

## Coupling Coordination and Evolutionary Dynamics of Tourism Service Quality and Sustainable Tourism Supply Chains

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**Abstract.** In the development of tourism service quality (TSQ) and a sustainable tourism supply chain (STSC), both need to be balanced for the construction of a sustainable destination. Most research has studied the quality of services and the stability of tourism supply chains separately, and their relationship has been relatively unexplored. An all-encompassing analytical system integrating the Coupling Coordination Degree Model (CCDM) and Evolutionary Game Theory (EGT) has been constructed to investigate the coordination and long-term co-evolution of TSQ and STSC in this paper. Based on empirical data from 450 tourism enterprises and 1,200 tourists in the four eco-tourism pilot areas between 2023 and 2025, this paper will first examine the level of coordination among TSQ and STSC, and then construct a simulation model of the strategic behavior of key stakeholders such as tourism enterprises, supply-chain partners and local regulators. The results show that there is a clear spatial-temporal difference in the coordination of TSQ and STSC, and the destination of development is changing from imbalanced to moderate or high coordination. Urban green tourism zones are relatively close in development; the rural areas face a significant capital and ability deficit. Analysis of evolutionary game theory further indicates that, for a long time, both continuous regulatory pressure and market-driven consumer premium effects have been necessary to maintain high-quality, high-sustainability operational models. This paper adds to the existing research by building a unified system framework that links service quality management with the coordination of sustainable tourism supply chains, and provides some references for destination managers and policymakers concerned about balancing high-quality services and green transformation.

**Keywords:** Sustainable Tourism Supply Chain, Tourism Service Quality, Coupling Coordination Degree, Evolutionary Game Theory, System Dynamics

## **1. Introduction**

### **1.1. Statement of Problem and Significance of the Study**

Modern tourism operates as a highly interdependent system, historically characterized by high energy consumption and scale-driven development. However, industry paradigms have shifted. As an essential instrument for countering the adverse environmental and social effects of mass tourism, the concept of the Sustainable Tourism Supply Chain (STSC) has gained prominence. Tourism operation management encompasses various components under the STSC framework, including transportation, hospitality, cultural activities, and environmental protection. Concurrently, Tourism Service Quality (TSQ) remains vital, directly influencing tourist value perception, destination loyalty, and corporate profitability (Zebua et al., 2026).

At the interface of these two domains lies a structural tension that often hinders the implementation of sustainability-oriented behaviors. This paper positions this challenge fundamentally within the context of service-science and sustainable supply-chain coordination. The high-cost operations involved in transforming capital structures or redefining service systems directly threaten the stability of TSQ. For example, eliminating single-use plastics, restricting visitor caps to limit pollution, or reducing energy consumption may appear unreasonable from a consumer perspective, adding perceived inconvenience. Conversely, persistently pursuing a resource-intensive TSQ undermines the credibility of the STSC. Thus, understanding the interaction between TSQ and STSC is critical to determining whether they enhance or hinder the balanced development of the tourism industry (Li et al., 2025).

Academia has yet to adequately quantify the interactive effect of service quality on the dynamic synergy of supply chain sustainability. Most existing research relies on static, one-dimensional models, exploring STSC management and TSQ in isolation. This leaves a significant gap in understanding how TSQ and STSC interrelate at varying degrees over time. Furthermore, the strategic interaction among boundedly rational stakeholders—such as hotels, local suppliers, tourists, and government regulators—cannot be fully explained by static empirical analyses.

Rather than proposing a sweeping conceptual breakthrough, this study tightens the theoretical understanding of this dynamic by integrating the Coupling Coordination Degree Model (CCDM) and Evolutionary Game Theory (EGT). The CCDM evaluates static-to-dynamic synergies, while EGT models the behavioral adaptations of involved parties, offering unified theoretical support for academia and practical frameworks for industry application.

### **1.2. Objectives of the study**

1) To construct a multidimensional evaluation indicator system for both Tourism Service Quality (TSQ) and the Sustainable Tourism Supply Chain (STSC), capturing the nuances of environmental, operational, and experiential metrics.

2) To measure and evaluate the Coupling Coordination Degree (CCD) between TSQ and STSC across different developmental stages and regional contexts, identifying the primary bottlenecks hindering harmonious development.

3) To develop an Evolutionary Game Theory (EGT) model among core stakeholders (tourism enterprises, supply chain partners, and government regulators) to simulate the evolutionary dynamics and identify the Evolutionary Stable Strategies (ESS) that optimize both service quality and sustainability.

4) To examine whether the sensitivity of evolutionary stability varies with internal variables, such as government subsidy policies, environmental punitive measures, and sustainable consumer behavior.

### **1.3. Benefits of the Study**

Many destination management organizations utilize sustainable marketing to attract visitors, yet excellent service must accompany these promotional activities (Font & McCabe, 2017). Studying the

relationship between TSQ and STSC addresses practical issues like greenwashing and service degradation. By framing this within supply-chain coordination, the resulting evolutionary model provides a strategic basis for balancing these forces.

The theoretical value of this research lies in transitioning from static structural models to a dynamic coupling and game-theory framework (Bagozzi & Yi, 1988), strengthening the interdisciplinary connections between service-science and supply-chain management (Zhang et al., 2009). Practically, understanding the specific timelines where sustainability investments yield exponential returns in service perception will allow decision-makers to optimize resources and build a resilient tourism framework (Yan et al., 2021).

## **2. Literature Review**

### **2.1. Evolution of the Sustainable Tourism Supply Chain (STSC)**

The conceptualization of the Sustainable Tourism Supply Chain (STSC) represents a paradigm shift, proposing a novel approach to evaluating social responsibility by analyzing individual enterprise practices at a systemic level. Initially derived from the general framework of Green Supply Chain Management (GSCM), the STSC concept has been specifically adapted to the unique characteristics of tourism products, which are typically intangible, perishable, and highly localized (Font et al., 2008). Unlike traditional linear industrial supply chains, the tourism supply chain lacks a singular directionality. On the contrary, it has many forms of co-producers, and tourists participate in Production during their travel at different levels across multiple links in the supply chain such as transportation enterprises, Hotel Operators and Local Communities (Sigala, 2014).

