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DO RECOMMENDER SYSTEMS ALWAYS BENEFIT FIRMS BY REDUCING CONSUMER SEARCH EFFORT?

Research-in-Progress

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Abstract

With the gain in popularity of the internet in the beginning of this decade, online shopping has witnessed a strong growth rate of about 25 percent per year. However, recent reports suggest that the growth rate is flattening. One of the key reasons for dwindling growth rate is the rise in expectations of the customers. Customers want that the retail websites should help them in finding products through recommendations. Therefore it is expected that firms would have higher profits by using recommender systems since that will boost their sales. However we show that increased profits are guaranteed only if a firm has the monopoly in the market. Market with two firms may not witness increased profits for both the firms. We analyze how the improvement in technology of recommender system affects the market, the price charged by the firms and therefore their profits.

Keywords: Analytical modeling, E-business, Economic modeling, Recommendation agent

Introduction

With the gain in popularity of the internet in the beginning of this decade, online shopping has witnessed a strong growth rate of about 25 percent per year (Maguire 2005). However, current reports about the future growth of online shopping businesses are not as encouraging. Jupiter expects online retailing to dip below double-digit percentage growth rates sometime around 2010, and to plateau at some future date after that (Linn 2007). There are several reasons for this dwindling growth rate. While the current economic crisis is clearly one of them, other factors are playing a significant role in this downward trend. A major contributor for the decline in the growth rate of online shopping is changing consumer expectations. A mere web presence is not enough for the firms anymore. Customers want a site that is easy to navigate and easy-to find and sort through the products they desire. They want product recommendations (Vasquez 2008).

A retail website generally contains thousands of products, scattered amongst various categories. As opposed to brick-and-mortar store, a customer is on her own to find a suitable product out of so many, a task requiring considerable time and effort. In such situations, recommender systems can play an important role in elevating the customer experience by reducing the search effort imposed on the customer (Häubl and Trifts 2000). A recent survey reveals that 77 percent of online shoppers make additional purchases when captivated by personalized cross-sell and up-sell recommendations (Cell 2008). Personalized recommendations have been found to be an effective tool for consumer marketing, building customer loyalty, improving merchandizing and elevating the online customer experience (Lovett 2007).

Since the use of recommender systems reduces the search cost imposed on the customer to find

a suitable product, it is expected that with use of recommender systems, (i) customers who are already the online shoppers should be able to find a product that better fits their needs as compared to a product that they find in the absence of the recommender system, and (ii) firms would have higher profits, as customers who were not interested in purchasing earlier due to high search cost would also start purchasing. Our goal in this paper is to model the search effort impact of recommender systems on the product price and the profit of firms. Our work contributes to the literature on recommender systems and helps firms with e-tailing websites in pricing products in the presence of recommender systems and ultimately in deciding whether it is good for them to implement a recommender system.

In a monopoly, we show that it is always profitable for a firm to provide recommendation services to its customers. However, product price may increase or decrease. In a duopoly, a better recommender system does not always result in increased profit. Once again, product price may increase or decrease.

Previous literature has looked at several aspects of product customization. For example, Shaffer and Zhang (1995) studied how two firm's coupon targeting strategies impact their pricing strategies and the market structure. Dewan et al. (2003) developed a model for determining pricing strategies and degree of product customization. Mendelson and Parlaktürk (2008) modeled the duopoly between a mass customization firm and a traditional firm. However, none of them considered a market that is heterogeneous in search cost of customers to analyze the impact of reduction in search cost.

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 considers a monopolistic market while Section 4 considers a duopoly. Section 5 summarizes our findings and concludes the paper.

The Model

In this section, we formalize the parameters, describe the interaction of the website with an online customer and setup the model.

