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Venice and Overtourism: Simulating Sustainable Development Scenarios through a Tourism Carrying Capacity Model

Dario Bertocchi ¹, Nicola Camatti ^{1,*}, Silvio Giove ¹ and Jan van der Borg ^{1,2}

¹ Department of Economics, Ca' Foscari University of Venice, San Giobbe 873, 30121 Venezia, Italy; dario.bertocchi@unive.it (D.B.); sgiove@unive.it (S.G.); jan.vanderborg@kuleuven.be or vdborg@unive.it (J.v.d.B.)

² Department of Earth and Environmental Sciences, KU Leuven, Oude Markt 13, 3000 Leuven, Belgium

* Correspondence: nicola.camatti@unive.it

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Abstract: Overtourism problems, anti-tourist movements and negative externalities of tourism are popular research approaches and are key concepts to better understand the sustainable development of tourism destinations. In many of the overtourism narratives, Venice is considered to be one of the most relevant cases of overtourism and therefore has become a laboratory for studying the different conflicts that emerge when tourism numbers continue to grow and the quality of the tourism flow continues to decline. This article is therefore focusing on Venice and on one of the possible solutions to mitigate the negative impacts of tourism represented by the concept of a tourist carrying capacity (TCC) in an urban destination. The aim of this paper is to discuss alternative methodologies regarding the calculation of the TCC, and to apply a fuzzy instead of a 'crisp' linear programming model to determine the scenarios of a sustainable number of tourists in the cultural destination of Venice, looking for the optimal compromise between, on the one hand, the wish of maximizing the monetary gain by the local tourism sectors and, on the other, the desire to control the undesirable effects that tourism exerts on a destination by the local population. To solve the problems related to tourism statistics and data availability, some uncertainty in the parameters has been included using fuzzy numbers. The fuzziness in the model was introduced on the basis of questionnaires distributed among both tourists and residents. By applying the fuzzy linear programming model to the emblematic case of Venice, it was shown that this approach can indeed help destinations to understand the challenges of sustainable tourism development better, to evaluate the impact of alternative policies of overtourism on the sustainability of tourism, and hence, to help design a strategy to manage tourist flows more adequately

Keywords: tourism carrying capacity; sustainable tourism solutions; cultural tourism destination; overtourism; Venice

1. Introduction

The Italian city of Venice has become an emblematic example of a destination struggling with what is now frequently called overtourism. As was illustrated in, for example, Van der Borg [1], over the past 25 years, the number of arrivals of tourism has quadrupled. The number of day-trippers was estimated to be around 5 million in 1988. At present, the number of excursionists is judged to amount to almost 22 million per year, almost five times as many as at the end of the 1980s.

According to the same author, this development has, first of all, been fueled by a continuous expansion of the global tourism market, and the United Nations World Tourism Organization (UNWTO) [2] forecasts a further doubling of international tourism between 2015 and 2030. In addition,

the quality of the visitors is considered to have changed dramatically. These changes are influenced by a number of fundamental developments in tourism, some of which have happened on a global level, others on a European or even an Italian level, such as:

- The emergence of *low-cost airlines* that allow more people to engage in city-tripping. This has certainly positively influenced the number of people who visit heritage cities in general, and Venice in particular. Moreover, in the case of Venice, it has allowed people to come from further away, and the dominance of the Austrian, Swiss, and German markets, observed in the 1980s and explained by their proximity, has been rapidly undermined;
- The rise of the sharing economy, facilitated by the diffusion of the *Internet* as an indispensable instrument for tourists to access information, reserve tourism products, and share their experience with others;
- The shift of the *economic barycenter* towards Central Europe, Asia, and South America. In fact, Brazilian, Chinese (the sixth market for Venice), and Russian clientele have gained importance, and their contribution to total tourist expenditure has grown considerably during the last decade;
- Instability on a global scale and terrorist attacks that have penalized some and benefited other destinations, including Venice;
- The increasing popularity of *cruise tourism* for which Venice is an attractive port of call, and since cruise ships have been growing increasingly large, its impact on Venice's relationship with tourism in general has become truly disturbing;
- The diversification of the *supply of accommodation*, from the year 2000 onwards, with the rise in the number of B&Bs, and more recently, of private apartments that are offered and reserved through dedicated web portals like *Airbnb*, and couch-surfing schemes. This emergence of cheaper forms of accommodation has probably helped overnight tourism at the expense of day-tripping and has, to a certain extent, enabled locals to have their part of the Venetian tourism cake.

These changes have without any doubt profoundly changed tourism in Venice and have led to an intensification of the discussion on whether tourism in Venice has become more or less sustainable over the years.

Since the end of the 1980s, sustainability of tourism development in Venice has been strongly linked with the concept of tourism carrying capacity. In fact, simulations of the carrying capacity of Venice by Costa and Van der Borg [3] and by Canestrelli and Costa [4] have confirmed that tensions exist between the city's tourism development process and the livability of the city for its inhabitants and non-touristic economic activities. In fact, in 1988, with an overall carrying capacity of around 10 million visitors per year, of which 45% were overnight tourists and 55% excursionists, and a quick rise to 14 million visitors per year equally distributed among tourists and excursionists, taking into account investments in local public transport, the management system of solid waste, and in particular, the expansion of the number of beds in tourist accommodation, it was already evident that the number of visitors was incompatible with the city's socio-economic needs. Moreover, the composition of the visitor ratio—20% of tourists to 80% of excursionists—was far from the optimal ratio of 50:50.