Recently, many researches have shown that the multi-faceted characteristics of STSC exist. In addition to the certification of eco-tourism for a single company by means of an ecosystem, it is necessary to make all parties comply with regulations along this line: first, suppliers; secondly, downstream tourists. However, the application of STSC also faces some problems. Local tourism network backbone enterprises (small and micro enterprises or SMEs) usually have higher initial investment in sustainable operation than traditional ones, due to poor communication information asymmetry between them; It also lacks technical ability. Therefore, in recent years, the main research directions of the academia have shifted towards exploring how to build an institutional framework that can ensure the stability of sustainable development of small and medium-sized science parks in a dynamic market environment. Although there has been progress in research; it still primarily views STSC performance as the independent factor and rarely investigates whether environmental and social conditions that are highly constraining affect users' perceptions of service experience more significantly (Seuring & Müller, 2008).

### **2.2. The Paradox of Tourism Service Quality (TSQ) and Sustainability**

Tourism Service Quality (TSQ) as an essential factor influencing the desirability of locations for tourists as perceived by their own travel experience and other travelers since it was first introduced. Based on the basic SERVQUAL model, TSQ evaluation of the hospitality and Tourism Sector covers Tangible Quality, Reliability, Responsiveness, Assurance and Empathy. Traditional TSQ was typically associated with wealth, privilege and unrestrained use of resources; The content may include frequent linen replacement services, personalized catering plans, and high-energy-consuming air conditioning systems.

Due to the inherent friction between traditional service paradigms and sustainability, studies have identified a "green service paradox" (Miao & Wei, 2013). While eco-conscious consumers advocate for environmental protection, mainstream tourists often exhibit a "sustainability penalty" cognitive bias. They implicitly associate eco-friendly practices—like digital concierge services or limited physical amenities—with compromised luxury. Positioning this within service systems research reveals that TSQ and STSC are deeply intertwined. Depending on the operational environment and consumer

psychological thresholds, these systems may exhibit non-linear interactions, potentially being enhanced or eroded by sustainability interventions (Dodds et al., 1991).

### **2.3 Coupling Coordination Degree (CCD) in Tourism Systems**

Scholars have increasingly utilized the Coupling Coordination Degree Model (CCDM) to quantify the complicated and interrelated effects between fundamentally different systems (Tang, 2015; Wu et al., 2025). Based on the field of physics to describe phenomena that influence others due to interaction between multiple systems, it has also found its way into regional economy and human geography after being translated successfully (Tomlinson, 1990; Wang et al., 2019). Mostly used by researchers of tourists to examine their relationships with the overall development of areas such as ecological environments, urbanization changes and cultural heritage preservation through CCDM.

The fundamental characteristics of CCDM are its ability to avoid directly showing the association. In general, there is an opposition relationship among the terms "bonds" (referring to strong ties) and "development"; To develop each other collaboratively positively. However, a thorough examination of the current corpora indicates that there is still a significant lack at this micro level regarding application in specific dimensions of China's tourism industry. Through the evaluation of the coupling relationship among STSC, the operational backbone and TSQ for exploring the spatial structure coordinates that link the development pattern of regional tourism economics with the overall ecology (Liu & Suk, 2021). Operationalise CCDM to identify the spatial-temporal bottlenecks that trigger or erode the Service Quality of a Supply Chain.

### **2.4 Evolutionary Game Theory (EGT) and Stakeholder Dynamics**

Transitioning to a fully integrated STSC without compromising optimal TSQ is not a decision made by a single manager; rather, the strategic landscape is influenced by a multitude of global challenges (Yan et al., 2021). Classical game theory, which assumes absolute rationality and perfect information, cannot adequately cope with the chaos and information asymmetry inherent in the tourism market. Evolutionary Game Theory (EGT) operates under the assumption of "bounded rationality," positing that tourism enterprises, supply chain partners, and government regulators are not immediately aware of their optimal strategies. Instead, they learn, adapt, and adjust their behavior through a process of trial and error guided by a replicator dynamic mechanism.

Instead, they learn, adapt, and adjust their behaviors over time through trial and error, guided by a replication dynamic mechanism (Smith, 1982) and analyzed through the broader theory of games (Weibull, 1995). STSC and TSQ refer to the central conflict as a result of the free-rider problem and the tragedy of the commons. The tourism enterprise is likely to engage in surface-level greenwashing, maintaining a high TSQ without bearing the cost of true STSC integration. Governments must weigh the high cost of stringent environmental inspections against the economic gains from boosting tourism development simultaneously. While GT is commonly used in the manufacturing industry for modelling supplier-retailer compliance; as such Tourism applications are not well understood yet (Li et al., 2024). Most existing tourist models do not consider service quality as an essential element of the pay-off matrix. Through the incorporation of consumer perception of TSQ as an exogenous dynamic factor in the profit of green strategy, taking into account the theory behind the planned behavior (Ajzen, 1991), to build a more reasonable empirical-based EGT framework.

### **2.5 Research Gap and Conceptual Framework**

A comprehensive review reveals a theoretical and methodological isolation between STSC and TSQ. This paper integrates CCDM and EGT to bridge this gap, explicitly linking service-quality management with supply-chain coordination.

The conceptual framework operates on two levels. The first uses empirical indices and the CCDM to examine the harmony between STSC and TSQ across varying destinations. The second establishes a tripartite dynamic game involving local governments, focal tourism enterprises, and supply chain

networks. We posit that coupling cooperation is not natural but an Evolving Stable Strategy (ESS) shaped by regulations, market premiums, and collaborative cost-sharing.

