based conditions to the model, such as another social structure and governmental interventions. Moreover, although the model was applied to tourism, its definition and results can be applied to other similar phenomenon where interactions between customers and stakeholders generate a sustainability problem.

### 5.2. Practical implications

The findings in this paper can be used to check the suitability of the policy measures currently implemented in certain destinations to manage over-tourism, such as limiting accommodation and service growth, banning tourist visits, imposing higher fees and taxes to tourists, and regulating tourist's behavior. Among them, those policies oriented to limit tourism growth and prevent high affluence of tourist, consequently reducing population density in the destination, are validated by our findings. In addition, measures to discourage or avoid spatial tourist mobility will favor long-term sustainability as well. However, regulations oriented to increase costs to tourists, such as fees or taxes, are not justified by our results.

Additionally, our findings can be employed to propose novel recommendations to help destination managers and decision makers when implementing sustainable policies. The outcome of the model shows that the elements governing the economic benefit and cost of tourism stakeholders are the key factors explaining over-tourism, independently on forces explaining tourist's decision. Therefore, managers have to first point actions to increase stakeholder revenues obtained with sustainable tourist practices, such as those respecting local culture, preserving environment and disturbing the least to the local lifestyle.

### 5.3. Limitations

This work presents some limitations. The phenomenon of over-tourism is complex and some aspects are not considered in this evolutionary model. One of these aspects is that the model only focuses on tourists and stakeholders' behavior, given aside other effects driving to over-tourism, such as the environmental conditions. Moreover, we do not include the features of the products or services offered by stakeholders nor the adaptation of their portfolio of assets for tourists.

## 6. Concluding remarks and future work

The study we present here models how over-tourism can arise from the dynamic interactions among tourists and local stakeholders. Players of the evolutionary game from both roles decide at every time step whether having a sustainable or unsustainable behavior and obtain a pay-off from these pair-wise interactions. Then, the model includes a dynamic mechanism in the agents' behavior to achieve a long-term situation with or without over-tourism. The model allows analyzing the influence of some factors on achieving long-term sustainable tourism.

Our results show that, in areas with high tourist density, the relative values between the benefit margin for cooperative stakeholders when interacting with a sustainable tourist and the cost for attending a tourist defector determines the final outcome. Thus, when the benefit margin is greater than the cost, a sustainable situation in the long term is expected. The opposite occurs if the benefit margin is lower than the cost. Other factors, such as the tourist discomfort and the added values for tourist, play a lower role in sustainability.

The effect of the spatial migration or movements of the tourists as well as population have also been analyzed. The general finding is that migration and high density reduces the general levels of cooperation for tourists while polarize the results for the stakeholders population. In fact, cooperation is both maximum and minimum for stakeholders when having high density and tourists' migration. Finally, we also observed spatial formations in the lattice where we find islands of both roles (i.e., tourists and stakeholders) having the same strategy. These results are also found when the density is decreased and both with and without migration.

Future research can be extended in different ways. First, rewarding policies (Chen et al., 2015) can be applied to one or both of the player roles of the game to aid decision makers in their task to decide how they configure their incentivization policies. Second, more advanced migration processes, closer to the tourism reality, can be incorporated into the model. Finally, another interesting future path will be studying a more general evolutionary framework able to analyze and understand the effects of migration processes in asymmetric evolutionary games.

### CRedit authorship contribution statement

**Manuel Chica:** Software, Methodology, Validation, Investigation, Writing – original draft, Funding acquisition. **Juan M. Hernández:** Conceptualization, Investigation, Formal analysis, Writing – original draft. **Matjaž Perc:** Methodology, Formal analysis, Writing – review editing.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Acknowledgments

M.C. was supported by the Spanish Ministry of Science, Andalusian Government, University of Granada, and ERDF under grants SIMARK (P18-TP-4475), RYC-2016-19800, and PPJIA2020-09 (TURCOMPLEX). J.H. was supported by the University of Las Palmas de Gran Canaria, under grant COVID-19 04. M.P. was supported by the Slovenian Research Agency (Grant Nos. P1-0403 and J1-2457). Funding for open access charge: Universidad de Granada/CBUA.

