Frontiers in Business, Economics and Management
ISSN: 2766-824X | Vol. 19, No. 3, 2025

Research on the Participation Strategies of Enterprises, Power Grid Companies, and Local Governments Under Dual Subsidies and Revenue Sharing

Jingdu Yu

Department of Business Administration, Chongqing Technology and Business University, CO 400000, China

Abstract: Incentive-based demand response (DR) programs play a vital role in maintaining the stability and efficiency of power grid operations. However, enhancing enterprises' enthusiasm for participating in these programs remains a critical challenge. This study introduces a revenue-sharing contract between enterprises and power grid companies, while considering the impact of local government subsidies and rewards on the implementation of incentive-based DR programs. A tripartite evolutionary game model involving enterprises, power grid companies, and local governments is constructed, and numerical simulations are conducted using MATLAB. The results indicate that the intensity of subsidies from power grid companies significantly influences the strategic choices of both enterprises and power grid companies. Appropriate subsidy levels can guide enterprises to respond actively and sustain power grid companies' proactive subsidization. The revenue-sharing ratio critically guides enterprises' decisions to adopt active response strategies. Additionally, the outage risk cost borne by enterprises not only affects their willingness to respond actively but also serves as a key basis for determining subsidy intensity. This study further defines effective intervals for factors driving the system toward different stable states, providing theoretical references for strategic decision-making among enterprises, power grid companies, and local governments.

Keywords: Incentive-based demand response; Subsidy intensity; Revenue sharing; Tripartite evolutionary game; Dual subsidies.

1. Introduction

Demand response (DR) refers to the voluntary adjustment of electricity consumption by users through economic incentives during periods of short-term supply-demand imbalance or renewable energy integration challenges. This mechanism achieves peak shaving, enhances grid flexibility, ensures stable grid operations, and promotes renewable energy adoption [1]. As a key tool for improving power system regulation, DR effectively mitigates peak loads and alleviates supply shortages [2]. Pilot DR programs have been actively implemented in provinces such as Jiangsu, Shanghai, Zhejiang, Jiangxi, and Chongqing. By the end of 2021, State Grid Corporation had conducted 191 peak-shaving DR events, involving 255,024 users and a response capacity of 76.8066 million kW, alongside 85 valley-filling DR events with 36,795 users and 44.5771 million kW of response capacity [3]. Despite these efforts, the scale and frequency of DR implementation in China remain limited, failing to meet expectations. For instance, only 25 DR events were implemented across eight provinces in 2019 [4]. During the summer of 2022, Sichuan Province faced severe power shortages due to extreme heat, leading to forced outages for numerous enterprises and economic losses exceeding billions of yuan [5]. Although price incentives were offered to users participating in load-shifting programs, their effectiveness was suboptimal.

Incentive-based DR employs economic rewards to guide users in reducing electricity consumption during peak periods, thereby lowering grid peak loads. By aggregating flexible loads, it provides significant regulatory flexibility, addressing the insufficient adjustability of power systems [6]. In such programs, governments formulate policies, power grid companies execute them, and enterprises (as participants) interact to implement DR initiatives [7]. A fair settlement mechanism is essential for sustaining long-term DR strategies, ensuring that both enterprises and power grids derive reasonable benefits [8].

Revenue-sharing contracts, as effective tools for coordinating stakeholder interests, have garnered widespread attention in academia and industry [9]. For example, Gérard and Martin [10] examined revenue-sharing contracts in video rental supply chains, finding that such contracts harmonize retailer competition and profit allocation. Ting et al. [11] analyzed wholesale pricing and revenue-sharing contracts under cap-and-trade regulations, revealing that excessive carbon credit allocation may reduce manufacturer profits and hinder regulatory compliance. Wang et al. [12] designed a revenue-sharing mechanism for coal-fired power supply chains under carbon quotas, demonstrating enhanced profitability under coordinated decision-making. Building on these studies, this paper introduces revenue sharing into the DR context but focuses on its long-term impact on strategic evolution.

Despite progress, large-scale adoption of incentive-based DR faces challenges, including inconsistent subsidy standards across regions [23]. Excessive subsidies may waste fiscal resources, while insufficient subsidies fail to incentivize participation. This study establishes a dual-subsidy mechanism and quantifies subsidy levels. Existing research on dual subsidies, such as Liang et al. [13] and Zhu et al. [14], informs our approach. We extend these frameworks to explore subsidy impacts on equilibrium outcomes.