Notation

We consider a website that provides online recommendations to customers who visit the website. The recommender system reduces the search effort imposed on customers while finding a product that suits their needs. A normalized parameter $r \in [0,1]$ represents the degree of effectiveness of the recommender system. The customers are heterogeneous in their cost associated with one unit search effort denoted by $\theta \in [a,b]$, where a, $b \in [0,1]$. Hence depending on the type θ, every customer is willing to spend some effort in searching the right product for herself in the website. Therefore, the search space for the customer is the whole website containing all the products. The customer has a most preferred product, but in the absence of a recommender system, needs to search the entire search space to find this product. Most consumers cannot afford such a high level of search cost. Therefore a customer searches a fraction of the search space and purchases the product that is most preferred in that fraction search space that is explored. We represent the entire search space as *d*, and the fraction of the search space explored by the customer as *x*. We refer to *x* as the fit of the product with a fit cost of $f(x)$[1]. When *x* is equal to *d*, the fit cost is a minimum. Figure 1 depicts the above idea.

The parameters for the firm are Π, which denotes the profit of the firm, *q* which is the price of the products and N which denotes total number of potential customers, including shoppers and non-shoppers.

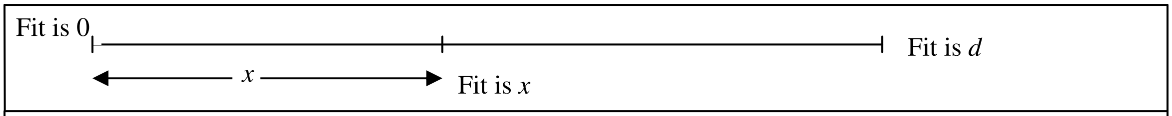

Figure 1: Fitness of a product

Table 1 summarizes all the parameters required in the model including the ones that are discussed above.

Table 1: Model Parameters	
x	Fit of a product
d	The entire search space
r	Effectiveness of the search engine
θ	Search cost of the customer
Π	Profit of the firm
q	Price of the products in the website
N	Number of customers

Interaction of a customer with the website

A customer shops on a retail website that provides product recommendations to her. Recommendation services help the customer in finding a product that is closer to her most preferred product, than if there were no recommendation. In other words, a recommender system helps the customer in her search process, thereby reducing her search cost. The price of all the products in the website is known upfront to all the customers. An example of such a website could be itunes. The price of every song in itunes is $0.99 and itunes provide recommendations through its engine named “Genius.”

Apart from *q*, the effectiveness of the recommender system (*r*) is known to customers. Since all the parameters are known to the customer, depending on the value of θ, she decides whether she should “search and buy” or not initiate the search at all by evaluating the surplus that she would have after purchasing the product. Let *S* be the surplus, *C* be the cost born by the customer after buying the product due to the fit of the product and search required to find the product, and *R* be the reservation price of the product.

We assume that *C* is *increasing* and *convex* in *x* and θ. Then,

$$S = R - C - q$$

In this case, $\frac{\partial C}{\partial \theta} > 0$ implies $\frac{\partial S}{\partial \theta} < 0$ since *R* and *q* are constant. Since the product with fitness *x* is far from the most preferred product of the customer, the customer incurs a cost referred as *fit cost* represented by $f(x)$. Also, while searching the product, the customer incurs the search cost represented by $g(x, r, \theta)$. The surplus is therefore

$$S = R - f(x) - g(x, r, \theta) - q \text{ where } C = f(x) + g(x, r, \theta) \quad (1)$$

We assume that $f(x)$ is *decreasing* and *convex* in *x* and $g(x,r,\theta)$ is *increasing* and *convex* in *x* and θ, while *decreasing* and *convex* in *r*. The objective of the customer is to choose *x* such that the surplus is maximized. The Individual Rationality (IR) constraint of the customer is $S \geq 0$. If the IR constraint of the customer is satisfied, the customer chooses to “search and buy", else the customer does not search and therefore does not buy. The “Search and buy" decision plays an important role in determining the size of the market, which in turn effects the profits of the firms and price of the product. In the forthcoming sections, we consider monopolistic and duopolistic markets to analyze the recommender system's effectiveness on the profit maximizing price and firm profit.

[1] Fit cost is a function of *x*, where *x* depends on *r* and θ. Thus, fit cost is an indirectly a function of *r* and θ.

