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Sustainable Cruise Tourism Management in Juneau: A Nonlinear Optimization Approach to Visitor Capacity and Tax Policy

Jiyang Yu

School of Mathematics, Southwestern University of Finance and Economics, Chengdu, China
jiyangyu0120@163.com

Abstract. With the continued growth of the tourism industry, increasing attention has been devoted in recent years to how tourist cities should formulate appropriate tourism policies. As a well-known cruise destination in Alaska, Juneau faces the critical challenge of balancing the economic growth generated by tourism with the visitor carrying capacity of the local area, which has become a key concern for local policymakers. This paper develops a GDP growth accounting model based on data on tourism consumption, tax revenue, and government investment. By formulating the maximization of tourism-driven GDP growth as the objective function, the model identifies the optimal number of visitors and the corresponding tax policy for the region, thereby providing concrete policy recommendations for local government decision-making. A sensitivity analysis with respect to the visitor-capacity limit further shows that relaxing the maximum visitor capacity increases both the feasible visitor scale and the upper bound of GDP gains, while the optimal tax policy remains relatively stable in the low-capacity region. These findings provide a quantitative basis for sustainable cruise-tourism management in Juneau and other small port destinations with similar structural characteristics.

Keywords: Sustainable Tourism Management, Juneau, Nonlinear Programming, Tourism Taxation, Carrying Capacity

1. Introduction

Juneau, Alaska, offers a useful empirical setting for examining sustainable tourism governance in small, cruise-dependent destinations. In 2023, the city received nearly 1.7 million cruise passengers from almost 700 port calls, generating about $375 million in direct spending. These figures indicate that cruise tourism is not a peripheral activity in Juneau; rather, it is a major component of the local economy and public finance system [1].

At the same time, the relevant policy problem in destinations such as Juneau is not tourism growth, but whether visitor intensity exceeds the destination's social, environmental, and infrastructural capacity. Mihalič conceptualizes over-tourism as a sustainability problem rather than a simple matter of high visitor numbers, while Tokarchuk et al. show that tourism intensity can be linked to residents' life satisfaction and used to approximate social carrying capacity [2,3]. In cruise

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destinations, this challenge is particularly acute because visitor flows are concentrated in time and space, placing disproportionate pressure on small port communities with limited room to absorb peak demand. Recent reviews of the cruise-tourism literature similarly show that destination-level sustainability debates revolve around governance, coexistence, and limits to growth, while environmental and public-health research has documented pressures on air quality, water systems, ecosystems, and port communities associated with cruise activity [4,5].

For small port cities, the central challenge is therefore to retain the economic benefits of tourism without undermining residents' well-being or overloading shared urban space and public services. Evidence from Sitka, Alaska, suggests that tourism growth can become a direct community well-being issue that prompts collaborative planning and local regulation, and studies in other cruise destinations report that residents commonly perceive a trade-off between socioeconomic gains and environmental or public-space costs [6,7].

This makes Juneau a suitable case for analyzing visitor volume and tourism taxation jointly. Research on Alaska's cruise passenger head tax suggests that such taxes are often justified as a means of internalizing part of the public costs created by cruise tourism, while broader tourism-taxation studies indicate that tourism taxes may both finance sustainability measures and affect destination demand [8,9]. From this perspective, the relevant policy question is not how to maximize arrivals unconditionally, but how to identify a visitor scale and tax regime that balance economic returns, local carrying capacity, and long-run destination sustainability.

2. Method

2.1. Data preparation

2.1.1. Consumption part

In order to examine the growth effect of tourism-related consumption on the local GDP, we divided the consumption activities into entertainment consumption, dining consumption and transportation consumption, in order to cover most of the consumption behaviors of cruise passengers onshore. The specific consumption data of each type is derived from the average consumption and customer selection data of Yelp and TripAdvisor.

2.1.2. Government procurement part

To examine the GDP growth resulting from the infrastructure construction expenditures made by the government to accommodate tourists, we collected the annual financial reports of the local government of Juneau and summarized the government's annual expenditures on tourism infrastructure and the corresponding actual number of tourists received each year, which are illustrated in Figure 1, and modeled the relationship between government spending and tourists' numbers.