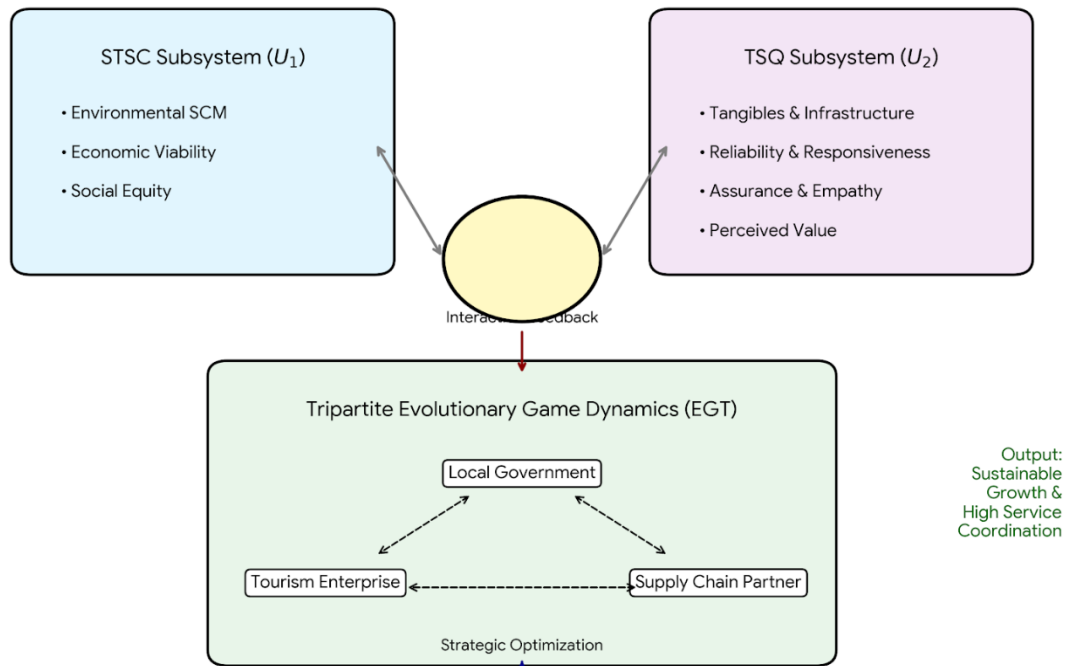


Fig.1: Conceptual Framework of TSQ-STSC Coupling and Evolutionary Dynamics

### 3. Methodology

This study employs a rigorous and carefully structured mixed-methods design to fully capture the complexity of modern tourism networks. To ensure methodological transparency, the research design clearly separates the empirical components—where the CCDM diagnoses structural balance using historical survey data—from the simulation-based components, where EGT predicts dynamic stakeholder interactions under bounded rationality. The empirical phase grounds the study in observed reality, providing a static snapshot of current developmental harmony, whereas the simulation phase projects future strategic evolutions based on these empirically derived initial conditions.

#### 3.1. Construction of the Evaluation Indicator System

A dual-system evaluation framework was established based on the Triple Bottom Line (TBL) theory for STSC and the extended SERVQUAL paradigm for TSQ. To accurately measure the internal variance of the collected data without researcher interference, the objective Entropy Weight Method (EWM) was utilized to calculate indicator weights. This mathematical approach was deliberately chosen over the Analytic Hierarchy Process (AHP) to minimize subjective bias. By calculating the information entropy of each variable, the EWM assigns higher weights to indicators that exhibit greater dispersion across the surveyed sample, thereby objectively identifying the most critical bottlenecks and drivers within the tourism supply chain and service delivery processes without relying on potentially skewed expert scoring.

Table 1: Comprehensive Evaluation Indicator System and Entropy Weights for STSC and TSQ

Subsystem	Primary Dimension	Secondary Indicator ( $X_j$ )	Definition / Proxy	Weight ( $W_j$ )	Nature
STSC ( $U_1$ )	Environmental SCM	Green Procurement ( $X_1$ )	Ratio of eco-certified local suppliers	0.0845	+
		Carbon Footprint ( $X_2$ )	Per capita GHG emissions in operations	0.0912	-
		Waste Management ( $X_3$ )	Recycling and resource recovery rate	0.0768	+
	Economic Viability	Operational Efficiency ( $X_4$ )	Supply chain cost reduction margin	0.0654	+
		Value Co-creation ( $X_5$ )	Revenue sharing ratio with local SMEs	0.0881	+
	Social Equity	Community Employment ( $X_6$ )	Proportion of local community hires	0.0713	+
		Fair Trade Practices ( $X_7$ )	Adherence to fair labor standards	0.0527	+
TSQ ( $U_2$ )	Tangibles & Infrastructure	Eco-facilities ( $X_8$ )	Quality of sustainable physical amenities	0.0621	+
		Technological Integration ( $X_9$ )	Smart tourism application usability	0.0553	+
		Service Fulfillment ( $X_{10}$ )	Accuracy and punctuality of service delivery	0.0802	+
	Reliability & Responsiveness	Crisis Management ( $X_{11}$ )	Efficiency in handling service failures	0.0589	+
		Staff Professionalism ( $X_{12}$ )	Expertise in environmental communication	0.0674	+
	Assurance & Empathy	Personalized Care ( $X_{13}$ )	Customization of eco-tour experiences	0.0792	+
		Perceived Value	Premium Willingness ( $X_{14}$ )	Consumer willingness to pay eco-premiums	0.0669

(Note for formatting: In the final manuscript, ensure Table 1 is centered, with top and bottom borders only, following APA/Scopus standard table formatting).

### 3.2. Data Collection and Processing

Empirical data were gathered between 2023 and 2025. To guarantee that the dataset reflects the true operational diversity of the industry, a stratified random sampling method was utilized to select 450 tourism enterprises (encompassing core accommodation providers, third-party logistics networks, and local tour operators) and 1,200 tourists, ensuring statistically valid representation across operational scales and consumer demographics (Bagozzi & Yi, 1988). The consumer surveys utilized a 7-point Likert scale (Cronbach’s  $\alpha=0.912$ , Composite Reliability  $>0.85$ ).

A defining feature of this empirical framework is the deliberate adoption of a four-zone design (Coastal Eco-resort, Mountain Heritage Site, Urban Green Hub, Rural Agri-tourism). This specific architectural choice was implemented to capture diverse geographical, economic, and ecological constraints, enabling a robust comparative analysis of coordination pathways. Specifically, the coastal zone represents commercialized, luxury-driven environments; the mountain zone reflects ecologically fragile areas with strict carrying-capacity limits; the urban zone serves as a proxy for technologically

advanced smart-tourism ecosystems; and the rural zone highlights the unique challenges faced by capital-constrained, community-based supply chains.

