IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received November 24, 2021, accepted January 3, 2022, date of publication January 14, 2022, date of current version February 4, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3143703

Product Innovativeness Strategy With Crowdsourcing

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ABSTRACT This study focuses on the manufacturer's strategy of product innovation when a set of potential consumers are involved in product innovation through crowdsourcing. Two models are built for developing incremental and radical products to capture the manufacturer's optimal strategy in a supply chain which includes one supplier, one manufacturer, and some potential consumers. In addition, the effort compensation mechanism has been designed to improve the profits of the manufacturer and supplier, and consumer surplus. Finally, the innovativeness strategy is explored based on the manufacturer providing compensation for crowdsourcing consumers. The results show the following: 1) if the degree of preference dispersion is low, the percentage of crowdsourcing consumers is large, or the degree of knowledge spillover is high, the manufacturer prefers radical innovation. It also implies the negative relationship between the manufacturer's profit and innovation level. Otherwise, the manufacturer prefers incremental innovation, which implies the positive correlation between the manufacturer's profit and innovation level; 2) under the optimal product innovativeness strategy, supplier's profit and consumer surplus also are improved; and 3) under certain conditions, offering compensation for crowdsourcing consumers is Pareto improvement strategy for the manufacturer, the supplier, and crowdsourcing consumers.

INDEX TERMS Crowdsourcing, innovativeness strategy, knowledge spillover.

I. INTRODUCTION

Currently, product innovation is being used as a strategic decision to gain a competitive advantage [1]. Research on product innovation has made progress in different areas and it is diverse while varying in scope, depth, and objective. The different types of innovations identified by researchers include administrative and technical, product and process, technological and architectural, and incremental and radical [2]. Following this literature, this study researches incremental innovation and radical innovation. Reference [3] defines radical innovation as new products for both the firm and market, including technological revolutions and new knowledge. It completely replaces existing products or services. This type of innovation involves a high level of risk and uncertainty concerning technology, customers' needs, and competitors' actions. Examples of this type of innovation include the first CD player, Internet service, and Web-TV service. In contrast, the technology of incremental innovation is similar to a company's production processes and conventional business practices used previously [4]. Incremental innovation refers to the continuous or improved activities when compared to the previous product based on experience, knowledge, and capabilities that already exist in the firm [5]. Instances of this type of innovation include an extension of the product line and an improvement of the production process. The difference between incremental innovation and radical innovation is whether or not the innovation incorporates technology that is a clear and risky departure from existing practice [6].

The market demand for new products, particularly radical products, is highly complex and uncertain [7]. Reference [8] highlight that customers involvement provides more new information and knowledge, which is advantageous for the firm to reduce the uncertainty of new product development in a fast-moving environment. In other words, when there is higher uncertainty and complexity in products, more customers are required to be involved [3]. Thus, to get ahead of innovation, firms have realized that they need to obtain knowledge, technology, and labor from outside to jointly

The associate editor coordinating the review of this manuscript and approving it for publication was Nikhil Padhi.

develop products [9], [10]. In addition, consumers no longer passively accept the product provided by the enterprise but participate in developing and designing products and other aspects of product innovation to co-create value to actively meet their own needs [11]. Customer participation not only strengthens an enterprise's competitive advantage, reduce the development cycle time [2], and improve the performance of products [13], but also improves product innovation ability, and offers perfect product and service [14].

Crowdsourcing is an important approach adopted for customer involvement in new product innovation. The term "crowdsourcing" was coined in 2005 by Howe Jeff [15], an editor at Wired, to describe how businesses use the Internet to "outsource work to the crowd," which quickly led to the portmanteau "crowdsourcing." There are two types of crowdsourcing; competitive crowdsourcing and collaborative crowdsourcing. Competition crowdsourcing involves a set of workers who seek solutions for tasks offered by the firm, but only one solution is adopted by the firm [16]. TopCoder and InnoCentive are the typical competitive crowdsourcing platforms. Collaborative crowdsourcing involves a set of workers with complementary skills who form groups and collaborate to perform complex tasks, such as editing, product design, and citizen science; these are considered to be critical components of next-generation crowdsourcing [17], [18]. For example, Haier Tianzun air conditioner was launched in October 2013 as a result of the interaction between 673,372 consumers and Haier Company. It successfully solved consumers' complaints about the air-conditioning disease and the excessively cold wind, and met their needs of natural wind and remote control.

This paper studies the co-creation strategy based on the interactions of consumers involved in innovation for a common product (incremental or radical product) and this innovation was dominated by the manufacturer who took decisions on production and pricing. Therefore, both the firm and consumers contribute to the product design, and there is knowledge spillover from consumers to the firm due to crowdsourcing. As a result, consumers can not only benefit from the firm's effort but also from crowdsourcing consumers. The product developing process of Xiaomi Company is an example of such an innovation. Firstly, it released a new version of the MIUI system on the online network platform and owns several different functions. Secondly, through an online platform, consumers discussed the problems of this MIUI system, provided their solutions, and revised it. Then, by voting, the consumers decided the function that should be reserved. Lastly, Xiaomi Company produced this product and sold it in the market.

This paper captures the following three different aspects: (1) the manufacturer and consumers develop the product jointly; (2) consumers participate in innovation based on crowdsourcing; and (3) they cooperate for two product types—incremental product and radical product. The difference between the types of products is in their innovation degree. The innovation degree of a radical product is higher than an incremental product. However, there remain some problems. Which product type is an optimal strategy for a manufacturer under the condition of crowdsourcing and collaboration? What is the relationship between the degree of innovation and the manufacturer's profit? How does consumer involvement impact a firm's strategy selection? How does the optimal strategy impact the supplier's profit as well as the consumers surplus? If the manufacturer provides compensation for crowdsourcing consumers, what is the difference when compared with no compensation? Therefore, this paper compares the manufacturer's and supplier's profits as well as consumer surplus in developing radical and incremental product environments.

The rest of the paper is organized as follows. Section 2 describes the relevant literature and section 3 describes the general model. Section 4 presents the analyses and discusses the equilibrium results and comparative statics. Section 5 extends the research to consider manufacturers compensating for consumers' efforts. Finally, section 6 concludes the study.

II. LITERATURE REVIEW

This paper is related to several literature streams. First, it is associated with the literature on product innovativeness. Product innovativeness is an important classifier of new products as it reflects a choice, either explicit or implicit, of product strategy. Further, it can be described along several dimensions. The classification of new products by the consulting firm Booz Allen Hamilton Inc. in the 1980s is the most popular. It identified six distinct categories based on newness to the market and newness to the firm, that is new-to-the-world, new-to-the-company, additions to existing product lines, improvement in/revision to the current product, repositioning, and cost reductions [19]. Based on the typology of Booz Allen Hamilton Inc., Cooper and Kleinschmidt [20] constructed seven classes of new product types ranging from real innovations to relatively minor modifications. Roberts and Berry [21] distinguished new product types based on newness to the company by two dimensions, namely technology employed and market served. Crawford [22] described pioneering, adaptation, and imitation innovation. Further, there are some different categories based on other characteristics [23], [24]. Since many scholars have adopted the binary innovation structure of radical innovation and incremental innovation [6], [25].

In addition, a large number of scholars have systematically analyzed the relationship between radical and incremental innovations and market performance. There are four viewpoints about this relationship—positive influence [26], [7], U-shaped relationship [27], inverted U-shaped relationship [28], [29], and independent [30]. Song and Montoya-Weiss [7] examined the development of 163 new products and 169 incremental new products in the American high-technology industry and found that when compared to incremental products, radical products have significantly higher profitability levels. Kleinschmidt and Cooper [27] demonstrated that the relationship between product innovativeness and commercial success is U-shaped based on the data of 195 new products from 125 industrial companies. In other words, products that are both high and low on innovation are more likely to be more successful than those in-between. Reference [28] suggested an almost inverted U-shaped relationship between financial performance and the degree of innovativeness of a new financial service based on 84 financial companies providing data for 132 new financial services. Based on data of 117 cross-industry enterprises from Denmark and Austria, Schultz *et al.* [29] found that there is an inverted U-shaped relationship between innovativeness and market performance. However, when the market novelty is not considered, innovativeness (including the other three dimensions) has a negative influence on market performance. These scholars undertook research adopting the empirical method and lacking quantitative analysis. In addition, they did not consider the actual situation of more consumers participating in product innovation.

Crowdsourcing is an effective strategy that can solve problems for developers [30]. Crowdsourcing can reduce development costs [31], increase the speed to market [32], improve product quality [33], strengthen product flexibility [34], and enhance product scalability [31] and diversity [33]. Further, several scholars noted the challenges of crowdsourcing, including task-design [35], motivational problems [36] and incentive systems [35], task-routing and task coordination [37], quality control of work results [38], task-aggregation [39], and platform management [40]. However, the scholars researched crowdsourcing phenomena by primarily using case studies [41], crowdsourcing experiments [33], [34], and surveys/interviews [42], and fostered theoretical understanding primarily by analytical [43] and technological [38] contributions. However, quantitative analysis was seldom used. Archak and Sundararajan [31] provided a game model of the crowdsourcing contest. Attention is particularly given to the asymptotic behavior of the contest outcome. The result shows that all significant outcomes of crowdsourcing contests are determined by contestants in a small neighborhood (core) of the most efficient contestant type. Dai *et al.* [44] were interested in how the price and minimum production quantity (MPQ) decisions are made in designer platform service (DPS) with consideration of the entrant designer's objective, decision sequences, and customer demand structures. Thus, they developed Stackelberg games to model and derive the equilibrium solutions under individual scenarios. However, research is lacking in product innovativeness strategy selection using the mathematical model based on collaborative crowdsourcing.

Effective knowledge spillover drives organizational and personal learning, which in turn accelerates and improves the quality of product innovation [1]. The original research of knowledge spillover was based on the network [45]. Companies and people working in these organizations share knowledge, information, goods, and services with others inside and outside their organizations, which is the building block of social networks [46]. Therefore, knowledge spillover often comes from alliances between these organizations and social relationships among employees of different enterprises [47]. Further, with the development of industry, researchers found that trade and industry have begun to undergo geographical aggregation [48], [49], which range from crowded rural stores to world trade enterprises [50], [51]. In the process of aggregation, if firms focus only on internal innovation, they could lose many opportunities and most of these opportunities may exceed the enterprise's existing business organization ability or may require the use of external technology to be created. Therefore, increasingly more firms apply external knowledge and ideas to their innovation, and the knowledge spillover turns into an effective combination of external resources [52]. In other words, geographical aggregation is a benefit for knowledge spillover. With the development of network technology, the space distance between consumers is shortening. Thus, crowdsourcing is an important method of gaining access to external knowledge or for organizations that have networks of crowdsourcing consumers and overcomes the geographic division through the Internet.