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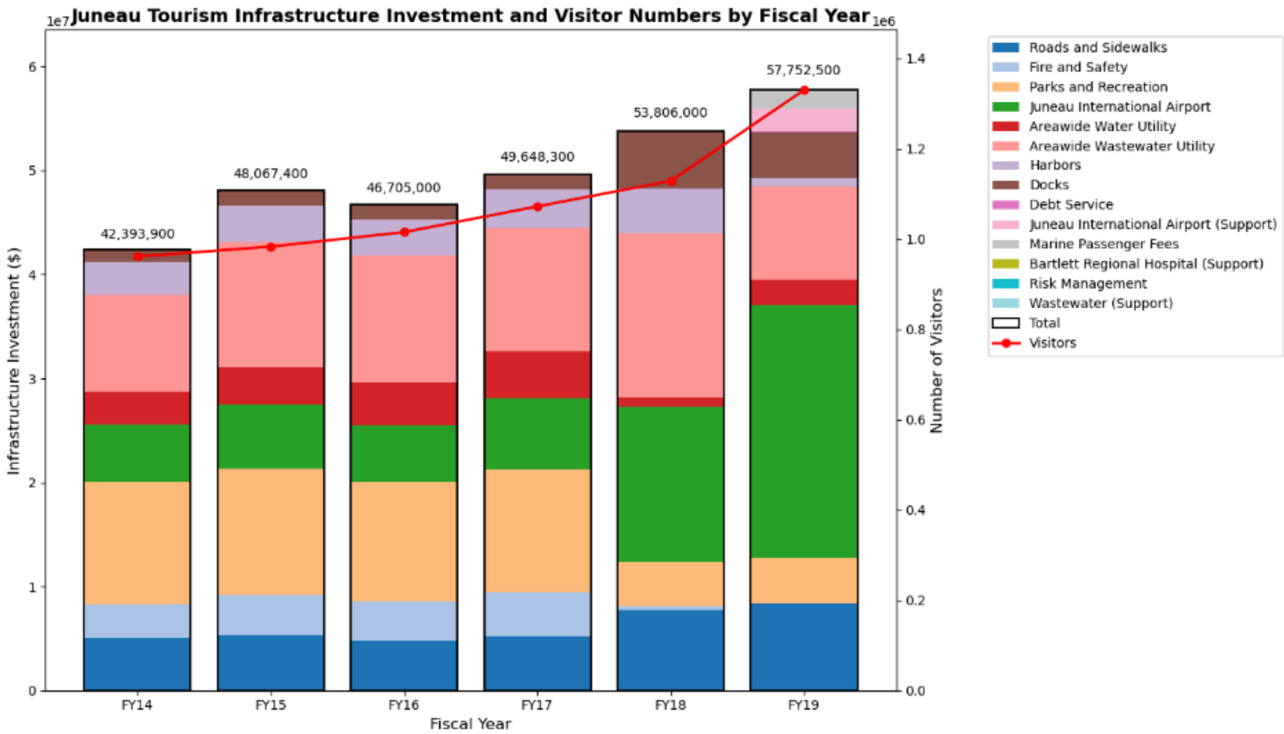

Figure 1. Waterfall decomposition of tourism-induced GDP change in Juneau

2.1.3. Tax disincentive part

To examine the negative impact of the taxes imposed by the government on tourists on the local GDP, we collected all the tax items levied on tourists in Juneau City in 2023, and used the tax level in 2023 as the benchmark. The data is from the ‘ECONOMIC IMPACT OF Juneau'S CRUISE INDUSTRY’ report written by the McKinley Research Group. 2023.

2.1.4. Maximum number of tourists

Based on objective geographical conditions and past visitor data provided by the McKinley Research Group, nearly 99% of visitors to Juneau arrive via cruise ships [1]. This study collected all cruise itineraries scheduled to stop in Juneau in 2025 and their corresponding passenger capacities through the official websites of various cruise companies. The scope of collection includes the official websites of Carnival Cruises, Norwegian Cruise Line, Oceania Cruises, Princess Cruises, Celebrity Cruises, Cunard Line, Disney Cruise Line, Holland America Line, Regent Seven Seas, Royal Caribbean, Seabourn Cruises, Silversea Cruises, and Viking Ocean Cruises.