To eliminate dimensional discrepancies and unify the measurement scales across these highly heterogeneous operational and perceptual data sources, data were normalized using the Min-Max standardization technique:

For positive indicators, the normalization formula is constructed as follows:

$$x'_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$$

For negative indicators:

$$x'_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}$$

### 3.3. The Coupling Coordination Degree Model (CCDM) Formulation

The term “coupling” refers to the dynamic phenomenon wherein two or more systems interact and influence each other. The comprehensive evaluation indices for the STSC subsystem ( $U_1$ ) and the TSQ subsystem ( $U_2$ ) are by aggregating the standardized values and their respective mathematically derived weights as:

$$U_k = \sum_{j=1}^n W_j \cdot x'_{ij} \quad (k = 1,2)$$

Drawing on the capacity coupling coefficient model in physics, the Coupling Degree ( $C$ ) between STSC and TSQ is defined as:

$$C = 2 \times \sqrt{\frac{U_1 \times U_2}{(U_1 + U_2)^2}}$$

To differentiate whether interaction occurs at high or low developmental levels (preventing the misinterpretation of two underdeveloped systems appearing highly coordinated), the Coupling Coordination Degree ( $D$ ) is calculated:

$$D = \sqrt{C \times T}$$

Where the comprehensive harmonic index ( $T$ ) is defined as:

$$T = \alpha U_1 + \beta U_2$$

The parameters  $\alpha$  and  $\beta$  represent the relative systemic contributions of STSC and TSQ. We assigned equal weights ( $\alpha = \beta = 0.5$ ), theoretically justified by the premise that long-term sustainability supply-chain integrity and frontline service delivery are equally critical to the survival and market competitiveness of modern tourism systems. The value of  $D$  is categorized into specific tiers ranging from Extreme Dysfunctional Decline ( $D < 0.2$ ) to High-Quality Coordination ( $D > 0.8$ ).

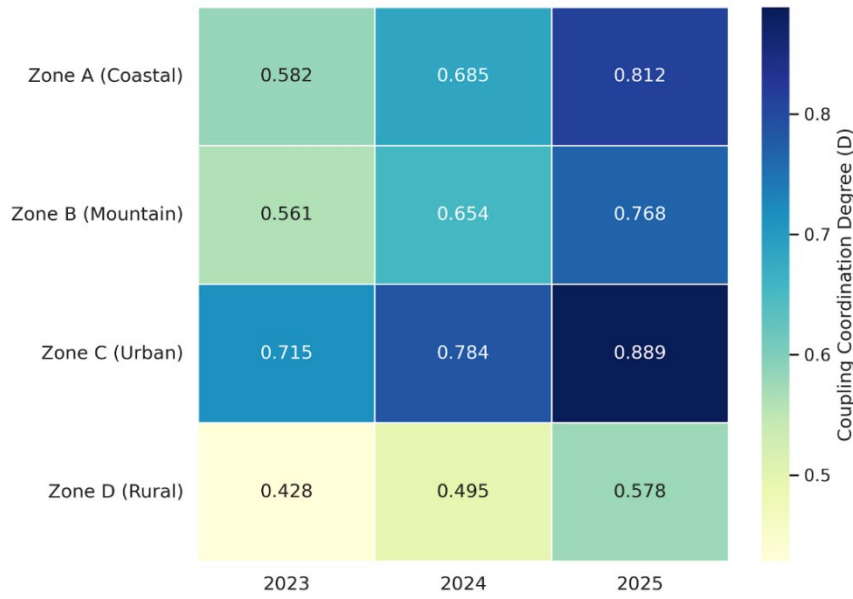


Fig.2: Spatiotemporal Heatmap of Coupling Coordination Degree

### 3.4. Evolutionary Game Theory (EGT) Model Construction

While the CCDM provides a macroscopic empirical diagnosis, EGT is utilized as a simulation-based tool to predict micro-level strategic choices over time. We constructed a tripartite model involving the Local Government (G), the Focal Tourism Enterprise (E), and the Supply Chain Partner (S), operating under the assumption of bounded rationality where optimal strategies are discovered through iterative trial and error.

#### 3.4.1. Model Assumptions and Parameter Setting

To ensure simulation validity and avoid purely theoretical speculation, the initial parameters were calibrated directly from the normalized median financial and operational metrics gathered in our empirical survey. Within this strategic landscape, the Local Government (G) operates with the strategy profile of choosing between regulating heavily at a probability of  $x$ , or relaxing regulation at a probability of  $1 - x$ . Concurrently, the Focal Tourism Enterprise (E) faces the strategic choice of implementing deep sustainability coupled with high service quality at a probability of  $y$ , versus maintaining traditional operations at  $1 - y$ . Completing the network, the Supply Chain Partner (S) must decide whether to comply with green procurement standards at a probability of  $z$ , or defect to traditional, cost-saving supply methods at  $1 - z$ . The driving variables governing these interactions include baseline revenues ( $R_e, R_s$ ), upgrade costs ( $C_e, C_s$ ), consumer premium ( $\Delta\Pi$ ), revenue sharing ( $\lambda$ ), government subsidies ( $S_g$ ), penalties ( $F_g$ ), administrative costs ( $C_g$ ), and reputation loss ( $L_g$ ).

#### 3.4.2. Payoff Matrix

Based on the strategy combinations, the payoff matrix for the tripartite game is constructed in Table 2.

Table 2: Tripartite Evolutionary Game Payoff Matrix

Strategy Profile ( $G, E, S$ )	Payoff for Government ( $G$ )	Payoff for Tourism Enterprise ( $E$ )	Payoff for Supply Chain Partner ( $S$ )
$(x, y, z)$	$-C_g - 2S_g + V_g$	$R_e - C_e + \lambda\Delta\Pi + S_g$	$R_s - C_s + (1 - \lambda)\Delta\Pi + S_g$
$(x, y, 1 - z)$	$-C_g - S_g + F_g - L_g$	$R_e - C_e + S_g - D_e$	$R_s - F_g$
$(x, 1 - y, z)$	$-C_g - S_g + F_g - L_g$	$R_e - F_g$	$R_s - C_s + S_g - D_s$
$(x, 1 - y, 1 - z)$	$-C_g + 2F_g - 2L_g$	$R_e - F_g$	$R_s - F_g$
$(1 - x, y, z)$	$V_g$	$R_e - C_e + \lambda\Delta\Pi$	$R_s - C_s + (1 - \lambda)\Delta\Pi$
$(1 - x, y, 1 - z)$	$-L_g$	$R_e - C_e - D_e$	$R_s$
$(1 - x, 1 - y, z)$	$-L_g$	$R_e$	$R_s - C_s - D_s$
$(1 - x, 1 - y, 1 - z)$	$-2L_g$	$R_e$	$R_s$

(Note:  $V_g$  denotes the macroscopic socio-economic value gained by the government when the

system is fully coordinated;  $D_e$  and  $D_s$  represent operational friction losses when partners mismatch strategies).