The importance of knowledge spillover has been recognized. For example, the benefit of knowledge spillover is that firms can be more strategic with less effort and costs [53]. However, integration into the domain of supply chain management continues to lacking [54]. Reference [55] found that the impact of ordinary knowledge spillover on supplier performance improvement does not change with buyer-supplier relationship duration, but the impact of higher-level knowledge spillover is more positive with an increase in relationship duration. In addition, Lin and Wu [56] showed that collaborative relationships with customers and suppliers effectively enhance the firm's competitiveness. Reference [57] approved that knowledge sharing and learning have a positive impact on the performance of the supply chain. Hult *et al.* [58] also found that a culture of knowledge development has a positive effect on supply chain performance with the data collected from 201 firms. Reference [59] found the positive impact of internal and external knowledge spillover on supply chain flexibility based on data from procurement and supply chain professionals in Germany. Further, these researchers do not consider the crowdsourcing environment and study the relationship between knowledge spillover and innovativeness strategy.

III. BASIC MODE

This study considers a supply chain that consists of one supplier, one manufacturer, where the supplier provides raw materials for the manufacturer at the wholesale price w and a unit cost is v. The unit cost v is different in incremental and radical strategies, and are v^i and v^r, respectively. Considering that radical innovation requires new materials and technologies, it is also assumed that $v^i < v^r$. Further, the manufacturer collaborates with crowdsourcing consumers, who are also potential consumers, to create a product and sell it to the market at price p. In co-creation, the effort level of the manufacturer is e_f and the effort level of the crowdsourcing consumer is e_u. The number of potential consumers is n and the number of crowdsourcing consumers is αn. Therefore, others who do not participate in product development are $(1-\alpha)n$, where α is the percentage of participating in co-creation by all potential consumers, $0 < \alpha < 1$. See Figure 1 for the supply chain structure with crowdsourcing.

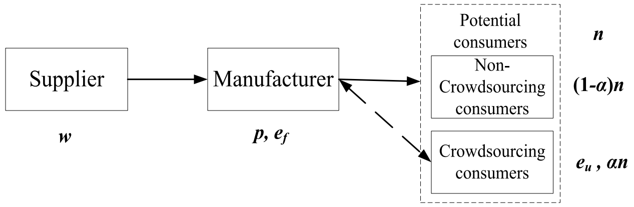

FIGURE 1. New product innovation supply chain with crowdsourcing.

All consumers benefit from the total effort of crowdsourcing consumers and the manufacturer. However, the manufacturer is the leader in product innovation. The firm collects and integrates consumers' ideas, but it cannot fully utilize these ideas as not all customers are professionals, and customers' efforts cannot substitute the firm's effort completely. Therefore, consumer benefit b is defined as

$$b = e_f + \delta \alpha n e_u. \tag{1}$$

Also, a convex cost of effort is assumed as

$$C(e_i) = ce_i^2. \tag{2}$$

The total consumer surplus is given as

$$S_u = b - p - C(e_u) + \varepsilon. \tag{3}$$

where δ represents the benefit to the firm from a unit effort exerted by crowdsourcing consumers. It can also represent the knowledge spillover degree of crowdsourcing consumers. c is the effort cost coefficient, and i is crowdsourcing consumers u or the manufacturer f. ε is a zero mean random variable representing consumer preference. In this paper, it is assumed that ε is distributed uniformly on $[-\theta, \theta]$, and θ represents the degree of preference dispersion. Further, during the development stage, ε is unknown by consumers, but once the product is sold in the market, it is revealed. The firm only knows the distribution of this parameter in the population [60].

Given a price p, consumers make their purchase decisions based on consumer surplus. In this paper, the cost of efforts is considered to be sunk [60]. So, consumers buy the product only when $\varepsilon \geq p - b$. Further, there are three cases based on further analysis. First, when the price is $0 < p \leq b - \theta$, all consumers purchase the product. In other words, the probability of buying is one. Second, when the price is $b - \theta < p < b + \theta$, the probability of buying is $r = \Pr\{\varepsilon \geq p - b\} = (b - p + \theta)/(2\theta)$. Third, when the price is $p \geq b + \theta$, no consumer purchases the product. However, when the probability is 0, the profits of the supplier and manufacturer are 0. Further, when the probability is 1, consumers do not involve in product development.[1] As such, this study only considers the case of the probability is

$$r = (b - p + \theta)/(2\theta). \tag{4}$$

Therefore, the surplus of crowdsourcing consumers is

$$\begin{aligned} E[S_u] &= E[b - p + \varepsilon | \, \varepsilon \geq p - b] \cdot \Pr\{\varepsilon \geq p - b\} - C(e_u) \\ &= \frac{(b - p + \theta)^2}{4\theta} - ce_u^2 \end{aligned} \tag{5}$$

The manufacturer profit function is

$$\begin{aligned} \pi_f &= rn(p - w) - C(e_f) \\ &= \frac{n(b - p + \theta)(p - w)}{2\theta} - ce_f^2. \end{aligned} \tag{6}$$

Finally, the supplier profit function is

$$\begin{aligned} \pi_s &= rn(w - v) \\ &= \frac{n(b - p + \theta)(w - v)}{2\theta}. \end{aligned} \tag{7}$$

Then, two types of product innovativeness strategies were analyzed—incremental innovation and radical innovation based on crowdsourcing.

The subscript u, f, and s represent crowdsourcing consumers, manufacturer, and supplier, respectively; and the superscript i and r represent the incremental product and radical product, respectively in the following paragraphs.

A. INCREMENTAL INNOVATION WITH CROWDSOURCING

In this section, the manufacturer and crowdsourcing consumers develop the incremental product based on crowdsourcing. As previously mentioned, incremental innovation does not require too many changes in technology; it only improves previous products partially. In other words and in this context, the supplier's wholesale price of raw materials is the same as when the manufacturer and consumers develop the product jointly. Therefore, the competitive environment of developing incremental products unfolds in three stages. In the first stage, the supplier determines the wholesale price. In the second stage, both the crowdsourcing customers and the manufacturer determine their innovation effort levels and then exert that effort. In the third stage, the prototype is available, and by observing effort levels, the manufacturer determines the price. In the last stage, all potential consumers evaluate the fit of the product and make their purchase decisions. Figure 2 depicts this timeline.

In stage 3, the manufacturer chooses p^i optimally; the FOC gives the price in terms of the efforts $p^i = (b + w + \theta)/2$. Then, the probability of buying, the consumer's surpluses,

[1] When the price is $0 < p \leq b - \theta$, all consumers will purchase the product. Considering the manufacturer's profit, it increases as the price increases. So the optimal price is $p = b - \theta$. However, in this condition, the consumer surplus is $S_u = \theta - C(e_u) + \varepsilon$; it decreases with the e_u. Then, consumers do not participate in crowdsourcing.

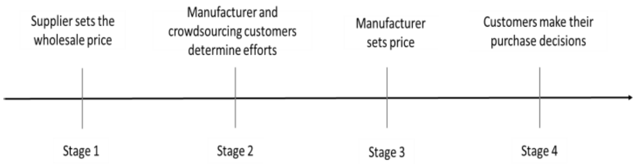

FIGURE 2. Timeline of developing incremental products.

and the expected profit of the manufacturer after price are incorporated into (1)-(4) as follows:

$$\begin{aligned} r^i &= (b^i - w^i + \theta)/(4\theta) \\ E[S_u]^i &= (b^i - w^i + \theta)^2/(16\theta) - ce_u^{i2} \\ \pi_f^i &= n(b^i - w^i + \theta)^2/(8\theta) - ce_f^{i2} \\ \pi_s^i &= (n(w^i - v^i)(b^i - w^i + \theta))/(4\theta). \end{aligned}$$

In the second stage, to characterize the efforts e_f^i and e_u^i in equilibrium, the focus is on the problem of consumers and the manufacturer. The two FOCs for consumers and the manufacturer were given as

$$\begin{aligned} \frac{\partial \pi_f^i}{\partial e_f^i} &= \frac{n(e_f^i + n\alpha\delta e_u^i - w^i + \theta) - 8c\theta e_f^i}{4\theta} \\ \frac{\partial E[S_u]^i}{\partial e_u^i} &= \frac{n\alpha\delta(e_f^i + \delta\alpha n e_u^i - w^i + \theta) - 16c\theta e_u^i}{8\theta}. \end{aligned}$$

The optimal efforts of consumers and the manufacturer are given by solving the above two FOCs simultaneously.

$$e_f^i = \frac{2n(\theta - w^i)}{16c\theta - 2n - n^2\alpha^2\delta^2} \quad e_u^i = \frac{n\alpha\delta(\theta - w^i)}{16c\theta - 2n - n^2\alpha^2\delta^2}.$$

Finally, in the first stage, to characterize the wholesale price w^i in equilibrium, the supplier's profit after the price has been incorporated is $\pi_s^i = \frac{4cn(w^i - v^i)(\theta - w^i)}{16c\theta - 2n - n^2\alpha^2\delta^2}$. Further, the supplier's FOC is $\frac{\partial \pi_s^i}{\partial w^i} = \frac{4cn(\theta + v^i - 2w^i)}{16c\theta - 2n - n^2\alpha^2\delta^2}$. Thus, the optimal wholesale price is $w^{i*} = (v^i + \theta)/2$.

The optimal wholesale price is substituted in the probability, the price, the effort levels of manufacturer and crowdsourcing consumers, and profits of the supplier and manufacturer. The expectation of consumer surplus become

$$\begin{aligned} r^{i*} &= \frac{2c(\theta - v^i)}{16c\theta - 2n - n^2\alpha^2\delta^2} \\ p^{i*} &= \frac{1}{2}(v^i + \theta + \frac{8c\theta(\theta - v^i)}{16c\theta - 2n - n^2\alpha^2\delta^2}) \\ e_f^{i*} &= \frac{n(\theta - v^i)}{16c\theta - 2n - n^2\alpha^2\delta^2} \\ e_u^{i*} &= \frac{n\alpha\delta(\theta - v^i)}{2(16c\theta - 2n - n^2\alpha^2\delta^2)} \\ \pi_s^{i*} &= \frac{cn(\theta - v^i)^2}{16c\theta - 2n - n^2\alpha^2\delta^2} \\ \pi_f^{i*} &= \frac{cn(\theta - v^i)^2(8c\theta - n)}{(16c\theta - 2n - n^2\alpha^2\delta^2)^2} \\ E[S_u]^{i*} &= \frac{c(\theta - v^i)^2(16c\theta - n^2\alpha^2\delta^2)}{4(16c\theta - 2n - n^2\alpha^2\delta^2)^2}. \end{aligned}$$

B. RADICAL PRODUCT INNOVATION WITH CROWDSOURCING

In this section, the manufacturer and some consumers co-develop the radical product based on crowdsourcing. As mentioned previously, radical product innovation refers to new technology. Considering new technology, materials are also new. It is necessary to find suitable and matching raw material suppliers. As such, the supplier is different. Accordingly, after the radical product was developed by the manufacturer and crowdsourcing consumers, the manufacturer seeks the supplier to offer the required raw materials at a wholesale price. Therefore, the competitive environment of developing the radical product unfolds in three stages. In the first stage, both the crowdsourcing customers and the manufacturer determine their innovation effort levels and then exert that effort. In the second stage, the supplier determines the wholesale price. In the third stage, the prototype is available and by observing effort levels, the manufacturer determines the price. In the last stage, all potential consumers evaluate the fit of the product and make their purchase decisions. Figure 3 depicts this timeline of developing the radical product.