With the above-mentioned changes in the global tourism market, and especially the continuous expansion of international tourism, it makes considerable sense to update the simulations that were made more than 30 years ago, introducing some new methodological calculation expedients. This is precisely what this paper sets out to accomplish. More specifically, four main aspects were analyzed and introduced in the calculation: (1) The difficulties to collect the data at municipality level of the changes in the tourism sector described before, solved by representing the physical constraints of the destination not by introducing fixed numbers but by making use of intervals. (2) Consider the different mobility and behavior of visitors even in the same cluster of user (not all tourists sleeping in a hotel behave in the same ways; this is the reason why fuzziness has been introduced in the usage rate). (3) Realize a model able to simulate the impact that alternative policies for managing tourist flows can have on limiting the effects of excessive tourist pressure on certain tourism subsystems. (4) Define,

following the outcomes of the model, a possible tourism strategy that might not only be relevant for Venice but also for other destinations that have to cope with overtourism.

2. Literature Review

2.1. *Tourism Carrying Capacity: Some Conceptual Issues*

The growing pressure that the current explosion of tourist demand is exerting on tourist destinations is reaching such a dramatic level that tourism flow management is becoming a priority theme on the agenda of all the local governments that have decided to intervene effectively on the consequences induced by overtourism. Particularly, the knowledge of how many tourists a place, town, or larger destination can tolerate is turning out to be among the major challenges seized by an ever-increasing number of policymakers and scholars.

In fact, while on the one hand tourism can represent an important development opportunity, for example in terms of job chances [5–7], income, or new infrastructures [8–11], on the other it can be the cause of different costs for the community [12]. Undesirable effects can concern cost of living [13], changes in tradition [14], social conflicts [15,16], pollution, or congestion [17–19]. In general, it can be noted that tourists consume services, products, and other assets that are very often rival goods contended with residents. Tourists also make use of other resources, directly or indirectly related to the tourism sector, that in some cases are non-reproducible.

All these factors explain why local governments today are increasingly struggling with the choice of restricting the number of tourist presences, even though aware that an excessive reduction in visitor numbers can also negatively affect the monetary gain of the local tourism sectors.

How to determine and achieve the ‘best’ compromise between these two opposite needs is one of the ultimate goals pursued by studies on tourism carrying capacity (TCC) and various policies experimented by many destinations affected by overtourism [4].

Returning to a convenient explanation of TCC provided by the UNWTO in 1981, which defines it as “the maximum number of people that may visit a tourist destination at the same time, without causing destruction of the physical, economic and socio-cultural environment and unacceptable decrease in the quality of visitors’ satisfaction,” we could also state that TCC is a “multi-dimensional compromise” that embraces heterogeneous groups of physical, social, and economic effects induced by tourism, each of which is characterized by its own individual characteristics and consequences.

Social TCC, for example, refers to the effects induced by tourism pressure on the local population examined by authors such as Smith [20], Cooke [21], Pizam [8], and Saveriades [22], who specifically consider the degree of tolerance of the host population and quality of tourist experience. Models representing the relationship between residents and visitors have also been proposed, for example by Marzetti and Mosetti in 2004 [23] and Bimonte and Punzo in 2007 [24]. In relation to the physical and ecological carrying capacity, Mc Kercher [25] remarked that tourism, as an industrial activity, consumes local resources, makes use of infrastructures and produces waste. In fact, by its very nature, tourism is dependent on environmental influences and the fragile ecosystems involved need visitor control as underlined by Romeril [26].

Since TCC can be studied both in relation to its specific aspects and by a holistic approach, utilizing various different methodologies and approaches, the result is that no single and universal calculation method emerges [27]. The difficulty of determining a maximum visitor number, given the different carrying capacities each with a different dimension of sustainability, is also commented on by Seidl and Tisdell [28] and by Saarinen [29], according to whom the weakness of the concept lies in the use of values and perceptions on which it is based.

However, other authors assume a more open position. Watson and Kopachevsky [30] argue that the lack of tools by no means legitimizes dismissing TCC. They encourage critics to avoid neglecting the normative and discursive dimensions that lie behind it. Papageorgiou and Brotherton in 1999 [31] claim that TCC remains a useful concept for environmental management since it allows for the

deepening of relationships between the environment and human activities, while Mexa and Coccossis in 2004 [32] stress the importance of TCC as a valuable concept for the planning and management of sustainable tourism. One of the most proactive contributions is the work by Shelby and Heberlein [33]. They proposed, as reported in Coccossis et al. [34], a process of defining TCC based on two parts: A descriptive part, which aims to explain how the destination as a system works in relation to the triple bottom line and its main constraints, bottlenecks, and specific tourism problems; and an evaluative part, whose purpose is to finally identify the management strategies that should be undertaken to pursue the given goals.

