European Journal of Operational Research 246 (2015) 949–957

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Short Communication

Consignment contract for mobile apps between a single retailer and competitive developers with different risk attitudes

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ARTICLE INFO

Article history:
Received 2 September 2014
Accepted 4 May 2015
Available online 9 May 2015

Keywords:
Supply chain
Risk attitude
Consignment
Supplier competition

ABSTRACT

Consider n mobile application (app) developers selling their software through a common platform provider (retailer), who offers a consignment contract with revenue sharing. Each app developer simultaneously determines the selling price of his app and the extent to which he invests in its quality. The demand for the app, which depends on both price and quality investment, is uncertain, so the risk attitudes of the supply chain members have to be considered. The members' equilibrium strategies are analyzed under different attitudes toward risk: risk-aversion, risk-neutrality and risk-seeking. We show that the retailer's utility function has no effect on the equilibrium strategies, and suggest schemes to identify these strategies for any utility function of the developers. Closed-form solutions are obtained under the exponential utility function.

1. Introduction

Mobile applications (apps) are software programs designed to run on smartphones and tablets. They are commonly downloaded through application distribution platforms, such as the Apple (iTunes) App Store, Google Play, the Windows Phone Store and BlackBerry App World. As suggested by Apple's central marketing message—"there's an app for that"—the market for apps is crowded and diverse (BBC Trust, 2010). At the same time, there is intense competition among companies marketing similar apps. For example, the iTunes App Store offers at least 12 device finder apps, similar to "Find My iPhone"; these apps compete with one another in terms of both price and quality (Myers, 2012). Clearly, the question of how to manage brand competition and channel competition is important both for app developers (the suppliers) and the platform distributor (i.e., the app retailer).

This study considers a supply chain of a single platform distributor and n competitive app developers, where the vertical business relationships are delineated by a contract. Many platform distributers propose consignment contracts to app developers, based on a revenue sharing policy (Gans, 2012; Jiang, 2012; Wang, Jiang & Shen, 2004; Zhang, De Matta & Lowe, 2010). In this type of contract, the developer continues to own the app and typically bears sole responsibility for determining its selling price. For every sold app, the platform distributor charges the developer an agreed percentage of the selling price (Hsieh & Hsieh, 2013).

Most research on consignment contracts has focused on a channel structure consisting of a single supplier and a single retailer (Jiang, 2012; Li, Zhu & Huang, 2009; Ru & Wang, 2010; Wang et al., 2004). Only a few papers have studied the effect of competition among suppliers (Adida & Ratisoontorn, 2011; Wang, 2006), as we do here. Furthermore, whereas most work thus far has assumed that supply chain members are risk-neutral, we study the influence of different risk attitudes on the supply chain performance. In addition, while the papers above study the competition effect only via prices, we extend it to consider investment in the quality of the app as well (El Ouardighi & Kim, 2010; Hasan, Zaidi, Haider, Hassa, & Amin, 2012; Spriestersbach & Springer, 2004; Xie, Yue, Wang & Lai, 2011).

In what follows we formulate the objectives of the supply chain members and provide a procedure to obtain the equilibrium solution. We analyze the effects of vertical and horizontal competition in the supply chain, and show that, owing to the property of first order stochastic dominance, the retailer's utility function has no effect on the equilibrium solution. Moreover, we show that the equilibrium selling prices can be set in advance of the other decision variables regardless of the developers' utility functions. On the other hand, the quality investments of the developers and their revenue shares are affected by their risk attitudes. Notably, we find that, under the exponential utility function, the equilibrium revenue share of each developer is dependent on the developer's risk sensitivity level but is not affected by the horizontal competition. We provide closed-form solutions and sensitivity analysis regarding the risk aversion levels of the developers. We show that risk-seeking behavior of the developer can

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http://dx.doi.org/10.1016/j.ejor.2015.05.016
0377-2217/

produce higher expected profit than risk-neutral behavior, and that the retailer benefits from developers who are risk-seeking.