Stage 3 in this section is the same as the preceding section. Therefore, the optimal price of the manufacturer is $p^r = (b^r + w^r + \theta)/2$, the expected profit of the supplier is $\pi_s^r = (n(w^r - v^r)(e_f^r + n\alpha\delta e_u^r - w^r + \theta))/(4\theta)$, and the probability is $r^r = (b^r - w^r + \theta)/(4\theta)$.

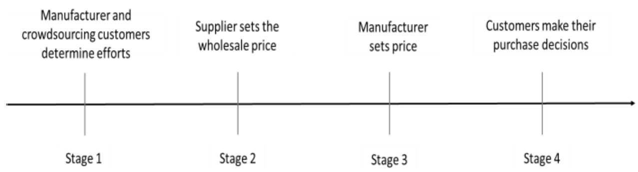

FIGURE 3. Timeline of developing the radical product.

However, in the second stage, the supplier characterizes the wholesale price w^r in equilibrium. The supplier's FOC is $\frac{\partial \pi_s^r}{\partial w^r} = (n(e_f^r + n\alpha\delta e_u^r - 2w^r + v^r + \theta))/(4\theta)$. Therefore, the optimal wholesale price of the supplier was given as $w^r = (e_f^r + n\alpha\delta e_u^r + \theta + v^r)/2$.

Finally, in the first stage, to characterize the efforts e_f^r and e_u^r in equilibrium, the focus is on the problem of consumers and the manufacturer. The manufacturer's profit and the consumer surplus, the two FOCs for consumers and the manufacturer are given as follows:

$$\begin{aligned} E[S_u]^r &= \frac{(\theta + e_f^r + n\alpha\delta e_u^r - v^r)^2}{64\theta} - ce_u^{r2} \\ \pi_f^r &= \frac{n(\theta + n\alpha\delta e_u^r + e_f^r - v^r)^2}{32\theta} - ce_f^{r2} \\ \frac{\partial \pi_f^r}{\partial e_f^r} &= \frac{n(\theta + e_f^r + n\alpha\delta e_u^r - v^r) - 32c\theta e_f^r}{16\theta} \\ \frac{\partial E[S_u]^r}{\partial e_u^r} &= \frac{n\alpha\delta(\theta + e_f^r + n\alpha\delta e_u^r - v^r) - 64c\theta e_u^r}{32\theta}. \end{aligned}$$

The optimal efforts of consumers and the manufacturer are given by solving the above two FOCs simultaneously.

$$e_f^{r*} = \frac{2n(\theta - v^r)}{64c\theta - 2n - n^2\alpha^2\delta^2}$$
$$e_u^{r*} = \frac{n\alpha\delta(\theta - v^r)}{64c\theta - 2n - n^2\alpha^2\delta^2}.$$

The optimal efforts of the supplier and manufacturer are substituted in the probability, the wholesale price, the price, and profits of the supplier and manufacturer. The expectation of consumer surplus become

$$r^{r*} = \frac{8c(\theta - v^r)}{64c\theta - 2n - n^2\alpha^2\delta^2}$$
$$w^{r*} = \frac{32c\theta(\theta - v^r)}{64c\theta - 2n - n^2\alpha^2\delta^2} + v^r$$
$$p^{r*} = \frac{48c\theta(\theta - v^r)}{64c\theta - 2n - n^2\alpha^2\delta^2} + v^r$$
$$\pi_s^{r*} = \frac{256c^2n\theta(\theta - v^r)^2}{(64c\theta - 2n - n^2\alpha^2\delta^2)^2}$$
$$\pi_f^{r*} = \frac{4cn(\theta - v^r)^2(32c\theta - n)}{(64c\theta - 2n - n^2\alpha^2\delta^2)^2}$$
$$E[S_u]^{r*} = \frac{c(\theta - v^r)^2(64c\theta - n^2\alpha^2\delta^2)}{(64c\theta - 2n - n^2\alpha^2\delta^2)^2}.$$

IV. COMPARISON AND ANALYSIS

In this section, the comparative analysis of the results related to developing the incremental and radical products are presented, particularly the manufacturer's profit, to provide theoretical references for the manufacturer. The following results were obtained.

A. IMPACT OF THE PERCENTAGE OF CROWDSOURCING CONSUMERS ON THE MANUFACTURER'S PRODUCT INNOVATIVENESS STRATEGY

For the probability of purchasing the product $0 < r < 1$, the following are required: $0 < r^i < 1$, $0 < r^r < 1$. For these to be satisfied, the following are required $0 < \alpha^i < (14c\theta - 2n + 2cv^i)^{1/2}/(n\delta)$, $0 < \alpha^r < (56c\theta - 2n + 8cv^r)^{1/2}/(n\delta)$. Note that in order to ensure that feasibility of analysis, it is assumed that α is within a reasonable range (i.e., $0 < \alpha < 1$).

Obviously, when $0 < \alpha^i < (14c\theta - 2n + 2cv^i)^{1/2}/(n\delta)$, the manufacturer develops the incremental product, and when $0 < \alpha^r < (56c\theta - 2n + 8cv^r)^{1/2}/(n\delta)$, the manufacturer develops the radical product.

As the probability of buying is $r = (b - w + \theta)/(4\theta)$, all potential consumers will buy the product and the manufacturer's profit will reach a maximum if the benefit is $b = (3\theta + w)$. In other words, the benefit b is not more than $3\theta + w$. Further, as the wholesale price is irrelevant to efforts of the crowdsourcing consumers and the manufacturer when the manufacturer offers the incremental product, and the wholesale price increases in efforts of the crowdsourcing consumers and the manufacturer when the manufacturer offer the radical products, the wholesale price of the incremental product is lower when compared to the radical product's wholesale price. Therefore, the benefit is higher when the manufacturer develops the radical product to maximize its profit. Consequently, more efforts are needed to develop a radical product (i.e., when the manufacturer develops the radical product, more consumers are needed to involve participating in crowdsourcing). However, when the manufacturer develops an incremental product, more consumers are not needed.

Proposition 1: Irrespective of the type of innovation, the manufacturer's profit increases in the percentage of crowdsourcing consumers ($\partial\pi_f^i/\partial\alpha > 0$, $\partial\pi_f^r/\partial\alpha > 0$).

From Proposition 1, it can be stated that when the percentage of crowdsourcing consumers is high, the manufacturer's profit is more. Further, this is not related to product innovativeness. This result indicates that the manufacturer should get more consumers involved in crowdsourcing to earn more profits and improve market competitiveness. The direct effect is that the efforts of the manufacturer and consumers increase in the percentage of crowdsourcing consumers. The indirect effect is that the benefit and price, as well as the probability of buying all increase at the same rate as crowdsourcing consumers. Overall, the manufacturer will benefit.

In addition, it can be observed that when $0 < \alpha < (14c\theta - 2n + 2cv^i)^{1/2}/(n\delta)$, the manufacturer can develop both incremental and radical products, but if $((14c\theta - 2n + 2cv^i)^{1/2}/(n\delta)) < \alpha < ((56c\theta - 2n + 8cv^r)^{1/2}/(n\delta))$, developing a radical product is the only option for the manufacturer. Therefore, the optimal strategy of the manufacturer satisfies the following conditions:

Proposition 2: i) The manufacturer prefers developing an incremental product ($\pi_f^i > \pi_f^r$) if the percentage is located $0 < \alpha < (14c\theta - 2n + 2cv^i)^{1/2}/(n\delta)$.

ii) The manufacturer prefers developing a radical product if the percentage is located $((14c\theta - 2n + 2cv^i)^{1/2}/(n\delta)) < \alpha < (56c\theta - 2n + 8cv^r)^{1/2}/(n\delta)$.

Proposition 2 shows that when the percentage of crowdsourcing consumers is in a lower range, when compared to developing a radical product, the manufacturer's profit is more when they develop an incremental product. Therefore, on this condition, the optimal strategy of the manufacturer is developing the incremental product. If crowdsourcing consumers are more than the threshold value, the manufacturer's profits from radical innovation are more than incremental innovation. In other words, the optimal strategy of the manufacturer is developing a radical product. It also means that when the number of crowdsourcing consumers is low, the innovation level is lower; otherwise, the innovation level is higher. On the other hand, if the manufacturer decides to undertake incremental innovation, they should control the involvement of consumers' quantity to be in a reasonable range. If the manufacturer wants to develop a radical product, they should promise there are more enough crowdsourcing consumers, but not too much.

It can also be observed that when the percentage of crowdsourcing consumers is in a lower range, the price charged by the manufacturer always increases with an increase in wholesale price, but the probability of buying always decreases with an increase in wholesale price, irrespective of the product type. In contrast, when the manufacturer and consumers develop an incremental product, the wholesale price is not related to the crowdsourcing efforts, but it increases with crowdsourcing efforts when developing a radical product. In other words, the wholesale price of a radical product's materials is higher than the incremental product's materials. Though the effort cost of the manufacturer in developing an incremental product is higher, it is not too large when compared with the effort cost of developing the incremental product. Considering all these reasons, when the percentage of crowdsourcing consumers is lower, the profit of developing an incremental product is always higher than developing a radical product.

Figure 4 is provided to better understand the above two results in which parameters are defined as $c = 1$, $n = 100$, $\theta = 15$, $\delta = 0.2$, $v^i = 0.1$, and $v^r = 0.2$.

As shown in Figure 4, when the percentage of crowdsourcing consumers is low, the manufacturer can offer incremental and radical products, but the profit of offering incremental products is more. When the percentage of the crowdsourcing consumers is large, the profit gap of the manufacturer is smaller between these two types of products. In other words, when the rate of crowdsourcing consumers is higher as well as in the small range, the advantage of developing an incremental product is more prominent. In addition, the manufacturer's profit increases in the rate of crowdsourcing consumers.