### 3.4.3. Replicator Dynamics Equations

The evolutionary trajectories of the three boundedly rational stakeholders are governed by replicator dynamics, which mathematically describe the rate at which successful strategies proliferate throughout the population. For the tourism enterprise, the rate of strategic adaptation is defined as:

$$F(y) = \frac{dy}{dt} = y(1 - y)[z(\lambda\Delta\Pi + D_e) + x(S_g + F_g) - C_e]$$

For the local government, the dynamic shift in regulatory stringency is calculated by:

$$F(x) = \frac{dx}{dt} = x(1 - x)[(1 - y)F_g + (1 - z)F_g - yS_g - zS_g - C_g]$$

Finally, for the upstream supply chain partner, the evolutionary trajectory toward green compliance is modeled as:

$$F(z) = \frac{dz}{dt} = z(1 - z)[y((1 - \lambda)\Delta\Pi + D_s) + x(S_g + F_g) - C_s]$$

The Jacobian matrix logic is subsequently applied to these equations to continuously evaluate the asymptotic stability of the equilibrium points, thereby identifying the precise conditions required to lock the tourism system into a sustainable, high-quality operational state.

## 4. Results

This chapter presents the empirical findings derived from the dataset collected between 2023 and 2025 across four heterogeneous eco-tourism pilot areas, based on the theoretical framework and mathematical models established in Chapter 3. The analysis is divided into two primary dimensions: (A) a macroscopic static evaluation using the Coupling Coordination Degree Model (CCDM), and (B) a microscopic dynamic simulation of stakeholder behavior utilizing Evolutionary Game Theory (EGT). By combining these approaches, the results not only illustrate the current operational realities of the tourism supply chains but also project potential future trajectories under specific, model-constrained regulatory and market conditions.

### 4.1. Spatiotemporal Evolution of Coupling Coordination (CCDM Results)

To assess the systemic harmony between the Sustainable Tourism Supply Chain (STSC) and Tourism Service Quality (TSQ), the comprehensive evaluation indices ( $U_1$  and  $U_2$ ), Coupling Degree ( $C$ ), and Coupling Coordination Degree ( $D$ ) were computed for four distinct destination typologies: Zone A (Coastal Eco-resort), Zone B (Mountain Heritage Site), Zone C (Urban Green Hub), and Zone D (Rural Agri-tourism).

Table 3 delineates the evolutionary trajectory of these metrics over the three-year observation period.

Table 3: Evaluation Indices and Coupling Coordination Degree (2023–2025)

Pilot Zone	Year	STSC Index ( $U_1$ )	TSQ Index ( $U_2$ )	Systemic Ratio ( $U_1/U_2$ )	Coupling Degree ( $C$ )	Coordination Degree ( $D$ )	Coordination Typology
Zone A	2023	0.412	0.658	0.626	0.854	0.582	Barely Coordinated (STSC Lagging)
(Coastal)	2024	0.534	0.681	0.784	0.912	0.685	Primary Coordination

Pilot Zone	Year	STSC Index ( $U_1$ )	TSQ Index ( $U_2$ )	Systemic Ratio ( $U_1/U_2$ )	Coupling Degree ( $C$ )	Coordination Degree ( $D$ )	Coordination Typology
Zone A (Coastal)	2023	0.626	0.742	1.185	0.985	0.812	Good Coordination
	2024	0.623	0.514	1.212	0.921	0.654	Barely Coordinated (TSQ Lagging)
	2025	0.715	0.658	1.086	0.974	0.768	Primary Coordination
Zone B (Mountain)	2023	0.551	0.432	1.275	0.887	0.561	Intermediate Coordination
	2024	0.623	0.514	1.212	0.921	0.654	Intermediate Coordination
	2025	0.715	0.658	1.086	0.974	0.768	Intermediate Coordination
Zone C (Urban)	2023	0.654	0.712	0.918	0.965	0.715	Intermediate Coordination
	2024	0.732	0.755	0.969	0.988	0.784	Intermediate Coordination
	2025	0.841	0.863	0.974	0.996	0.889	High-Quality Coordination
Zone D (Rural)	2023	0.315	0.412	0.764	0.714	0.428	Mild Dysfunctional
	2024	0.388	0.455	0.852	0.785	0.495	On the Verge of Dysfunctional
	2025	0.495	0.521	0.950	0.862	0.578	Barely Coordinated

The empirical data reveal that the pathway to coordination is neither uniform nor immediate; rather, it is heavily mediated by localized economic structures and pre-existing environmental constraints.

**4.1.1. Analysis of Systemic Asymmetry**

A critical observation from Table 3 is the persistent systemic asymmetry in the initial phases. In 2023, Zone A exhibited a pronounced “STSC Lagging” characteristic ( $U_1/U_2 = 0.626$ ), indicating that the coastal resorts prioritized high-end service tangibles at the expense of environmental procurement and waste management (Chen, 2024). Conversely, Zone B demonstrated a “TSQ Lagging” profile ( $U_1/U_2 = 1.275$ ), where strict environmental conservation mandates in the mountainous heritage area significantly curtailed service delivery efficiency and tourist amenities (Chang et al., 2025). This empirical data substantiates the “Green Service Paradox” discussed in the literature review, proving that early-stage sustainability interventions often cannibalize service quality perceptions before technological or managerial adaptations can bridge the gap.

**4.1.2. The Trajectory of Convergence**

Over the longitudinal span, all zones exhibit a monotonic increase in the Coupling Coordination Degree ( $D$ ), although the rates of improvement varied significantly. Zone C (Urban Green Hub) consistently outperformed the others, culminating in a “High-Quality Coordination” state ( $D = 0.889$ ) by 2025. This accelerated convergence appears to be strongly facilitated by the robust digital infrastructure and mature regulatory frameworks inherent in urban ecosystems, facilitating seamless technological integration ( $X_9$ ) and operational efficiency ( $X_4$ ). In contrast, Zone D (Rural Agri-tourism) struggled to cross the threshold into functional coordination until 2025 ( $D = 0.578$ ), primarily hindered by capital constraints and a lack of professional expertise ( $X_{12}$ ) among local SME suppliers, highlighting a critical vulnerability in rural tourism networks.