The Monopoly Case

In this section, we consider a monopolistic firm that employs a commendation for all its customers. As mentioned earlier, the objective of the customer is to maximize her surplus. By differentiating equation (1) and equating it to 0, we can easily find the optimal fit $x^*(r, \theta)$ of the product that customer would like to find in order to maximize her surplus. It can be shown that the surplus decreases monotonically with increase in θ; we suppress the details because of lack of space. Therefore with increase in the value of search type θ, the surplus falls from positive value to 0, and after that surplus is negative. The I.R. constraint is tight for a customer whose surplus is 0. Such a customer is the marginal customer and her type is denoted by ($\bar{\theta}(r, q)$). The value of search type of a marginal customer can therefore be found using

$$S = R - f\big(x*(r,\theta)\big) - g\big(x*(r,\theta), r, \theta\big) - q = 0$$

Therefore if the type of a customer is $\theta \in [a, \bar{\theta}\ (r,q)]$ the customer does "search and buy" and if the type of customer is $\theta \in [\bar{\theta}\ (r,q), b]$ the customer does not "search and buy". The pool of customers who decide to "search and buy" is referred to as the "market". Thus an analysis of the relationships between $\bar{\theta}$ and r and those between q and r and Π and r should provide insights about how recommendation systems can affect the market, market price and firm profit. Lemma 1 states how $\bar{\theta}$ varies with changes in r and q.

Lemma 1: With increase in r, market will always expand since $\bar{\theta}$ increases, whereas with increase in q the market always shrinks as $\bar{\theta}$ decreases i.e. $\frac{d\bar{\theta}}{dr} > 0$ and $\frac{d\bar{\theta}}{dq} < 0$.

Proof: Details are suppressed because of lack of space.

The result is intuitive and expected, since with an improvement in the recommendation technology, the search cost (g) goes down and hence some customers of type $\theta > \bar{\theta}$ should now get a positive surplus after searching for and purchasing a product, thus causing an increase in the size of the market. On the other hand, from equation (1) we infer that the increase in price reduces the surplus to zero from positive for the customers close to the marginal customer. As a result, some customers including the marginal customer no more find it beneficial to purchase a product from the firm. This should impact the pricing strategy of the firm and its profit, which are discussed in the next section.

Profit of the Monopolist

The profit of the firm is the product of the market size and the price of the product. We assume that the marginal cost of the technology is 0. Also, without loss of generality, we assume the product cost to be zero. Therefore

$$\Pi = N\frac{(\bar{\theta}(r,q) - a)}{b-a}q \qquad (2)$$

The firm optimizes the profit function to determine the price ($q^*(r)$) of the products by differentiating equation (2) and equating it to 0 (details are suppressed due to lack of space). The firm's objective is to get maximum profits that may require the firm to increase or decrease the price of the product in response to improvements in recommendation technology (a higher value of r). Part A of Proposition 1 states the condition in which firm would increase the price of the products. However, as stated in part B of the proposition, the firm will always have higher profits as recommendation technology improves.

Proposition 1:

(A) If $\frac{\partial^2\bar{\theta}}{\partial q \partial r} > 0$ then, $\frac{dq*}{dr} > 0$

else if $\frac{\partial^2\bar{\theta}}{\partial q \partial r} < 0$, then

Case I: $\frac{dq*}{dr} > 0$ if $q^* * \frac{\partial^2\bar{\theta}}{\partial q \partial r} + \frac{d\bar{\theta}}{dr} > 0$

Case II: $\frac{dq*}{dr} < 0$ if $q^* * \frac{\partial^2\bar{\theta}}{\partial q \partial r} + \frac{d\bar{\theta}}{dr} < 0$

(B): Firm profits are always increase in r, i.e. $\frac{d\Pi}{dr} > 0$

Proof: Details are suppressed because of lack of space.

The above proposition states that if the impact of market size is less than the impact of price at higher levels of recommendation technology, the firm should always charge a higher price when recommendation technology improves. Otherwise, the firm needs to consider the overall impact of increasing the price and improvements in recommendation technology to decide whether to increase or decrease the price.

When the price is increased by the firm with increase in r, the firm loses some customers as increase in price reduces the size of the market. However, the loss of revenue due to lost market is compensated through increased price that leads to higher profit for the firm. On the other hand, if the firm reduces the price of the product, the size of the market grows. The profit due to growth in size of the market compensates for the loss due to reduction in price, causing increase in the profits of the firm. Therefore, the higher profit is driven by both the price as well as the size of the market for the firm.