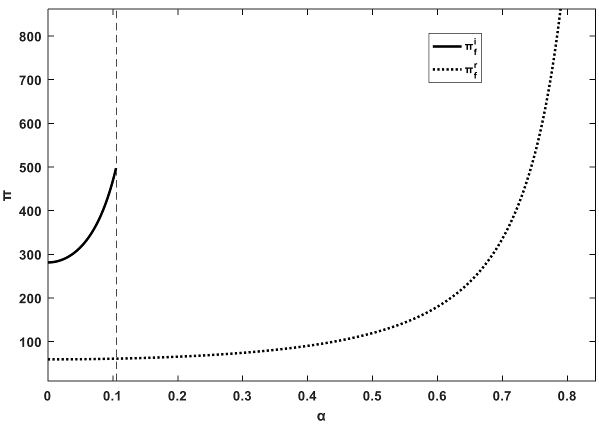

FIGURE 4. **Manufacturer's profit changes as a percentage of crowdsourcing consumers.**

B. IMPACT OF PREFERENCE DISPERSION DEGREE ON THE MANUFACTURER'S PRODUCT INNOVATIVENESS STRATEGY

For the probability $0 < r < 1$, the following are required: $0 < r^i < 1$, $0 < r^r < 1$. For these to be satisfied, the following are required: $\theta^i > (2n + \alpha^2 n^2 \delta^2 - 2cv^i)/(14c)$, $\theta^r > (2n + \alpha^2 n^2 \delta^2 - 8cv^r)/(56c)$. When $\theta^i > (2n+\alpha^2 n^2 \delta^2 - 2cv^i)/(14c)$, the manufacturer develops an incremental product and when $\theta^r > (2n+\alpha^2 n^2 \delta^2 - 8cv^r)/(56c)$, the manufacturer develops a radical product.

As the probability of buying is $r = (b - w + \theta)/(4\theta)$, all potential consumers will buy the product and the manufacturer's profit will reach the maximum if $\theta = (b-w)/3$. Thus, the preference dispersion degree is not less than $(b - w)/3$. Similar to §3.1, the wholesale price of developing an incremental product is not related to the efforts of the manufacturer and the crowdsourcing consumers, and the wholesale price of the radical product increases with efforts. On this condition, the preference dispersion degree of the incremental product is higher than the radical product. Consequently, a lower preference dispersion degree is needed by the radical product innovation (i.e., if the manufacturer predicts that the degree of the new product deviating from consumers' requirements is sufficiently low, they should develop a radical product). In other words, radical product innovation is suitable for a lower market risk environment.

Given

$$\theta_1 = \frac{((2n - 16cv^i + \alpha^2 n^2 \delta^2)(2n - 16cv^i + 9\alpha^2 n^2 \delta^2))^{1/2}}{32c} + \frac{6n + 3\alpha^2 n^2 \delta^2}{32c} - \frac{v^i}{2}$$

$$\theta_2 = \frac{((2n - 64cv^r + \alpha^2 n^2 \delta^2)(2n - 64cv^r + 9\alpha^2 n^2 \delta^2))^{1/2}}{128c} + \frac{6n + 3\alpha^2 n^2 \delta^2}{128c} - \frac{v^r}{2}.$$

Proposition 3: i) When the manufacturer develops an incremental product, if $(2n + \alpha^2 n^2 \delta^2 - 2cv^i)/(14c) < \theta < \theta_1$, the manufacturer's profit decreases as the degree of preference dispersion increases ($\partial \pi_f^i/\partial \theta < 0$), and if $\theta > \theta_1$, the manufacturer's profit increases as the degree of preference dispersion increases ($\partial \pi_f^i/\partial \theta > 0$).

ii) When the manufacturer develops a radical product, if $((2n + \alpha^2 n^2 \delta^2 - 8cv^r)/56c) < \theta < \theta_2$, the manufacturer's profit decreases as the degree of preference dispersion increases ($\partial \pi_f^r/\partial \theta < 0$), and if $\theta > \theta_2$, the manufacturer's profit increases as the degree of preference dispersion increases ($\partial \pi_f^r/\partial \theta > 0$).

Considering Proposition 3, irrespective of the product that the manufacturer develops, the manufacturer's profit always first decreases and then increases with an increase in the degree of preference dispersion. The optimal effort of the manufacturer and the crowdsourcing consumers decrease in θ. Further, the benefit decreases in θ. Thus, the probability of buying reduces more with the increase of θ. However, the marginal return $(b + \theta - w)/2$ decreases with the increase in the benefit and increase in the preference dispersion. Therefore, if θ is sufficiently large, the marginal return increases; otherwise, the marginal return decreases. Overall, the profit decreases as an increase in θ when θ is in a smaller range, the profit increases as an increase in θ when θ in a larger range. It also shows that irrespective of the product developed by the manufacturer, the moderate difference of preference is not in favor of the profit. The larger or smaller difference of preferences is better.

In addition, it can be observed that if $\theta > (2n + \alpha^2 n^2 \delta^2 - 2cv^i)/(14c)$, the manufacturer can develop both incremental and radical products, but if $[(2n + \alpha^2 n^2 \delta^2 - 8cv^r)/(56c)] < \theta < (2n + \alpha^2 n^2 \delta^2 - 2cv^i)/(14c)$, developing an incremental product is the only option for the manufacturer. Therefore, the optimal strategy of the manufacturer satisfies the following conditions.

Proposition 4: i) If the degree of preference dispersion is $\theta > (2n + \alpha^2 n^2 \delta^2 - 2cv^i)/(14c)$, the manufacturer prefers an incremental product.

ii) If the degree of preference dispersion is $[(2n + \alpha^2 n^2 \delta^2 - 8cv^r)/(56c)] < \theta < (2n + \alpha^2 n^2 \delta^2 - 2cv^i)/(14c)$, the manufacturer prefers a radical product.

Proposition 4 shows that the degree of preference dispersion impacts product type decisions. Specifically, when the degree of preference dispersion is in a lower range and when compared with developing the incremental product, the manufacturer's profit is more for developing the radical product. Therefore, on this condition, the optimal strategy of the manufacturer is developing the radical product. However, if the preference dispersion degree is higher, the manufacturer should only improve the existing product. In other words, the optimal strategy of the manufacturer is developing the incremental product.

From the analysis of proposition 3, the marginal return is $(b + \theta - w)/2$. It can be observed that when the wholesale price is higher, the marginal return is less and the wholesale price of developing the incremental product is higher than developing the incremental product. Therefore, the marginal return is higher in the condition of developing the incremental product if the degree of preference dispersion is the same.

This result also shows that when the manufacturer develops the radical product, the demand and preference information of consumers need to hold more exactly and realized it through the new product to meet their need; or it can launch the radical product in a targeted market. In reality, there are several market surveys in the product research and development (R&D) process to decrease the uncertainty of needs, especially for a new product.

Figure 5 is provided to better understand the results in which the parameters are defined as $c = 1, \alpha = 0.1, n = 100$, $\delta = 0.01$, $v^i = 0.1$, and $v^r = 0.2$. As shown in Figure 5, when the degree of preference dispersion is a vast range, the manufacturer can provide both incremental and radical products, but the profit of offering an incremental product is more. Further, in this case, when the degree of preference dispersion is larger, the profit gap of the manufacturer is smaller in providing these two types of products. In other words, when the degree of preference dispersion increases in the broader range, the advantage of developing the incremental product is more inconspicuous. In addition, the manufacturer's profit first decreases and then increases in the degree of preference dispersion.

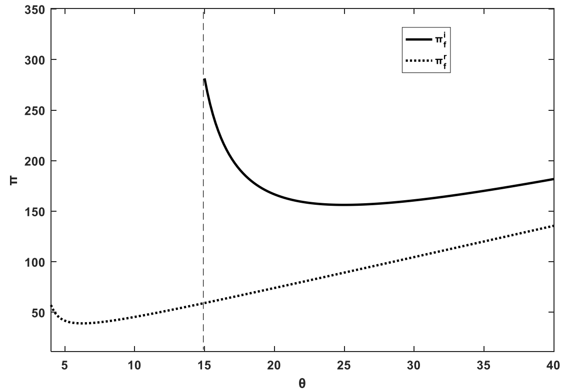

FIGURE 5. Preference dispersion degree impacts on the manufacturer's profit.

C. IMPACT OF KNOWLEDGE SPILLOVER ON THE MANUFACTURER'S PRODUCT INNOVATIVENESS STRATEGY

For the probability $0 < r < 1$, the following are required: $0 < r^i < 1, 0 < r^r < 1$. For these to be satisfied, the following are required: $0 < \delta^i < (14c\theta - 2n + 2cv^i)^{1/2}/(an)$, $0 < \delta^r < (56c\theta - 2n + 8cv^r)^{1/2}/(an)$. Similarly, it is supposed that the condition $0 < \delta < 1$ is satisfied. When $0 < \delta^i < (14c\theta - 2n+2cv^i)^{1/2}/(an)$, the manufacturer develops the incremental product and when $0 < \delta^r < (56c\theta - 2n + 8cv^r)^{1/2}/(an)$, the manufacturer develops the radical product.

Similar to the above, all potential consumers will buy the product and the manufacturer's profit will reach the maximum if the benefit is $b = 3\theta + w$. Further, as the benefit is $b = e_f + \delta\alpha n e_u$ and the probability is not more than 1, the knowledge spillover is less than $(3\theta + w - e_f)/\alpha n e_u$. In addition, $w^i = (\theta + v^i)/2$ and $w^r = (e_f + n\alpha\delta e_u + \theta + v^r)/2$. Thus, the maximal knowledge spillover of developing the incremental product is always less than the maximal knowledge spillover of developing the radical product.

Proposition 5: Irrespective of the type of innovation, the manufacturer's profit increases with an increase in the knowledge spillover ($\partial \pi_f^i/\partial \delta > 0$, $\partial \pi_f^r/\partial \delta > 0$).

Proposition 5 shows that irrespective of whether the manufacturer provides a radical product or an incremental product, the higher the knowledge spillover, the more is the manufacturer's profit as the spillover of the crowdsourcing consumer increases the benefit. Further, the price charged by the manufacturer and the probability of buying also increases indirectly. In addition, the cost is not too high as the crowdsourcing consumers share a part of the developing cost. Thus, the manufacturer will benefit. It also shows that irrespective of the type of product that the enterprise develops, the enterprise should pay more attention to strengthening communication with consumers to obtain more effective consumer efforts.