From the point of view of the practical calculation of TCC, one of the most proactive lines of research is dedicated to the use of linear programming models. A recurring example is Soleimani and Jahanshahloo [35]. Within this line of research, a contribution that emerges due to its suitability for the study of different forms of carrying capacity of urban tourism destinations is the one by Canestrelli and Costa in 1991 [4]. That contribution is based on a fuzzy linear programming approach tested in the case of the historical center of Venice. The authors, referring to Fisher and Krutilla [36], highlight that TCC can be assumed as the maximum number of visitors that can be accommodated with a constant quality of their experience, by a given destination under conditions of maximum stress. That leads the authors to conceptualize TCC as a problem of benefits maximization under the presence of constraints representing the maximum stress bearable by the tourism subsystems of a destination which must not be violated by the entire system. Examples of subsystems are transport, accommodation, catering facilities, cultural offerings, and other facilities.

3. Materials and Methods

3.1. The Fuzzy Linear Programming (LP) Approach for the TCC. The Basic Model.

According to the basic linear programming model (BLP), the study of TCC is associated to a problem of maximizing the economic benefit generated by tourists in a destination, subject to several socio-environmental constraints. Given that the benefit is the sum of the different economic incomes, and that the constraints are the sum of the relative impacts in line with the type of tourist, the BLP model can be written in the canonical form:

$$\begin{cases} \max c^T x \\ Bx \leq d \\ x \geq 0 \end{cases} \quad (1)$$

where c_i : coefficients of the objective function, b_{ij} : technical coefficients, d_j : second side coefficients. Following the general TCC model presented by Canestrelli and Costa [4] for the case of Venice, three types of tourists and seven constraints can be considered. Tourists can be in fact divided into the three categories TH, NTH, and E. The first two are visitors that spend more than one day in the destination: Tourists in hotels (TH) and tourists in other types of accommodation, such as B&Bs and similar structures (NTH). Moreover, the center of Venice is also visited by excursionists, or day tourists (E). The constraints of the model instead refer to Venice's most intensively used tourism subsystems and to the level of tourist stress they can bear. The first two constraints include two upper bounds that limit the number of tourists, that is the number of available hotels and the availability of beds in accommodations such as B&B rooms. The third constraint refers to the restaurant capacity to serve meals, the fourth to the availability of parking places, and the fifth to the capacity of public transportation on the canals of the historical center (the so-called *vaporetti*). Finally, the last two restrictions refer respectively to the CC of the waste treatment system and to the maximum number of people that can be hosted in St Mark's Square (the non-reproducible resource of our model). On the other side, the coefficients of the objective function are formed by the daily expenditure of each of the three types of tourists considered.

Consequently, the model becomes:

$$\begin{cases} \max_x c_1 TH + c_2 NTH + c_3 E \\ TH \leq d_1 \\ TNH \leq d_2 \\ b_{3,1} TH + b_{3,2} NTH + b_{3,3} E \leq d_3 \\ b_{5,1} TH + b_{5,2} NTH + b_{5,3} E \leq d_5 \\ b_{6,1} TH + b_{6,2} NTH + b_{6,3} E \leq d_6 \\ b_{7,1} TH + b_{7,2} NTH + b_{7,3} E \leq d_7 \\ TH, NTH, E \geq 0 \end{cases} \quad (2)$$

where $b_{i,j}$, d_j are the left and right side constraints coefficients respectively. For instance, $b_{6,1}$ is the unitary daily waste production of tourist sleeping in hotels (TH).

3.2. The Interval and Fuzzy Coefficient LP Model (FCLP)

If in the linear programming models, as briefly presented in Section 2.1, the parameters were originally supposed to be perfectly known and uncertainty was not included, several more recent contributions exceed these limitations by introducing interval and fuzzy extensions of linear programming problems as underlined by Kuchta [37] and Chinneck and Ramadan [38]. We recall in particular Shaocheng's approach [39], which introduced uncertainty in the parameters, and the parametric programming method, which used multi-objective functions (as in goal programming). The use of the fuzzy parametric programming approach to study TCC optimization was originally proposed by Canestrelli and Costa [4] to analyze the specific context of Venice and it has not been further developed, to the best of our knowledge, in the direction of other solutions capable of taking into account the uncertainty of all the model parameters, as is proposed in this paper. More recently, the same approach has been proposed by studying an application to the case of Rome by Miarelli and Feliziani [40].

The fuzzy interval linear programming model presented by Shaocheng in 1994 [39] is as follows:

$$\begin{cases} \max_x \sum_{i=1}^n [\gamma_j, \delta_j] x_j \\ \sum_{i=1}^n [\alpha_{ij}, \beta_{ji}] x_j \leq [\varepsilon_i, \eta_i], i = 1, \dots, m \\ x \geq 0 \end{cases} \quad (3)$$

where $[\gamma_j, \delta_j]$, $[\alpha_{ij}, \beta_{ji}]$, $[\varepsilon_i, \eta_i]$ are intervals of the real line. Given that $[\gamma_j, \delta_j]$ are intervals (interval number), even the objective function $z = \sum_{i=1}^n [\gamma_j, \delta_j] x_j$ is an interval number too, and the Author showed that the solution of the above problem, under quite general hypotheses, can be obtained by the solutions of the two following crisp sub-problems:

$$SP.1 \begin{cases} \max_x \sum_{i=1}^n \gamma_j x_j \\ \sum_{i=1}^n \beta_{ji} x_j \leq \varepsilon_i, i = 1, \dots, m \\ x \geq 0 \end{cases} \quad SP.2 \begin{cases} \max_x \sum_{i=1}^n \delta_j x_j \\ \sum_{i=1}^n \alpha_{ij} x_j \leq \eta_i, i = 1, \dots, m \\ x \geq 0 \end{cases} \quad (4)$$

If the optimal solution of the two sub-problems are respectively:

$$x'_1, x'_2, \dots, x'_n; z', x''_1, x''_2, \dots, x''_n; z''$$

then the optimal target of the ILP problem is the interval $[z', z'']$ and the optimal solution will be found by a set of intervals $\{[x'_1, x''_1], [x'_2, x''_2], \dots, [x'_n, x''_n]\}$.