This paper constructs a tripartite evolutionary game model involving enterprises, power grid companies, and local governments. Evolutionary game theory, suited for analyzing bounded rationality and dynamic interactions, reveals how stakeholders adapt strategies over time [25]. For instance, Zhou et al. [18] applied this method to industrial internet platforms, highlighting the role of revenue-sharing ratios. Our contributions include: (1) treating governments as independent actors in DR programs; (2) proposing dual subsidies and revenue-sharing mechanisms in DR contexts; and (3) identifying optimal subsidy and revenue-sharing intervals through evolutionary game analysis.

2. Model Assumptions and Construction

2.1. Model Assumptions

Participants: A tripartite evolutionary game model involving enterprises, power grid companies, and local governments, all with bounded rationality.

Strategy Spaces: Enterprises: {Active Response x, Passive Response $(1-x)$ }. Power Grid Companies: {Active Subsidy y, Passive Subsidy $(1-y)$ }. Local Governments: {Active Governance z, Passive Governance $(1-z)$ }.

Costs: Enterprises: Equipment cost C_h, operational adjustment costs C_{ph} (active) and C_{pl} (passive), outage risk probabilities k_1 (active) and k_2 (passive), outage loss d. Power Grid Companies: Lost revenue from reduced sales $p*Q_1$. Local Governments: Cost C_g under active governance.

Subsidies and Rewards: Power Grid Companies: Subsidies S_e (active) and S_m (passive) per kWh. Local Governments: Subsidies S_{eh} (active) and S_{el} (passive) to power grid companies; rewards A from higher-level governments.

Revenues: Enterprises: Production revenues R_m (active) and R_n (passive), saved electricity costs R_t (active) and R_k (passive).

Power Grid Companies: Revenue R from successful DR implementation, shared with enterprises at ratio θ.

Local Governments: Social benefits U_h (active) and U_l (passive)

2.2. Model Construction

The mixed-strategy payoff matrix for the tripartite game is shown in Table 1. Replicator dynamics equations are derived for each participant, and stability analyses are conducted using Jacobian matrices and Lyapunov methods.

Table 1. Mixed-Strategy Payoff Matrix for Enterprises, Power Grid Companies, and Local Governments

Power Grid Companies			Local Governments	
			(z)	$(1-z)$
Enterprises	(x)	(y)	$R_m + R_t + aQ_1S_e + \theta R + S_{bh}$ $-C_{ph} - C_h - k_1 d$ $R_a + (1-\theta)R + S_{eh} - aQ_1S_e$ $-pQ_1$ $U_h + A - C_g - S_{eh} - S_{bh}$	$R_m + R_t + aQ_1S_e + \theta R + S_{bl}$ $-C_{ph} - C_h - k_1 d$ $R_a + (1-\theta)R + S_{el} - aQ_1S_e$ $-pQ_1$ $U_h - S_{el} - S_{bl}$
		(1-y)	$R_m + R_t + aQ_1S_m + \theta R + S_{bh}$ $-C_{ph} - C_h - k_1 d$ $R_b + (1-\theta)R + S_{el} - aQ_1S_m$ $-pQ_1$ $U_h + A - C_g - S_{el} - S_{bh}$	$R_m + R_t + aQ_1S_m + \theta R + S_{bl}$ $-C_{ph} - C_h - k_1 d$ $R_b + (1-\theta)R + S_{el} - aQ_1S_m$ $-pQ_1$ $U_h - S_{el} - S_{bl}$
	(1-x)	(y)	$R_n + R_k - C_{pl} - C_h - k_2 d$ $R_a + S_{eh} - pQ_2$ $U_l + A - C_g - S_{eh}$	$R_n + R_k - C_{pl} - C_h - k_2 d$ $R_a + S_{el} - pQ_2$ $U_l - S_{el}$
		(1-y)	$R_n + R_k - C_{pl} - C_h - k_2 d$ $R_b + S_{el} - pQ_2$ $U_l + A - C_g - S_{el}$	$R_n + R_k - C_{pl} - C_h - k_2 d$ $R_b + S_{el} - pQ_2$ $U_l - S_{el}$

2.3. Model Analysis

Use American English when writing your paper. The serial comma should be used ("a, b, and c" not "a, b and c"). In American English, periods and commas are within quotation marks, like "this period." Other punctuation is "outside"! The use of technical jargon, slang, and vague or informal English should be avoided. Generic technical terms should instead be used.