In addition, it can be observed that if $0 < \delta^i < (14c\theta - 2n + 2cv^i)^{1/2}/(an)$, the manufacturer can develop both incremental and radical products, but if $[(14c\theta - 2n + 2cv^i)^{1/2}/(an)] < \delta < (56c\theta - 2n + 8cv^r)^{1/2}/(\alpha n)$, developing the radical product is the only option for the manufacturer. Therefore, the optimal strategy of the manufacturer satisfies the following conditions.

Proposition 6: i) If the knowledge spillover of crowdsourcing consumers is $0 < \delta^i < (14c\theta - 2n + 2cv^i)^{1/2}/(an)$, the manufacturer prefers developing the incremental product $(\pi_f^i > \pi_f^r)$.

ii) If the knowledge spillover of crowdsourcing consumers is $[(14c\theta - 2n + 2cv^i)^{1/2}/(an)] < \delta < (56c\theta - 2n + 8cv^r)^{1/2}/(\alpha n)$,the manufacturer prefers developing the radical product.

Proposition 6 shows that when the knowledge spillover is lower, the manufacturer's profit from the incremental product innovation is more. As such, in this situation, developing an incremental product is the optimal strategy, while developing a radical product is the optimal strategy when the spillover is high.

Similar to the above analysis, when the marginal return is $(b+\theta-w)/2$, the probability of buying is $r = (\theta+b-w)/(4\theta)$. It can be observed that the marginal return and probability decrease when the wholesale price increases and owing to the increase in the spillover of crowdsourcing consumers. Considering the condition $w^i < w^r$ and the developing cost of the manufacturer, crowdsourcing consumers shared that they are not too high. Therefore, when the spillover of crowdsourcing consumers is the same while developing both the products, the manufacturer's profit of developing an incremental product is more than developing a radical product.

This result also shows that when the manufacturer develops an incremental product, they only need to obtain certain basic information from consumers, such as color, shape, and size. However, when the manufacturer develops a radical product, they need to exploit professional or implicit knowledge information from consumers.

Figure 6 is provided to better understand this result in which the parameters are defined as $c = 1$, $\alpha = 0.25$, $n = 100$, $\theta = 15$, $v^i = 0.1$, and $v^r = 0.2$.

As shown in Figure 6, when the knowledge spillover is in a small range, the manufacturer can provide two types of products, but the profit of providing an incremental product is more. Further, the higher the knowledge spillover, the larger is the profit gap of the manufacturer in proving these two types of products. In other words, when the knowledge spillover increases in a small range, the advantage of providing the incremental product is more clear. Also, when the spillover is more, the manufacturer's profit is higher.

Proposition 7: The optimal product development strategy achieves a win-win situation for the manufacturer, supplier, and consumers (i.e., when the optimal strategy is developing a radical product, there are always $\pi_s^{r*} > \pi_s^{i*}$ and $E[S_u]^{r*} > E[S_u]^{i*}$; when the optimal strategy is developing an incremental product, this is the only option for the manufacturer; thus, the supplier's profit and consumer surplus are optimal).

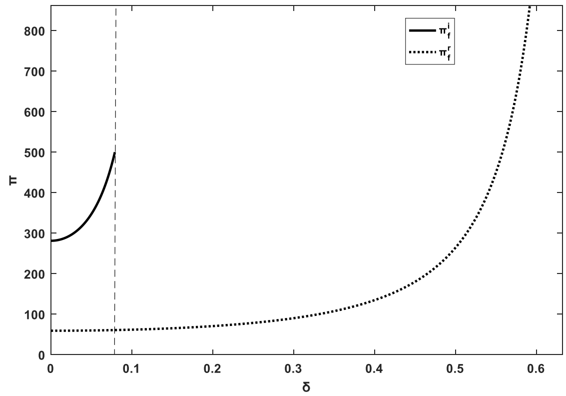

FIGURE 6. **Knowledge spillover impacts on the manufacturer's profit.**

Proposition 7 reveals that when the optimal decision is developing an incremental product, the supplier and consumers favor this decision; and when the manufacturer's optimal choice is providing a radical product, the supplier and consumers prefer this decision too. It also shows that the condition of the manufacturer having more profit for itself is also the condition of achieving a win-win for the supplier and consumers. In other words, the optimal decision of the manufacturer is also the optimal strategy of the supply chain.

V. EXTENSION

In this section, it is considered that the manufacturer provides compensation for consumers' efforts paid in product innovation through crowdsourcing. For example, to motivate consumers to participate in product design more actively, Xiaomi adopted a series of measures, such as a bonus points plan, where specific points can be converted to goods. The points were easy to obtain by answering questions in BBS. In addition, fans were encouraged to shoot videos and trophies were awarded to those selected from millions of people in the community. In addition, the fans gained an opportunity to become the magazine cover of popcorn. Many scholars have proved that money and reputation are the main motivations for users to participate in crowdsourcing [61]. Brabham [30] conducted interviews 17 times with the crowd in the Threadless community through instant messaging tools and found that making money, developing their creativity, the potential of being a freelance, and the passion of the Threadless community are the four main motivations for the participants. Therefore, the organizer needs to choose the right reward scheme [16]. Based on a winner-take-all scheme, Ales *et al.* [16] found that when the firm is interested in obtaining a larger number of good solutions, it should provide a larger winner prize, but interestingly, the firm does not have to raise the winner prize when expecting more participants in a contest. Archak and Sundararajan [31] found that when participants are risk-neutral, the firm should optimally allocate all budgets to the top prize even if it values multiple submissions. On the contrary, when participants are sufficiently risk-averse, the firm may optimally offer more prizes than the expected number of submissions. DiPalantino and Vojnovic [62] modeled contests as all-pay auctions on the condition of incomplete information and found that rewards yield logarithmically diminishing returns with participation levels. However, previous research generally focuses on contest crowdsourcing and pays limited attention to cooperative crowdsourcing with compensation. In previous studies particularly, the participant who gets the prize is the one with the best solution, while the others get nothing. Therefore, in this section, the compensation mechanism designed based on everyone obtaining compensation for their efforts has been studied. Further, this section studies the innovativeness strategy selection with compensation.

To model the manufacturer's compensation for crowdsourcing consumers, let $B(e) = \beta e_u^2$ be the compensation of exerting effort level e_u, where $B(0) = 0$, $B'(e_u) > 0$, $B''(e_u) > 0$, and β is the compensation coefficient. In other words, compensation can reduce the cost of participating in crowdsourcing for consumers.

Therefore, the supplier's profit function is still equation (4). The manufacturer's profit function is

$$\begin{aligned}\pi_f &= npr - ce_f^2 - n\alpha\beta e_u^2\\ &= np\frac{b-p+\theta}{2\theta} - ce_f^2 - n\alpha\beta e_u^2. \end{aligned} \tag{8}$$

The consumer surplus is

$$E[S_u] = \frac{(b-p+\theta)^2}{4\theta} - (c-\beta)e_u^2. \tag{9}$$

The superscript I, R represents the incremental product and radical product under the condition of providing compensation in the following paragraphs.

A. INCREMENTAL INNOVATION WITH COMPENSATION

Similar to the game sequence in part III, for the linear benefit and quadratic cost case, the optimal wholesale price of the manufacturer is given as $w^{I*} = (\theta + v^I)/2$, where $v^I = v^i$.

The optimal wholesale price is substituted in the probability, price, effort levels of manufacturer and crowdsourcing consumers, and profits of supplier and manufacturer. The expectations of consumer surplus become

$$\begin{aligned}
r^{I*} &= \frac{2c(\theta - v^I)}{16c\theta - 2n - \eta\alpha^2n^2\delta^2}\\
p^{I*} &= \frac{8c\theta(\theta - v^I)}{16c\theta - 2n - \eta\alpha^2n^2\delta^2} + \frac{\theta + v^I}{2}\\
e_f^{I*} &= \frac{n(\theta - v^I)}{16c\theta - 2n - \eta\alpha^2n^2\delta^2}\\
e_u^{I*} &= \frac{\eta\alpha n\delta(\theta - v^I)}{2(16c\theta - 2n - \eta\alpha^2n^2\delta^2)}\\
\pi_s^{I*} &= \frac{cn(\theta - v^I)^2}{16c\theta - 2n - \eta\alpha^2n^2\delta^2}\\
\pi_f^{I*} &= \frac{c(\theta - v^I)^2(32c\theta n - 4n^2 - (\eta-1)c\alpha^3n^3\delta^2)}{4(16c\theta - 2n - \eta\alpha^2n^2\delta^2)^2}\\
E[S_u]^{I*} &= \frac{c(\theta - v^I)^2(16c\theta - \eta\alpha^2n^2\delta^2)}{4(16c\theta - 2n - \eta\alpha^2n^2\delta^2)^2}\\
b^{I*} &= \frac{(\theta - v^I)(2n + \eta\alpha^2n^2\delta^2)}{2(16c\theta - 2n - \eta\alpha^2n^2\delta^2)}.
\end{aligned}$$

B. RADICAL INNOVATION WITH COMPENSATION

Similarly, for the linear benefit and quadratic cost case, the optimal efforts of the manufacturer and the supplier are given as $e_f^{R*} = \frac{2n(\theta - v^R)}{64c\theta - 2n - \eta\alpha^2n^2\delta^2}$ $e_u^{R*} = \frac{\eta\alpha n\delta(\theta - v^R)}{64c\theta - 2n - \eta\alpha^2n^2\delta^2}$, where $v^R = v^r$.

The optimal wholesale price is substituted in the probability, wholesale price, price, and profits of supplier and manufacturer. The expectations of consumer surplus are given as

$$\begin{aligned}
r^{R*} &= \frac{8c(\theta - v^R)}{64c\theta - 2n - \eta\alpha^2n^2\delta^2}\\
w^{R*} &= \frac{32c\theta(\theta - v^R)}{64c\theta - 2n - \eta\alpha^2n^2\delta^2} + v^R\\
p^{R*} &= \frac{48c\theta(\theta - v^R)}{64c\theta - 2n - \eta\alpha^2n^2\delta^2} + v^R\\
\pi_s^{R*} &= \frac{256c^2n\theta(\theta - v^R)^2}{(64c\theta - 2n - \eta\alpha^2n^2\delta^2)^2}\\
\pi_f^{R*} &= \frac{c(\theta - v^R)^2(128c\theta n - 4n^2 - (\eta-1)c\alpha^3n^3\delta^2)}{(64c\theta - 2n - \eta\alpha^2n^2\delta^2)^2}\\
E[S_u]^{R*} &= \frac{c(\theta - v^R)^2(64c\theta - \eta\alpha^2n^2\delta^2)}{(64c\theta - 2n - \eta\alpha^2n^2\delta^2)^2}\\
b^{R*} &= \frac{(\theta - v^R)(2n + \eta\alpha^2n^2\delta^2)}{64c\theta - 2n - \eta\alpha^2n^2\delta^2}.
\end{aligned}$$

where $\eta = c/(c-\beta) > 1$.

