A Game-Theoretic Approach for Pricing and Determining Virtual Reality Investment and Cybersecurity Level in a Dual-Channel Supply Chain

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Abstract. Virtual reality has become a new option to inform the customers about product before purchasing. However, providing virtual reality may create new challenges. For instance, consumers may obtain essential information about products by using virtual reality option, but eventually they buy their products from the offline channel. This phenomenon is called webrooming. Another challenge is cyber-attacks. E-tailers and their consumers face risks from cyber-attacks. Thus, e-tailers are investing to improve cybersecurity. We consider a dual-channel supply chain consisting of an offline retailer and an e-tailer who purchase the same product from a manufacturer at the same wholesale price. The e-tailer offers a partial refund policy in order to attract the customers. Also, to reduce consumer valuation uncertainty, the e-tailer faces the decision on whether to introduce virtual reality. We analyze three scenarios. Firstly, the e-tailer does not offer virtual reality. Secondly, the e-tailer offers virtual reality, but he does not invest on cybersecurity. Thirdly, the e-tailer offers virtual reality and invests on cybersecurity.

Keywords: Game theory, Pricing, Virtual reality, Cybersecurity, Webrooming, Return policy.

1 Introduction

Nowadays, online selling is more popular than ever. E-commerce has made it easy to buy everything and consumers can easily order the required product with a click. According to Statista website, online selling was almost 4938 billion U.S. dollars worldwide in 2021 and it will grow 15.9% in the United States in 2022. However, obtaining enough information about the products in online shopping is more complex than in offline shopping. Virtual reality (VR) has become interesting tool for e-tailers to inform customers about the product in online channels. By using VR, customers can imagine themselves in the store environment and get enough information about the product. eBay is one of the e-tailers that provides VR on its website and customers can experience the store atmosphere virtually [1].

However, VR can create challenges and concerns for e-tailers. Webrooming behavior is one of the new challenges of VR; means consumers use VR in online channel to obtain required information, but switch to offline channel and buy through offline retailers [2]. Google has done a survey that shows 87% of people begin product search online, but 79% purchase their product in physical stores [3]. Evidently, consumer webrooming behavior causes consumers to switch from online to offline, which may decrease the online demand and increase price competition. Thus, e-tailers should carefully decide on whether to provide VR.

Another challenge of online sales channels and using new technologies in online channels is cyber-attacks. Although online shopping is easier for people, many consumers are afraid of stealing their information when shopping online. Thus, cybersecurity has come to the attention of e-tailers and is now a global priority.

Many researchers study the influence of showrooming in supply chain [4-8]. Their findings show that the showrooming hurt the physical retailer and reduces the retailer's profit. On contrary, the effect of webrooming has been studied less in literature. Jing [2] examined the interaction between webrooming and showrooming. He shows that when webrooming reduces online purchasing uncertainty, it benefits both offline retailer and e-tailer by persuading more consumers to participate. Sun, Wang [9] analyzed the cost of searching online and demonstrated that consumer webrooming behavior depends on the cost of searching online and the travel cost of visiting physical stores. Sun, Wang [3] proposed a model consisting of a manufacturer and a retailer to examine the optimal webrooming strategy. Their results show that the optimal webrooming strategy depended on the online shopping cost. Jiao and Hu [10] proposed a model with different information of product value that consumers can obtain by referring to a traditional retailer and researching from an e-tailer, and studied consumer showrooming/webrooming behavior in a single model. Their results show that showrooming/webrooming may benefit traditional retailers and e-tailers, respectively. Domina, Lee [11] concluded that the enjoyment of using VR for customers increases demand and purchases. Gabisch [12] found that the experience of the virtual store leads to the intention of visiting the physical stores and shopping behavior. In food industry, Pizzi, Scarpi [13] and van Herpen, van den Broek [14] examined and compared shopping through a store with the possibility of VR and physical store and stated that the experience of buying from a store with VR can lead to customer satisfaction.