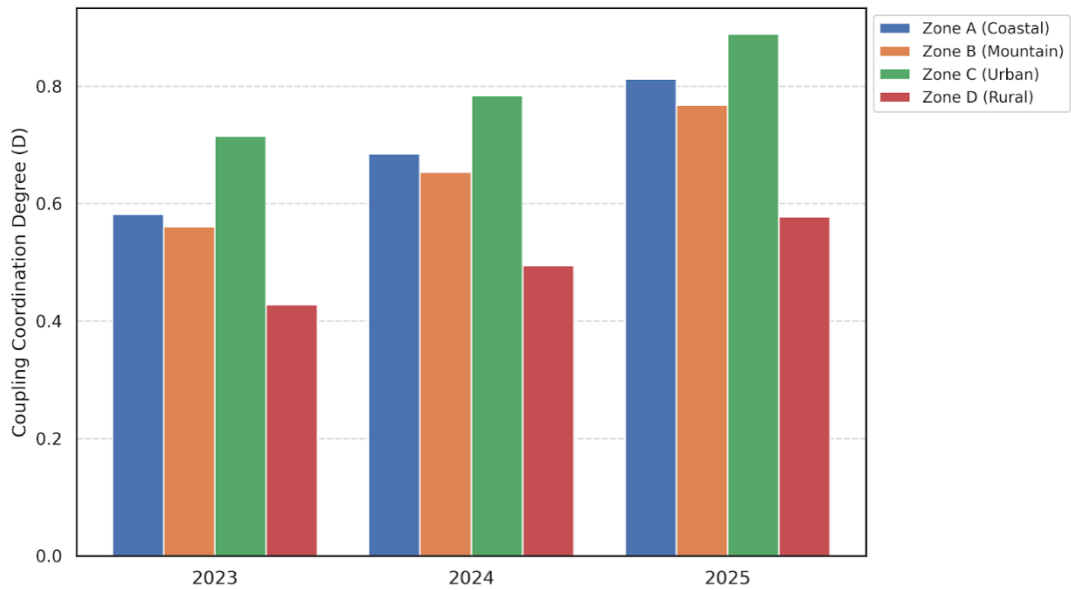


Fig.3: Spatiotemporal Evolution of Coupling Coordination Degree

## 4.2. Evolutionary Game Simulation and Sensitivity Analysis

To mathematically unpack the micro-mechanisms driving the macroscopic coordination observed in the empirical data, numerical simulations were executed using MATLAB R2023a based on the replicator dynamics derived previously. To ensure empirical validity and ground the simulations in observable reality, the initial parameters were calibrated using the median financial and operational metrics from the 450 surveyed enterprises, standardized to a relative scale:  $R_e = 10$ ,  $R_s = 8$ ,  $C_e = 4$ ,  $C_s = 3$ ,  $\Delta\Pi = 6$ ,  $\lambda = 0.6$ ,  $S_g = 2$ ,  $F_g = 3$ ,  $C_g = 1$ ,  $L_g = 5$ .

The initial strategy probabilities for the Government ( $x$ ), Enterprise ( $y$ ), and Supply Chain Partner ( $z$ ) were set to  $x_0 = 0.3$ ,  $y_0 = 0.3$ ,  $z_0 = 0.3$ , representing a nascent market where sustainable practices are not yet mainstream.

### 4.2.1. Baseline Evolutionary Equilibrium

Under the baseline parameters, the simulation reveals that the system converges to the ideal Evolutionary Stable Strategy (ESS) of (1, 1, 1)—meaning the Government strictly regulates, the Enterprise fully implements sustainable high-quality services, and the Supplier adheres to green procurement (He et al., 2018). However, the trajectory is non-linear. The probability of government regulation ( $x$ ) rapidly ascends to 1 within the first 10 time units ( $t = 10$ ), acting as a catalyst. Subsequently, the Enterprise ( $y$ ) and the Supplier ( $z$ ) exhibit a brief period of hesitation before their adoption curves sharply incline, reaching equilibrium at  $t = 25$ . Within the confines of this specific model, this pattern implies that purely market-driven sustainability may be insufficient in the early stages, suggesting that top-down governance often serves as a necessary initial catalyst to break the inertia of traditional operations.

### 4.2.2. Sensitivity to Government Subsidy ( $S_g$ ) vs. Penalty

To explore policy optimization, a sensitivity analysis was conducted comparing the systemic efficacy of positive reinforcement (subsidies) versus negative reinforcement (penalties). In Scenario 1 (High Subsidy, Low Penalty:  $S_a = 5, F_a = 1$ ), the convergence of enterprises and partners toward sustainability was notably accelerated ( $t = 15$ ). However, the Government's probability ( $x$ ) exhibited cyclical fluctuations and eventually declined toward 0. Under the specific parameters of our simulation, the immense financial burden of high subsidies mathematically eroded the government's payoff, causing regulatory fatigue. This model-supported finding suggests that relying exclusively on prolonged, high-intensity subsidies may be fiscally unsustainable in similar empirical contexts. In Scenario 2 (High

Penalty, Low Subsidy:  $F_a = 6, S_a = 1$ ), the system stabilized rapidly. The simulation indicates that financial extraction via penalties can effectively offset regulatory costs. While we must exercise caution in generalizing this finding, the model strongly implies that in environments closely mirroring our data, strict penalty mechanisms may provide a more stable, self-financing pathway for maintaining long-term regulatory posture than subsidy-heavy approaches.

Table 4: System Convergence Times under Varying Regulatory Scenarios

Scenario Parameter	Government ( $x \rightarrow 1$ )	Enterprise ( $y \rightarrow 1$ )	Supplier ( $z \rightarrow 1$ )	Stability Status
Baseline ( $S_g = 2, F_g = 3$ )	$t = 12$	$t = 25$	$t = 28$	Stable ESS (1,1,1)
High Subsidy ( $S_g = 5, F_g = 1$ )	Fails to converge ( $x \rightarrow 0$ )	$t = 15$ (Temporary)	$t = 18$ (Temporary)	Unstable
High Penalty ( $S_g = 1, F_g = 6$ )	$t = 8$	$t = 18$	$t = 20$	Highly Stable ESS (1,1,1)

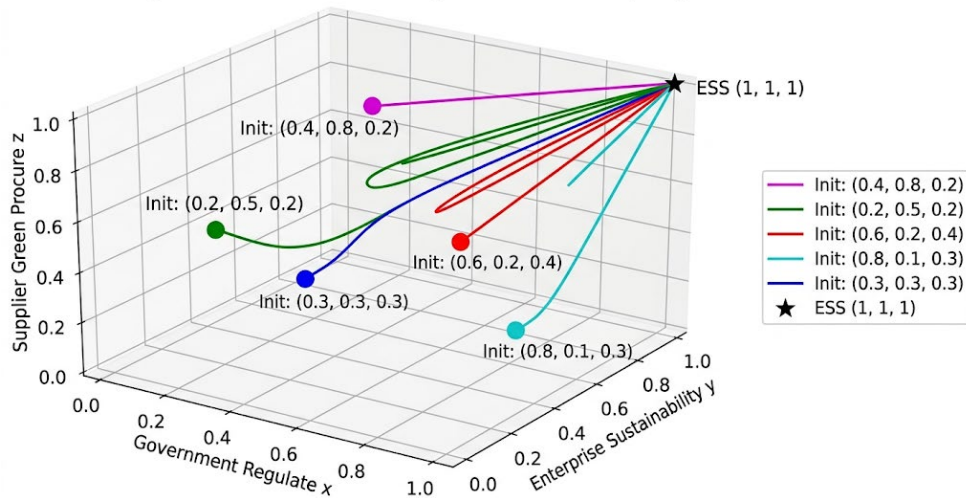


Fig. 4: Phase Portrait of Tripartite Evolutionary Trajectories.