2.2. Method

2.2.1. Nonlinear programming model

The model aims to maximize economic benefits. The objective function is constructed based on the GDP accounting model (three-sector economy) using the expenditure approach in macroeconomics.

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$$GDP = C + I + G \tag{1}$$

Given that investment remains relatively stable in the short term, the change in investment is assumed to be zero in this model for the time being. Meanwhile, By applying the multiplier effect and the tax inhibition theory for measuring GDP changes in macroeconomics, we obtain the following formula:

$$\Delta GDP = C(x) \cdot \mathrm{k_C} + G(x) \cdot \mathrm{k_C} + T(\mathrm{x}) \cdot \mathrm{k_r} \tag{2}$$

x : the number of tourists.
k_C : the consumption multiplier or the government purchase multiplier.

$$\mathrm{k_C} = \frac{1}{1-\mathrm{MPC}} \tag{3}$$

k_r : the tax offset multiplier.
$C(x)$: the consumption function with respect to x .
$G(x)$: the function of the government's investment in tourism infrastructure.
$T(x)$: the government's tax function regarding x .

For the consumption portion, C_0 represents the average transportation expenditure of tourists. C_1 represents the average expenditure of tourists on catering and retail. $C_2(x)$ represents the total expenditure of all tourists on scenic-spot entertainment within one day and is a piece wise function of x. From the data set, C_0 = 56.24811 and C_1 = 6. According to a McKinley Research report on Juneau's tourism industry, 30% of all cruise passengers disembarking on the island visit attractions and engage in entertainment spending. The remaining 70% choose to shop and dine only in the city center, making no entertainment expenditures at attractions. Combining our assumptions with the data set, we derive $C_2(x)$ as

$$\begin{cases} C_{21} = 0.3a \times (0.55 \times 187 + 0.45 \times 283)\, if 0.3a \leq 8525 \\ C_{22} = 4650 \times 187 + (0.3a - 4650) \times 283 if X_1 < 0.3a \leq 9982 \\ C_{23} = 465 \times 187 + 5332 \times 283 if 0.3a > 9982 \end{cases} \tag{4}$$

a represents the estimated average daily number of visitors to Juneau City, 8525 is the number of tourists who, when choosing scenic spots proportionally, cause one of the scenic spots to reach full capacity first and 9982 represents the maximum daily capacity of tourists in the scenic area.

Regarding the tax component, the government generates tourism revenue by imposing taxes on cruise companies. As Juneau is a popular tourist destination, tickets for sightseeing cruises are often in short supply. This creates an incentive for profit-maximizing cruise companies, who also have the capacity to pass on part of the tax burden to passengers with weaker bargaining power by raising ticket prices. Given passengers limited disposable income, the taxes they pay for cruise tickets suppress their spending in Juneau, creating a tax suppression effect. μ reflects the relative change degree of tax-related indicators caused by factors such as tax policy adjustments and changes in tax collection and management intensity. T represents the average tax amount contributed by a single

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tourist in 2023, which is \$13.35 per person. k_r represents the degree of the inhibitory effect of tax changes on economic activities. Therefore, we can express the change in tax revenue generated by tourism in the Juneau in 2025 as

$$\mu \cdot T \cdot x \cdot k_r \tag{5}$$

Based on the above analysis, the objective function of this model is:

$$\Delta GDP = ((\mathrm{C}_0 + \mathrm{C}_1) \cdot \mathrm{x} + \mathrm{C}_2(\mathrm{x}) \cdot 150) \cdot \mathrm{k}_\mathrm{C} + G(\mathrm{x}) \cdot \mathrm{k}_\mathrm{C} + \mu \cdot T \cdot x \cdot \mathrm{k}_\mathrm{r} \tag{6}$$

2.2.2. Assumptions

In this paper we assume that the number of tourists arriving each day is evenly distributed. According to the data on the cruise company's ticketing official website, the itinerary of the vast majority of cruise ships is 7 to 8 days. This means that weekends are not more likely to be chosen as travel times due to holidays.

Besides, BEA data indicate that U.S. households maintained a high spending share of disposable income in 2023. For simplicity, this paper calibrates $\mathrm{MPC} = 0.9$, which implies a simple Keynesian consumption multiplier of 10.