2.3.1. Enterprise Strategy Stability

The replicator dynamics equation for enterprises is:

$$F(x) = \frac{dx}{dt} = x(1-x)A(y,z) \tag{1}$$

Where A(y, z) combines subsidy, revenue-sharing, and risk factors. Stable strategies depend on threshold conditions for y and z.

Corollary 1: The probability of active response increases with higher subsidies, production revenue R_m, revenue-sharing ratio θ, outage risk k_1, and grid benefits R, but decreases with passive revenue R_n, outage risk k_2, and loss d.

Corollary 2: Active response probability rises with increased subsidy intensity y or government engagement z.

2.3.2. Power Grid Company Strategy Stability

The replicator dynamics equation for power grid companies is:

$$F(y)=\frac{dy}{dt}=y(1-y)W(x,z) \tag{2}$$

Where $W(x,z)$ balances subsidy costs and revenues.

Corollary 3: Active subsidy probability increases with higher active revenue R_a, government subsidies S_{eh}, and normal subsidies S_m, but decreases with passive revenue R_b. subsidy intensity a, and maximum subsidies S_e.

Corollary 4: Active subsidy probability declines with higher enterprise participation x but rises with government engagement z.

2.3.3. Local Government Strategy Stability

The replicator dynamics equation for governments is:

$$F(z)=\frac{dz}{dt}=z(1-z)\ U(\text{x, y}) \tag{3}$$

Where $U(x,y)$ weighs rewards against costs.

Corollary 5: Active governance probability increases with higher rewards A, passive subsidies S_{el}, but decreases with governance costs C_g and active subsidies S_{eh}.

Corollary 6: Active governance probability rises when enterprise x or power grid y participation is low.

3. Simulation Analysis

To validate the effectiveness of the evolutionary stability analysis, numerical simulations were conducted using MATLAB R2021a. Given the variations in demand response (DR) policies and implementation rules across provinces and cities, this study adopts Tianjin—a city with successful DR policy outcomes—as a representative case. Data were sourced from the 2022 Tianjin Electricity Demand Response Implementation Rules. The maximum subsidy amount provided by power grid companies to enterprises, denoted as S_e, was set to 5 CNY/kWh based on the emergency peak-shaving DR subsidy standard specified in the Tianjin rules. The normal subsidy amount S_m, was assigned 2 CNY/kWh according to the incentive-based peak-shaving DR policy. Other parameters were assigned values based on simulation requirements while adhering to stability conditions. Drawing on the parameter assignment approaches of Liu et al. and Du zhi Ping et al., and considering interactions among parameters, the model parameters were initialized as follows: $C_{ph}=6$, $C_{pl}=3$, $R_t=2$, $R_k=1$, $R_n=7$, $R_m=3$, $S_e=5$, $S_m=2$, $a=0.5$, $\theta=0.2$, $R=5$, $R_a=2$, $R_b=4$, $C_g=2$, $S_{bh}=1$, $S_{bl}=0.5$, $S_{eh}=8.5$, $S_{el}=3$, $A=9$, $Q_1=2$, $Q_2=1$, $k_1=0.2$, $k_2=0.6$, $d=5$.

Based on the conditions satisfying Corollary 9, the impacts of a, θ on the evolutionary game process and outcomes are analyzed.

First, to analyze the impact of subsidy intensity aa on the evolutionary game process and outcomes, values of a were assigned as 0.15, 0.35, 0.55, and 0.75. The simulation results of the replicator dynamics equations over time are shown in Figure 1. Subsequently, to examine the influence of the revenue-sharing ratio θ, values of θ were set to 0.15, 0.35, 0.75, and 1. The corresponding temporal evolution of the replicator dynamics equations is illustrated in Figure 2.

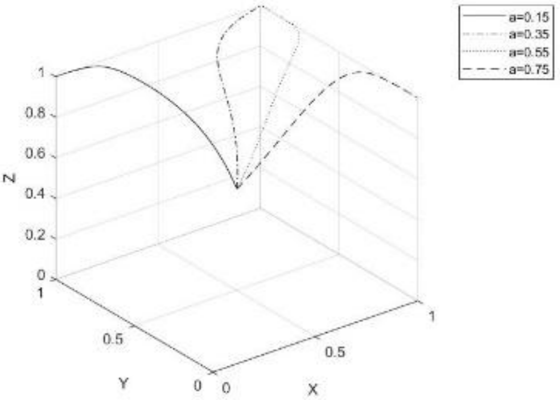

Figure 1. Effect of Subsidy Level

As shown in Figure 1, when $a=0.15$, the system satisfies Condition B, and the evolutionarily stable strategy converges to $E_7(0,1,1)$, where enterprises adopt a passive response, power grid companies implement active subsidies, and local governments maintain active governance. As a increases, the probability of enterprises choosing an active response strategy rises.