If the LP problem parameters are fuzzy numbers, we obtain a fuzzy linear programming problem (FLP).

We also emphasize that the same approach can be applied to a sequence of *alpha*-cuts of the parameters by solving an ILP problem for *each cut* as following:

$$SP.1(\lambda) \begin{cases} \max_x \sum_{j=1}^n \gamma_j(\lambda)x_j \\ \sum_{i=1}^n \beta_{ji}(\lambda)x_j \leq \varepsilon_i(\lambda) \\ x \geq 0 \end{cases} \quad SP.2(\lambda) \begin{cases} \max_x \sum_{j=1}^n \delta_j(\lambda)x_j \\ \sum_{i=1}^n \alpha_{ji}(\lambda)x_j \leq \eta_i(\lambda) \\ x \geq 0 \end{cases} \quad (5)$$

with $i = 1, \dots, m$ and $\gamma_j(\lambda), \beta_{ji}(\lambda), \varepsilon_i(\lambda), \delta_j(\lambda), \alpha_{ji}(\lambda), \eta_i(\lambda)$ are the *alpha*-cuts of level $\lambda \in [0, 1]$ of the objective functions and of technical coefficients.

3.3. The Fuzzy Parametric Programming Model (FPP)

Chanas’s approach [41] can be also used in the calculation of TCC to achieve the maximization of goals, i.e., the membership functions of both target and constraints. Membership function of goal, $\mu_0(\mathbf{x})$, and constraints, $\mu_i(\mathbf{x})$, are as follows:

$$GOAL \mu_0(\mathbf{x}) = \begin{cases} 0, \mathbf{c}\mathbf{x} < b_0 - p_0 \\ 1 - t, \mathbf{c}\mathbf{x} < b_0 - tp_0 \quad (0 \leq t \leq 1) \\ 1, \mathbf{c}\mathbf{x} > b_0 \end{cases} \quad CONSTRAINTS \mu_i(\mathbf{x}) \begin{cases} 0, \mathbf{a}_i\mathbf{x} > b_i - p_i \\ 1 - t, \mathbf{a}_i\mathbf{x} = b_i - tp_i \quad (0 \leq t \leq 1) \\ 1, \mathbf{a}_i\mathbf{x} < b_i \end{cases} \quad (6)$$

where b_0, b_i are the *aspiration* levels, and p_0, p_i the *minimum acceptable* levels for goal and constraints respectively. A *fuzzy optimal decision* is a fuzzy set D such that:

$$D : \max_D [\mu_0(\mathbf{x}) \wedge \mu_C(\mathbf{x})] \quad (7)$$

with $\mu_C(\mathbf{x}) = \mu_1(\mathbf{x}) \wedge \dots \wedge \mu_m(\mathbf{x})$. The Authors showed how using the Chanas resolving approach, this problem can be transformed into the following (parametric) LP problem, depending on the parameter $\theta \in [0, 1]$:

$$\begin{aligned} \max z &= \mathbf{c}\mathbf{x} \\ \mathbf{a}_i\mathbf{x} &\leq b_i + \theta p_i, i = 1, 2, \dots, m \\ \mathbf{x} &\geq 0 \end{aligned} \quad (8)$$

and the *optimal* value for the parameter θ^* is chosen such that both target and constraint membership share the same value of the control parameter: $\theta^* = \mu_0(\mathbf{x}) = \mu_C(\mathbf{x})$.

3.4. The Case of Venice. The FCLP Model Revisited

The usefulness of applying the FCLP model in determining the TCC can be shown through the Venice case study considered by many scholars and policymakers alike as an emblematic case for analyzing the effects that excessive tourism pressure can have on the sustainable tourism development of a destination [42–45].

For this purpose, according to the approach proposed by Canestrelli and Costa [4] and what has already been discussed in Section 2.1, the following tourism subsystems of Venice and types of daily expenditure of visitors should be considered and deeply analyzed:

- Accommodation sector. This system has been divided into two different categories: The hotel sector, and the extra-hotel sector. Tourism business in Venice is continuously developing especially regarding accommodation. New big high-quality hotels are opening on the islands in the lagoon, increasing the number of hotels (272 structures in 2016 offering the total number of 18,000 beds). The extra-hotel sector has grown considerably for two reasons: Regional law n. 33 (2002) that stimulates the opening of new tourism facilities connected to the accommodation category called “complementary accommodation facilities” such as B&Bs, hostels, and vacation rentals (from 126 structures in 2000 to 3200 in 2016), and the disruptive phenomenon of the sharing economy in

tourism represented by the *Airbnb* platform (around 6000 listings in the municipality of Venice in 2016).