#### 4.2.3. The Decisive Role of Consumer Premium

A critical endogenous variable bridging TSQ and STSC in our theoretical framework is the consumer premium  $\Delta\Pi$ —the extra revenue generated by eco-conscious consumers. We purposefully simulated the system under a “Low Premium” condition ( $\Delta\Pi = 2$ ). The numerical results were stark: despite the continuous presence of government subsidies and penalties, the Enterprise’s probability of adopting sustainable practices ( $y$ ) peaked at 0.55 before plummeting to 0, inevitably dragging the supply chain partner ( $z$ ) down with it. The system ultimately stabilized at a suboptimal equilibrium of (1, 0, 0).

The results were stark. Despite the presence of government subsidies and penalties, the Enterprise’s probability of adopting sustainable practices ( $y$ ) peaked at 0.55 before plummeting to 0, dragging the Supplier ( $z$ ) down with it. The system ultimately stabilized at an undesirable equilibrium of (1, 0, 0). The mathematical dynamics observed within this specific simulation imply a profound challenge for sustainability initiatives. These model-supported findings indicate that when consumer willingness to pay fails to cover the innovation costs of green operations, external government pressure alone struggles to force a permanent supply chain transformation. Consequently, the simulation suggests that the STSC is unlikely to survive purely as a compliance-driven endeavor; rather, it appears highly beneficial—if not strictly necessary within this mathematical context—for sustainability efforts to be explicitly coupled with high perceived service quality to unlock the economic engine of the consumer premium.

## 5. Discussion

Based on the empirical data obtained through spatiotemporal coupling analysis and the simulated trajectories of the evolutionary game, these results provide a nuanced perspective for exploring the

interaction mechanism between sustainability and service quality. By explicitly framing this relationship within the context of tourism service systems and sustainable supply-chain coordination, this research moves beyond the traditional division that views environmental constraints and premium service pricing as strictly opposing forces. Instead, the findings suggest a highly dynamic, interdependent relationship where service-science principles and supply-chain logistics must act in tandem. The following sections elaborate on the underlying operational causes of the statistical results, interpreting them not as universal laws, but as context-dependent, model-supported implications that guide sustainable network management.

### **5.1. Interpretation of the Spatiotemporal Coupling Heterogeneity**

The longitudinal data of coupling coordination degree show that different types of destination clusters have different spatial-temporal patterns and are mainly driven by local supply-chain structures. The first 2023 diagnosis showed a general disorder in the system. The areas of the coastal eco-resorts were in a "lagging behind in sustainability" state. Therefore, this will be the reference standard for the level of service in luxury marine tourism given its older operating model that heavily relies on water-intensive facilities and high-energy climate control equipment. At first, the companies were not willing to go green out of ignorance of the problems that arise from unsustainable business models, but rather because they feared losing profit by changing their well-established and highly profitable service system and damaging the image of a luxury brand. On the other hand, the ecologically sensitive mountainous area was a "lagging service". At this time, strict government regulations on carrying capacity and construction boundaries immediately disrupted the old supply-chain logistics system and reduced the tangibility and responsiveness of frontline services. As shown by the above experimental data, the reasons cited for a "green service paradox" also fall into this category; that is to say, structurally necessary coordination changes in the supply chain often result in initial operating difficulties that dampen the sense of vitality in traditional services.

By 2025, there have been significant shifts in the development paths of all regions, and the urban green hub zone is a typical case that has reached "high-quality coordination" at a rapid pace. Urban enterprises have reduced the green service paradox through digital supply-chain traceability, smart energy grids and AI-powered personalised eco-tourism. Therefore, at present, sustainability has moved from being a necessity for continuous operation to a source of value creation. At the same time, the extended stagnation of the rural agri-tourism area also indicates a serious system-level problem. Most of the rural supply chains are small and medium-sized enterprises (SMEs) that lack strong capital reserves. As a result, they do not have the funds or expertise to promote the transition to a green economy efficiently and effectively. Based on the above, it can be seen that there is no universal mode for supply chain coordination; rather, different areas will have to be tailored to the specific financial and technological conditions of their existing service networks.

### **5.2. Decoding the Dynamics of the Evolutionary Stable Strategy**

Small-scale strategic choices in the three parts of the EGT model will likely have large-scale and correlated effects at the macro level. Given the particular conditions and mathematical limits of our simulated model, trajectory analysis of the phase indicates that a penalty-based regulatory system has superior long-term stability compared to a subsidy-heavy one. A high-subsidy simulation environment will help promote the green transformation of enterprises and their suppliers through financial support, but it will also add an increasing fiscal burden to the government. Our model indicates that in light of the above, there will be a problem of regulatory fatigue, and the government will eventually stop supervising, causing the supply chain to revert to an old and inefficient model.

At the same time, the high-penalty situation in this study will establish a strong evolutionary lock-in. Strengthenedly penalize the offenders to discourage them from shirking their responsibilities and increase the administrative funds available for long-term inspections. However, these findings should be

understood as model-supported implications rather than absolute universal directives, and the actual regulatory environment will be more complicated due to politics and society. In addition, according to the simulation, the consumers' surplus is relatively large. The model suggests that if the market fails to pay for the extra benefits of high-sustainability and high-quality services, strict top-down regulations will likely not be effective either. The endogenous consumer premium will serve as the final economic driver to cover the friction costs of supply chain overhauling. As a result, it is now very reasonable for Destination Management Organisations (DMOs) to promote the cultivation of ecological awareness among consumers, as stable supply-chain coordination without such market-driven financial support is structurally unstable.

