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SALES OR RENTALS? PRICE AND SERVICE DECISIONS FOR ELECTRIC VEHICLE MANUFACTURERS

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Abstract. Innovative business models are emerging to promote the popularization of electric vehicles. This study investigates a firm's service innovation strategy and the choice between sales and rental business models in the presence of consumer behavioral preferences and service innovation subsidies within a given supply chain. The optimal price and service quality decisions are unique and determined by a profit-maximization model. We find that when customers have an obvious preference for high quality service or a relatively low preference for traditional sales model, the firm will profitably invest in service innovation. The firm will choose the rental model and offer a higher level of service rather than the sales model when the customer preference for traditional sales is relatively low or customers are more constrained by the initial purchase price. We also examine the efficiency of service innovation subsidy policy and find that service innovation subsidy will promote the adoption of electric vehicles and improve service quality. Our analysis also suggests that policy makers should set the appropriate service innovation subsidy rather than the higher the better.

1. **Introduction.** With decreasing oil reserves and mounting environmental problems, the automotive industry is investing heavily in electric vehicles in hopes of dramatically reducing fossil fuel consumption and pollutant emissions (Lim et al., 2015[28]). However, the high sales price and concerns about the convenience of use (such as battery endurance, insufficient efficiency of charging infrastructure, lack of self-owned parking spaces, difficulty in grid expansion, etc.) and resale anxiety have become the bottlenecks in the popularity of electric vehicles. Such backgrounds have inspired automobile companies to explore an emerging business model, namely,

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"separation of vehicle and electricity" mode. Take NIO's battery rental services, Battery as a Service (Baas), as an example, it allows customers to rent the battery by paying a monthly fee from the battery assets company and provides a comprehensive service of battery rechargeable, exchangeable and upgradable. After signing up for a battery rental service, buying a new electric vehicle can remove the battery cost, which significantly reduces initial purchase costs and eliminates the concerns about battery attenuation for consumers. Except for the battery rental service, NIO has built an energy service system that provides users with well-rounded power-up services based on energy cloud technology for better user experience, such as battery switching station, mobile charging vehicles and super charging piles. These creative energy replenishment services can alleviate range anxiety and reduce psychological costs for consumers over the vehicle's lifecycle (Avci et al., 2015[6]; Huang et al., 2021[20]). Compared with regular charging method that takes hours to recharge, battery switching mode can complete the energy replenishment by replacing a depleted battery with a fully charged one within a few minutes, which greatly improves the energy replenishment efficiency. In addition, the battery switching mode can make better use of the difference between peak and valley electricity prices to reduce electricity costs. Centralized monitoring and maintenance of batteries in the battery switching station can also prolong battery life. Therefore, battery rental business model and battery replacement service innovations are expected to open up consumer acceptance and thus may become a complementary solution to the mass adoption of electric vehicles.

The component leasing mode and the battery replacement mode are not entirely new and have already been applied in practice. For example, engine leasing has a long history in the aviation industry. In the early days, engine leasing is mainly to meet the demand for short and medium-term when the engine was returned to the factory for maintenance, whereas at present, long leases of 5 to 10 years have become the mainstream product of the engine leasing market. Better Place (now bankrupt) offers customers a battery switching network and a battery leasing service charged by per mile driven (Avci et al., 2015[6]). Currently, there are some companies around the world that are trying to use battery swapping technology like NIO, Xiaopeng, and Ample. The first two are dedicated to serving their own brand of private electric vehicles, while the latter aims to offer battery replacement service for different brands of electric vehicles. In public transport, BAIC BJEV has been laying out an operation network of battery switching stations in fifteen cities in China for taxi business since 2016.

Although the benefits of electric switching mode are obvious for consumers, there are still some difficulties for electric vehicle companies in implementing and adopting it on a large scale. On the one hand, the construction of battery switching station has high early-stage investment cost, which requires the support of multilayer industrial chains. This is inseparable from the policy of vigorously supporting the electric switching mode. Sound policy interventions (such as subsidies, taxes, technical support, standardization, etc.) can promote the large-scale application of electric switching mode, thus encouraging more automobile enterprises to establish new business models adapted to battery switching service. For example, the Chinese government has explicitly supported the development of separation of vehicle and electricity, and the battery switching stations have been included in the new infrastructure sector. Subsequently, the government further provides guidance for the health and safety development of the industry through the formulation of electric vehicle safety standards. On the other hand, battery switching stations need to hold a number of extra batteries to replace the depleted batteries, which hinges on the customer dynamic demand and the level of service companies wish to provide. This requires close cooperation between automobile enterprises and battery suppliers to form a sustainable supply chain model. For instance, NIO is responsible for the battery switching service and customer connections in Baas mode, and Ningde Times, as one of the biggest battery suppliers in China, is in charge of battery management and energy storage business.

We are motivated to investigate the following questions: (i) How to invest in service innovation (i.e., battery switching service for electric vehicles) for the manufacturer under government subsidy support? (ii) How does the manufacturer choose between the sales business model and rental business model? (iii) What are the optimal pricing decisions of the manufacturer and the supplier? To answer these questions, we formulate an analytical model that describes the differences between the two business models in the presence of consumer behavioral preferences and service innovation subsidies within a given supply chain. The contributions and main findings of this paper are summarized as follows:

(i) First, a supply chain model is proposed for service innovation and business model selection between sales and rentals in which the firm obtains the support from the government's service innovation subsidies and the supplier's service spare parts (e.g., electric vehicle batteries). We find that when customers pursue innovative services or have relatively low preference for traditional sales model, the firm will profitably invest in service innovation. This finding discloses why battery switching services are becoming increasingly popular.

(ii) Second, our model considers the effect of the significant reduction of initial purchase cost and the discretization of regular rental cost on customers' purchasing behavior. We find that when the customer preference for traditional sales is relatively low or customers are more constrained by the initial purchase cost, it is more profitable to provide higher level services and choose the rentals model rather than the sales model.

(iii) Third, our analyses indicate that the service innovation subsidy will promote the adoption of electric vehicle and improve the service quality. Interestingly, we find that a higher service innovation subsidy does not necessarily lead to a greater incentive effect on manufacturers. It depends on many external factors, such as customer behavior preferences and service investment coefficient.

(iv) Finally, we characterize the pooling factor associated with the service quality and the component sharing ability. The analyses reveal that a higher component sharing ability facilitates the service innovation investment and promotes the service quality in both sales and rentals models. There are some similarities and differences in conclusions between our work and the related references. Similar to Lim et al. (2015)[28], we conclude that the business model that allows customers to lease the batteries may promote the adoption of electric vehicles when customer preference for leasing is relatively high. Different from the conclusion of Lim et al. (2015)[28] that battery leasing service improves the firm's profit, this paper finds that only when customer preference for leasing is relatively high, the battery rental strategy helps boost the manufacturer's profit as well as the supplier's profit. Unlike the conclusion of Hu et al. (2023)[19] that incentive programs on battery switching benefit the overall social welfare, this paper shows that government subsidy on battery switching service may be harmful to the manufacturer's profit, the supplier's profit and the adoption of electric vehicles.

The rest of the paper is organized as follows. We position our study in Section 2 and introduce the model formulation in Section 3. The model analysis and main results of the model are presented in Section 4. Section 5 provides a numerical analysis on the optimal decisions. We conclude the paper and indicate the potential future research directions in Section 6.

2. **Literature review.** Our work contributes to the stream of literature focusing on leasing vs. selling. The lease-versus-sell model decision faced by a firm from the profitability perspective has been studied extensively. The benefits of leasing rather than selling in mitigating competition from the second-hand market for a durable-goods monopoly firm are observed by Bulow (1982)[12]. Bulow (1986)[13] further finds that reducing durability and increasing the leasing ratio can benefit oligopolists. Desai and Purohit (1998[15], 1999[16]) draw the attention to the factors that influence the optimal combination of leasing and selling. To investigate the optimal marketing strategies of durable goods in a monopolistic environment, Desai and Purohit (1998)[15] find that the relative profitability of leasing and selling depends on the depreciation rates of leased and sold products. Extend to the duopoly environment, Desai and Purohit (1999)[16] conclude that the optimal proportion of leasing and selling hinges on a firm's competitiveness and product reliability in the competitive durable market. They find that the optimal marketing strategy involes a mix of leasing and selling or only selling. Subsequent researches expand their work to include different aspects. Bhaskaran and Gilbert (2005)[8] investigate the trade-off between leasing and selling for a durable goods manufacturer faced with a complementary product produced by an independent firm. Saggi and Vettas (2000)[32] study a three-period asymmetric duopoly model in which two firms choose their volume of leasing and sales, and find that the inefficient and an increased unit costs lead to a higher ratio of leased units to sales. Poddar (2004)[30] addresses the optimal strategic choice of renting and selling between two symmetric durable good firms, and shows that selling is the unique dominating strategy of the firms. Bhattacharya et al. (2019)[11] shows that the selling policy performs better in a monopolistic environment while the installed base policy (i.e., the manufacturer leases the product to customers and bundles repair and maintenance services along with the product) performs better in a competitive environment. In the literature on vertical competition environment, some researchers study how the manufacturer's product durability influences the interactions between the channel structure and lease-versus-sell mode (Bhaskaran and Gilbert, 2009[9], 2015[10]; Goering, 2010[17]; Xiong et al., 2012[38]). More recently, Abhishek et al. (2021[1]) investigate the impacts of consumer heterogeneity in usage rates on the manufacturer's choice among four different business models in the presence of peer-to-peer rental markets. The study of Li et al. (2022)[25] shows that the capital constraint of consumers affects the leasing or selling market strategy of a monopoly manufacturer. Several literature concerns about the environmental performance of the lease-versus-sell model decision. Agrawal et al. (2012)[4] examine the conditions when leasing is more profitable and has lower environmental impacts than selling. To explore the implications of leasing and modularity strategies for a durable goods manufacturer, Agrawal et al. (2021)[2] further find that implementing leasing separately is greener than adopting the combination of leasing and modularity strategies.

Different from the existing literature, this paper formulates the influence of the significant reduction in one-time purchase cost of durable goods on customer behavior. We contribute to this stream of literature by investigating how the firm's service quality and price decisions differ across leasing and selling models when customer preference and government subsidy are considered. This allows us to capture how a firm chooses between a sales and a rentals business model and decides service quality and prices simultaneously based on the operational characteristics such as the pooling effect.