Firstly, how the compensation coefficient β impacts the manufacturer's profit is analyzed and the result is as follows.

Proposition 8: i) When the manufacturer develops the incremental product, if $0 < \beta^I < \frac{c((16c\theta-2n)(4-\alpha)+n^2\alpha^3\delta^2)}{(16c\theta-2n)(4+\alpha)}$, the manufacturer's profit increases with the compensation coefficient $\beta(\partial\pi_f^{I*}/\partial\beta > 0)$, and if $\frac{c((16c\theta-2n)(4-\alpha)+n^2\alpha^3\delta^2)}{(16c\theta-2n)(4+\alpha)} < \beta^I < \frac{c(16c\theta-2n-n^2\alpha^2\delta^2)}{16c\theta-2n}$, the manufacturer's profit decreases with the compensation coefficient $\beta(\partial\pi_f^{I*}/\partial\beta < 0)$.

ii) When the manufacturer develops the radical product, if $0 < \beta^R < \frac{c((64c\theta-2n)(4-\alpha)+n^2\alpha^3\delta^2)}{(64c\theta-2n)(4+\alpha)}$, the profit of the manufacturer increases with the compensation coefficient $\beta(\partial\pi_f^{R*}/\partial\beta > 0)$, and if $\frac{c((64c\theta-2n)(4-\alpha)+n^2\alpha^3\delta^2)}{(64c\theta-2n)(4+\alpha)} < \beta^R < \frac{c(64c\theta-2n-n^2\alpha^2\delta^2)}{64c\theta-2n}$, the manufacturer's profit decreases with the compensation coefficient $\beta(\partial\pi_f^{R*}/\partial\beta < 0)$.

Proposition 8 shows that irrespective of the type of product being developed, when the unit effort cost is large, the manufacturer's profit first increases and then decreases with an increase in the compensation coefficient β. It also means that the manufacturer gains the maximum profit when the compensation coefficient β is moderate.

These results are due to the behavior of the compensation which decrease the cost of consumer, thus the efforts of the consumer increase; directly, the benefit increases. Indirectly, the probability of buying and the price increase, increasing the manufacturer's earnings. The manufacturer also prefers to

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exert effort to increase the benefit, further increasing the probability of buying and the price. Overall, the manufacturer's profit increases. However, the manufacturer cannot afford all the costs of the consumers. Otherwise, the manufacturer's cost is too high. Therefore, the profit decreases. It indicates that compensation is not better if it is more or bad if it is less. Thus, a more reasonable compensation standard should be established for the manufacturer to earn profits.

The profits of the manufacturer in these cases of compensation and non-compensation were compared. Is the manufacturer willing to provide compensation or not? Moreover, what happens to the profits of the supplier and consumer surplus if the manufacturer compensates for crowdsourcing consumers?

Given that

$$\beta^{I'} = \frac{1}{4}c\left(8 + \frac{n^2\alpha^3\delta^2}{8c\theta - n} - \frac{4(4+\alpha)(8c\theta - n)}{32c\theta - 4n - n^2\alpha^2\delta^2}\right),$$
$$\beta^{R'} = \frac{1}{4}c\left(8 + \frac{n^2\alpha^3\delta^2}{32c\theta - n} - \frac{4(4+\alpha)(32c\theta - n)}{128c\theta - 4n - n^2\alpha^2\delta^2}\right).$$

Proposition 9: i) When the manufacturer develops the incremental product, if $0 < \beta^I < \beta^{I'}$, then $\pi_f^{I*} > \pi_f^{i*}$, $\pi_s^{I*} > \pi_s^{i*}$, $E_u^{I*} > E_u^{i*}$.

ii) When the manufacturer develops the radical product, if $0 < \beta^R < \beta^{R'}$, then $\pi_f^{R*} > \pi_f^{r*}$, $\pi_s^{R*} > \pi_s^{r*}$, $E_u^{R*} > E_u^{r*}$.

Proposition 9 shows that irrespective of the type of product developed by the manufacturer, when the compensation is within a specific scope, it is not only beneficial for the manufacturer but also for the consumers and the supplier. Therefore, under a certain condition, the compensation results in a Pareto improvement for the manufacturer, the supplier and consumers. Then, their profits and surplus can be optimized by providing some compensation for crowdsourcing consumers. In other words, compensable crowdsourcing is better than free crowdsourcing for all—manufacturer, consumers, and supplier. From the other perspective, this condition of improving the manufacturer's profit is also fit for consumers and the supplier. In other words, the upstream and downstream both prefer the compensation as long as the manufacturer can benefit for the following reasons.

From Proposition 8, it is known that the manufacturer cannot afford more cost to the consumers. Otherwise, the manufacturer's profit will become less. Therefore, the compensation coefficient is not less than the threshold; the profit of compensation is higher than the profit of no compensation. It also means that the crowdsourcing consumers share the cost of the manufacturer which reduces the product developing risk of the manufacturer. In particular, supposing $\beta = c$, the manufacturer pays for all costs of effort or means that the consumers do not participate in crowdsourcing. However, the result is that the profit of $\beta = c$ is less than $0 < \beta < c$. As such, the condition of $\beta = c$ is bad for the manufacturer. In contrast, the consumers' participation in crowdsourcing is beneficial for the manufacturer. Thus, the firm should stimulate consumers involved in innovation. For

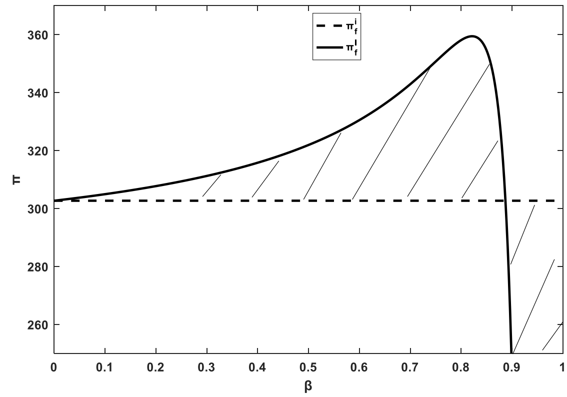

FIGURE 7. Compensation coefficient impacts on the manufacturer's profit of an incremental innovation.

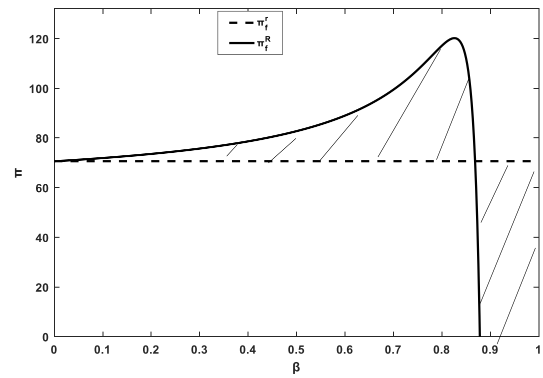

FIGURE 8. Compensation coefficient impacts on the manufacturer's profit of a radical innovation.

crowdsourcing consumers, the improvement of the probability of buying indicates the increase in customers' satisfaction; as such, they benefit. The improvement of the probability of buying also equals to the sales volume increase. Thus, the compensation behavior is good for the supplier too.

Figure 7 and Figure 8 are provided to better understand Proposition 8 and 9, in which the parameters are defined as $c = 1, \alpha = 0.25, n = 100, \theta = 15, \delta = 0.2, v^i = v^I = 0.1$ and $c = 1, \alpha = 0.25, n = 100, \theta = 15, \delta = 0.03, v^r = v^R = 0.2$.

As shown in Figure 7 and Figure 8, when compensation is involved, the manufacturer's profit first increases and then decreases in compensation coefficient, irrespective of the product type. Moreover, the profit when compensation is involved is not always more than the profit without compensation. When the compensation coefficient is small, the manufacturer's strategy is compensating for crowdsourcing consumers. Otherwise, the optimal strategy is no compensation.

As the compensation plan is feasible, this section discusses what is the optimal product innovativeness strategy for the manufacturer under compensation? Supposing the standard of compensation (β) is the same and $0 < \beta < \min\{\beta^I, \beta^R\}$. The main conclusion is as follows.

Proposition 10: Under the condition of compensation,

1) If $0 < \alpha < (\frac{14c\theta-2n+2cv^I}{\eta n^2\delta^2})^{1/2}$ or $\theta > \frac{2(n-cv^I)+\eta\alpha^2n^2\delta^2}{14c}$ or $0 < \delta < (\frac{14c\theta-2\alpha n+2cv^I}{\eta\alpha^2n^2})^{1/2}$, the manufacturer prefers developing an incremental product.

2) If $(\frac{14c\theta-2n+2cv^I}{\eta n^2\delta^2})^{1/2} < \alpha < (\frac{56c\theta-2n+8cv^R}{\eta n^2\delta^2})^{1/2}$ or $\frac{2n+\eta\alpha^2n^2\delta^2-8cv^R}{56c} < \theta < \frac{2n+\eta\alpha^2n^2\delta^2-2cv^I}{14c}$ or $(\frac{14c\theta-2\alpha n+2cv^I}{\eta\alpha^2n^2})^{1/2} < \delta < (\frac{56c\theta-2n+8cv^I}{\eta\alpha^2n^2})^{1/2}$, the manufacturer prefers developing a radical product.

Proposition 10 is similar to Proposition 2, 4, and 6. When the manufacturer provides compensation for crowdsourcing consumers, if the percentage of crowdsourcing consumers is small, the consumer preference dispersion degree is large, or the knowledge spillover is low, the incremental innovation is the optimal strategy for the manufacturer as the profit is higher; otherwise, radical product innovation is an optimal strategy for the manufacturer.

From the conclusions of Proposition 2, 4, 6, and 10, the following conclusion of the relationship between the manufacturer's profit and innovation level is achieved.