2.2.3. Constraint conditions

It is required that the government's revenue from the tourism industry can cover its expenditures on maintaining the sustainable development of the tourism industry. An important condition for sustainable development is that the tax revenue the government obtains from the tourism industry can cover the government's expenditures on tourism - related infrastructure construction.

$$\mu \cdot T \cdot x \geq G(x) \tag{7}$$

The tax-change constraint requires that the tax-rate fluctuation in a region should not be too large.

$$1.15 \geq \mu \geq 0.85 \tag{8}$$

By adding up the capacity of all cruise lines, we get the traffic constraints as follows:

$$x \leq 1{,}361{,}081 \tag{9}$$

3. Conclusions

MATLAB was employed to determine the optimal solution for our nonlinear programming model. The optimal number of tourists (x) is 1,361,081, the optimal tax change multiplier (μ) is 0.8675, and

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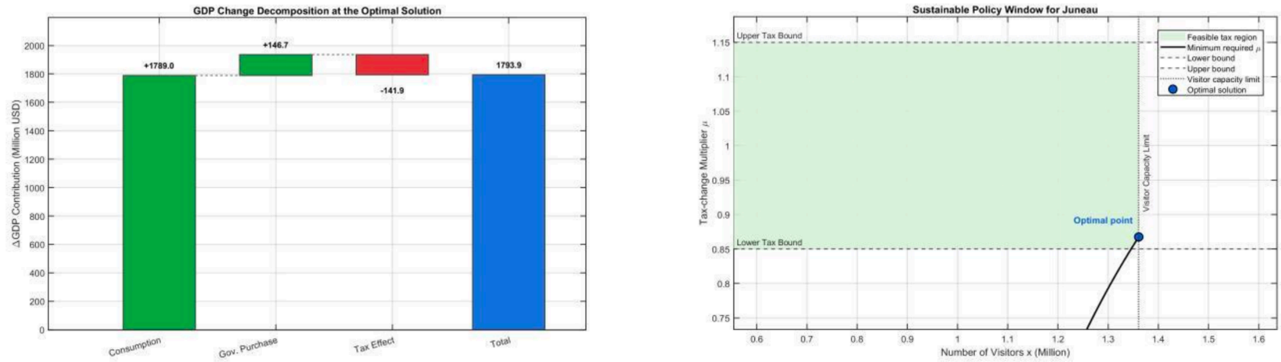
the maximum GDP change caused by tourism (ΔGDP^*) is $1,793,865,177.50. This means that in 2025, traffic constraints will be the tightest constraint on our optimal number of tourists. Under such circumstances, to ensure the maximum GDP growth driven by Juneau's tourism industry, the Juneau municipal government should implement a tax reduction policy compared to 2023. The optimal tax reduction rate should reach 13.25%. Only in this way can the tourism industry in Juneau in 2025 achieve the maximum increase in GDP through all direct and indirect influences.



(a) GDP Change Decomposition at the Optimal Solution

(b) Sustainable Policy Window for Juneau

Figure 2. Main results of the nonlinear optimization model

As illustrated in Figure 2, the chart on the left shows a waterfall chart illustrating the changes in GDP driven by the tourism industry in Juneau. As shown, consumer spending is the primary driver of GDP growth; under the most favorable conditions, it contributes $1,789 million in GDP growth to Juneau. Government investment in tourism infrastructure and the impact of taxes largely offset each other, each amounting to over $140 million. Ultimately, under the most favorable conditions, the tourism industry would generate $1,793.9 million in growth for Juneau. Figure 2 (right) displays the feasible region of the optimization model; our optimal solution ultimately lies at a value of μ = 0.8675.

4. Sensitivity analysis

The sensitive analysis aims to explore the dynamic relationship between the maximum visitor - capacity constraint $X_{\max}$, the optimal number of tourists x^* , the optimal tax change multiplier μ^* , and the maximum ΔGDP^* . Through the interpolation method and difference method in numerical analysis, the correlation among these variables is quantified, so as to provide scientific basis for policy making.

Under the current policy framework, when the optimal number of tourists is determined to be 1,361,081, the model further reveals how changes in traffic capacity affect the optimal tourism scale and the corresponding tax policy, so as to achieve the dual goals of maximizing resource utilization efficiency and sustainable development.