The Duopoly Case

Here we analyze a duopolistic market where there are two competing firms (1 and 2) that serve the market. The firms choose prices q_1 and q_2 and use the recommender systems with effectiveness r_1 and r_2. For example, Netflix and Blockbuster provide recommendations to their customers so that the customers can find the right movie to maximize surplus. The product with optimal fit for the same customer in the website of firm 1 may be different from the product of optimal fit for the customer in the website of firm 2, since the optimal fit depends on r_1 and r_2 in addition to the customer type θ.

The customer evaluates her surplus at firm 1 and compares that with the surplus at firm 2 to decide on which firm to "search and buy" or not visit either firm. We denote the fit of the product purchased from firm i as x_i where $i = 1, 2$, and the price of a product as q_i. The surplus the customer generates by purchasing from firm i is S_i, the fit cost is $f(x_i)$, and search cost is $g(x_i, r_i, \theta)$.

The two firms can have recommender systems with same effectiveness or different effectiveness. We focus here on the case where the firms are asymmetric in the effectiveness of the recommender system technology employed, i.e. $r_1 \neq r_2$. We assume that the market is divided into two segments[2] on the basis of search type θ, one segment of the market purchases products from firm 1 which provides a surplus (S_1) to the customers, and the other segment purchases products from firm 2, which provides a surplus (S_2) to the customers. We refer to these segments as segment I and segment II respectively. In general, if S is the surplus of a customer, then the decision problem of a customer can be formulated as

$$S = \max\left(\max_{x_1}(S_1(x_1, r_1, \theta, q_1)), \max_{x_2}(S_2(x_2, r_2, \theta, q_2))\right) \quad (4)$$

Such that

$$\max\left(S_1^*(x_1^*(\theta_1, r_1), r_1, \theta, q_1), S_2^*(x_2^*(\theta_2, r_2), r_2, \theta, q_2)\right) \geq 0 \qquad \text{(I.R. constraint)} \quad (5)$$

Similar to the monopoly case, the marginal customer is a customer whose IR constraint is tight, i.e. the surplus of a marginal customer is zero after finding a product that maximizes her surplus. Therefore all the customers, whose search type is greater that the search type of marginal customer, will not search and buy. Using the I.R. constraint, the search type of marginal customer can be found by

$$max\left(S_1^*(x_1^*(\theta, r_1), r_1, \theta, q_1), S_2^*(x_2^*(\theta, r_2), r_2, \theta, q_2)\right) = 0 \quad (6)$$

Clearly $S_1 \geq S_2$ for a customer in segment I and $S_2 \geq S_1$ for a customer in segment II. Without loss of generality, suppose that the marginal customer is a type II customer. Therefore we refer to the search type of marginal customer as $\bar{\theta}_2$. The search type of the marginal customer $\bar{\theta}_2(r_2, q_2)$ can be found using the following equation

$$S = S_2^*(x_2^*(\theta, r_2), r_2, \theta, q_2) \quad (7)$$

Since there are only two segments in the market, there is only one type of customer with search type θ_s such that these customers are indifferent between purchasing products from firm 1 and firm 2. Therefore segment I customers are of type $\theta \epsilon [a, \theta_s]$ and segment II customers are of type $\theta \epsilon [\theta_s, \bar{\theta}_2]$. For an indifferent customer, $S_1^* = S_2^*$, i.e.

$$S_1^* = R - f\left(x_1^*(r_1, \theta_s)\right) - g(x_1^*(r_1, \theta_s), r_1, \theta_s) - q_1 = R - f\left(x_2^*(r_2, \theta_s)\right) - g\left(x_2^*(r_2, \theta_s), r_2, \theta_s\right) - q_2 = S_2^* \quad (8)$$

Using equation (8), we can find $\theta_s(q_1, q_2, r_1, r_2)$. Figure 2 illustrates the market and the surpluses for the customers who purchase products. For illustration purposes, we have shown the surpluses to decrease linearly with θ.

Using the market share of the firms and the prices of the products sold by the two firms, we can formulate the profit function of the two firms as

$$\Pi_1 = N\frac{(\theta_s - a)}{b-a}q_1 \quad (9)$$

$$\Pi_2 = N\frac{(\bar{\theta}_2 - \theta_s)}{b-a}q_2 \quad (10)$$

[2] It is possible to have more than two contiguous segments in the market, such that each alternate segment is served by the same firm. The segmentation depends on the IR constraints of the customers. However, for analytical tractability, we assume that the market is divided into two segments only.