The literature on leasing strategy in automobile industry has also been widely researched. Some scholars study the issue of the traditional lease (i.e., pay for the length of the lease) of a vehicle or fleet of vehicles (Lazov, 2017[23]; Li and Pang, 2017[24]; Oliveira et al., 2017[29]). Cheng et al. (2020)[14] investigate the channel selection problem of an automobile manufacturer to provide leasing services, that is, conducting leasing service by itself or an independent leasing company. Liao et al. (2018)[27] explore whether an alternative option of leasing increases the adoption of electric vehicles, and they show that the impact of vehicle lease depends on individual characteristics and attitudes and can be positive or negative. From the perspective of sharing economy, Bellos et al. (2017)[7] study whether a manufacturer implements a car sharing model by considering the tradeoff between driving performance and fuel efficiency. Most of the existing literature in this stream discusses the responses and decisions of enterprises and consumers to the whole-vehicle leasing activities (no matter periodic leasing or per-use rentals). Few studies focus on the leasing strategy of vehicle's major component (e.g., the power battery of an electric vehicle). Hu et al. (2023)[19] study the optimal pricing strategy between subsrciption and pay-per use for a swapping service provider based on battery rental through a game-theoretical model. Lim et al. (2015)[28] compare the effectiveness of four business models for the mass adoption of electric vehicles, that is, own battery with regular charging model, lease battery with regular charging model, own battery with enhanced charging model, and lease battery with enhanced charging model. Although they also concentrate on the leasing strategy of electric vehicle power batteries, it is different from this paper. At first, they analyze the competition between new and used electric cars in the secondary market and focused on the impact of customers' range and resale anxiety. In our setting, customers make purchase decisions based on the amount and the time of payment, as well as the quality of service in leasing model. We factor the range and resale anxiety into the overall level of customer preference for selling or leasing. At second, their model ignores the pool effect caused by the battery leasing strategy and battery switching service, while this paper takes it into account.

Our work also builds on and contributes to the literature on servitization. Servitization is considered as selling the functionality of a product rather than the product itself. Kanatlı and Karaer (2021)[21] state that customers are charged by use amount or use duration in the servitization business model, and the service fee covers the costs related with usage, such as maintenance and operation costs. They compare the economic and environmental performance of servitization versus sales business model and find that servitization leads to higher durability and environment friendliness. Arani et al. (2023)[5] investigate the economic, environmental, and welfare implications of a service provider's pricing scheme (charge customers per use or per period) in a servicizing business model. Agrawal and Bellos (2016)[3] present that a hybrid business model with pay-per-use service and sales mode is more profitable and environmentally superior under strong pooling. Focus on the pricing problem for per-use rentals and sales simultaneously in the presence of vertical differentiation, Yu et al. (2018)[41] reveal that a firm should provide a relatively high quality in per-use rental services under strong pooling effect. The study of Yan et al. (2020)[40] analyzes the optimal price and production quantity in a traditional sale model, a per-use rental model, and a hybrid model. Extend the pay-per-use service in duopolistic competition when considering the production cost, Ladas et al. (2021)[22] conclude that pay-per-use business model is more profitable than sales when the delivery costs are not too high or consumer usage is not fully observed. Wang et al. (2022)[34] investigate the optimal service mode among trade-in for new mode, leasing mode, or the mixed mode for a monopolistic recycling platform, and they find that the mixed mode performs better only when the durability of leased refurbished product is relatively high. The background of this paper can also be considered as a servitization business model. Customers pay for the driving function of the electric vehicle power battery and are charged by the use duration. The rental fee includes the service cost for switching batteries in battery swap stations and the cost of battery maintenance and testing during the period of use. Different from the literature that product leasing can create a pooling effect so that fewer products are required to meet demands than the number of customers who adopt the leasing model, component leasing leads to more component production in this paper because the firm needs to equip with extra component to provide replacement services in addition to the component in use.

3. **Model formulation.** We formulate a firms-customer game in a supply chain where one manufacturer and one core component supplier make the profit-maximizing decisions followed by the customers. The manufacturer can sell the whole product in sales model (hereafter whole product) or a product without the core component in rental model (hereafter incomplete product). The supplier provides the core components to the manufacturer in sales model and leases the right of use to customers in rental model. Customers who choose sales buy the whole product and own them, whereas customers who choose rentals buy the incomplete product and rent the core component.

We consider three models in this paper: benchmark model (B model), pure sales business model (S model), and pure rental service business model (R model). In B model, the manufacture abandons the service innovation initiatives and sells the whole product equipped with the supplier's core component to customers with basic services which can be normalized to be zero. The supplier determines the component wholesale price and then the manufacturer releases its whole product price. This business model is widely used by electric vehicle manufacturers, who sell complete cars and provide charging piles as basic recharge services. In S model, the manufacturer announces a service innovation program (i.e., battery switching service program) and chooses to sell the whole product to customers. Subsequently, the supplier sets the component wholesale price, and then the manufacturer determines the whole product price and service quality. This is the business model currently used in BAIC BJEV, who sells vehicles to customers, invests in vehicle electric separation technology and establishes a large number of battery switching stations. In R model, the manufacturer announces a service innovation program and chooses to sell the incomplete product to customers. Then, the supplier entrusts the manufacturer to lease the use of the component to customers and sets the component rental price. At last, the manufacturer determines the incomplete product price and service quality. This business model is proposed by NIO who offers battery rental option and battery switching services to customers. We use the superscript $i \in \{\text{B,S,R}\}$ to indicate the benchmark model (i.e., $i = \text{B}$), S model (i.e., $i = \text{S}$), or the R model (i.e., $i = \text{R}$) and the subscript $j \in \{\text{s,r}\}$ to denote the sales (i.e., $j = \text{s}$) or the rentals option (i.e., $j = \text{r}$). The three business models of B, S, and R are illustrated in Figure 1. The notations used in this study and their meanings are shown in Table 1.

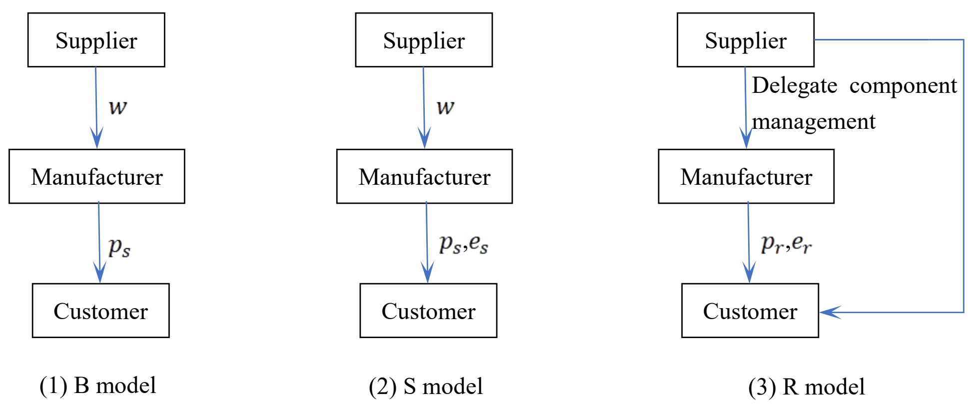


FIGURE 1. Three alternative business models

TABLE 1. Notations

Notations	Definitions
Decision variables:	
p_s	Manufacturer's sales price of the whole product
p_r	Manufacturer's sales price of the incomplete product
e_j	Service quality provided from the manufacturer when customers choose sales (j = s) or rentals (j = r)
w	Supplier's wholesale price of the core component
h	Supplier's rental price of the core component
Other variables:	
d	Manufacturer's basic market scale
c	Production cost of supplier's core component
g	Government subsidy ratio of the service innovation cost
k	Service cost coefficient
α	Sales price sensitivity coefficient
β	Rental price sensitivity coefficient
θ	Service quality sensitivity coefficient
ρ	Market preference for choosing sales
ε	Pooling effect on the supply side
τ	Ability to share the components
γ_1	The proportion of customers who prefer rentals but accept the sales option
γ_2	The proportion of customers who prefer sales but accept the rentals option
D_j^i	Customer demand in model i when choose j option, $i \in \{\text{B,S,R}\}$, $j \in \{\text{s,r}\}$
π_M^i	Profit of the manufacturer in model i, $i \in \{\text{B,S,R}\}$
π_S^i	Profit of the supplier in model i, $i \in \{\text{B,S,R}\}$

3.1. **Customers' decision.** Similar to Pu et al. (2017)[31] and Yan et al. (2020)[39], we assume that customers have different preference for sales and rentals due to their personal preferences and purchase habits. The parameter $\rho \in (0, 1)$ denotes the market preference for choosing sales, and $1 - \rho$ describes the market preference for choosing rentals. Besides, refer to Hu et al. (2017)[18], it is assumed that the whole product and incomplete product are partial substitutable for customers. We use $\gamma_1 \in (0,1)$ describes the proportion of customers who prefer rentals but are willing to accept the sales option in S model, and $\gamma_2 \in (0,1)$ denotes the proportion of customers who prefer sales but are willing to choose rentals in R model. That is, when only sales (rentals) option is available, a γ_1 (γ_2) fraction of the customer group that has a preference for the rentals (sales) option will also purchase the whole (incomplete) product. According to the above assumptions, the potential market scale (when the product is free and no service is offered) in S model can be expressed by the formula $\rho d + \gamma_1(1-\rho)d$, and the potential market scale in R model can be formulated as $(1-\rho)d + \gamma_2\rho d$.

Moreover, customers make their purchase choices based on the expenditure for using the product (i.e., the whole product sales price in S model or the incomplete product sales price plus component rental price in R model) and the service quality offered by the manufacturer. A lower price or a higher service quality can increase the buying inclination for customers. Similar to Wang et al. (2020)[35] and Xiao and Xu (2013)[37], we assume a linear demand function that slopes downward with the price and rises with the service quality. The difference is that in R model, we separately depict the impact of rental price on customers. Customers who choose rentals are also charged a leasing expense of the core component except the sales price at regular intervals, such as monthly or yearly. Let h capture the total rental price of a core component over its life cycle. Because rental payments are scattered and hysteretic, we assume that customers are less sensitive to the rental price compared to the sales price, i.e., $\beta \leq \alpha$. Represent the demand faced in S model and R model by D_s^S and D_r^R. We have the following linear price and service dependent demand functions in S model and R model, respectively.

(1)Customer demand in S model:

$$D_s^S = \rho d + \gamma_1(1-\rho)d - \alpha p_s + \theta e_s \tag{1}$$

(2)Customer demand in R model:

$$D_r^R = (1-\rho)d + \gamma_2\rho d - \alpha p_r - \beta h + \theta e_r \tag{2}$$

where p_s and p_r denote the sales price of the whole product and incomplete product, adjusted for any governmental policy of fiscal subsidies offered to customers. To avoid irrational solutions, we assume that $p_s > p_r$ because a complete product is definitely more expensive than an incomplete one in reality. e_s (e_r) denotes the service quality that a customer obtains from the manufacturer when choosing sales (rentals). Parameters d, α, β, θ, ρ, γ_1 and γ_2 are positive constants. d represents the basic market, which parameterizes the scale of the manufacturer's potential market. The sensitivities of the demand with respect to the sales price, rental price, and service quality are reflected by α, β, and θ, respectively.