When $0 < \alpha < (14c\theta - 2n + 2cv^i)^{1/2}/(n\delta)(0 < \alpha < [(14c\theta - 2n + 2cv^I)/(\eta n^2\delta^2)]^{1/2})$ or $\theta > (2n + \alpha^2n^2\delta^2 - 2cv^i)/(14c)$ $(\theta > (2(n - cv^I) + \eta\alpha^2n^2\delta^2)/(14c))$ or $0 < \delta < (14c\theta - 2n + 2cv^i)^{1/2}/(an)(0 < \delta < ((14c\theta - 2\alpha n + 2cv^I)/(\eta\alpha^2n^2))^{1/2})$, the relationship between the profit and innovation level based on crowdsourcing is negative. When $[(14c\theta - 2n + 2cv^i)^{1/2}/(n\delta)] < \alpha < (56c\theta - 2n + 8cv^r)^{1/2}/(n\delta)$ $((\frac{14c\theta-2n+2cv^I}{\eta n^2\delta^2})^{1/2} < \alpha < (\frac{56c\theta-2n+8cv^R}{\eta n^2\delta^2})^{1/2})$ or $[(2n + \alpha^2n^2\delta^2 - 8cv^r)/(56c)] < \theta < (2n + \alpha^2n^2\delta^2 - 2cv^i)/(14c)((2n + \eta\alpha^2n^2\delta^2 - 8cv^R)/(56c) < \theta < (2n + \eta\alpha^2n^2\delta^2 - 2cv^I)/(14c))$ or $[(14c\theta - 2n + 2cv^i)^{1/2}/(\alpha n)] < \delta < (56c\theta - 2n + 8cv^r)^{1/2}/(\alpha n)((\frac{14c\theta-2\alpha n+2cv^I}{\eta\alpha^2n^2})^{1/2} < \delta < (\frac{56c\theta-2n+8cv^I}{\eta\alpha^2n^2})^{1/2})$, the relationship between the profit and innovation level based on crowdsourcing is positive.

This is because, when $0 < \alpha < (14c\theta - 2n + 2cv^i)^{1/2}/(n\delta)(0 < \alpha < ((14c\theta - 2n + 2cv^I)/(\eta n^2\delta^2))^{1/2})$ or $\theta > (2n + \alpha^2n^2\delta^2 - 2cv^i)/(14c)(\theta > (2(n - cv^I) + \eta\alpha^2n^2\delta^2)/(14c))$ or $0 < \delta < (14c\theta - 2n + 2cv^i)^{1/2}/(an)(0 < \delta < ((14c\theta - 2\alpha n + 2cv^I)/(\eta\alpha^2n^2))^{1/2})$, the profit of the manufacturer is higher for an incremental innovation when compared to a radical innovation. In other words, when the innovation level is lower, the profit is more. Similarly, when $(14c\theta - 2n + 2cv^i)^{1/2}/(n\delta) < \alpha < (56c\theta - 2n + 8cv^r)^{1/2}/(n\delta)$ $((\frac{14c\theta-2n+2cv^I}{\eta n^2\delta^2})^{1/2} < \alpha < (\frac{56c\theta-2n+8cv^R}{\eta n^2\delta^2})^{1/2})$ or $[(2n + \alpha^2n^2\delta^2 - 8cv^r)/(56c)] < \theta < (2n + \alpha^2n^2\delta^2 - 2cv^i)/(14c)$ $([(2n + \eta\alpha^2n^2\delta^2 - 8cv^R)/(56c)] < \theta < (2n + \eta\alpha^2n^2\delta^2 - 2cv^I)/(14c))$ or $[(14c\theta - 2n + 2cv^i)^{1/2}/(an)] < \delta < (56c\theta - 2n + 8cv^r)^{1/2}/(an)$ $((\frac{14c\theta-2\alpha n+2cv^I}{\eta\alpha^2n^2})^{1/2} < \delta < (\frac{56c\theta-2n+8cv^I}{\eta\alpha^2n^2})^{1/2})$, the higher the innovation level, the more is the profit.

VI. CONCLUSION AND FUTURE RESEARCH

With the popularization of the Internet, the cooperation between the manufacturer and consumers in product R&D is also more wide and deep. In particular, it is more general of many consumers co-developing the product with the firm by crowdsourcing. Despite a great deal of interest in crowdsourcing, academic research in this field is not sufficient, especially to develop mathematical models of this phenomenon. Moreover, many scholars are interested in the degree of product innovation. However, there has been limited academic research to develop economic models of the degree of innovation. This paper focuses on those gaps. Further, both in practice and academic research, compensating for consumers' effort is common. Therefore, what happened to the manufacturer with compensation.

This study models a supply chain including a supplier, a predominant manufacturer, and the manufacturer can develop incremental and radical products with crowdsourcing consumers. Further, the problem is what is the optimal product strategy for the manufacturer. The result shows that when the percentage of crowdsourcing consumers is low or the degree of preference dispersion is high, or the spillover of consumers' effort is small, the manufacturer prefers the incremental innovation (the lower innovation level); otherwise, they prefer radical innovation (the higher innovation level). This result is irrespective of the product type. In addition, whether the manufacturer compensates for crowdsourcing consumers or not, the optimal product strategy does not change. The above result also indicates that when the percentage of crowdsourcing consumers is low, or the degree of preference dispersion is high, or the spillover of consumers' effort is small, the relationship between innovation level and the manufacturer profit is negative; otherwise, the relationship is positive. In addition, compensation is always better than no compensation for all—the supplier, manufacturer, and consumers. Further, another result is that the optimal strategy of the manufacturer is also suitable for the supplier and consumers.

The analysis of this paper has clear managerial implications. First, the manufacturer should try to identify and stimulate more consumers to participate in crowdsourcing, and strengthen communication with consumers to make better use of their efforts. Second, the manufacturer should provide compensation for crowdsourcing consumers to stimulate them to exert more efforts. This behavior is beneficial for all members of the supply chain. Third, when there are not sufficient people involved or low-efficiency involvement or acceptability for a new product, a lower innovation level is better; otherwise, a higher innovation level is more beneficial.

The research of this paper provides theoretical support for manufacturers' product innovation decisions on crowdsourcing and has certain practical guiding significance. However, some limitations exist in this article, such as not considering co-creation behavior that impacts consumers' preferences.

Further, if more people are involved, the cost for the manufacturer is higher. These points need further study.

APPENDIX

For the Strategy I, we can derive

$$E[S_u]^i = \frac{(e_f^i + \delta\alpha n e_u^i - p^i + \theta)^2}{4\theta} - ce_u^{i2} \tag{A1}$$

$$\pi_f^i = n\frac{(e_f^i + \delta\alpha n e_u^i - p^i + \theta)}{2\theta}(p^i - w^i) - ce_f^{i2} \tag{A2}$$

$$\pi_s^i = n\frac{(e_f^i + \delta\alpha n e_u^i - p^i + \theta)}{2\theta}(w^i - v^i) \tag{A3}$$

Taking the first derivative of Eq. (A2) with respect to p^i:

$$\frac{\partial \pi_f^i}{\partial p^i} = \frac{n\left(-2p^i + w^i + \theta^i + e_f^i + n\alpha\delta e_u^i\right)}{2\theta} = 0 \tag{A4}$$

And we can derive the second derivative with respect to p^i:

$$\frac{\partial^2 \pi_f^i}{\partial p^i} = -\frac{n}{\theta} < 0 \tag{A5}$$

Eq. (A5) guarantees concavity of the profit function $\pi_f^i(p^i)$. Solving Eq. (A4), we obtain the retail price which is a function of efforts and the wholesale price:

$$p^i = (e_f^i + n\alpha\delta e_u^i - w^i + \theta)/2 \tag{A6}$$

Manufacturer uses the retail prices (A6) in function (A1) and (A2), and takes the first derivatives w.r.t. e_f^i and e_u^i:

$$\frac{\partial E[S_u]^i}{\partial e_u^i} = \frac{n\alpha\delta(e_f^i + \delta\alpha n e_u^i - w^i + \theta) - 16c\theta e_u^i}{8\theta} = 0$$

and

$$\frac{\partial \pi_f^i}{\partial e_f^i} = \frac{n(e_f^i + n\alpha\delta e_u^i - w^i + \theta) - 8c\theta e_f^i}{4\theta} = 0 \tag{A7}$$

And we can derive the second derivative with respect to e_f^i and e_u^i:

$$\frac{\partial^2 E[S_u]^i}{\partial e_u^{i2}} = -2c + \frac{n^2\alpha^2\delta^2}{8\theta} \text{ and } \frac{\partial^2 \pi_f^i}{\partial e_f^{i2}} = -2c + \frac{n}{4\theta} \tag{A8}$$

To guarantee Eq. (A8) concavity of the profit function $E[S_u]^i(e_u), \pi_f^i(e_f^i)$, we need $16c\theta - n^2\alpha^2\delta^2 > 0$ and $8c\theta - n < 0$. Solving Eq. (A7), we obtain the effort which is a function of the wholesale price:

$$e_f^i = \frac{2n(\theta - w^i)}{16c\theta - 2n - n^2\alpha^2\delta^2} \text{ and } e_u^i = \frac{n\alpha\delta(\theta - w^i)}{16c\theta - 2n - n^2\alpha^2\delta^2} \tag{A9}$$

Supplier uses the (A9) in function (A3), and takes the first derivatives w. r.t. w^i:

$$\frac{\partial \pi_s^i}{\partial w^i} = \frac{4cn(\theta + v^i - 2w^i)}{16c\theta - 2n - n^2\alpha^2\delta^2} = 0 \tag{A10}$$

And we can derive the second derivative with respect to w^i:

$$\frac{\partial^2 \pi_s^i}{\partial w^{i2}} = -\frac{8cn}{16c\theta - 2n - n^2\alpha^2\delta^2} \tag{A11}$$

To guarantee Eq. (A11) concavity of the profit function $\pi_s^i(w^i)$, we need $16c\theta - 2n - n^2\alpha^2\delta^2 > 0$. Solving Eq. (A10), we obtain the wholesale price:

$$w^{i*} = (v^i + \theta)/2 \tag{A12}$$

Due to $w^i > v^i$, there is $\theta > v^i$. Substituting w^{i*} into (A9), we get equilibrium efforts and the retail price. And substituting w^{i*}, e_f^{i*}, e_u^{i*}, and p^{i*} into Eq. (1)-(3), we get surplus and profits.

Finally, we need $16c\theta - 2n - n^2\alpha^2\delta^2 > 0$ and $\theta > v^i$

Similarly, strategy "r"need to satisfy the conditions $64c\theta - 2n - n^2\alpha^2\delta^2 > 0$ and $\theta > v^r$.

Proof of Proposition 1:

Proof: We have $\frac{\partial \pi_f^{i*}}{\partial \alpha} = \frac{4cn^3\alpha\delta^2(8c\theta - n)(v^i - \theta)^2}{(16c\theta - 2n - n^2\alpha^2\delta^2)^3} > 0$ and $\frac{\partial \pi_f^{r*}}{\partial \alpha} = \frac{16cn^3\alpha\delta^2(32c\theta - n)(v^r - \theta)^2}{(64c\theta - 2n - n^2\alpha^2\delta^2)^3} > 0$.