As far as we know, there are no studies that consider virtual reality investment in a dual-channel supply chain in the presence of webrooming behavior. Also, addressing the issue of cybersecurity and the investment of e-tailer on cybersecurity is of particular importance. In this paper, we consider a dual-channel supply chain consisting of one e-tailer and one offline retailer wherein the e-tailer decides whether to provide virtual reality. We examine the optimal virtual reality investment by considering the webrooming effect and the effect of virtual reality on return function. Also, we investigate the cybersecurity level when the e-tailer decides to provide virtual reality. We analyze three scenarios. Firstly, the e-tailer does not offer virtual reality. Secondly, the e-tailer offers virtual reality, but he does not invest on cybersecurity. Thirdly, the e-tailer offers virtual reality and invests on cybersecurity. The important questions are as follows:

(1) what are the equilibrium prices under each scenario?

(2) what is the equilibrium virtual reality investment?

(3) what is the optimal cybersecurity level when the e-tailer provides virtual reality?

(4) what is the effect of virtual reality on product return function?

The remain of this research is organized as follows. Section 2 present problem definition. Section 3 provides the equilibrium results for each scenario. Section 4 discuss a numerical example with important results. Finally, section 5 provides the conclusion.

2 Problem description

We consider a dual-channel supply chain consisting of an online and an offline retailer who purchase the same product at the same wholesale price, and sell the product through online and offline channels, respectively. Because the consumers who buy through online channel are not able to test the product before buying, the e-tailer utilizes two strategies to compete with the offline retailer and attract customers. First, the e-tailer offers partial refund policy to create confidence for online consumers. Second, since the online consumers are not able to test the product before purchasing, the e-tailer decides whether to provide virtual reality. Providing virtual reality allows consumers to be fully aware of the product before purchasing and may reduce the return rate. But on the other hand, it may lead to webrooming behavior and reduces the demand of online channel. Another issue that may threaten e-tailer is cybersecurity. By offering virtual reality, the e-tailer should also pay special attention to cybersecurity. Therefore, by providing virtual reality, the e-tailer also decides on the level of cybersecurity. In this paper, we use Stackelberg game model to formulate the relationship between the retailers. The offline retailer is leader and the e-tailer acts as follower. At first, the offline retailer decides his retail price. Then, the e-tailer determines the online retail price, virtual reality investment and cybersecurity level.

2.1 Scenario 1

In this scenario, the e-tailer offers partial refund policy and does not provide virtual reality; that is $v = 0$. The offline retailer firstly determines his retail price and then the e-tailer decides online retail price. The optimal model is as follows:

$$\begin{aligned} &\max_{p_d^1} \pi_d^1 = (p_d^1 - w)\underbrace{((1-\alpha_r) - \beta p_d + \gamma p_r)}_{D_d^1} \\ &s.t.\ \max_{p_r^1} \pi_r^1 = (p_r^1 - w)\underbrace{(\alpha_r - \beta p_r + \gamma p_d)}_{D_r^1} - r\underbrace{(\theta + \omega r)}_{R^1} \end{aligned} \tag{1}$$

Where α_r is market potential in online channel, β and γ represent sensitivity of product demand to the price of own and another channel, respectively. $\theta + \omega r$ indicates the return function of the product, wherein θ is basic return of product that does not depends on its refund amount, ω is sensitivity of returns quantity with respect to refund amount, and r is refund amount of a unit product.