3.2. **Manufacturer's decision.** We consider a market segment where a manufacturer is already present by purchasing core components from the supplier and selling the whole product to customers, and the initial service quality is normalized to be zero, which is our benchmark model. As the government encourages and subsidizes service innovation, the manufacturer may invest in service innovation to upgrades service quality. On the basis of service innovation, the manufacturer can choose the most profitable business model: S model or R model. Given the business model choice and the supplier's pricing decision, the manufacturer decides its sales price and service quality to maximize the total profit. The manufacturer invests in service innovation at a cost $C(e_j)$. We consider the service innovation cost of building the service infrastructure, which is a convex function of e_j, and $C(e_j) = ke_j^2$, $j \in \{s, r\}$ (Shen et al., 2017[33]; Li et al., 2019[26]; Wang et al., 2020[35]). To be specific, in S model, the manufacturer procures the core component from the supplier, sells the whole product and provides an advanced service quality of e_s. In R model, the manufacturer introduces a core component rental option and only sells the incomplete product bundled with a service quality of e_r. In practice, the Chinese government encourages new energy vehicle enterprises to carry out the application of electricity swap mode (New Energy Vehicle Industry Development Plan (2021-2035)). Under this policy environment, the electric vehicle manufacturer may innovate battery charging services by laying out the construction of battery switching stations, so as to alleviate customers' anxiety about vehicle endurance and the long waiting time for recharging to a large extent. On this basis, the manufacturer can choose the whole vehicle sales strategy (i.e., S model) or incomplete vehicle sales with battery leasing strategy (i.e., R model). The service quality of this innovative battery switching service is related to the number and location of the battery switching stations, which can be set to different values in the S model and the R model. Without loss of generality, we assume that the manufacturer's production cost is zero and then the sales prices p_s and p_r can be interpreted as the marginal profit of the whole product and the incomplete product. Therefore, the profit expressions for the manufacturer in S model and R model are as follows:

(1)Manufacturer's profit in S model:

$$\pi_M^S = (p_s - w)D_s^S - (1-g)ke_s^2 \tag{3}$$

(2)Manufacturer's profit in R model:

$$\pi_M^R = p_r D_r^R - (1-g)ke_r^2 \tag{4}$$

where $k > 0$ is the service innovation cost coefficient. $g \in (0, 1)$ captures the ratio that the government subsides the service innovation cost to the manufacturer.

3.3. **Supplier's decision.** The problem for the supplier is to set the optimal component wholesale price or component rental price by anticipating the manufacturer's business model choice and customers' reactions. To characterize the costs of the supplier for cooperating with the manufacturer to offer a superior service (e.g., battery replacement service for electric vehicles in the use phase), we introduce the pooling factor ε. The supplier needs to produce εD_j^i units of components to serve a market with a consumer demand D_j^i. For example, to serve a market of ten thousand electric cars, the supplier may need to provide five thousand spare batteries for the battery switching stations. The pooling factor is formulated to increase with the service quality, i.e., $\varepsilon = \tau e_j$ to represent the proportion of components required to provide in a given service quality. The exogenous parameter $\tau \in (0, 1]$ captures the ability to share the component when the service quality equals to 1, and it depends on the probability distribution of customer arrivals and the manufacturer's ability to operate and manage the components. The higher the value of the parameter τ, the lower the component sharing ability. Hence, we formulate the supplier's profit function under the two business models as follows:

(1)Supplier's profit in S model:

$$\pi_S^S = (w - c)D_s^S - \tau e_s c D_s^S \tag{5}$$

(2)Supplier's profit in R model:

$$\pi_S^R = (h - c)D_r^R - \tau e_r c D_r^R \tag{6}$$

4. **Model analysis.** In this section, we aim to find the subgame-perfect Nash equilibrium based on the multistage game model in Section 3. To solve the model, we use the backward induction method. We first examine the subgame equilibria of manufacturer's pricing and service quality decisions and supplier's pricing decision for all possible outcomes of manufacturer's business model choice in Section 4.1. Then we solve for the equilibrium of manufacturer's business model choice based on these subgame equilibria in Section 4.2.

To ensure that the model is meaningful and the decisions are positive, it is assumed that the model parameters meet the conditions that $4\alpha k(1-g) > \theta^2$, $\alpha c < \rho d + \gamma_1(1-\rho)d$, and $\beta c < d(1-\rho+\gamma_2\rho)$. We assume that the manufacture and the supplier are risk neutral and focus on maximizing profits.

4.1. **Optimal pricing and service quality decisions.**

4.1.1. *Sales model without service innovation (B model).* Recall the benchmark model mentioned in Section 3, the customer demand function eliminates the impact of service quality compared with that in S model as $D_s^B = \rho d + \gamma_1(1-\rho)d - \alpha p_s$, the manufacturer sells the whole product and provides the basic service with the profit function $\max_{p_s} \pi_M^B = (p_s - w)[\rho d + \gamma_1(1-\rho)d - \alpha p_s]$, and the supplier offers the component to the manufacturer with the profit function $\max_w \pi_S^B = (w-c)[\rho d+\gamma_1(1-\rho)d-\alpha p_s]$. Then we derive the optimal solutions and profits in the benchmark model: $p_s^{B*} = [3\rho d+3\gamma_1(1-\rho)d+\alpha c]/4\alpha$, $w^{B*} = [\rho d+\gamma_1(1-\rho)d+\alpha c]/2\alpha$, $\pi_M^{B*} = [\rho d + \gamma_1(1-\rho)d - \alpha c]^2/16\alpha$, and $\pi_S^{B*} = [\rho d + \gamma_1(1-\rho)d - \alpha c]^2/8\alpha$.

4.1.2. *Sales model with service innovation (S model).* Under the government service innovation subsidy, the manufacturer is committed to upgrading the service quality to stimulate the demand. To adapt to the change of manufacturer's service, the supplier needs to provide an extra number of components for sharing and circulation. By this time, the manufacturer sells physical components or the right to use components on behalf of the supplier, and the supplier entrusts the manufacturer to operate and manage the components. Following we analyze the manufacturer's optimal pricing and service quality decisions as well as the supplier's optimal pricing decisions in S model.

In this case, by forecasting the manufacturer's sales price and service quality, the supplier first determines the wholesale price of the component w and prepares the number of $\tau e_s D_s^S$ components for the advanced service. Then the manufacturer determines the sales price of the whole product p_s and service quality e_s to maximize its profits. The equilibrium solutions are obtained by solving the profit-maximization problems of Eq.(3) and Eq.(5). As a result, we derive the optimal sales price and the optimal service quality of the manufacturer, the optimal wholesale price of the supplier, and the optimal profits of two participants:

$$p_s^{S*} = \frac{d(\gamma_1+\rho-\gamma_1\rho)(3\lambda_1+\theta^2+4\alpha\tau\theta c) - \alpha c(\theta^2-\lambda_1)}{4\alpha(\alpha\tau\theta c+\lambda_1)} \tag{7}$$

$$e_s^{S*} = \frac{\theta[d(\gamma_1+\rho-\gamma_1\rho) - \alpha c]}{2(\alpha\tau\theta c+\lambda_1)} \tag{8}$$

$$w^{S*} = \frac{\alpha c\lambda_1 + d(\gamma_1+\rho-\gamma_1\rho)(\lambda_1+2\alpha\tau\theta c)}{2\alpha(\alpha\tau\theta c+\lambda_1)} \tag{9}$$

$$\pi_M^{S*} = \frac{\lambda_1[d(\gamma_1+\rho-\gamma_1\rho) - \alpha c]^2(\theta^2+\lambda_1)}{16\alpha(\alpha\tau\theta c+\lambda_1)^2} \tag{10}$$

$$\pi_S^{S*} = \frac{[d(\gamma_1 + \rho - \gamma_1\rho) - \alpha c]^2(\theta^2 + \lambda_1)}{8\alpha(\alpha\tau\theta c + \lambda_1)} \tag{11}$$

where $\lambda_1 = 4\alpha k(1-g) - \theta^2$.

Proof. In S model, the equilibrium solutions of participants obtain from solving the following profit-maximization problems:

$$\max_{p_s, e_s} \pi_M^S(p_s, e_s) = (p_s - w)[\rho d + \gamma_1(1-\rho)d - \alpha p_s + \theta e_s] - (1-g)ke_s^2 \tag{12}$$

$$\max_{w} \pi_S^S(w) = (w - c - \tau e_s c)[\rho d + \gamma_1(1-\rho)d - \alpha p_s + \theta e_s] \tag{13}$$

The Hessian matrix of $\pi_M^S(p_s, e_s)$ is:

$$H = \begin{bmatrix} \partial^2\pi_M^S/\partial p_s^2 & \partial^2\pi_M^S/\partial p_s\partial e_s \\ \partial^2\pi_M^S/\partial e_s\partial p_s & \partial^2\pi_M^S/\partial e_s^2 \end{bmatrix} = \begin{bmatrix} -2\alpha & \theta \\ \theta & -2k(1-g) \end{bmatrix} = 4\alpha k(1-g) > 0$$

So, the profit function is concave and the optimal solution of π_M^S exists. Then, substituting in $\partial\pi_M^S/\partial p_s = 0$ and $\partial\pi_M^S/\partial e_s = 0$, we have:

$$p_s^{S*} = \frac{[2\alpha k(1-g) - \theta^2]w + 2kd(1-g)(\gamma_1 + \rho - \gamma_1\rho)}{4\alpha k(1-g) - \theta^2}, \tag{14}$$

$$e_s^{S*} = \frac{\theta[d(\gamma_1 + \rho - \gamma_1\rho) - \alpha w]}{4\alpha k(1-g) - \theta^2} \tag{15}$$

By substituting Eq.(14) and Eq.(15) into the supplier's profit function Eq.(13), we derive $\partial^2\pi_S^S/\partial w^2 = -\alpha(\alpha\tau\theta c + \lambda_1)(\lambda_1 + \theta^2)/\lambda_1^2 < 0$. That is, π_s^S is a concave function of w. Let $\partial\pi_S^S/\partial w = 0$, we derive:

$$w^{S*} = \frac{\alpha c\lambda_1 + d(\gamma_1 + \rho - \gamma_1\rho)(\gamma_1 + 2\alpha\tau\theta c)}{2\alpha(\alpha\tau\theta c + \lambda_1)}$$

Where $\lambda_1 = 4\alpha k(1-g) - \theta^2$. By substituting Eq.(9) into Eq.(14) and Eq.(15), we obtain the optimal sales price and the optimal service level, and then derive the optimal profits of the participants as Eqs.(7)-(11) show. □

Proposition 4.1. *e_s^{S*}, π_M^{S*}, and π_S^{S*} are negatively related with τ and w^{S*} is positively related with τ. When $2\alpha k(1-g) > \theta^2$, p_s^{S*} is positively related with τ.*

Proof. Because of $\frac{\partial p_s^{S*}}{\partial\tau} = \frac{\theta c[2\alpha k(1-g)-\theta^2][d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]}{2(\alpha\tau\theta c+\lambda_1)^2}$, when $2\alpha k(1-g) > \theta^2$, $\frac{\partial p_s^{S*}}{\partial\tau} > 0$; Since $\alpha c < \rho\ d + \gamma_1(1-\rho)d$ according to the assumption, $\frac{\partial e_s^{S*}}{\partial\tau} = \frac{\alpha\theta^2 c[\alpha c - d(\gamma_1+\rho-\gamma_1\rho)]}{2(\alpha\tau\theta c+\lambda_1)^2} < 0$; Similarly, $\frac{\partial w^{S*}}{\partial\tau} = \frac{\theta c\lambda_1[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]}{2(\alpha\tau\theta c+\lambda_1)^2} > 0$, $\frac{\partial\pi_M^{S*}}{\partial\tau} = -\frac{\alpha\theta ck\lambda_1(1-g)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2}{2(\alpha\tau\theta c+\lambda_1)^3} < 0$, $\frac{\partial\pi_S^{S*}}{\partial\tau} = -\frac{\alpha\theta ck(1-g)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2}{2(\alpha\tau\theta c+\lambda_1)^2} < 0$. □

Proposition 4.1 shows that enhancing the component sharing ability contributes to improving the service quality and profits of each participant, while reducing wholesale price. When $2\alpha k(1-g) > \theta^2$, that is, the sensitivity coefficient of service quality is relatively small, sales price decreases with the improvement of the component sharing ability. This is because increasing component sharing ability will lead to a sharp drop in service costs for supplier, then the supplier will cut wholesale price to promote sales. As the procurement cost of components decreases, the manufacturer will increase the investment in service innovation for higher service quality. Meanwhile, to ensure profits, the manufacturer will cut down its sales price to promote sales when customers have low preference for the advanced service. This proposition implies that a higher component sharing ability can encourage investments in service innovation by both participants. Therefore, in the actual service innovation process, manufacturers who choose a pure sales model should focus on consolidating for higher component sharing ability, such as optimizing service network layout by fully analyzing customer usage data and battery scheduling control strategy.