2. Model formulation

Consider a competition among n developers who sell their different apps via a single dominant retailer. As in the case of virtual products (Chernonog & Avinadav, 2014), distribution of mobile apps is characterized by a negligible unit distribution cost and ample capacity to fulfill demand. Therefore, our model does not include either holding or shortage costs, and the only relevant cost component is the investment in app quality, K_i, made by developer i ($i = 1, \ldots, n$). Each developer determines his selling price per unit, p_i, whereas the retailer demands a fraction η_i of the selling price from developer i for every sold unit (i.e., the revenue share). Since demand is affected by price and quality, and since our model assumes a stochastic demand for each developer, we deal with a decision dependent randomness case (Hrabec, Popela, Novotny, Haugen, & Olstad, 2012). Let $\vec{K} = (K_1, \ldots, K_n)$, $\vec{p} = (p_1, \ldots, p_n)$ and $\vec{\eta} = (\eta_1, \ldots, \eta_n)$. We adopt the multiplicative-separable form of introducing random demand: $\tilde{D}_i(\vec{p}, \vec{K}) = D_i(\vec{p}, \vec{K})\varepsilon$, where $D_i(\vec{p}, \vec{K})$ is the expected demand for developer i, and ε is a non-negative random variable with cumulative distribution function (CDF) $F_\varepsilon(\cdot)$ and expectation $E(\varepsilon) = 1$. This multiplicative form was originally suggested by Karlin and Carr (1962), and is common in the literature (see a review by Petruzzi & Dada, 1999). Clearly, the expected demand, $D_i(\vec{p}, \vec{K})$, increases in K_i and $p_j,\ j \neq i$, and decreases in p_i and $K_j,\ j \neq i$.

Accordingly, the profit of the retailer is $\tilde{\pi}_r(\vec{\eta}) = \varepsilon \sum_{i=1}^{n} \eta_i p_i D_i(\vec{p}, \vec{K})$, and the profit of developer i is $\tilde{\pi}_i(p_i, K_i) = (1 - \eta_i) p_i D_i(\vec{p}, \vec{K})\varepsilon - K_i$. Their expected profits are, respectively,

$$\pi_r(\vec{\eta}) = \sum_{i=1}^{n} \eta_i p_i D_i(\vec{p}, \vec{K}) \tag{1}$$

and $$\pi_i(p_i, K_i) = (1 - \eta_i) p_i D_i(\vec{p}, \vec{K}) - K_i. \tag{2}$$

Since the unit distribution cost of a mobile app is negligibly small, the profit of the retailer is also his revenue, whereas the revenue of developer i is $(1 - \eta_i) p_i D_i(\vec{p}, \vec{K})\varepsilon$. The property we use in the following theorem is (first order) stochastic dominance: $\tilde{X}$ stochastically dominates $\tilde{Y}$ (denoted by $\tilde{X} \succ \tilde{Y}$) if $\Pr(\tilde{X} > x) \geq \Pr(\tilde{Y} > x)\ \forall x$.

Theorem 1. *(i) The retailer's profit with the largest expectation stochastically dominates any other profit of the retailer. (ii) For a given K_i ($i = 1, \ldots, n$), the profit of developer* i *with the largest expectation stochastically dominates any other profit of developer i.*

Proof. See Appendix A. □

The stochastic order characterizing the retailer's potential profit distributions implies that maximizing the retailer's expected profit (Eq. (1)) actually maximizes the expected value of any non-decreasing function of his profit, and in particular of any utility function of his profit. Thus, the objective of the retailer, regardless of his risk attitude or the distribution of ε, is to maximize his expected profit. Similarly, for a given K_i, developer i should determine p_i exactly as in a deterministic demand model.

Theorem 2. *There is no stochastic dominance of developer i's profit distributions with respect to the quality investment for a given selling price.*

Proof. See Appendix B. □

Theorem 2 indicates that there is no value of K_i that optimizes all utility functions of $\tilde{\pi}_i$, so that optimal K_i depends on the specific utility function of the developer and on the distribution of ε. Denoting the utility function of developer i by u_i, the problem of developer i is $\max_{p_i, K_i} E[u_i(\tilde{\pi}_i(p_i, K_i))]$. By Theorem 1(ii), this problem can be solved in two stages:

$$\max_{K_i} E[u_i(\tilde{\pi}_i(p_i(K_i), K_i))], \tag{3}$$

$$\text{where } p_i(K_i) = \arg\max_{p_i}\{p_i D_i(\vec{p}, \vec{K})\}. \tag{4}$$