- Food and beverage category. Tourists as visitors and city users, as well as walking around Venice and visiting museums and churches, also need a place to sit for lunch or dinner. The food and beverage sector therefore plays a key role in the Venetian tourism systems and it is necessary to monitor the performance (number of shifts per day) and the capacity (number of sits) of this department.
- Mobility and transportation facilities. This system has been divided into two categories: The number of parking places in the historical center of Venice and in the main gateways of the mainland, and the capacity of the boat lines (*vaporetti* in Italian) as the main means of public transportation in Venice.
- Environmental issues and waste management. Even if waste management, collecting process, and disposal in the historical center of Venice has improved greatly in recent decades, it is still a big issue due to the small number of official residents (around 53,000 in 2018) and the continuous high number of arrivals of city users such as workers and students (around 20,500 per day), and visitors and tourists (66,800 per day on average).
- Culture sector (regarding a cultural destination). This is the main attraction of a destination. It is one of the main reasons that determines the motivation to visit a destination, and it is the main point of interest and visit. In our case, we have considered St Mark's Square the main sight of Venice.
- Taking into account the possible users of these sub-systems as far as TCC is concerned, it is possible to identify different profiles such as: Italian and foreign tourists who decide to stay in Venice for a minimum of one night in a hotel (TH); Italian and foreign tourists who decide to sleep in an extra-hotel accommodation such as B&B or *Airbnb* (NTH); excursionists who come to visit Venice for different purposes (leisure or business), but decide to return home or not to sleep in Venice's historical center (E). The chosen scheme of visiting Venice (type and choice of accommodation) also affects the visitors' daily budget.

For each of these systems it will therefore be necessary to provide an estimate of the maximum number of visitors bearable under conditions of maximum stress (or a level to which to aspire for the first two subsystems). That is to say:

HB = number of available beds in hotels

NHB = number of available beds in extra-hotels

L = number of lunches which can be served daily

P = number of individual available parking places

T = number of individual available urban trips

WD = solid waste capacity

SMV = maximum number of visitors that can be hosted in St Mark's Square

Furthermore, an estimate of their utilization rate by type of visitor TH, NTH and the average daily expenditure of each individual visitor must be indicated.

This way of operating, which is inevitable given the structure of the model itself, nevertheless leads to introducing a degree of *uncertainty* in determining model parameters. In fact, it will be necessary to combine different sources not always linked with a common methodology, based on interviews that imply different answers depending on the interviewee's opinion as well as on the involvement of expert assessment of other specific values.

Given the uncertainty characterizing the parameters of the model (i.e., most of them are described by a *central* value with left and right uncertainty), the use of a fuzzy (or interval) approach seems to be the best-suited interface for their elicitation.

To this end and choosing the application of the FCLP model, we note that if $\tilde{a} = (a_i, a_0, a_s)$ is a triangular fuzzy number whose membership function is:

$$\mu_a(x) = \begin{cases} 0, & x < a_i \\ \frac{x-a_i}{a_0-a_i}, & a_i \leq x \leq a_0 \\ \frac{x-a_s}{a_0-a_s}, & a_0 \leq x \leq a_s \\ 0, & x > a_s \end{cases} \quad (9)$$

The basic TCC problem becomes the fuzzy TCC (FTCC) problem as follows:

$$\begin{cases} \max_x \tilde{c}_1 TH + \tilde{c}_2 NTH + \tilde{c}_3 E \\ TH \leq \tilde{d}_1 \\ TNH \leq \tilde{d}_2 \\ \tilde{b}_{3,1} TH + \tilde{b}_{3,2} NTH + \tilde{b}_{3,3} E \leq \tilde{d}_3 \\ \tilde{b}_{4,1} TH + \tilde{b}_{4,2} NTH + \tilde{b}_{4,3} E \leq \tilde{d}_4 \\ \tilde{b}_{5,1} TH + \tilde{b}_{5,2} NTH + \tilde{b}_{5,3} E \leq \tilde{d}_5 \\ \tilde{b}_{6,1} TH + \tilde{b}_{6,2} NTH + \tilde{b}_{6,3} E \leq \tilde{d}_6 \\ \tilde{b}_{7,1} TH + \tilde{b}_{7,2} NTH + \tilde{b}_{7,3} E \leq \tilde{d}_7 \\ TH, NTH, E \geq 0 \end{cases} \quad (10)$$

whose solution can be obtained by the FLP solving method as above explained in Section 2.

4. Results and Discussion

According to the last formulation of the TCC problem obtained at the end of the previous section (FTCC) in view of our Venice case study, the fuzzy parameter $\tilde{c}_1, \tilde{c}_2, \tilde{c}_3$ we considered are:

$$\tilde{c}_1 = (190, 210, 230), \tilde{c}_2 = (140, 160, 180), \tilde{c}_3 = (45, 60, 80) \quad (11)$$