### Appendix

Here we analyze the asymptotic stable points for the bi-matrix game with pay-off shown in Table 1, assuming a well-mixed infinite population.

A simple algebraic manipulation of the pay-off matrix leads to conclude that double-defection strategy is a strict Nash equilibrium (NE) if and only if  $\gamma > \epsilon - 1$  and therefore it is the asymptotically stable strategy (Cressman and Tao, 2014).

To analyze the case  $\gamma \leq \epsilon - 1$ , we make use of the replicator equation (Hofbauer and Sigmund, 2003). First, by adding convenient constants to the columns, we transform the pay-off matrix in Table 1 into two square pay-off matrices with diagonal terms equal zero, they are

$$T = \begin{pmatrix} 0 & -\tau \\ 0 & 0 \end{pmatrix}, \quad S = \begin{pmatrix} 0 & \epsilon - 1 - \gamma \\ -(\epsilon - 1) & 0 \end{pmatrix}.$$

Matrix  $T$  and  $S$  have the same replicator equation than the pay-off matrices for tourists and stakeholders, respectively. We note  $x$  and  $y$  the proportion of cooperators in the tourist and stakeholder population, respectively. It is clear that  $0 \leq \{x, y\} \leq 1$ . Then, the dynamic evolution of these variables is governed by the following differential equations:

$$\begin{aligned} \dot{x} &= -\tau x(1-x)(1-y), \\ \dot{y} &= \gamma y(1-y) \left( \frac{\epsilon-1-\gamma}{\gamma} + x \right). \end{aligned} \quad (2)$$

Given that  $\epsilon - 1 - \gamma \geq 0$ , the equilibrium or rest points of this system are  $(x_1, y_1) = (0, 0)$ ,  $(x_2, y_2) = (1, 0)$  and the segment formed by  $y = 1$  and any value  $x \in [0, 1]$ . Analyzing the Jacobian matrix of the system (2), points  $(x_1, y_1) = (0, 0)$  and  $(x_2, y_2) = (1, 0)$  are unstable. However, any point in the segment  $y = 1$  and  $0 \leq x \leq 1$  is stable. Then, these infinite points are potential asymptotic stable strategies, which are characterized by pure cooperation for stakeholders and any cooperation level for tourists. The specific asymptotic strategy of tourists depends on the initial cooperation levels in the two populations.