Proof of Proposition 2:

Proof: When $0 < \alpha < (14c\theta - 2n + 2cv^i)^{1/2}/(n\delta)$, assume $v^r = v^i + X$, $\pi_f^{r*} - \pi_f^{i*}$, as shown at the bottom of the next page.

Proof of Proposition 3:

Proof: Similarly, we have $\frac{\partial \pi_f^{i*}}{\partial \theta}$, as shown at the bottom of the next page.

Let $\frac{\partial \pi_f^{i*}}{\partial \theta} = 0$, we have θ, as shown at the bottom of the next page.

Let θ_1, as shown at the bottom of the next page.

So, when $\frac{2n + \alpha^2 n^2\delta^2 - 2cv^i}{14c} < \theta < \theta_1$, there is $\frac{\partial \pi_f^{i*}}{\partial \theta} < 0$. When $\theta > \theta_1$, there is $\frac{\partial \pi_f^{i*}}{\partial \theta} > 0$.

Similarly, let $\frac{\partial \pi_f^{r*}}{\partial \theta} = 0$, we have θ, as shown at the bottom of the next page.

Let θ_2, as shown at the bottom of the next page.

So, when $\frac{2n + \alpha^2 n^2\delta^2 - 8cv^r}{56c} < \theta < \theta_2$, there is $\frac{\partial \pi_f^{r*}}{\partial \theta} < 0$. When $\theta > \theta_2$, there is $\frac{\partial \pi_f^{r*}}{\partial \theta} > 0$.

Proof of Proposition 4:

Proof: Similar with the Proposition 2. When $\theta > \frac{2n + \alpha^2 n^2\delta^2 - 2cv^i}{14c}$, we always have $\pi_f^{i*} - \pi_f^{r*} > 0$.

Proof of Proposition 5:

Proof: Similarly, we have

$$\frac{\partial \pi_f^{i*}}{\partial \delta} = \frac{4cn^3\alpha^2(v^i - \theta)^2\delta(8c\theta - n)}{\left(16c\theta - 2n - n^2\alpha^2\delta^2\right)^3} > 0,$$

$$\frac{\partial \pi_f^{r*}}{\partial \delta} = \frac{16cn^3\alpha^2(v^r - \theta)^2\delta(32c\theta - n)}{\left(64c\theta - 2n - n^2\alpha^2\delta^2\right)^3} > 0$$

Proof of Proposition 6:

Proof: Similar with the Proposition 2. When $0 < \delta^i < \frac{(14c\theta - 2n + 2cv^i)^{1/2}}{\alpha n}$, we always have $\pi_f^{i*} - \pi_f^{r*} > 0$.

Proof of Proposition 7:

Proof: We have

$$\pi_s^{i*} - \pi_s^{r*} = \frac{cn^2\theta^2\left(2+n\alpha^2\delta^2\right)\left(2\left(n+64c\theta\right)+n^2\alpha^2\delta^2\right)}{\left(16c\theta-2n-n^2\alpha^2\delta^2\right)\left(2n-64c\theta+n^2\alpha^2\delta^2\right)^2} > 0.$$

Due to

$$E[S_u]^{i*} = \frac{c\theta^2(\theta-v^i)^2}{4\left(16c\theta-2n-n^2\alpha^2\delta^2\right)} + \frac{2nc\theta^2}{4\left(16c\theta-2n-n^2\alpha^2\delta^2\right)^2},$$
$$E[S_u]^{r*} = \frac{c(\theta-v^r)^2}{4\left(64c\theta-2n-n^2\alpha^2\delta^2\right)} + \frac{2nc\theta^2}{4\left(64c\theta-2n-n^2\alpha^2\delta^2\right)^2},$$

we have $E_u^{i*} > E_u^{r*}$.

Proof of Proposition 8:

Proof: Let $\frac{\partial\pi_f^{I*}}{\partial\beta}$, as shown at the top of the next page, we have $\beta^I = \frac{c((16c\theta-2n)(4-\alpha)+n^2\alpha^3\delta^2)}{(16c\theta-2n)(4+\alpha)}$. Let $\frac{\partial\pi_f^{R*}}{\partial\beta}$, as shown at the top of the next page, we have $\beta^R = \frac{c((64c\theta-2n)(4-\alpha)+n^2\alpha^3\delta^2)}{(64c\theta-2n)(4+\alpha)}$.

Proof of Proposition 9:

Proof: Let $\pi_f^{I*} - \pi_f^{i*} = 0$, we have $\beta = \frac{1}{4}c\Big(8+\frac{n^2\alpha^3\delta^2}{8c\theta-n} - \frac{4(4+\alpha)(8c\theta-n)}{32c\theta-4n-n^2\alpha^2\delta^2}\Big)$ and $\beta - c = -\alpha\Big(4\left(n-8c\theta\right)^2 + 4n^2\alpha\left(1-\alpha\right)\left(8c\theta-n\right)\delta^2 + n^4\alpha^4\delta^4\Big) < 0$.

Similarly, let $\pi_f^{R*} - \pi_f^{r*} = 0$, we have $\beta = \frac{1}{4}c\left(8+\frac{n^2\alpha^3\delta^2}{32c\theta-n} - \frac{4(4+\alpha)(32c\theta-n)}{128c\theta-4n-n^2\alpha^2\delta^2}\right)$. due to $\beta - c < 0$.

And we have

$$\pi_s^{I*} - \pi_s^{i*} = \frac{cn^2\left(c-\beta\right)\theta^2}{2\left(c-\beta\right)\left(8c\theta-n\right)-cn^2\alpha^2\delta^2} \times \Big(\frac{4\left(c-\beta\right)^2\left(n+64c\theta\right)+c^2n^3\alpha^4\delta^4}{\left(2\left(c-\beta\right)\left(32c\theta-n\right)-cn^2\alpha^2\delta^2\right)^2} + \frac{4cn\alpha^2\delta^2\left(c-\beta\right)\left(n+32c\theta\left(4c-4\beta-1\right)\right)}{\left(2\left(c-\beta\right)\left(32c\theta-n\right)-cn^2\alpha^2\delta^2\right)^2}\Big) > 0.$$

Because

$$E[S_u]^{i*} = \frac{c\theta^2(\theta-v^i)^2}{4(16c\theta-2n-n^2\alpha^2\delta^2)} + \frac{2nc\theta^2}{4(16c\theta-2n-n^2\alpha^2\delta^2)^2},$$
$$E[S_u]^{I*} = \frac{c(\theta-v^I)^2}{4(16c\theta-2n-n^2\alpha^2\delta^2)} + \frac{2c\theta^2 n}{4(16c\theta-2n-n^2\alpha^2\delta^2)^2},$$

$$\pi_f^{r*} - \pi_f^{i*} = -\frac{3cn^2(v^i-\theta)^2\left((64c\theta-2n)\left(16c\theta-2n\right)\left(1+n\alpha^2\delta^2\right)-n^3\alpha^4\delta^4\left(40c\theta-n\right)\right)}{\left(64c\theta-2n-n^2\alpha^2\delta^2\right)^2\left(16c\theta-2n-n^2\alpha^2\delta^2\right)^2} - \frac{4cnX\left(2v^i-2\theta+X\right)\left(32c\theta-n\right)}{\left(64c\theta-2n-n^2\alpha^2\delta^2\right)^2} < 0$$

$$\frac{\partial\pi_f^{i*}}{\partial\theta} = \frac{2cn(v^i-\theta)\left((16c\theta-2n)(4c\theta-4v^i-n)+n^2\alpha^2\delta^2\left(12c\theta-4v^i-n\right)\right)}{\left(16c\theta-2n-n^2\alpha^2\delta^2\right)^3}.$$

$$\theta = \frac{6n+3\alpha^2n^2\delta^2+((2n-16cv^i+\alpha^2n^2\delta^2)(2n-16cv^i+9\alpha^2n^2\delta^2))^{1/2}}{32c} - \frac{v^i}{2}.$$

$$\theta_1 = \frac{6n+3\alpha^2n^2\delta^2+(((2n-16cv^i+\alpha^2n^2\delta^2)(2n-16cv^i+9\alpha^2n^2\delta^2))^{1/2}}{32c} - \frac{v^i}{2}$$

$$\theta = \frac{6n+3\alpha^2n^2\delta^2+((2n-64cv^r+\alpha^2n^2\delta^2)(2n-64cv^r+9\alpha^2n^2\delta^2))^{1/2}}{128c} - \frac{v^r}{2}.$$

$$\theta_2 = \frac{6n+3\alpha^2n^2\delta^2+((2n-64cv^r+\alpha^2n^2\delta^2)(2n-64cv^r+9\alpha^2n^2\delta^2))^{1/2}}{128c} - \frac{v^r}{2}.$$

$$\frac{\partial\pi_f^{I*}}{\partial\beta}=\frac{c^2n^3\alpha^2\left(v^I-\theta\right)^2\delta^2\left(-2\left(\left(\alpha-4\right)c+\left(\alpha+4\right)\beta\right)\left(8c\theta-n\right)+cn^2\alpha^3\delta^2\right)}{4\left(2\left(c-\beta\right)\left(8c\theta-n\right)-cn^2\alpha^2\delta^2\right)^3}=0,$$

$$\frac{\partial\pi_f^{R*}}{\partial\beta}=\frac{c^2n^3\alpha^2(v^R-\theta)^2\delta^2\left(-2\left(\left(\alpha-4\right)c+\left(\alpha+4\right)\beta\right)\left(32c\theta-n\right)+cn^2\alpha^3\delta^2\right)}{\left(2\left(c-\beta\right)\left(32c\theta-n\right)-cn^2\alpha^2\delta^2\right)^3}=0,$$

And

$$E[S_u]^{r*}=\frac{c(\theta-v^r)^2}{64c\theta-2n-\eta\alpha^2n^2\delta^2}+\frac{2c\theta^2n}{(16c\theta-2n-\eta\alpha^2n^2\delta^2)^2},$$

$$E[S_u]^{R*}=\frac{c(\theta-v^R)^2}{64c\theta-2n-\eta\alpha^2n^2\delta^2}+\frac{2c\theta^2n}{(16c\theta-2n-\eta\alpha^2n^2\delta^2)^2},$$

and $v^i=v^I, v^r=v^R$, there are $E[S_u]^{I*}>E[S_u]^{i*}$ and $E[S_u]^{R*}>E[S_u]^{r*}$.

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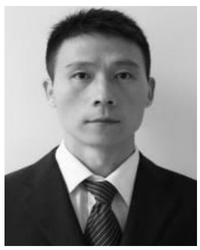

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