while

$$\begin{aligned} \tilde{d}_1 &= (13000, 14400, 15500), \tilde{d}_2 = (18500, 20400, 22000) \\ \tilde{b}_{3,1} &= (0.675, 0.75, 0.825), \tilde{b}_{3,2} = (0.18, 0.2, 0.22), \tilde{b}_{3,3} = (0.585, 0.65, 0.715), \tilde{d}_3 = (23300, 24000, 24700) \\ \tilde{b}_{4,1} &= (0.297, 0.33, 0.363), \tilde{b}_{4,2} = (0.297, 0.33, 0.363), \tilde{b}_{4,3} = (0.675, 0.75, 0.825), \tilde{d}_4 = (19000, 20000, 21000) \\ \tilde{b}_{5,1} &= (0.9, 1.0, 1.1), \tilde{b}_{5,2} = (0.9, 1.0, 1.1), \tilde{b}_{5,3} = (0.9, 1.0, 1.1), \tilde{d}_5 = (45000, 46000, 47000) \\ \tilde{b}_{6,1} &= (2.1, 2.3, 2.5), \tilde{b}_{6,2} = (1.8, 2.0, 2.2), \tilde{b}_{6,3} = (0.9, 1.0, 1.1), \tilde{d}_6 = (90000, 100000, 110000) \\ \tilde{b}_{7,1} &= (0.3, 0.4, 0.5), \tilde{b}_{7,2} = (0.2, 0.3, 0.4), \tilde{b}_{7,3} = (0.6, 0.7, 0.8), \tilde{d}_7 = (90000, 100000, 110000) \end{aligned} \quad (12)$$

These data and their sources are listed in detail in Table 1.

Table 2 describes the complete list of the parameters, together with the solution (fuzzy variables TH, NTH, E, and the objective function). Moreover, the results of two possible policies of preventing excursionists (case 2) and all visitors (case 3) from accessing St Mark's Square (easily obtainable in the model by simulating a utilization rate of the non-renewable resource equal to zero) are reported.

The simulations suggest that the optimum number of visitors to Venice per day is equal to 52,111 people, of which 15,500 are tourists sleeping in hotels, 22,000 are people sleeping in other forms of accommodation and 14,611 are day trippers. This generates an income from tourism of 8,693,889 euros per day. On a per year basis, Venice will be visited, in this scenario, by 19,020,515 visitors, of which just 28% are excursionists. A crucial element in all this is St Mark's Square, a tourism asset that cannot be reproduced or enlarged, but only managed much better or differently, as some local politicians seem to be suggesting. In any case, not only is the total number of visitors that currently visit Venice much higher than the optimal number, the actual composition of the visitor flux is also skewed towards excursionism, a segment of the Venetian tourism market that represents almost 80% of its visitors. Lastly, it should be noted that the previous evaluations of the TCC of Venice elaborated by Canestrelli and Costa [4], identified as a possible "optimal solution," the presence of 9780 tourists who use hotel accommodation, 1460 tourists in non-hotel accommodation and a daily maximum of 10,857 day-trips. Our results clearly show that the situation has changed considerably.

Table 1. The case of Venice: Sources and data.

Tourism Sub-System	Description	Max Capacity of People Per Tourism Sub-System	Hotel Tourist Utilization Rate (TH)	Extra-Hotel Tourist Utilization Rate (NTH)	Visitor/Day-Tripper Utilization Rate (E)	Source of the Data
Accommodation—Hotel facilities	Number of bed places in hotel facilities (from 1 to 5 stars) in the historical centre of Venice area.	18,000 If we assume a highly satisfactory rate of occupancy of 80%, the aspiration is 14400.	1	0	0	Source: Istat (Italian national statistical institute) and Municipality of Venice (statistical and tourism departments)
Accommodation—Extra-hotel facilities	This sub-system includes the number of bed places available for tourist in official extra-hotel facilities (B&B, Hostels, Vacation rentals, etc.) and unofficial facilities (number of available bed places in the listing of <i>Airbnb</i> platform) in the historical centre of Venice.	34,000 If we assume a highly satisfactory rate of occupancy of 60%, the aspiration is 20,400.	0	1	0	Source: Istat (Italian national statistical institute), Municipality of Venice (statistical and tourism departments) and AirDna (private company selling <i>Airbnb</i> platform data)
Food and beverage industry—restaurants	This is the number of sitting places in restaurants, pizzeria, and dining rooms in historical centre of Venice. It has been calculated asking the capacity of the room (number of sits) multiplied by the number of lunch turns/shifts.	240,000	0.75	0.65	0.2	Source: survey conducted by the Ca 'Foscari University of Venice in 2018
Parking facilities	This is the number of available parking places in the historical centre of Venice (4 parking) and the parking place of the principal gateways to Venice (3 parking in Mestre).	20,000	0.33	0.33	0.75	Source: AVM (AVM holding manages public parking areas in Venice and Mestre), Garage San Marco, Venice City Park srl and Green Park websites
Public transportation—public boat	This has been calculated taking in consideration the total capacity of people per two types of public transportation boats per the number of line and shift passing through the Grand Canal from 8 to 20.	46,000	1	1	1	Source: AVM holdings manages public transportation in Venice municipality through ACTV spa (Azienda Comunale Trasporti Pubblici)
Waste management	This is the daily rate of waste production in Kilograms imputable of tourists in the historical center of Venice.	100,000	2.3	2	1	Source: Gruppo Veritas (public multiutility for waste, water and energy facilities)
Cultural sights and attractions	This refers to the maximum number of people can enter St Mark's Square for security reasons.	10,000	0.4	0.3	0.7	This data has been calculated using this formula: max occupancy = (flow rate) × (time) × (total egress width)

Table 2. Fuzzy tourist carrying capacity (FTCC) problem results and simulations.