3. Game theory approach

The relationship between the retailer and the developers is formulated as a sequential non-cooperative game in which the retailer is the leader of the supply chain and the developers are the followers. This type of game is known as a Stackelberg model (see, e.g., Osborne & Rubinstein, 1994), and it assumes perfect information, specifically in this model, knowledge of the developers' risk attitudes and of the demand function. In practice, such an assumption holds, for example, when the supply chain parties have previously concluded contracts with one another, and when the parties are able to obtain information on demand from public media (see, for example, Gan, Sethi & Yan, 2004; Wang et al., 2004; Wei & Choi, 2010; Xie et al., 2011). In this game, the retailer first announces the revenue share to be charged each developer; the developers observe their revenue shares, and then each decides on his own retail price and quality investment. The competition among the developers is modeled as a non-cooperative simultaneous game in which the solution is Nash equilibrium. To solve and find the relevant equilibrium, the retailer, who starts by announcing the revenue shares $\vec{\eta}$, first finds the Nash equilibrium with respect to $\vec{p}$ and $\vec{K}$ for all $\vec{\eta}$. Then, following Theorem 1, he maximizes $\pi_r(\vec{\eta}) = \sum_{i=1}^{n} \eta_i p_i D_i(\vec{p}, \vec{K})$ to find the best value of $\vec{\eta}$.

To obtain analytical resuls, we assume that selling price and quality investment have separable, multiplicative effects on the demand function:

$$D_i(\vec{p}, \vec{K}) = g_i(\vec{p}) h_i(\vec{K}), \quad i = 1, \ldots, n, \tag{5}$$

where $g_i(\vec{p})$ is strictly decreasing in p_i and strictly increasing in $p_j,\ j \neq i$, whereas $h_i(\vec{K})$ is strictly increasing and concave in K_i and strictly decreasing in $K_j,\ j \neq i$ (according to the law of diminishing marginal returns). The multiplicative form in (5) is common in the literature dealing with demand functions that are affected by selling price and by an additional factor (see, e.g., Aust & Buscher, 2012; Avinadav, Chernonog, & Perlman, 2014; Avinadav, Herbon & Spiegel, 2013; Avinadav, Herbon, & Spiegel, 2014; Maihami & Nakhai Kamalabadi 2012; Xie & Wei 2009).

The following procedure summarizes the optimization steps taken by the retailer:

Step 1. Find p_i^*, $i = 1, \ldots, n$, by maximizing $p_i g_i(\vec{p})$, $i = 1, \ldots, n$.

Step 2. Find the best developers' responses $K_i(\vec{\eta})$, $i = 1, \ldots, n$, by maximizing each $E[u_i(p_i^* g_i(\vec{p}^*)(1 - \eta_i) h_i(\vec{K})\varepsilon - K_i)]$, $i = 1,\ldots,n$.

Step 3. Find $\vec{\eta}^*$ that maximizes $\sum_{i=1}^{n} \eta_i h_i(\overrightarrow{K(\vec{\eta})})$ and obtain $\vec{K}^* = \overrightarrow{K(\vec{\eta}^*)}$.

Theorem 3. *$\vec{\eta}^*$, $\vec{p}^*$ and $\vec{K}^*$ are Nash equilibrium strategies.*

Proof. See Appendix C. □

By Theorem 1, $\vec{p}^*$ is independent of the retailer's and the developers' risk attitudes, and is also independent of the demand distribution, so it can be obtained exactly as in a deterministic demand model. Moreover, due to the multiplicative separable demand structure, in Step 1 of the procedure, $\vec{p}^*$ can be determined regardless of the decisions on quality investments and revenue shares (which can be postponed). On the other hand, $\vec{\eta}^*$ and $\vec{K}^*$ do depend on the developers' risk attitudes and on the demand distribution. In what follows, we study the effect of risk sensitivity level on equilibrium revenue shares and quality investments.

4. The effect of risk sensitivity level on equilibrium

Numerous theoretical and applied works in the areas of decision theory and finance consider exponential utility function