Proposition 4.2. *p_s^{S*}, e_s^{S*}, and w^{S*} are negatively related with k. When $\alpha\tau\theta^2 c > \lambda_1(\theta - 2\alpha\tau c)$, π_M^{S*} is positively related with k, and when $\theta < \alpha\tau c$, π_S^{S*} is positively related with k.*

Proof. $\frac{\partial p_s^{S*}}{\partial k} = \frac{\theta(1-g)(\theta+\alpha\tau c)[\alpha c - d(\gamma_1+\rho-\gamma_1\rho)]}{(\alpha\tau\theta c+\lambda_1)^2} < 0$; $\frac{\partial e_s^{S*}}{\partial k} = \frac{2\alpha\theta(1-g)(\theta+\alpha\tau c)[\alpha c - d(\gamma_1+\rho-\gamma_1\rho)]}{(\alpha\tau\theta c+\lambda_1)^2} < 0$; $\frac{\partial w^{S*}}{\partial k} = \frac{2\alpha\tau\theta c(1-g)[\alpha c - d(\gamma_1+\rho-\gamma_1\rho)]}{(\alpha\tau\theta c+\lambda_1)^2} < 0$; $\frac{\partial \pi_M^{S*}}{\partial k} = \frac{\theta(1-g)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2[\lambda_1(2\alpha\tau c-\theta)+\alpha\tau\theta^2 c]}{4(\alpha\tau\theta c+\lambda_1)^3}$, when $\alpha\tau\theta^2 c > \lambda_1(\theta - 2\alpha\tau c)$, $\frac{\partial \pi_M^{S*}}{\partial k} > 0$; $\frac{\partial \pi_S^{S*}}{\partial k} = \frac{\theta(1-g)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2(\alpha\tau c-\theta)}{2(\alpha\tau\theta c+\lambda_1)^2}$, when $\theta < \alpha\tau c$, $\frac{\partial \pi_S^{S*}}{\partial k} > 0$. □

As indicated in Proposition 4.2, the service cost coefficient has a negative effect on sales price, service quality, and wholesale price. When $\theta > 2\alpha\tau c$, that is the sensitivity coefficient of service quality is relatively large, the profit of manufacturer increases initially and then decreases with the service cost coefficient. When $k = \theta^2(\theta - \alpha\tau c)/[4\alpha(1-g)(\theta - 2\alpha\tau c)]$, manufacturer's profits reach the maximum. The reason is that a higher service cost coefficient means a higher service cost for the manufacturer, leading the manufacturer to decrease service quality to adjust the investment amount. Due to the loss of customers who prefer superior service, the manufacturer will reduce sales price to attract customers who are price sensitive. Moreover, the decrease of service quality will result in a decrease in service cost for the hpplier, which ultimately makes the supplier reduce the wholesale price to promote sales. For the manufacturer, when customers are very sensitive to the service quality, the increase of the service cost coefficient will lead to a less degradation in the service quality and make sales price decrease faster than wholesale price. At this time, the benefits brought by the increase in sales can make up for the losses caused by the increase in service costs and the decrease in marginal revenue. However, due to the continuous rise in service cost coefficient, the decline rate of service quality accelerates, which may decrease the sales and eventually lead to a decline in manufacturer's profit. When $\alpha\tau c < \theta < 2\alpha\tau c$, that is the sensitivity coefficient of service quality is moderate, the profit of manufacturer increases with the service cost coefficient. When $\theta < \alpha\tau c$, that is the sensitivity coefficient of service quality is relatively small, the marginal revenue of manufacturer increases with the service cost coefficient, which results in an initial decrease and a latter increase for manufacturer's profits. For the supplier, due to the decrease in service costs and a possible increase in sales, its profits always increase with the service cost coefficient when customers are not sensitive to superior service (i.e., $\theta < \alpha\tau c$).

Proposition 4.3. *p_s^{S*}, e_s^{S*}, and w^{S*} are positively related with g. When $\alpha\tau\theta^2 c > \lambda_1(\theta - 2\alpha\tau c)$, π_M^{S*} is negatively related with g, and when $\theta > \alpha\tau c$, π_S^{S*} and D_s^{S*} are positively related with g.*

Proposition 4.3 states that manufacturer enables a better focus on service innovation investments since the government increases the subsidy ratio. As the government subsidy ratio improves, service quality, sales price, and wholesale price increase, while the variation trend of manufacturer and supplier's profit are also related to customers' service sensitivity. For the manufacturer, when customers tend to seek advanced service (i.e., $\theta > 2\alpha\tau c$), its profits increase initially and then decrease with government subsidy ratio, and when $g = 1 - \frac{\theta^2(\theta-\alpha\tau c)}{4\alpha k(\theta-2\alpha\tau c)}$, the profit reaches the maximum. When the customer preference for service quality are not obvious (i.e., $\alpha\tau c < \theta < 2\alpha\tau c$), the profit always decreases with the government subsidy ratio. When the superior service is less attractive to customers (i.e., $\theta < \alpha\tau c$), the profit first decreases and then increases. For the supplier, as long as the customer preference for service quality is relatively large (i.e., $\theta > \alpha\tau c$), the profit and sales volume increase with the government subsidy rate. This proposition reveals that there is no universal subsidy scheme tailored to all situations. In the actual process of promoting service innovation, policy makers should choose the applicable subsidy scheme according to the characteristics of market and its different objectives. For example, to improve the quality of services, policy makers can increase the subsidy rate, but it will not always be beneficial to encourage enterprises to initiate service innovation projects. To spread electric vehicle ownership, policy makers should increase the subsidy rate when the market shows a clear preference for high quality services.

Proposition 4.4. *p_s^{S*}, e_s^{S*}, and w^{S*} are positively related with θ. When $\alpha\tau\theta^2 c > \lambda_1(\theta - \alpha\tau c)$, π_M^{S*} is negatively related with θ, and when $2\theta < \alpha\tau c$, π_S^{S*} is negatively related with θ.*

Proof. $\frac{\partial p_s^{S*}}{\partial\theta} = \frac{[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c][\tau\theta^2 c+2k(1-g)(2\theta+\alpha\tau c)]}{2(\alpha\tau\theta c+\lambda_1)^2} > 0$; $\frac{\partial e_s^{S*}}{\partial\theta} = \frac{(\lambda_1+2\theta^2)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]}{2(\alpha\tau\theta c+\lambda_1)^2} > 0$; $\frac{\partial w^{S*}}{\partial\theta} = \frac{\tau c(\lambda_1+2\theta^2)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]}{2(\alpha\tau\theta c+\lambda_1)^2} > 0$; $\frac{\partial \pi_M^{S*}}{\partial\theta} = -\frac{(k(1-g)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2[\lambda_1(\alpha\tau c-\theta)+\alpha\tau\theta^2 c]}{2(\alpha\tau\theta c+\lambda_1)^3}$, when $\alpha\tau\theta^2 c > \lambda_1(\theta-\alpha\tau c)$, $\frac{\partial \pi_M^{S*}}{\partial\theta} < 0$; $\frac{\partial \pi_S^{S*}}{\partial\theta} = \frac{(k(1-g)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2(2\theta-\alpha\tau c)}{2(\alpha\tau\theta c+\lambda_1)^2}$, when $2\theta < \alpha\tau c$, $\frac{\partial \pi_S^{S*}}{\partial\theta} < 0$. □

Proposition 4.4 illustrates that sales price, service quality, and wholesale price will increase with service quality sensitivity coefficient. This is because as customer preference for service quality increases, they are willing to pay more for high quality service, which leads the manufacturer to improve service quality to stimulate demands and raise sales price. Therefore, in order to ensure profitability, the manufacturer needs to balance the increased cost of service investment against the benefits of increased sales and higher sales price. For the supplier, increasing the sensitivity of service quality will also lead to an increase in its service cost, thus, higher wholesale prices are set to ensure revenue. As a result, when the customer preference for service quality is weak (i.e., $\theta < \alpha\tau c/2$), the incremental marginal revenue and sales volume are not enough to compensate for the increased cost of service quality. As the impact factor of service quality on customers continues to grow (i.e., $\theta > \alpha\tau c/2$), the sales volume increases sharply, thus making the supplier more profitable.

4.1.3. *Rentals model with service innovation (R model).* Under this case, the supplier first decides the rental price of the component h and reserves the number of $\tau e_r D_r^R$ components to support the superior service through predicting the sales price and service quality of the manufacturer. Afterwards, the manufacturer sets the sales price of the incomplete product p_r and service quality e_r. By solving the profit-maximization problems of Eqs.(4) and (6), we obtain the equilibrium solutions and the optimal profits of two participants:

$$p_r^{R*} = \frac{(\theta^2+\lambda_1)[d(1-\rho+\gamma_2\rho)-\beta c]}{4\alpha(\beta\tau\theta c+\lambda_1)} \tag{16}$$

$$e_r^{R*} = \frac{\theta[d(1-\rho+\gamma_2\rho)-\beta c]}{2(\beta\tau\theta c+\lambda_1)} \tag{17}$$

$$h^{R*} = \frac{\beta c\lambda_1 + d(1-\rho+\gamma_2\rho)(\lambda_1+2\beta\tau\theta c)}{2\beta(\beta\tau\theta c+\lambda_1)} \tag{18}$$

$$\pi_M^{R*} = \frac{\lambda_1[d(1-\rho+\gamma_2\rho)-\beta c]^2(\theta^2+\lambda_1)}{16\alpha(\beta\tau\theta c+\lambda_1)^2} \tag{19}$$

$$\pi_S^{R*} = \frac{[d(1-\rho+\gamma_2\rho)-\beta c]^2(\theta^2+\lambda_1)}{8\beta(\beta\tau\theta c+\lambda_1)} \tag{20}$$

Proof. The equilibrium solutions of participants in R model obtain from solving the following profit-maximization problems:

$$\max_{p_r,e_r} \pi_M^R(p_r,e_r) = p_r[(1-\rho)d+\gamma_2\rho d-\alpha p_r-\beta h+\theta e_r]-(1-g)ke_r^2 \tag{21}$$

$$\max_h \pi_S^R(h) = (h-c-\tau e_r c)[(1-\rho)d+\gamma_2\rho d-\alpha p_r-\beta h+\theta e_r] \tag{22}$$

Backward induction is applied to find the optimal decisions. The derivative process is similar to S model. According to Eq.(21), the Hessian matrix of $\pi_M^R(p_r,e_r)$ is the same as that of $\pi_M^S(p_s,e_s)$. So, the profit function is concave and the optimal solution of π_M^R exists. Then, substituting in $\partial\pi_M^R/\partial p_r = 0$ and $\partial\pi_M^R/\partial e_r = 0$, we have:

$$p_r^{R*} = \frac{2k(1-g)[d(1-\rho+\gamma_2\rho)-\beta h]}{4\alpha k(1-g)-\theta^2} \tag{23}$$

$$e_r^{R*} = \frac{\theta[d(1-\rho+\gamma_2\rho)-\beta h]}{4\alpha k(1-g)-\theta^2} \tag{24}$$

By substituting Eq.(23) and Eq.(24) into the supplier's profit function Eq.(22), we derive that $\frac{\partial^2\pi_S^R}{\partial h^2} = -\frac{\beta(\beta\tau\theta c+\lambda_1)(\lambda_1+\theta^2)}{\lambda_1^2} < 0$. So, π_S^R is a concave function of h. Let $\partial\pi_S^R/\partial h = 0$, we derive Eq.(18). By substituting Eq.(18) into Eq.(23) and Eq.(24), we obtain the optimal sales price of the incomplete product and the optimal service level, and then derive the optimal profits of the participants as Eqs.(16)-(20) show. □

Based on the outcomes, we can find that e_r^{R*}, h^{R*}, π_M^{R*} and π_S^{R*} have the same monotonicity as e_s^{S*}, w^{S*}, π_M^{S*} and π_S^{S*} about τ, k, g, and θ as shown in Proposition 1-4, just replace α with β in the corresponding conditions. Then, we present the following different properties in R model.