Objective Function									
	coef_TH_lower	coef_TH_central	coef_TH_higher	coef_NTH_lower	coef_NTH_central	coef_NTH_higher	coef_E_lower	coef_E_central	coef_E_higher
	190	210	230	140	160	180	45	60	80
constraints coefficients									
	coef_TH_lower	coef_TH_central	coef_TH_higher	coef_NTH_lower	coef_NTH_central	coef_NTH_higher	coef_E_lower	coef_E_central	coef_E_higher
HB	1	1	1	0	0	0	0	0	0
NHB	0	0	0	1	1	1	0	0	0
L	0.675	0.75	0.825	0.585	0.65	0.715	0.18	0.2	0.22
P	0.297	0.33	0.363	0.297	0.33	0.363	0.675	0.75	0.825
T	0.9	1	1.1	0.9	1	1.1	0.9	1	1.1
WD	2.1	2.3	2.5	1.8	2	2.2	0.9	1	1.1
SMV	0.3	0.4	0.5	0.2	0.3	0.4	0.6	0.7	0.8
Variable Values Result									
	TH_higher	TH_central	TH_lower	NTH_higher	NTH_central	NTH_lower	E_higher	E_central	E_lower
	15,500	9700	13,000	22,000	20,400	6250	3250	0	0
Output Objective Function									
	Z_lower	Z_central	Z_higher						
	3,345,000	5,301,000	7,785,000						
Comparative Simulations									
	Result current case of Venice			Result case 2: St Mark's Square closed to excursionists $\tilde{b}_{7,3} = (0, 0, 0)$			Result case 3 St Mark's Square closed to visitors $\tilde{b}_{7,1} = (0, 0, 0)$		
coef_TH=	15,500			coef_TH= 15,500			coef_TH= 15,500		
coef_NTH=	22,000			coef_NTH= 22,000			coef_NTH= 22,000		
coef_E=	3250			coef_E= 14,611			coef_E= 14,611		
Z=	7,785,000			Z= 8,693,889			Z= 8,693,889		

5. Conclusions

In this work, the challenge of calculating the TCC was taken up considering, for many discussions on the phenomenon of overtourism, the emblematic case of Venice. In order to specify a quantitative formulation of the original problem of how many tourists a destination can bear without compromising the quality of the tourist experience, the stress level of each tourism subsystem in Venice was analyzed taking into account two specific issues concerning the uncertainty in determining model parameters and effects of the home-sharing economy on the accommodation supply. The uncertainty underlying the measurement of the effects of tourist overcrowding has been included in our model and extended to the entire set of parameters by solving the TCC problem through a FCLP model. Such a model, therefore, makes it possible to consider with greater flexibility the uncertainty also relating to subjective assessments of the impacts of overcrowding. Operationally, in fact, faced with an inevitable high degree of uncertainty regarding the assessment of the impacts that the tourism phenomenon have on a destination and how they could be experienced by tourists or residents [28,29], the local planner can take these circumstances into account by making use of larger uncertainty intervals in the model presented in this paper. Moreover, as already highlighted, with the advantage of being able to intervene on the entire set of model parameters. Moreover, we designed a model for the Venice case study that was able to capture one of the greatest challenges that urban destinations are nowadays coping with, i.e., the effects of the home-sharing economy on the non-traditional accommodation supply. In fact, the accommodation capacity of Venice has been updated with the amounts of apartments rented through the *Airbnb* web portal.

A further novelty present in this model is the possibility of simulating the impact that alternative policies for managing tourist flows can have on limiting the effects of excessive tourist pressure on certain tourism subsystems. Hence, we simulated three different scenarios for our case study. The first case is characterized by local authorities' decision to allow all types of visitors to access Venice's main cultural resource. In this case, the optimal number of daily visitors turns out to be composed of 15,000 tourists sleeping in hotels, 22,000 people sleeping in other nontraditional accommodations (including apartments of *Airbnb*), and 3250 excursionists. Two other cases were also considered analyzing the scenario of preventing excursionists (case 2) and all visitors (case 3) from accessing St Mark's Square. For both of these two cases the optimal solution is equal to a total number of daily visitors of 52,111 people, of which 15,500 are tourists sleeping in hotels, 22,000 are people sleeping in other forms of accommodation, and 14,611 are excursionists. The application of the model to the Venice case study also allowed us to derive further considerations in support of a sustainable development of this emblematic destination. Indeed, these results lead to the need for a wider review of local policies, directly or indirectly focused on the management of Venice's non-reproducible cultural resources.

Therefore, in accordance with previous studies by Costa and Van der Borg [3] and Canestrelli and Costa [4], the tensions created by the tourism sector on the daily usability of the city by residents continue to persist. Although there has been a considerable change in the tourism accommodation offer of Venice, which has increased reaching the capacity of almost 43,000 beds per day, the tensions in some tourism subsystems still require attention. Taking into consideration the latest estimates on the number of day visitors provided by the City of Venice [46], which set the number of excursionists to around 53,000 per day, it can be easily understood how these tensions are still affecting the tourism subsystem of transport, parking, and the use of the cultural resource of St Mark's Square.