Equation (9) and (10) are used to find $q_1^*(r_1, r_2, q_2)$ and $q_2^*(r_1, r_2, q_1)$ by differentiating them with respect to q_1 and q_2 respectively and equating them to 0. $q_1^*(r_1, r_2, q_2)$ and $q_2^*(r_1, r_2, q_1)$ can be solved simultaneously to find $q_1^*(r_1, r_2)$ and $q_2^*(r_1, r_2)$. Details are suppressed because of lack of space.

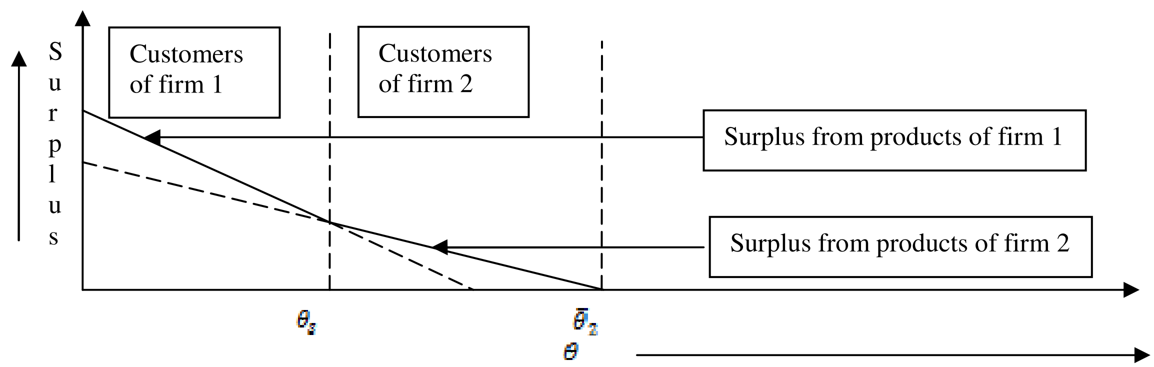

Figure 2: Market segments of firm 1 and firm 2

Similar to the monopoly case, it can be shown that the price of products charged by the two firms could increase as well as decrease with improvements in the recommendation technology employed at these firms. However, unlike the monopoly case, we show that an improvement in recommendation technologies does not necessarily increase firm profits.

Own-Technology effect on firm's profits

The technology impacts the profits of the firms by changing the size of the market and by changing the prices charged by the firms. However, unlike the monopoly case, the profit of a firm may go down despite an improvement in the recommender system's effectiveness. Of course when improvement in technology causes decrease in profits, firms would never improve their technology even if the improvement is free. Proposition 4 states the expression for the change in profit with change in technology for both the firms.

Proposition 2: (A) The rate of change of the profit of the firm 1 with respect to change in effectiveness of their recommender system is given by

$$\frac{d\Pi_1^*}{dr_1} = \frac{N}{b-a}\left(\frac{\partial\theta_s}{\partial r_1} + \frac{\partial\theta_s}{\partial q_2}\frac{dq_2^*}{dr_1}\right)q_1^*$$

(B) The rate of change of the profit of the firm 2 with respect to change in effectiveness of their recommender system is given by

$$\frac{d\Pi_2^*}{dr_2} = \frac{N}{b-a}\left(\frac{\partial\bar{\theta}_2}{\partial r_2} - \frac{\partial\theta_s}{\partial r_2} + \frac{\partial\theta_s}{\partial q_1}\frac{dq_1^*}{dr_2}\right)q_2^*$$

Proof: Details are suppressed because of lack of space.

The intuition behind the increase or decrease in profits is hard to visualize using general forms of $f(x)$ and $g(x, r, \theta)$. Therefore we introduce specific functional forms for both of them and analyze the results to find the reasons for increase and decrease of profits with improvement in technologies.

We assume $f(x) = d - x$ and $g(x) = \frac{Ax^2}{(1-\theta)r}$.