For $a=0.35$ and $a=0.55$, the system meets Condition C, leading to the $E_8(1,1,1)$, where all parties adopt active strategies (enterprises: active response, power grid: active subsides ,governments: active governance). When $a=0.75$, the system shifts to Condition A, stabilizing at $E_6(1,0,1)$, where enterprises remain active, power grid companies switch to passive subsidies, and governments stay active.

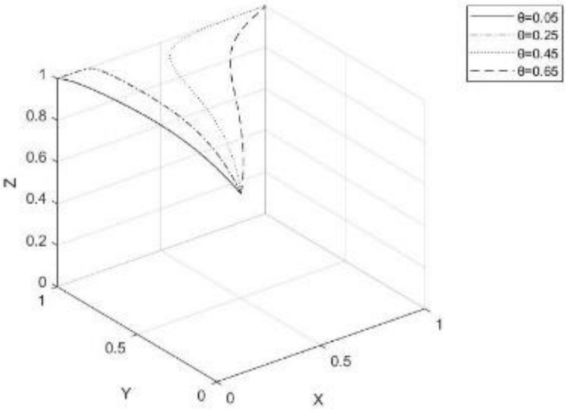

Figure 2. Effect of Revenue-Sharing Proportion

Analysis of Figure 2: As illustrated in Figure 2, when $\theta=0.15$ and $\theta=0.25$, the system satisfies Condition B, stabilizing at the evolutionarily stable strategy $E_7(0,1,1)$, where enterprises adopt a passive response, power grid companies implement active subsides, and local governments maintain active governance

For $\theta=0.45$ and $\theta=0.65$, the system meets

Condition C, converging to the $E_8(1,1,1)$, characterized by active strategies across all parties: enterprises respond actively, power grid companies subsidize actively, and governments govern actively.

4. Conclusion

Enterprises: Subsidy intensity, revenue sharing, outage risks, and cost differences dominate strategy choices. Optimal subsidies should balance outage risks and grid benefits.

Power Grid Companies: Subsidy intensity inversely affects active strategies, while government subsidies directly incentivize participation.

Local Governments: Higher rewards and lower governance costs promote active strategies.

Set subsidy intensities between critical thresholds. Adjust revenue-sharing ratios above 0.35 to incentivize enterprises.

Align government rewards with governance costs to ensure DR program success.

References

[1] Li, Z., Han, L., Li, Q., et al. Analysis and Suggestions on Demand Response in Send-End Grid Provinces [J]. Power Demand Side Management, 2023, 25(06): 69–75.

[2] Carbon Neutrality Development Institute. Current Status and Development Suggestions for Power Demand Response Technologies [EB/OL]. (2022-09-16). https://rich.sjtu.edu.cn/Web/Show/568

[3] China Power News Network. Analysis and Development Recommendations for China’s Power Demand Response [EB/OL]. (2022-08-11). http://mm.chinapower.com.cn/zx/zxbg/20200811/27296.html

[4] Sichuan Provincial Department of Economy and Information Technology. Emergency Notice on Expanding the Implementation Scope of Industrial Enterprises’ Electronic Participation [EB/OL]. (2022-08-14). https://jxt.sc.gov.cn/scjxt/tl/dh0/2022/8/16/e8797536a69e45a3b89a9b27ec9668a3.shtml

[5] Huo, J., Liu, X., Tan, H., et al. Practice and Reflections on China’s Power Demand Response Policies [J]. China Energy, 2022, 44(07): 35–43.

[6] Li, B., Chen, J., Li, D., et al. Key Issues and Prospects for Large-Scale Demand Response Implementation in China [J]. Power System Technology, 2019, 43(02): 694–704. DOI:10.13335/j.1000-3673.pst.2018.0737.

[7] Shen, Y., Yue, Y., Yan, H., et al. Aggregation and Regulation Strategies of Demand Response Resources in Regional Power Grids [J]. Power System Technology, 2017, 41(10): 3341–3348. DOI:10.13335/j.1000-3673.pst.2017.1025

[8] Govindan, K., Popiuc, M. N. Reverse Supply Chain Coordination by Revenue Sharing Contract: A Case for the Personal Computers Industry [J]. European Journal of Operational Research, 2014, 233(2): 326–336.