Proposition 4.5. *p_r^{R*} is negatively related with τ. When $\theta < \beta\tau c$, p_r^{R*} is positively related with k and negatively related with g, and when $\theta < \beta\tau c/2$, p_r^{R*} is negatively related with θ.*

Proof. $\frac{\partial p_r^{R*}}{\partial\tau} = -\frac{\beta\theta ck(1-g)[d(1-\rho+\gamma_2\rho)-\beta c]}{(\beta\tau\theta c+\lambda_1)^2}$, since $\beta c < d(1-\rho+\gamma_2\rho)$ according to the assumption, so $\frac{\partial p_r^{R*}}{\partial\tau} < 0$; $\frac{\partial p_r^{R*}}{\partial k} = \frac{\theta(1-g)[d(1-\rho+\gamma_2\rho)-\beta c](\beta\tau c-\theta)}{(\beta\tau\theta c+\lambda_1)^2}$, when $\theta < \beta\tau c$, $\frac{\partial p_r^{R*}}{\partial k} > 0$; $\frac{\partial p_r^{R*}}{\partial g} = \frac{\theta k[d(1-\rho+\gamma_2\rho)-\beta c](\theta-\beta\tau c)}{(\beta\tau\theta c+\lambda_1)^2}$, when $\theta < \beta\tau c$, $\frac{\partial p_r^{R*}}{\partial g} < 0$; $\frac{\partial p_r^{R*}}{\partial\theta} = \frac{k(1-g)[d(1-\rho+\gamma_2\rho)-\beta c](2\theta-\beta\tau c)}{(\beta\tau\theta c+\lambda_1)^2}$, when $\theta < \beta\tau c/2$, $\frac{\partial p_r^{R*}}{\partial\theta} < 0$. □

As indicated in Proposition 4.5, sales price decreases as the component sharing ability weakens in rental model. This is because that a weaker component sharing ability leads to a lower service quality, then the manufacturer cuts down the sales price to increase demands. When customers' preference for innovative services is not strong (i.e., $\theta < \beta\tau c$), with the increase of service cost coefficient or the decrease of government subsidy ratio, the reduced service quality will not lead to a large number of demand reductions, so the manufacturer will increase the sales price to increase its profits. Additionally, as customers' preference for service quality becomes obvious gradually, the manufacturer pays more attention to the improvement of service quality, which leads to the sales price in rental model first decreases and then increases.

Proposition 4.6. *p_r^{R*}, e_r^{R*}, h^{R*} are negatively related with α. π_M^{R*} first increases and then decreases with α, and when $\alpha = \frac{\beta\tau\theta c+\theta^2}{4k(1-g)}$, π_M^{R*} reaches the maximum. When $\theta < \beta\tau c$, π_S^{R*} is positively related with α.*

Proof. $\frac{\partial p_r^{R*}}{\partial\alpha} = \frac{4k^2(1-g)^2[\beta c-d(1-\rho+\gamma_2\rho)]}{(\beta\tau\theta c+\lambda_1)^2} < 0$; $\frac{\partial e_r^{R*}}{\partial\alpha} = \frac{2\theta k(1-g)[\beta c-d(1-\rho+\gamma_2\rho)]}{(\beta\tau\theta c+\lambda_1)^2} < 0$; $\frac{\partial h^{R*}}{\partial\alpha} = \frac{2\tau\theta ck(1-g)[\beta c-d(1-\rho+\gamma_2\rho)]}{(\beta\tau\theta c+\lambda_1)^2} < 0$; When $\alpha > \frac{\beta\tau\theta c+\theta^2}{4k(1-g)}$, $\frac{\partial\pi_M^{R*}}{\partial\alpha} = \frac{k^2(1-g)^2[\beta c-d(1-\rho+\gamma_2\rho)]^2[4\alpha k(1-g)-\theta^2-\beta\tau\theta c]}{(\beta\tau\theta c+\lambda_1)^3} > 0$; $\frac{\partial\pi_S^{R*}}{\partial\alpha} = \frac{\theta k(1-g)[\beta c-d(1-\rho+\gamma_2\rho)]^2(\beta\tau c-\theta)}{2\beta(\beta\tau\theta c+\lambda_1)^2}$, when $\theta < \beta\tau c$, $\frac{\partial\pi_S^{R*}}{\partial\alpha} > 0$. □

Proposition 4.6 states that the sales price sensitivity of customers has a negative effect on product sales price, component rental price, and manufacturer's service quality. When customers' sales price sensitivity increases (i.e., $\alpha < \frac{\beta\tau\theta c+\theta^2}{4k(1-g)}$), the decreasing service quality will lead to a decline in manufacturer's service investment, which increases the manufacturer's short-term profit. However, as customers' sales price sensitivity continues to increase (i.e., $\alpha > \frac{\beta\tau\theta c+\theta^2}{4k(1-g)}$), the reduced investment cost due to the decrease in service quality can not compensate for the reduced revenue caused by the decrease in marginal profit and sales, which impairs the manufacturer's profit. For the supplier, the increase in customers' sales price sensitivity will improve his own profit when customers' preference for superior service is not obvious (i.e., $\theta < \beta\tau c$).

Proposition 4.7. *p_r^{R*}, e_r^{R*}, h^{R*}, π_M^{R*}, and π_S^{R*} are negatively related with β.*

Proof. $\frac{\partial p_r^{R*}}{\partial\beta} = \frac{-c(\theta^2+\lambda_1)(\beta\tau\theta c+\lambda_1)-\tau\theta c(\theta^2+\lambda_1)[d(1-\rho+\gamma_2\rho)-\beta c]}{4\alpha(\beta\tau\theta c+\lambda_1)^2} < 0$;
$\frac{\partial e_r^{R*}}{\partial\beta} = \frac{-\theta c(\beta\tau\theta c+\lambda_1)-\tau\theta^2 c[d(1-\rho+\gamma_2\rho)-\beta c]}{2(\beta\tau\theta c+\lambda_1)^2} < 0$;
$\frac{\partial h^{R*}}{\partial\beta} = -\frac{\beta^2c^2\tau\theta\lambda_1+d(1-\rho+\gamma_2\rho)(\lambda_1^2+2\beta\tau\theta c\lambda_1+2\beta^2\tau^2\theta^2c^2)}{2\beta^2(\beta\tau\theta c+\lambda_1)^2} < 0$;
$\frac{\partial\pi_M^{R*}}{\partial\beta} = \frac{ck\lambda_1(1-g)[\beta c-d(1-\rho+\gamma_2\rho)][\lambda_1+\tau\theta d(1-\rho+\gamma_2\rho)]}{2(\beta\tau\theta c+\lambda_1)^3} < 0$;
$\frac{\partial\pi_S^{R*}}{\partial\beta} = -\frac{\alpha k(1-g)[d(1-\rho+\gamma_2\rho)-\beta c][\beta c\lambda_1+d(1-\rho+\gamma_2\rho)(2\beta\tau\theta c+\lambda_1)]}{2\beta^2(\beta\tau\theta c+\lambda_1)^2} < 0$. □

Proposition 4.7 implies that both the manufacturer and supplier enable a better focus on service innovation investments and service quality improvements when customers are less sensitive to the component rental price paid on a regular basis. This is because in rental model, the rental price decided by the supplier does not directly affect the sales price of the manufacturer, but indirectly affects the sales price by influencing the customer demand. As the rental price and service quality increase, the product sales price and profits of each participant will increase accordingly. Therefore, in the actual operation process, manufacturers should increase investment in service innovation, such as long-term service technology research and more advanced service stations construction for the enhancement of product service quality.

4.2. **Optimal business model choice.** This part mainly compares the service level and price decisions under different business models, revealing the conditions in which the manufacturer chooses S model or R model, and in what conditions the manufacturer and the supplier benefit from the service innovation investment.

Proposition 4.8. *When* $\rho < \rho_1$, $e_s^{S*} < e_r^{R*}$, $p_s^{S*} < p_r^{R*} + h^{R*}$, $w^{S*} < h^{R*}$, $\pi_M^{S*} < \pi_M^{R*}$, $\pi_S^{S*} < \pi_S^{R*}$.
Where $\rho_1 = \frac{c\lambda_1(\alpha-\beta)+d(\alpha\tau\theta c+\lambda_1)-\gamma_1 d(\beta\tau\theta c+\lambda_1)}{d(1-\gamma_2)(\alpha\tau\theta c+\lambda_1)+d(1-\gamma_1)(\beta\tau\theta c+\lambda_1)}$.