Here fit costs decrease linearly with the amount search or the fit level *x*. The symbol *d* represents the full search space. On the other hand, we allow the search costs to be quadratic in the amount of search and inversely proportional to the customer search effort type and the effectiveness of the recommendation system.

It can be easily shown that $\theta_s = 1 - \frac{4A(q_1 - q_2)}{r_1 - r_1}$, $\bar{\theta}_2 = 1 - \frac{4A(d + q_2 - R)}{r_2}$, $q_1^* = \frac{r_1 - r_2}{4r_1 - r_2}\left[\frac{(1-a)r_1}{2A} + (R - d)\right]$ and $q_2^* = \frac{r_1 - r_2}{4r_1 - r_2}\left[\frac{(1-a)r_2}{4A} + 2(R - d)\right]$. It can be easily shown that the firm with the better recommender system always serves the customers of segment I of Figure 2, and customers of segment 2 are served by the firm with the inferior recommender system. Hence, $r_1 > r_2$. Using the profits functions Π_1 and Π_2 described above, we find that $q_1^* > q_2^*$. By taking the second derivative we find that q_1^* and q_2^* maximizes the profits of firm 1 and firm 2, respectively, when $r_1 > r_2$. Details are suppressed due to lack of space.

The profits Π_1 and Π_2 as functions of r_1 and r_2 are given below.

$\Pi_1 = \frac{N}{A(b-a)} \frac{[(1-a)r_1+2A(R-d)]^2(r_1-r_2)}{(4r_1-r_2)^2}$ and $\Pi_2 = \frac{N}{A(b-a)} \frac{r_1(r_1-r_2)}{4r_2} \frac{[(1-a)r_2+8A(R-d)]^2}{(4r_1-r_2)^2}$.

Differentiating the profit functions with respect to r_1 and r_2 respectively, we get

$$\frac{\partial \Pi_1}{\partial r_1} = \frac{N}{A(b-a)}[(1-a)r_1 + 2A(R-d)]\frac{(1-a)(4r_1^2-3r_1r_2+2r_2^2)+2A(R-d)(-4r_1+7r_2)}{(4r_1-r_2)^3}, \text{ and}$$

$$\frac{\partial \Pi_2}{\partial r_2} = \frac{N}{4A(b-a)} r_1[(1-a)r_2 + 8A(R-d)]\frac{(1-a)(4r_1-7r_2)r_1r_2+8A(R-d)(-4r_1^2-2r_2^2+3r_1r_2)}{r_2^2(4r_1-r_2)^3} \quad (11)$$

From equation (11), it can be inferred that,

$$\frac{\partial \Pi_1}{\partial r_1}<0 \text{ if } [(1-a)r_1 + 2A(R-d)](1-a)(4r_1^2 - 3r_1r_2 + 2r_2^2) + 2A(R-d)(-4r_1 + 7r_2) < 0. \quad (12)$$

When $(R-d)$ is not very large the condition in (12) is an implication of the diminishing rate of returns of the improvement in the technology of the recommender system. Assuming that r_2 is constant, then the profits of firm 1 starts falling after a threshold value of r_1, which can be found from equation (12). The reason is that firm 1 can increase the price of its products with increase in r_1 is that at smaller values of r_1 the market is less sensitive to increase in price than improvement in technology. This is similar to the monopoly case. Further it can be shown that it is always optimal for firm 1 to increase the price of its products with improvement in technology. However increase in price also shrinks the market. After the threshold value of r_1, a further decrease of market hurts the firm, leading to reduction in profits.

When ($R < d$), the customers are highly sensitive to the price as they are not willing to pay a high price for the products. So the improvement in technology leading to increase in price beyond a point always hurts the firm. Therefore the firm should not further improve the technology once the threshold is reached.

The profits of firm 2 decreases with increase in profits if

$$[(1-a)r_2 + 8A(R-d)](1-a)(4r_1 - 7r_2)r_1r_2 + 8A(R-d)(-4r_1^2 - 2r_2^2 + 3r_1r_2) < 0.$$

This condition holds when the firm 2's technology is much inferior as compared to firm 1 and when $R > d$. It can be shown that firm 1 always reduces the price of its products when firm 2 improves its technology. Since r_1 is a high, customers of firm 1 are more sensitive to price than the technology of firm 1, and a reduction in price increases its market. As a result the market for firm 2 reduces leading to lower profits for firm 2. Therefore firm 2 should not improve its technology till it can closely match firm 1 in terms of technology. When $R < d$, it can be shown to be optimal for firm 2 to charge a higher price. However, a higher price shrinks the market for firm 2 since customers are not willing to pay high price for the products. Therefore, the profits of firm 2 decreases with increase in recommender system technology. In such a case firm 2 should not improve its technology further.