## References

- Adami, C., Schossau, J., Hintze, A., 2016. Evolutionary game theory using agent-based methods. *Phys. Life Rev.* 19, 1–26.
- Antoci, A., Borghesi, S., Galeotti, M., 2013. Environmental options and technological innovation: An evolutionary game model. *J. Evol. Econ.* 23, 247–269.
- BBC, 2018. Thai beach from leonardo DiCaprio film to close temporarily.
- Berlinghieri, L., 2021. Venezia a numero chiuso: dall'estate 2022 occorrerà prenotarsi e pagare l'accesso.
- Bramwell, B., Higham, J., Lane, B., Miller, G., 2017. Twenty-five years of sustainable tourism and the journal of sustainable tourism: looking back and moving forward. *J. Sustain. Tourism* 25, 1–9.
- Chen, X., Sasaki, T., Brännström, Å., Dieckmann, U., 2015. First carrot, then stick: how the adaptive hybridization of incentives promotes cooperation. *J. R. Soc. Interface* 12, 20140935.
- Cheung, K.S., Li, L.H., 2019. Understanding visitor–resident relations in overtourism: developing resilience for sustainable tourism. *J. Sustain. Tourism* 27, 1197–1216.
- Chica, M., Hernández, J.M., Bulchand-Gidumal, J., 2021. A collective risk dilemma for tourism restrictions under the covid-19 context. *Sci. Rep.* 11, 1–12.
- Cressman, R., Tao, Y., 2014. The replicator equation and other game dynamics. *Proc. Natl. Acad. Sci. USA* 111, 10810–10817.
- Dodds, R., 2007. Sustainable tourism and policy implementation: Lessons from the case of Calviá, Spain. *Curr. Issues Tourism* 10, 296–322.
- Goodwin, H., 2017. The challenge of overtourism.
- Goodwin, H., 2019. Overtourism solutions: Strategies to manage mass tourism.
- Guo, H., Li, X., Hu, K., Dai, X., Jia, D., Boccaletti, S., Perc, M., Wang, Z., 2020. The dynamics of cooperation in asymmetric sub-populations. *New J. Phys.* (22).
- Hauert, C., Saade, C., McAvoy, A., 2019. Asymmetric evolutionary games with environmental feedback. *J. Theoret. Biol.* 462, 347–360.
- He, P., He, Y., Xu, F., 2018. Evolutionary analysis of sustainable tourism. *Ann. Tourism Res.* 69, 76–89.
- Hofbauer, J., Sigmund, K., 2003. *Evolutionary Games and Population Dynamics*. Cambridge University Press.
- Khalil, S., 2017. Taj mahal dropped from tourism booklet of Uttar Pradesh.
- Koens, K., Postma, A., Papp, B., 2018. Is overtourism overused? Understanding the impact of tourism in a city context. *Sustain. (Switzerland)* 10, 1–15.
- Macal, C.M., North, M.J., 2005. Tutorial on agent-based modeling and simulation. In: *Proceedings of the 37th Conference on Winter Simulation*. ACM, pp. 2–15.
- McAvoy, A., Hauert, C., 2015. Asymmetric evolutionary games. *PLoS Comput. Biol.* 11, 1–26.
- Mihalic, T., 2016. Sustainable-responsible tourism discourse - towards 'responsustable' tourism. *J. Cleaner Prod.* 111, 461–470.
- Mihalic, T., 2020. Conceptualising overtourism: A sustainability approach. *Ann. Tourism Res.* (84).
- Milano, C., Novelli, M., Cheer, J.M., 2019. Overtourism and tourismphobia: A journey through four decades of tourism development, planning and local concerns. *Tourism Plan. Develop.* 8316.
- Ohtsuki, H., 2010. Stochastic evolutionary dynamics of bimatrix games. *J. Theoret. Biol.* 264, 136–142.
- Pacheco, J.M., Vasconcelos, V.V., Santos, F.C., 2014. Climate change governance, cooperation and self-organization. *Phys. Life Rev.* 11, 573–586.
- Seraphin, H., Sheeran, P., Pilato, M., 2018. Over-tourism and the fall of venice as a destination. *J. Destination Market. Manage.* 9, 374–376.
- Szabó, G., Fáth, G., 2007. Evolutionary games on graphs. *Phys. Rep.* 446, 97–216.
- Szolnoki, A., Perc, M., 2018. Evolutionary dynamics of cooperation in neutral populations. *New J. Phys.* (20).
- Traulsen, A., Nowak, M.A., Pacheco, J.M., 2006. Stochastic dynamics of invasion and fixation. *Phys. Rev. E* 74, 011909.
- UNWTO, 2004. Indicators of sustainable development for tourism destinations.
- UNWTO, 2022. Sustainable development. Definition. n.d., Retrieved 03/05/2022.
- Wang, W., Feng, L., Zheng, T., Liu, Y., 2021b. The sustainability of ecotourism stakeholders in ecologically fragile areas: implications for cleaner production. *J. Cleaner Prod.* 279, 123606.
- Wang, L.e., Filimonau, V., Li, Y., 2021a. Exploring the patterns of food waste generation by tourists in a popular destination. *J. Cleaner Prod.* 279, 123890.
- Wang, Y., Wang, X., Ren, D., Ma, Y., Wang, C., 2021c. Effect of asymmetry on cooperation in spatial evolution. *Phys. Rev. E* 103, 1–11.
- WCED, 1987. *Our Common Future*. Technical Report.
- Weaver, D.B., 2012. Organic, incremental and induced paths to sustainable mass tourism convergence. *Tour. Manag.* 33, 1030–1037.
- Zhang, L., Huang, C., Li, H., Dai, Q., Yang, J., 2021. Effects of directional migration for pursuit of profitable circumstances in evolutionary games. *Chaos Solitons Fractals* 144, 110709.
- Zhao, R., Geng, Y., Liu, Y., Tao, X., Xue, B., 2018. Consumers' perception, purchase intention, and willingness to pay for carbon-labeled products: A case study of chengdu in china. *J. Cleaner Prod.* 171, 1664–1671.