Proof. $e_r^{R*} - e_s^{S*} = \frac{\theta c\lambda_1(\alpha-\beta)+\theta d[(1-\rho+\gamma_2\rho)(\alpha\tau\theta c+\lambda_1)-(\gamma_1+\rho-\gamma_1\rho)(\beta\tau\theta c+\lambda_1)]}{2(\beta\tau\theta c+\lambda_1)(\alpha\tau\theta c+\lambda_1)}$, if $e_r^{R*} - e_s^{S*} > 0$, then we derive $\rho < \rho_1 = \frac{c\lambda_1(\alpha-\beta)+d(\alpha\tau\theta c+\lambda_1)-\gamma_1 d(\beta\tau\theta c+\lambda_1)}{d(1-\gamma_2)(\alpha\tau\theta c+\lambda_1)+d(1-\gamma_1)(\beta\tau\theta c+\lambda_1)}$. Similarly, $\pi_M^{R*} - \pi_M^{S*} = \frac{\lambda_1(\theta^2+\lambda_1)[[d(1-\rho+\gamma_2\rho)-\beta c]^2(\alpha\tau\theta c+\lambda_1)^2-[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2(\beta\tau\theta c+\lambda_1)^2]}{16\alpha(\beta\tau\theta c+\lambda_1)^2(\alpha\tau\theta c+\lambda_1)^2} > 0$ when $\rho < \rho_1$. From $\rho < \rho_1$, we derive that $\frac{d(1-\rho+\gamma_2\rho)-\beta c}{\beta\theta c+\lambda_1} > \frac{d(\gamma_1+\rho-\gamma_1\rho)-\alpha c}{\alpha\tau\theta c+\lambda_1}$, so $p_s^{S*} = \frac{[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c](3\lambda_1+\theta^2+4\alpha\tau\theta c)}{4\alpha(\alpha\tau\theta c+\lambda_1)} + c < \frac{[d(1-\rho+\gamma_2\rho)-\beta c](3\lambda_1+\theta^2+4\alpha\tau\theta c)}{4\alpha(\beta\tau\theta c+\lambda_1)} + c < \frac{[d(1-\rho+\gamma_2\rho)-\beta c][\beta(\theta^2+\lambda_1)+2\alpha(\lambda_1+2\beta\tau\theta c)]}{4\alpha\beta(\beta\tau\theta c+\lambda_1)} + c = p_r^{R*} + h^{R*}$; $h^{R*} - w^{S*} = \frac{\beta c\lambda_1+d(1-\rho+\gamma_2\rho)(\lambda_1+2\beta\tau\theta c)}{2\beta(\beta\tau\theta c+\lambda_1)} - \frac{\alpha c\lambda_1+d(\gamma_1+\rho-\gamma_1\rho)(\lambda_1+2\alpha\tau\theta c)}{2\alpha(\alpha\tau\theta c+\lambda_1)} = \frac{(\lambda_1+2\beta\tau\theta c)[d(1-\rho+\gamma_2\rho)-\beta c]}{2\beta(\beta\tau\theta c+\lambda_1)} - \frac{(\lambda_1+2\alpha\tau\theta c)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]}{2\alpha(\alpha\tau\theta c+\lambda_1)} > 0$; $\pi_S^{R*} - \pi_S^{S*} > \frac{[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2(\theta^2+\lambda_1)(\beta\tau\theta c+\lambda_1)}{8\beta(\alpha\tau\theta c+\lambda_1)^2} - \frac{[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2(\theta^2+\lambda_1)}{8\alpha(\alpha\tau\theta c+\lambda_1)} > 0$. □

Proposition 4.8 shows that the manufacturer will choose the rental model when customers' preference for choosing sales is not obvious. Under this circumstance, the manufacturer provides a higher service level than that in the sales model. Meanwhile, the total expenditure of customers purchasing the incomplete product and hiring the core components is higher than the purchase expenditure of a whole product. The component rental price set by the supplier in rental model is higher than the component wholesale price in sales model, which is also in line with the traditional practice that buying in bulk is more economical than individual consumption. It should be noticed that if the proportion of customers willing to choose sales is smaller or slightly greater than the proportion of customers willing to choose rentals (derive from $d[(\gamma_1+\rho-\gamma_1\rho)(\beta\tau\theta c+\lambda_1)-(1-\rho+\gamma_2\rho)(\alpha\tau\theta c+\lambda_1)] < c\lambda_1(\alpha-\beta)$), the manufacturer and supplier will benefit more from the rental model than that from the sales model. This is because that the manufacturer in rental model can make full use of the advantage that customers are less sensitive to the rental price, which increases the price of its incomplete product and supplier's rental components while minimizing the impact on the demand. Furthermore, when fewer customers are willing to choose rentals, service quality under rental model will be set higher to increase sales. The increase of revenue brought by the increase of marginal revenue and demand can make up for the increase of service investment cost caused by the improvement of service quality. Therefore, both the manufacturer and supplier are more willing to choose the rental model.

Proposition 4.9. *$p_s^{S*} > p_s^{B*}$; $w^{S*} > w^{B*}$; when $\theta > 2\alpha\tau c$ and $g < 1 - \frac{\theta(\theta-\alpha\tau c)^2}{4\alpha k(\theta-2\alpha\tau c)}$, $\pi_M^{S*} > \pi_M^{B*}$, $\pi_S^{S*} > \pi_S^{B*}$, $D_s^{S*} > D_s^{B*}$.*

Proof. $p_s^{S*} - p_s^{B*} = \frac{d(\gamma_1+\rho-\gamma_1\rho)(3\lambda_1+\theta^2+4\alpha\tau\theta c)-\alpha c(\theta^2-\lambda_1)}{4\alpha(\alpha\tau\theta c+\lambda_1)} - \frac{3d(\gamma_1+\rho-\gamma_1\rho)+\alpha c}{4\alpha}$ $= \frac{[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c](\theta^2+\alpha\tau\theta c)}{4\alpha(\alpha\tau\theta c+\lambda_1)} > 0$; $w^{S*} - w^{B*} = \frac{\tau\theta c[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]}{2(\alpha\tau\theta c+\lambda_1)} > 0$; $\pi_M^{S*} - \pi_M^{B*} = \frac{[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2[\lambda_1(\theta^2+\lambda_1)-(\alpha\tau\theta c+\lambda_1)^2]}{16\alpha(\alpha\tau\theta c+\lambda_1)^2}$, when $\lambda_1(\theta - 2\alpha\tau c) > \alpha^2\tau^2\theta c^2$, that is $\theta > 2\alpha\tau c$ and $g < 1 - \frac{\theta(\theta-\alpha\tau c)^2}{4\alpha k(\theta-2\alpha\tau c)}$, $\pi_M^{S*} - \pi_M^{B*} > 0$; $\pi_S^{S*} - \pi_S^{B*} = \frac{[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2(\theta^2-\alpha\tau\theta c)}{8\alpha(\alpha\tau\theta c+\lambda_1)}$, $D_s^{S*} - D_s^{B*} = \frac{[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c](\theta^2-\alpha\tau\theta c)}{4(\alpha\tau\theta c+\lambda_1)}$, when $\theta > \alpha\tau c$, $\pi_S^{S*} - \pi_S^{B*} > 0$, $D_s^{S*} - D_s^{B*} > 0$. □

Proposition 4.9 states that under sales model, the product sales price and the component wholesale price are higher than that in the benchmark model. The reason is that improving service level will attract customers who prefer advanced service, and at the same time increase the investment cost of service innovation for the manufacturer and supplier. As a result, both participants raise their selling prices to ensure their own profits. In addition, when customers have an obvious preference for high-quality service (i.e., $\theta > 2\alpha\tau c$) and the government subsidy rate is within a certain range (i.e., $g < 1 - \frac{\theta(\theta-\alpha\tau c)^2}{4\alpha k(\theta-2\alpha\tau c)}$), the investment in service innovation and the choice of the sales model will improve the manufacturer and supplier's interests, as well as the sales volume. As customers demand for electric vehicle range becomes higher and the battery switching service is a good solution to alleviate the range anxiety, so customers' preference for high-quality service is gradually growing. Manufacturers need to pay more attention to the innovation of service mode and the improvement of service level. In this environment, on the one hand, suppliers can benefit from the improvement of service level and support the manufacturers to carry out service innovation. On the other hand, the government can encourage manufacturer to invest in service innovation without blindly increasing the financial subsidy ratio.

Proposition 4.10. *When $\rho < \rho_2$, $\pi_M^{R*} > \pi_M^{B*}$, $\pi_S^{R*} > \pi_S^{B*}$, $D_s^{R*} > D_s^{B*}$. Where $\rho_2 = \frac{(d-\beta c)\sqrt{\lambda_1(\theta^2+\lambda_1)}-d\gamma_1(\beta\tau\theta c+\gamma_1)}{d(1-\gamma_1)(\beta\tau\theta c+\lambda_1)+d(1-\gamma_2)\sqrt{\lambda_1(\theta^2+\lambda_1)}}$.*

Proof. $\pi_M^{R*} - \pi_M^{B*} = \frac{\lambda_1[d(1-\rho+\gamma_2\rho)-\beta c]^2(\theta^2+\lambda_1)-[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2(\beta\tau\theta c+\lambda_1)^2}{16\alpha(\beta\tau\theta c+\lambda_1)^2}$, if $\pi_M^{R*} - \pi_M^{B*} > 0$, then $\rho < \rho_2 = \frac{(d-\beta c)\sqrt{\lambda_1(\theta^2+\lambda_1)}-d\gamma_1(\beta\tau\theta c+\gamma_1)}{d(1-\gamma_1)(\beta\tau\theta c+\lambda_1)+d(1-\gamma_2)\sqrt{\lambda_1(\theta^2+\lambda_1)}}$; When $\rho < \rho_2$, we can derive that $\lambda_1[d(1-\rho+\gamma_2\rho)-\beta c]^2(\theta^2+\lambda_1) > [d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2(\beta\tau\theta c+\lambda_1)^2$, then $\pi_S^{R*} - \pi_S^{B*} = \frac{\alpha(\theta^2+\lambda_1)[d(1-\rho+\gamma_2\rho)-\beta c]^2-\beta(\beta\tau\theta c+\lambda_1)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2}{8\alpha\beta(\beta\tau\theta c+\lambda_1)}$
$> \frac{\alpha(\beta\tau\theta c+\lambda_1)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2-\beta\lambda_1[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]^2}{8\alpha\beta\lambda_1} > 0$,
$D_s^{R*} - D_s^{B*} = \frac{(\theta^2+\lambda_1)[d(1-\rho+\gamma_2\rho)-\beta c]-(\beta\tau\theta c+\lambda_1)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]}{4(\beta\tau\theta c+\lambda_1)}$
$> \frac{\sqrt{\lambda_1(\theta^2+\lambda_1)}[d(1-\rho+\gamma_2\rho)-\beta c]-(\beta\tau\theta c+\lambda_1)[d(\gamma_1+\rho-\gamma_1\rho)-\alpha c]}{4(\beta\tau\theta c+\lambda_1)} > 0$. □

Proposition 4.10 illustrates that in rental model, the manufacturer sells more products and both players get higher profits than that under benchmark model when customers' preference for sales model is not significant. It means that the manufacturer needs to better focus on service innovation investment and rental business promotion, and the supplier is also willing to provide corresponding support. It can be seen from the above three propositions that the manufacturer's optimal business model always avails the supplier's interest when the preference for traditional sales is not obvious. Therefore, based on this supply chain structure, manufacturers can successfully carry out service innovations and business model innovations in considering the reality that customer groups are increasingly receptive to or even more preferred to the rental business model (i.e., when $\rho < \min\{\rho_1, \rho_2\}$). The reason is that, as battery rental and battery switching service release customer anxiety induced by the electric vehicle's limited range, battery degradation, and high battery cost, more customers prefer to the rental business model with service innovation. Therefore, it implies that rental business model can promote the adoption of electric vehicles.