The interpolation method fits the functions

$$x^* = f_1(X_{max}),\ \ \mu^* = f_2(X_{\max}),\ \ \Delta GDP^* = f_3(X_{\max}) \tag{10}$$

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Based on the possible conditions in Juneau, our team made scientific and reasonable changes to the traffic constraint without changing the other constraints that directly determine the feasible region of the model. Due to the variation of the constraint, a series of numerical points about X_{max}, x^*, μ^*, and ΔGDP^* is obtained. According to the distribution characteristics of these numerical points, our team decided to use piece wise quadratic interpolation for the sake of computational efficiency, fitting accuracy, and smoothness of the functions. In the process of piece wise interpolation, Newton's difference quotient is used to calculate the basic functions for the flexible processing of the data.

Calculate the derivatives and visualize them as follows:

$$\frac{dx^*}{dX_{\max}}, \quad \frac{d\mu^*}{dX_{\max}}, \quad \frac{d(\Delta GDP^*)}{dX_{\max}} \tag{11}$$

Using the finite difference method, the marginal effects of the visitor - capacity limit on the optimal solution can be quantitatively measured. Based on the fitted response functions and their numerical derivatives, the following conclusions can be drawn: when the maximum visitor - capacity constraint X_{max} increases, the optimal number of tourists x^* increases correspondingly; when the tax multiplier μ^* changes only slightly, the baseline tax policy is relatively robust; and when ΔGDP^* increases significantly, the model indicates that traffic capacity is the dominant bottleneck restricting Juneau's tourism growth. Therefore, for Juneau, relaxing the transportation - capacity constraint can directly increase the sustainable upper bound of visitor numbers and further improve the maximum GDP growth that can be achieved under the current policy framework.

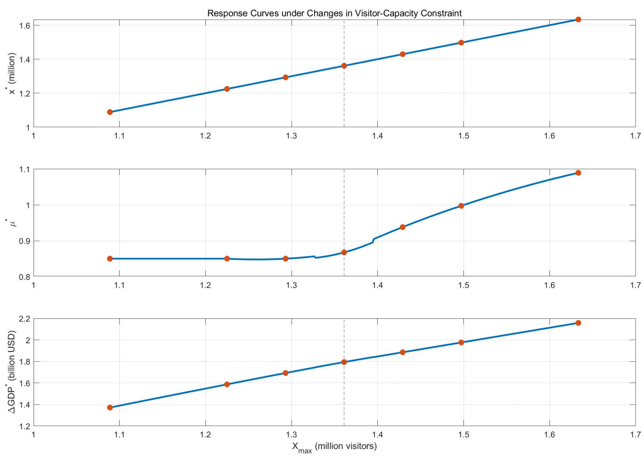

Figure 3. Response of the optimal solution to changes in visitor-capacity constraint

Table 1. Sensitivity results under perturbations of the visitor-capacity constraint

Capacity change	Perturbed $X_{\max}$	Optimal visitors x^*	Optimal tax multiplier μ^*	Maximum GDP change ΔGDP^* (billion USD)
-20%	1,088,865	1,088,865	0.8500	1.3717
-10%	1,224,973	1,224,973	0.8500	1.5868

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Table 1. (continued)

-5%	1,293,027	1,293,027	0.8500	1.6924
0%	1,361,081	1,361,081	0.8675	1.7939
+5%	1,429,135	1,429,135	0.9380	1.8849
+10%	1,497,189	1,497,189	0.9972	1.9758
+20%	1,633,297	1,633,297	1.0891	2.1575

Table 1 and Figure 3 present the sensitivity of the optimal solution to perturbations in the visitor-capacity constraint X_{max} .The results show that the optimal number of visitors x^* increases almost one-for-one with X_{max} , which indicates that the traffic-capacity constraint is binding throughout the considered range.Meanwhile, the optimal tax multiplier μ^* remains at or near its lower bound when capacity is relatively tight, but increases gradually as the capacity limit is relaxed. This suggests that the tax policy is locally stable in the low - capacity region but becomes more responsive once the feasible tourism scale expands. In addition, the maximum ΔGDP^* increases monotonically with X_{max} , confirming that transportation capacity is a dominant bottleneck for Juneau’s tourism-driven economic growth.

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