[9] Cachon, G. P., Lariviere, M. A. Supply Chain Coordination with Revenue-Sharing Contracts: Strengths and Limitations [J]. Management Science, 2005, 51(1): 30–44.

[10] Ji, T., Xu, X., Yan, X., et al. The Production Decisions and Cap Setting with Wholesale Price and Revenue Sharing Contracts under Cap-and-Trade Regulation [J]. International Journal of Production Research, 2020, 58(1): 128–147.

[11] Wang, B., Ji, F., Zheng, J., et al. Carbon Emission Reduction of Coal-Fired Power Supply Chain Enterprises under the Revenue Sharing Contract: Perspective of Coordination Game [J]. Energy Economics, 2021, 102: 105467.

[12] Liang, X., Wei, C. Research on Innovation and Coordination Strategies in Dual-Channel Supply Chains under Dual Subsidies [J]. Industrial Engineering and Management, 2020, 25(06):172–182. DOI:10.19495/j.cnki.1007-5429.2020.06.020

[13] Zhu, C., Ma, J., Li, Q. Supply Chain Decision-Making and Coordination Considering Low-Carbon Reputation under Dual Subsidies [J]. Control and Decision, 2023, 38(11): 3261–3270. DOI:10.13195/j.kzyjc.2022.0121

[14] Zhu, L., Zhang, J., Zhang, S. Tripartite Evolutionary Game and Simulation Analysis of Drug Safety Regulation under Government Reward-Punishment Mechanisms [J]. Chinese Journal of Management Science, 2021, 29(11): 55–67. DOI:10.16381/j.cnki.issn1003-207x.2019.0481

[15] Li, X., Yang, H., Zeng, L., et al. Tripartite Evolutionary Game for Enhancing Regional Public Brands of Agricultural Products [J]. Chinese Journal of Management Science, 2022, 30(08): 196–209. DOI:10.16381/j.cnki.issn1003-207x.2021.0740

[16] Zhou, X., Li, C., Liu, Y., et al. Tripartite Collaborative Evolution Strategies for Industrial Internet Platforms, Developers, and Enterprises: The Role of Government Subsidies and Revenue Sharing [J/OL]. Chinese Journal of Management Science: 1–14 [2023-11-05]. DOI:10.16381/j.cnki.issn1003-207x.2021.2558

[17] Tianjin Municipal Bureau of Industry and Information Technology. Notice on the Implementation Rules for 2022 Electricity Demand Response [EB/OL]. (2022-01-24). https://gyxxh.tj.gov.cn/ZWGK4147/ZCWJ6355/wjwj/202201/t20220124_5787811.html

[18] Jiangsu Provincial Development and Reform Commission. Notice on the Revised Implementation Rules for Jiangsu Electricity Demand Response [EB/OL]. (2018-06-18). http://fgggw.jiangsu.gov.cn/art/2018/6/18/art_51007_10655338.html

[19] Henan Provincial Development and Reform Commission. Notice on the Implementation of Electricity Demand Response in 2019 [EB/OL]. (2019-03-26). https://fgw.henan.gov.cn/2019/03-01/736154.html

[20] Shandong Provincial Development and Reform Commission. Notice on the Implementation of 2019 Electricity Demand Response (Lu Neng Dian Li Zi [2019] No. 176) [EB/OL]. (2019-07-10). http://nyj.shandong.gov.cn/art/2019/7/11/art_59960_6810471.html

[21] Xu, F., Sun, H., Guo, Q. Review and Prospects of Integrated Demand Response Research [J]. Proceedings of the CSEE, 2018, 38(24): 7194–7205+7446. DOI:10.13334/j.0258-8013.pcsee.180893

[22] Gao, P., Chen, X., Chen, J., et al. Measures and Application Methods for Power Demand Response in China [J]. Power Demand Side Management, 2013, 15(01): 1–46.

[23] Liu, X., Gao, T., Li, Y. Review of Game Theory Applications in Power Demand Side Management [J]. Power System Technology, 2018, 42(08): 2704–2711. DOI:10.13335/j.1000-3673.pst.2018.0039

[24] W.-K. Chen, Linear Networks and Systems (Book style). Belmont, CA: Wadsworth, 1993, pp. 123–135.