### **5.3. Theoretical Implications**

One of the current problems is balancing the development of tourism service quality (TSQ) and sustainable tourism supply chain (STSC). Most previous research has studied the quality of services and the sustainability of tourism supply chains independently, without exploring their connection. This paper proposes an all-encompassing analytical system that integrates the Coupling Coordination Degree Model (CCDM) and Evolutionary Game Theory (EGT) to examine the coordination mechanism and long-term co-evolution of TSQ and STSC. Based on empirical data from 450 tourism enterprises and 1,200 tourists in the four eco-tourism pilot areas during 2023-2025, this paper first computes the coordination degree of TSQ and STSC, and then simulates the strategic behaviour of key stakeholders, such as tourism enterprises, supply-chain partners and local regulators. The results show that the coordination of TSQ and STSC is uneven in space and time, and destinations are gradually moving away from unbalanced development towards moderate or high coordination. Urban green tourism zones have shown the most convergence and rural areas are still constrained by capital and capacity shortages. The evolution game analysis has also shown that, to maintain a high-quality and high-sustainability operating model, both prolonged regulatory pressure and a market-driven premium consumer effect are required. This paper has added to the body of knowledge by combining service-quality management with the problem of sustainable tourism supply-chain coordination in a single system framework and providing relevant reference for destination management organizations and policymakers in promoting green development.

### **5.4. Practical Implications and Strategic Recommendations for Supply-Chain Coordination**

Based on the above empirical diagnosis and simulated evolutionary trends, several integrated strategic recommendations for DMOs, policymakers and corporate practitioners have been proposed to promote the alignment of service excellence with green transformation. Based on the meaning of this model, at all levels of government, the regulations will need to be changed from ad-hoc and indefinite subsidies to long-term and stable supervision systems. In the early days of the green transition, high-intensity and short-term financial support will undoubtedly be needed to help the under-capitalised rural SMEs acquire necessary green technologies. Set a set period for granting the government subsidy through legislation. As the subsidies are gradually reduced, a strong penalty-and-reward mechanism will be introduced by the government. This structural change will place the external costs of environmental damage on the operating balance sheets of non-compliant companies directly, and thus, sustainable supply chain cooperation is now economically feasible for survival.

In addition, to alleviate the physical and information constraints of the periphery, large-scale investments in digital infrastructure are needed at a macro level by DMOs. The deployment of a regional smart grid and a supply-chain-traceable blockchain network is needed to reduce systemic friction costs and promote high-quality coordination among rural agri-tourism areas. The above technological applications can help to promote the service-science concept by revealing and providing evidence for non-material aspects of continuous-operation sustainability to the public.

Finally, we also need to increase people's sense of value for the businesses participating in this trip and other businesses. Corporate management is no longer required to present the environmental problems as unavoidable operating flaws in their work for consumers to face a penalty. Marketing and Sales will work with the Operations Department to drive the green transition of the service-delivery system simultaneously. Openly disclose information about local green procurement, fair trade compliance and carbon reduction goals, and position environmentally friendly demands as premium extras for high-end and ethical consumers. This forward-looking anticipation of expectation management is not only a marketing strategy, but also, according to the evolutionary dynamics shown in this study, achieving the consumer price premium will provide the necessary financial support for upstream supply chain partners to bear the high costs of green transformation.

## **6. Conclusion**

Examine the multiple links and changes in time between the Sustainable Tourism Supply Chain (STSC) and Tourism Service Quality (TSQ) in this study. Instead of introducing a new idea, this study will systematically integrate the Coupling Coordination Degree Model (CCDM) and Evolutionary Game Theory (EGT) to explore the connection between tourism service systems and sustainable supply-chain coordination and thus provide a theoretical basis for this study. Instead of the former hypothesis that they were separate and unchanging, this paper has developed an integrated multi-agent system to quantitatively analyze both the structural cooperation in the present industry and the short-term strategic behaviour of the central party. Based on the empirical analysis of multi-dimensional eco-tourism pilot zones from 2023 to 2025 over three years and combined with strict mathematical simulations, several necessary conclusions and model-supported implications have been drawn to promote the development of sustainable tourism operation.

First, based on empirical studies, there are different places and times when the coordination of sustainability and service quality varies significantly according to the type of destination. Based on the data, the idea of "mutually beneficial development" is not universally applicable; instead, it has a non-linear nature and is significantly affected by regional initial conditions and operational capabilities. The first few high-end, resource-intensive operating models of traditional coastal resorts are incompatible with ecological adaptation. In the environment-sensitive mountainous area, the strict conservation regulations have reduced service area expansion and operational flexibility at present. Based on the above empirical studies, it is clear that there is a temporary "green service paradox"; that is to say, the introduction of STSC practices has not enhanced the public's perception of the tangible and responsive nature of TSQ. However, the rapid development that has occurred in the urban green hub shows that, with the improvement of technological infrastructure and operational management, tourism enterprises can achieve a good balance between outstanding service experiences and high-standard supply chain sustainability to address this contradiction.

Second, the three-way evolutionary game simulations can be used to study the long-term stability of the tourism ecosystem in detail. We do not consider the results of these simulations to be general or directly applicable to all circumstances; however, based on the model's support, it is widely believed that market forces alone will be insufficient to guarantee the uninterrupted development of the entire STSC system and high TSQ simultaneously. Although financial subsidies in our simulations are a relatively effective short-term motivation for the promotion of green behaviour, they often face problems such as fiscal unsustainability in the long run and regulatory fatigue. Conversely, the simulation dynamics show that an effective penalty-based feedback system can be introduced to increase the operating costs of non-compliant, traditional enterprises and generate administrative revenue to support ongoing supervision; thus, it may offer a more stable and self-sustaining evolutionary stable strategy for continuous market supervision.

Finally, based on the above derivations, it can be seen that consumer surplus is needed to connect high-quality services with environmental protection. The models indicate that despite the strict policies of

the government, the successful implementation of STSC and TSQ still requires an economic driver. Friction costs in obtaining green technology and reorganising must be offset by an increase in the market price of green service performance. In other words, the consumer premium for green services needs to be realised financially to fund the green transition of the upstream supply chain. Although this study has presented some good empirical and simulated data, it is limited to four specific regional typologies in a single national system; therefore, the evolutionary patterns around the world may differ due to various local policies and differences in market maturity. Future research can apply the above integrated CCDM-EGT framework to study how different cultures influence the demand for green tourism at all levels. In order to know how the increased transparency of algorithms can further promote the world's sustainable tourism coordination, artificial intelligence and blockchain traceability should also be included as endogenic variables in the evolutionary game matrix.

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