Cross-Technology effect on firm's profits

As stated earlier, the improvement in technology by one firm affects the optimal pricing decision and market share of other firm, so naturally the profit of other firm is also impacted. Therefore it would be interesting to see the change in profit of one firm because of change in technology of the other firm. Proposition 5 states the expressions for rate of change of profits of one firm with respect to the change in effectiveness of recommender system of the other firm.

Proposition 3: (A) The rate of change of the profit of the firm 1 with respect to change in effectiveness of recommender system of firm 2 is given by

$$\frac{d\Pi_1^*}{dr_2} = \frac{N}{b-a}\left(\frac{\partial \theta_s}{\partial r_2} + \frac{\partial \theta_s}{\partial q_2}\frac{dq_2^*}{dr_2}\right)q_1^*$$

(B) The rate of change of the profit of the firm 2 with respect to change in effectiveness of recommender system of firm 1 is given by

$$\frac{d\Pi_2^*}{dr_1} = \frac{N}{b-a}\left(-\frac{\partial \theta_2}{\partial q_2}\frac{dq_2^*}{dr_1} + \frac{\partial \theta_s}{\partial q_1}\frac{dq_1^*}{dr_1}\right)q_2^*$$

Proof: Details are suppressed because of lack of space.

We know that $\frac{\partial \theta_2}{\partial q_2} < 0$, but the signs of other derivatives can be either positive or negative. Therefore, we use the same functional forms introduced in the previous section to illustrate the above trends. It can be shown that

$$\frac{\partial \Pi_1}{\partial r_2} = -\frac{N}{A(b-a)}[(1-a)r_1 + 2A(R-d)]^2\frac{(2r_1+r_2)}{(4r_1-r_2)} < 0 \text{ and}$$

$$\frac{\partial \Pi_2}{\partial r_1} = \frac{N}{4A(b-a)}[(1-a)r_2 + 8A(R-d)]^2\frac{(2r_1r_2+r_2^2)}{r_2(4r_1-r_2)^3} \geq 0$$

The above result is expected for firm 1. As firm 2 improves its technology, it gets closer to firm 1 in terms of technology thereby pushing the firm to engage in a price war, leading to reduced profits for firm 1. On the other hand, interestingly, improvement in r_1 always benefits firm 2 because improvement in r_1 increases the gap between the technologies thereby reducing the chances of price war by creating a differentiated market.

However, the functional form assumed here is limited and incapable to show that the profits of firm 1 and 2 can also increase with improvement in technology of firm 2 and 1 respectively.

Conclusions, limitations and future research

This work is an attempt to understand the impact of recommender systems on purchasing behavior of online shoppers in terms of their decisions of search and buy the product or not doing so by analyzing the impact on the market size and prices charged by the firms for their products. This research answers some important questions relevant to managers of retail website regarding adoption of recommender system, or improving the existing technology. We have done a quantitative analysis of the role of recommendation technology in increasing the profits of the firms using recommender systems. We showed that the firms will always realize higher profits in a monopoly, however increased profits are not guaranteed for the firms in a duopoly, even if the marginal cost of technology is zero. The prices of the products can increase or decrease with adoption of better recommender system in both cases.

More analysis of the cases and some more specific functional forms need to be investigated to gain a deeper understanding of the profit impacts of recommendation technologies. Also, it would be interesting to examine customer surplus and societal surplus, and how these change with improvements in recommendation technology. In future, we intend to address these questions. Also we will consider the case of multiple products (within different prices) that share the same recommendation system.

In future, we will analyze the impact of considering the cost of recommendation on the profits of the firms. Currently, we have treated recommendation effectiveness as an exogenous parameter for the two firms. We will also analyze the changes in profits while treating them as endogenous.

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