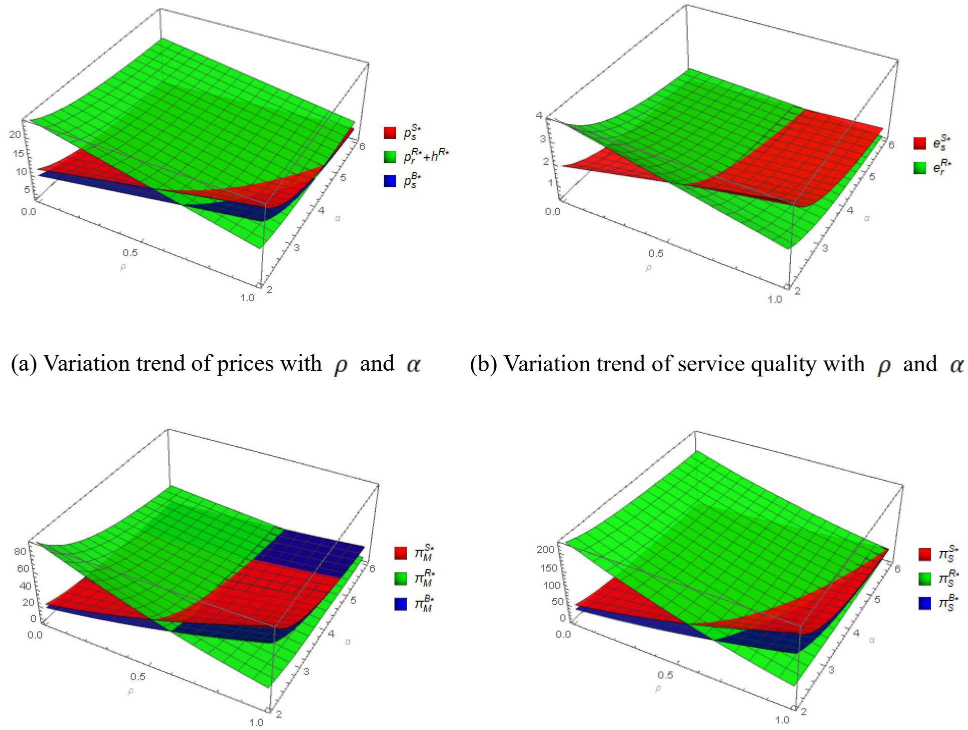
5. **Numerical analysis.** To illustrate the main results and obtain additional insight into the differences among the business models, numerical examples are used to analyze the impact of parameters on the optimal decisions.

5.1. **Numerical analysis of comparison between different models.** Following Wang et al. (2020)[35], Wu (2012)[36], and Yu et al. (2018)[41] and considering general products, suppose that $d = 50$, $\beta = 1.8$, $\theta = 3$, $\gamma_1 = 0.5$, $\gamma_2 = 0.5$, $c = 1$, $k = 4$, $g = 0.2$, $\tau = 0.3$, $\rho \in [0, 1]$, $\alpha > 1.8$, the variation trend of decision variables and participants' profits with ρ and α are shown in Figure 2. Figure 2 verifies the conclusions of Proposition 4.8-4.10 and shows that:

(i)From Figure 2(a)-(d), we can find that the impact factor of market preference for choosing sales (ρ) has a positive correlation with sales price, profit of the manufacturer and supplier in S model and B model, as well as service quality in S model. However, the total price that a customer needs to pay, the service quality, and profit of the manufacturer and supplier in R model decrease with the market preference for choosing sales, and the extent of the reduction is related to the customer sensitivity of sales price (α). Meanwhile, as the customer sensitivity of product sales price increases, all the decision variables and profits decrease.

(ii)As shown in Figure 2(a), with the market preference for choosing sales increases, the sales price and its growth rate under S model is greater than that in B model. Unless the market preference for choosing sales is obvious and the customer sensitivity of product sales price is relatively weak, the total cost of purchasing an incomplete product and renting a core component in R model is always higher than the cost of purchasing the whole product in S model and B model. Figure 2(b) confirms that when the market preference for choosing sales is not obvious, the service quality offered in R model is better than that under S model.

(iii)Figure 2(c) illustrates that the manufacturer will invest in service innovation and choose R model when the market preference for choosing sales is not obvious regardless of the customer sensitivity of product sales price. With the increase of sales price sensitivity, the manufacturer's profit under S model decreases faster than that in B model. Therefore, the manufacturer will initially choose the S model and turn to the B model as the sales price sensitivity increases when the market preference for choosing sales is obvious. For the supplier, Figure 2(d) indicates that regardless of whether the manufacture's optimal choice is the S model or R model, the supplier's profit will be improved over the B model. On the one hand, the increased profit of choosing the S model increases faster than that of choosing the B model as customer's preference for choosing sales increases. Thus, the supplier



(a) Variation trend of prices with ρ and α (b) Variation trend of service quality with ρ and α

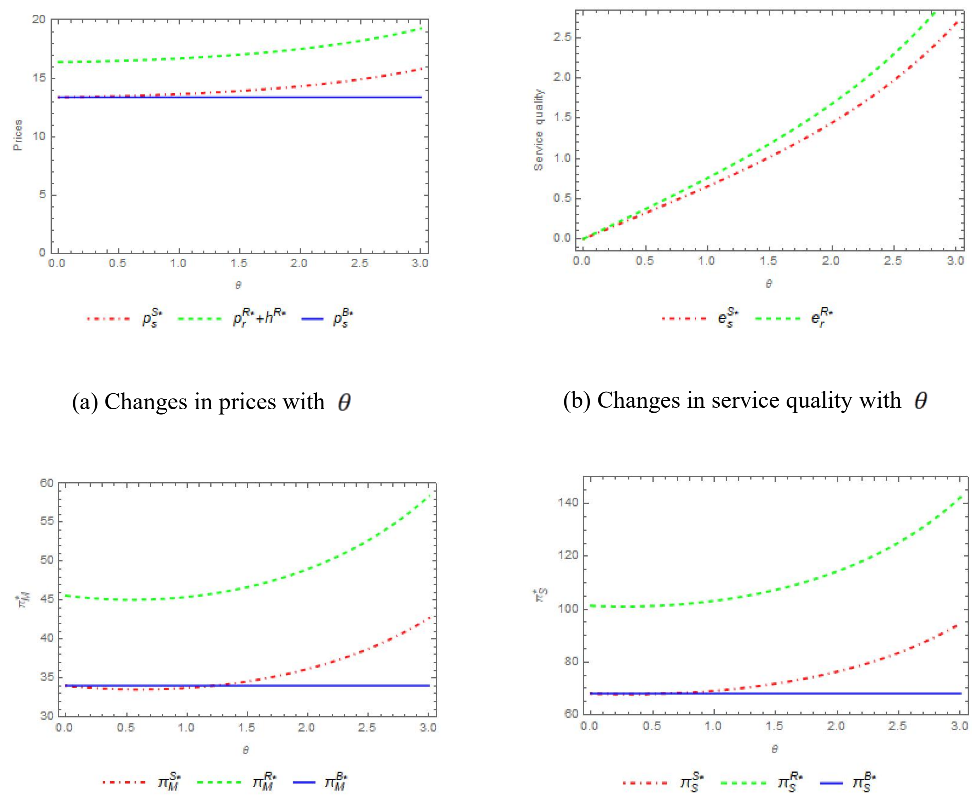
(c) Variation trend of π_M^* with ρ and α (d) Variation trend of π_S^* with ρ and α

FIGURE 2. Variation trend of decision variables and profits with ρ and α

will always support manufacturer's business model transformation from the B model to the S model. On the other hand, when customer's preference for choosing sales is not obvious and the manufacturer prefers R model, the supplier's profit is the highest among the three models.

5.2. **The effect of service quality sensitivity.** Based on the above values of parameters ($d = 50$, $\beta = 1.8$, $\gamma_1 = 0.5$, $\gamma_2 = 0.5$, $c = 1$, $k = 4$, $g = 0.2$, $\tau = 0.3$), we assume that $\rho = 0.4$ and $\alpha = 2$ to analyze the effect of service quality sensitivity coefficient (θ) on the decision variables and participants' profits.

Figure 3(a, b) shows that the sales price in S model, the sum of the incomplete product sales price and component rental price in R model, and the service quality increase with the service quality sensitivity. The first two grow at similar rates that are first slow and then accelerated, while the growth rate of the service quality in R model is greater than that in S model. This implies that customers can enjoy a low level of innovative service at little extra cost, whereas the high level of service will lead to a relatively rapid increase in the cost of payment. Moreover, it indicates that when customers' sensitivity to service quality is enhanced, the rental model can enable customers to enjoy a higher level of service with a similar increase in the payment cost. Figure 3(c, d) illustrates that the profits of manufacturer and supplier first decrease and then increase as the service quality sensitivity increases.



(a) Changes in prices with θ

(b) Changes in service quality with θ

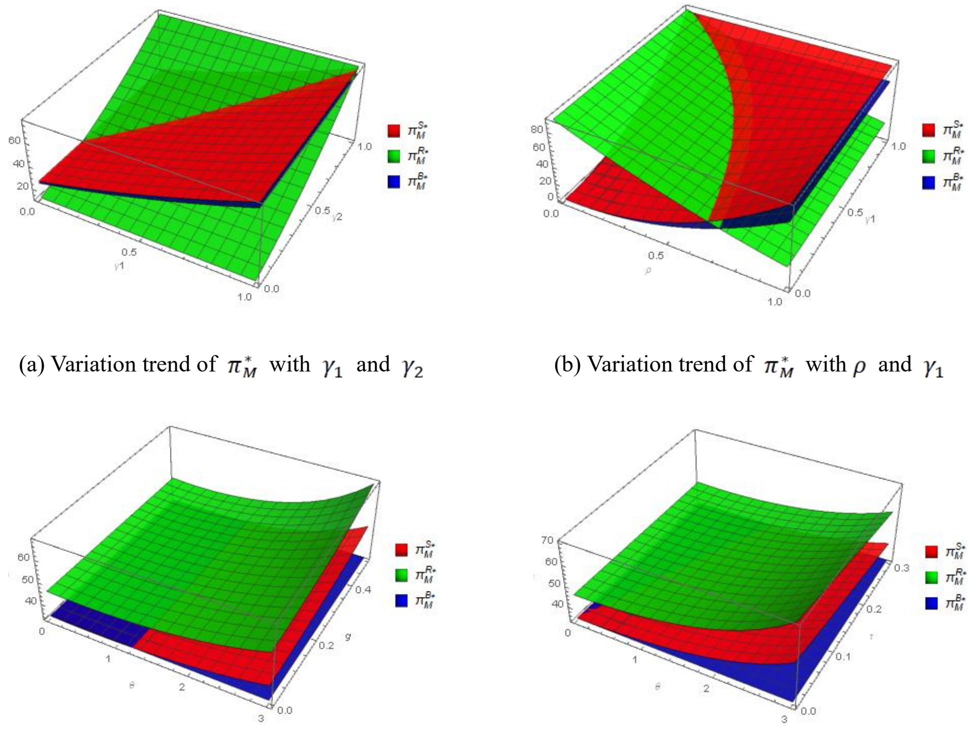
(c) Changes in π_M^* with θ

(d) Changes in π_S^* with

FIGURE 3. Changes in decision variables and profit with θ

Based on Figure 3, we find that choosing R model can maximize the benefits of both parties and provide the highest level of service. Meanwhile, customers are willing to pay the highest price in R model.