According to Peeters et al. [46] the European Parliament pointed out some policy responses and policy measures able to mitigate overtourism impacts. Those practical implications are referring to tourism policies and destination management plans of European destinations frequently focusing on developing and growing tourism, recent specific literature regarding overtourism measures and policies according to Jordan et al. [47], Koens & Postma [48]; McKinsey & Company & World Travel & Tourism Council [49] and Postma et al. [50] and based on case studies. With this research we focused on one of these measures, a measure that is able to calculate the sustainable limit of tourists and visitors of one of the most famous case studies regarding overtourism, trying to answer the necessity mentioned

by the Tourism Sustainability Group (2007) [51] to “set and respect limits” [46:102] representing the tourism carrying capacity of urban destinations, cultural sites, and wider areas able to limit (or give sustainable scenarios) the amount of tourism development (tourism sub-systems) and volume of tourist flows. Regarding the specific case study of Venice and to set and respect limits it is possible to summarize the key points regarding sustainable actions connected to the social and physical carrying capacity of the city.

As can easily be concluded from the simulations made in the previous section, stopping the process of the further “Venetianization” of Venice is not some kind of snobbish wish of a Venetian elite to curb the number of mass tourists, thus keeping Venice to themselves. Rather, it is a fundamental ingredient of a deliberate urban strategy to economically and socially revitalize the city so that its economic base can become sufficiently strong and diversified to proudly conserve itself. This will eventually also benefit the people who wish to visit this authentic world heritage site in the future. Let us have a quick look at what such a “disruptive” tourism policy for a destination like Venice might look like. First of all, since Venice is a collection of islands in a lagoon, a buffer of terminals might be created around the historical center to intercept the flow of visitors before they mix with the flow of commuters, both of which are endeavoring to enter the historical center. Dividing the incoming and outgoing visitor flow from the commuter flow allows the local transportation company to avoid congestion, thus reducing capacity costs, and moreover, to diversify access points away from the Santa Lucia train station and the bus station at Piazzale Roma, terminals that especially in the height of the tourism season frequently collapse. Locations for these terminals might be at Fusina, to intercept visitors arriving from the south, at Tessera, close to the airport of Venice and also able to intercept visitors arriving from the north, together with a terminal at the foot of the Ponte della Libertà causeway which connects the historical center to the mainland. This latter terminal might serve people arriving by train and from Padua, Vicenza, Verona, Brescia, and Milan. Punta Sabbioni is already being used as a terminal from which visitors coming from the beach resorts north of Venice depart. Obviously, together with the terminals, transport facilities to and from the historical center also need to be provided. The system that results is very similar to that implemented successfully by the city of Salzburg in the 1980s.

Secondly, a reservation system for visiting Venice should be put in place. Not only would such a system make all visitors, including day-trippers, aware of the scarcity of the product of Venice, and therefore force people to plan their visit rather than improvise, but it might also interrupt the automatism with which quite a large number of excursionists come to the historical city. Using the reservation system would not be mandatory, but Venice would prove to be difficult and very expensive without a reservation, and easy and relatively cheap for those who “plan in advance”. For those who use the system, fast lanes would be created, and a package of discounts would become available, not only for public transportation use and museum entries, but also for private facilities such as hotels, restaurants, and shops. Restricted access to St Mark’s Square, as some are now suggesting, might be the killer application that determines the success of such a system. It would be anti-constitutional to close all access to Venice and impose an entrance fee.

The idea of a reservation system was tested with some success from 2002 until 2005. After just three years, the municipal company in charge of the project had issued 180,000 Venice Cards and succeeded in breaking even, showing it to be on the right track. Since then, the opportunities that innovative technologies are offering, such as social media, smart phones and tablets, and electronic payment platforms, have grown exponentially and make it easy to concretely work on a system that regulates access to Venice through reservation.

Thirdly, and especially in the case of such acute problems, new technologies might be used to manage internal visitor flows more effectively. Reading the images provided by security cameras that can be found all over Venice, in combination with the results of an analysis of the data collected through the cells that facilitate the use of mobile phones, might allow a sort of central control room to feed suggestions of alternative modes of transport, terminals, and routes in real time, thus helping to

anticipate congestion problems and solve them well before they arise. Again, the solution seems to lie in the organizational sphere rather than in the technological one.

Fourthly, the City of Venice has started very timidly to promote alternative routes under the label “Detourism”. In 2014, it spent 7000 (!) euros on the project, and in 2015 the budget was doubled to 14,000 euros, a clear indication of the marginal weight local policymakers have been giving to tourism policy.

What should be avoided at all costs, however, is putting an explicit cap on the development of tourist accommodation, as Amsterdam and Barcelona are currently considering. This was tried in Venice in the 1980s and 1990s, and instead of stopping the process of gentrification, it merely boosted excursionism. Entrepreneurs immediately turned to the areas close to Venice to continue to construct hotels and hostels, and by offering very competitive prices with respect to the historical center, transforming residential tourism into what has been labelled by Van der Borg in 1991 [52] “false excursionism”. In an unpublished paper, Prud’homme [53] argued that the process of gentrification can be stopped not by brutally obstructing the growth of the tourism sector, but simply by facilitating all those activities that offer an alternative to tourism, for example, by fostering non-tourist economic activities or by subsidizing housing. Also, the introduction of a tax on overnight stays incentivizes day tourism and penalizes residential tourism, and should be reconsidered. A tax on all the movements to and from the historical center should take its place. Cruise tourism should be regulated and restricted with determination. It is a form of tourism that possesses the same characteristics as false day tourism, and therefore it contributes only marginally to the destination’s economy.

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