5.3. **The effect of parameters on business model choices.** Figure 4 shows the impacts of some parameters on the manufacturer's profit under three business models. It illustrates that the manufacturer can benefit from implementing the service innovation strategy, whereas the choice between S model and R model depends on the situation. From Figure 4(a), when customer acceptance of rentals (γ_2) is weak, the manufacturer will choose S model. In the region where the customer acceptance of rentals gradually increases while the acceptance of sales (γ_1) grows slowly, the manufacturer's optimal business model choice will become R model. As shown in Figure 4(b), we find that the manufacturer can benefit from choosing R model when both the market preference for choosing sales (ρ) and customer acceptance of sales (γ_1) are relatively small. When customers are obviously biased towards sales, the S model is more attractive to decision makers regardless of customer acceptance of sales. Figure 4(c) shows that the manufacturer's profit increases with the service quality sensitivity coefficient (θ) and government subsidy ratio (g) under S model and R model. Although the manufacturer's profit under S model will be damaged when customers are not sensitive to innovative services, choosing R model will always obtain the highest profits. According to Figure 4(d), as the service quality sensitivity (θ) increases or the ability to share the core component (τ) increases, the profit of manufacturer will show an increasing trend. In addition, R model is still the best choice for decision makers.



(a) Variation trend of π_M^* with γ_1 and γ_2

(b) Variation trend of π_M^* with ρ and γ_1

(c) Variation trend of π_M^* with θ and g

(d) Variation trend of π_M^* with θ and τ

FIGURE 4. Variation trend of π_M^* with parameters

6. **Conclusion.** Motivated by the practical business model of NIO, this paper establishes a profit-maximization model for a two-echelon supply chain that one manufacturer (Stackelberg-leader) determines on a service innovation investment strategy and a choice of the sales or rental business model and one supplier complies with the manufacturer's service decisions and offers core component to the manufacturer or the customer. The service innovation investment considered in this paper is the battery replacement service in electric vehicle battery switching station. Once the innovation service is promised, the supplier needs to offer some spare core components whose amount is related to the sharing ability, the service level, and the end-product volume on use. The equilibrium prices and equilibrium service quality for the B, S, and R models are derived. We find that the business model choice and its service quality decision, that is, the customer behavior differences towards the two purchase options and the provided service (i.e., demand

side) and the manufacturer's service investment cost (i.e., supply side) significantly influence a manufacturer's potential profitability. Our results provide some management insights for managers into how firms choose service level between the sales and rental business models, as well as for policy makers into how to play a leading role in promoting the service innovation and mass adoption of electric vehicles, which can be summarized as follows: (i)With the continuous improvement of consumers' acceptance and preference for rentals, manufacturers should pay more attention to the innovation of service model and business model, increase rental options for customers, and improve the service quality from all aspects. In this way, customers' purchasing desires can be enhanced, a good corporate image can be established, and market competitiveness can be increased. (ii)In the environment where rental options are not widely accepted by consumers, manufacturers can also win consumers' favor and loyalty through service innovation. In this way, it is possible to stabilize and expand the market, and stand out in homogeneous competition. (iii)There is no universal subsidy scheme tailored to all situations. To promote service innovation, policy makers should choose the applicable subsidy scheme according to the characteristics of market and its different objectives. (iv)If a manufacturer decides to start the service innovation investment, he should focus on improving the component sharing ability, such as optimizing service network layout by analyzing customer usage data through Internet of Things and big data technology. In this way, the benefits of the system and the competitiveness of the supply chain can be improved.

There are some limitations to our study. First, we mainly focus on enterprise competition and cooperation from the vertical perspective of supply chain (i.e., the supplier and the manufacturer). However, it would also be interesting to study the business model selection and service competition from a lateral perspective (i.e., competing manufacturers). Moreover, in our model, the innovative service is invested and operated by the manufacturer, and the supplier undertakes the supply of spare components. Thus, the multi-player game behavior of supply chain after the participation of the third-party service provider can be studied in the future.

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REFERENCES

[1] V. Abhishek, J. A. Guajardo and Z. Zhang, Business models in the sharing economy: Manufacturing durable goods in the presence of peer-to-peer rental markets, *Information Systems Research*, **32** (2021), 1450-1469.

[2] V. V. Agrawal, A. Atasu and S. Ülkü, Leasing, modularity, and the circular economy, *Management Science*, **67** (2021), 6782-6802.

[3] V. V. Agrawal and I. Bellos, The potential of servicizing as a green business model, *Management Science*, **63** (2016), 1545-1562.

[4] V. V. Agrawal, M. Ferguson, L. B. Toktay and V. M. Thomas, Is leasing greener than delling?, *Management Science*, **58** (2012), 523-533.

[5] H. V. Arani, M. Pourakbar, E. Laan and R. Koster, How to charge in servicizing: Per period or per use?, *European Journal of Operational Research*, **304** (2023), 981-996.

[6] B. Avci, K. Girotra and S. Netessine, Electric vehicles with a battery switching station: Adoption and environmental impact, *Management Sciences*, **61** (2015), 772-794.

[7] I. Bellos, M. Ferguson and L. B. Toktay, The car sharing economy: Interaction of business model choice and product line design, *Manufacturing and Service Operations Management*, **19** (2017), 185-201.

[8] S. R. Bhaskaran and S. M. Gilbert, Selling and leasing strategies for durable goods with complementary products, *Management Sciences*, **51** (2005), 1278-1290.

[9] S. R. Bhaskaran and S. M. Gilbert, Implications of channel structure for leasing or selling durable goods, *Management Sciences*, **28** (2009), 918-934.

[10] S. R. Bhaskaran and S. M. Gilbert, Implications of channel structure and operational mode upon a manufacturer's durability choice, *Production and Operations Management*, **24** (2015), 1071-1085.

[11] S. Bhattacharya, A. Robotis and L. N. Van. Wassenhove, Installed base management versus selling in monopolistic and competitive environments, *European Journal of Operational Research*, **273** (2019), 596-607.

[12] J. I. Bulow, Durable-goods monopolists, *Journal of Political Economy*, **90** (1982), 314-332.

[13] J. I. Bulow, An economic theory of planned obsolescence, *The Quarterly Journal of Economics*, **101** (1986), 729-749.

[14] L. Cheng, X. Guo and B. Wang, Manufacturer's leasing channel management in a car supply chain, *Asia-Pacific Journal of Operational Research*, **37** (2020).

[15] P. S. Desai and D. Purohit, Leasing and selling: Optimal marketing strategies for a durable goods firm, *Management Sciences*, **44** (1998), 19-34.

[16] P. S. Desai and D. Purohit, Competition in durable goods markets: The strategic consequences of leasing and selling, *Management Sciences*, **18** (1999), 42-58.

[17] G. E. Goering, Distribution channel decentralization and strategic durability choice, *International Journal of the Economics of Business*, **17** (2010), 167-186.

[18] B. Hu, M. Hu and Y. Yang, Open or closed? Technology sharing, supplier investment and competition, *Manufacturing and Service Operations Management*, **19** (2017), 132-149.

[19] X. Hu, Z. Yang, J. Sun and Y. Zhang, Optimal pricing strategy for electric vehicle battery swapping: Pay-per-swap or subscription?, *Transportation Research Part E: Logistics and Transportation Review*, **171** (2023).

[20] Y. Huang, L. Qian, S. Didier and T. David, Buy, lease, or share? Consumer preferences for innovative business models in the market for electric vehicles, *Technological Forecasting and Social Change*.

[21] M. A. Kanatlı and Ö. Karaer, Servitization as an alternative business model and its implications on product durability, profitability & environmental impact, *European Journal of Operational Research*, **301** (2021), 546-560.

[22] K. Ladas, S. Kavadias and C. Loch, Product selling vs. pay-per-use service: A strategic analysis of competing business models, *Management Science*, **68** (2021), 4964-4982.

[23] I. Lazov, Profit management of car rental companies, *European Journal of Operational Research*, **258** (2017), 307-314.

[24] D. Li and Z. Pang, Dynamic booking control for car rental revenue management: A decomposition approach, *European Journal of Operational Research*, **256** (2017), 850-867.

[25] J. Li, H. Wang, Z. Deng, W. Zhang and G. Zhang, Leasing or selling? The channel choice of durable goods manufacturer considering consumers' capital constraint, *Flexible Services and Manufacturing Journal*, **34** (2022), 317-350.

[26] Q. Li, X. Chen and Y. Huang, The stability and complexity analysis of a low-carbon supply chain considering fairness concern behavior and sales service, *International Journal of Environmental Research and Public Health*, **16** (2019), 2711.

[27] F. Liao, E. Molin, H. Timmermans and B. Wee, The impact of business models on electric vehicle adoption: A latent transition analysis approach, *Transportation Research Part A: Policy and Practice*, **116** (2018), 531-546.

[28] M. K. Lim, H. Mak and Y. Rong, Toward mass adoption of electric vehicles: Impact of the range and resale anxieties, *Manufacturing and Service Operations Management*, **17** (2015), 101-119.

[29] B. B. Oliveira, M. A. Carravilla and J. F. Oliveira, Fleet and revenue management in car rental companies: A literature review and an integrated conceptual framework, *Omega*, **71** (2017), 11-26.

[30] S. Poddar, Strategic choice in durable goods market when firms move simultaneously, *Research in Economics*, **58** (2004), 175-186.

[31] X. Pu, L. Gong and X. Han, Consumer free riding: Coordinating sales effort in a dual-channel supply chain, *Electronic Commerce Research and Applications*, **22** (2017), 1-12.

[32] K. Saggi and N. Vettas, Leasing versus selling and firm efficiency in oligopoly, *Economics Letters*, **66** (2000), 361-368.

[33] B. Shen, R. Qian and T. M. Choi, Selling luxury fashion online with social influences considerations: Demand changes and supply chain coordination, *International Journal of Production Economics*, **185** (2017), 89-99.

[34] K. Wang, Y. Li, X. Yue and C. Fan, Leasing, trade-in for new, or the mixed of both: An analysis of new recycling modes driven by industry 4.0 technologies, to appear, *International Journal of Production Research*.

[35] Y. Wang, R. Fan, L. Shen and M. Jin, Decisions and coordination of green e-commerce supply chain considering green manufacturer's fairness concerns, *International Journal of Production Research*, **58** (2020), 7471-7489.

[36] C. Wu, Price and service competition between new and remanufactured products in a two-echelon supply chain, *International Journal of Production Economics*, **140** (2012), 496-507.

[37] T. Xiao and T. Xu, Coordinating price and service level decisions for a supply chain with deteriorating item under vendor managed inventory, *International Journal of Production Economics*, **145** (2013), 743-752.

[38] Y. Xiong, W. Yan, K. Fernandes, Z. Xiong and N. Guo, "Bricks vs. Clicks" the impact of manufacturer encroachment with a dealer leasing and selling of durable goods, *European Journal of Operational Research*, **217** (2012), 75-83.

[39] N. Yan, Y. Liu, X. Xu and X. He, Strategic dual-channel pricing games with e-retailer finance, *European Journal of Operational Research*, **283** (2020), 138-151.

[40] P. Yan, J. Pei and A. Chinchuluun, Strategic decisions of sales and pay-per-use rentals under incomplete product availability, *Journal of Global Optimization*, **78** (2020), 671-691.

[41] Y. Yu, Y. Dong and X. Guo, Pricing for sales and per-use rental services with vertical differentiation, *European Journal of Operational Research*, **270** (2018), 586-598.

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