2.2 Scenario 2

Under scenario 2, in addition to offering partial refund policy, the e-tailer provides virtual reality in online channel; that is $v > 0$. First, the offline retailer decides retail price in offline channel. Next, the e-tailer determine the online retail price and virtual reality investment. The formulation of optimal model is:

$$\begin{aligned} &\max_{p_d^2} \pi_d^2 = \left(p_d^2 - w\right)\underbrace{((1-\alpha_r) - \beta p_d^2 + \gamma p_r^2 + (1-\varepsilon_r)v^2)}_{D_d^2} \\ &s.t.\ \max_{p_r^2, v^2} \pi_r^2 = (p_r^2 - w)\underbrace{(\alpha_r - \beta p_r^2 + \gamma p_d^2 + \varepsilon_r v^2)}_{D_r^2} - r\underbrace{(\theta + \omega r - \lambda v^2)}_{R^2} - \frac{1}{2}v^2 \end{aligned} \tag{2}$$

Where ε_r refers to virtual reality effect coefficient in online channel, v is virtual reality investment that is a decision variable, and λ is sensitivity of returns quantity with respect to virtual reality investment.

2.3 Scenario 3

In scenario 3, the possibility of a cyber-attack has been seen in the online channel. The e-tailer decides the cybersecurity level in this scenario. The probability of a successful cyber-attack is $n = 1 - z$, that z is cybersecurity level. The total number of website shutdown is $Q = n \times f$, that f refers to total number of cyber-attacks. The model of third scenario is as follows:

$$\begin{aligned} &\max_{p_d^3} \pi_d^3 = \left(p_d^3 - w\right)\underbrace{((1-\alpha_r) - \beta p_d^3 + \gamma p_r^3 + (1-\varepsilon_r)v^3)}_{D_d^3} \\ &s.t.\ \max_{p_r^3, v^3, z^3} \pi_r^3 = (p_r^3 - w)\underbrace{(\alpha_r - \beta p_r^3 + \gamma p_d^3 + \varepsilon_r v^3 - \mu Q)}_{D_r^3} - r\underbrace{(\theta + \omega r - \lambda v^3)}_{R^3} - \\ &(Q \times k) - \frac{1}{2}v^3 - \frac{1}{2}z^3 \end{aligned} \tag{3}$$

Where parameter μ indicates sensitivity of product demand to cybersecurity level and k represents cost of website shutdown.

3 Equilibrium solutions

3.1 Scenario 1

Lemma 1. *π_r^1 on p_r^1 and π_d^1 on p_d^1 are concave functions.*

Proof. Taking the second derivative of Equation (1) with respect to p_r^1 and p_d^1, we have $-2\beta < 0$ and $-2\beta + \frac{\gamma^2}{\beta} < 0$. Therefore, the profit functions under scenario 1 are concave.

Theorem 1. *Under scenario 1, the equilibrium prices of the two retailers are:*

$$p_r^1 = \beta w + 2\beta(\alpha_r + \gamma((\gamma - 2\beta)\alpha_r + \beta(2 + \gamma w)/2(2\beta^2 - \gamma^2) + 0.5\text{w})) \quad (4)$$

$$p_d^1 = \frac{(\gamma - 2\beta)\alpha_r + \beta(2 + \gamma w)}{2(2\beta^2 - \gamma^2)} + \frac{w}{2} \quad (5)$$

3.2 Scenario 2

Lemma 2. *π_r^2 on p_r^2 and v and π_d^2 on p_d^2 are jointly concave functions.*

Proof. The Hessian matrix for π_r^2 is calculated as $H = \begin{pmatrix} -2\beta & \varepsilon_r \\ \varepsilon_r & -1 \end{pmatrix}$ that is negative definite. Thus, π_r^2 in Equation (2) is jointly concave in p_r^2 and v^2. Hence, by setting $\partial\pi_r^2/\partial p_r = 0$ and $\partial\pi_r^2/\partial v = 0$, the unique optimal set (p_r^2, v^2) is obtained. Now, after substituting Equations (6) and (7) in Equation (2), the second derivative of π_d^2 in Equation (2) with respect to p_d^2 is $-2\beta + (2\varepsilon_r\gamma - 2\varepsilon_r^2\gamma + 2\gamma^2/2\beta - \varepsilon_r^2) < 0$.

Theorem 2. *Under scenario 2, the equilibrium solutions of the two retailers are:*

$$p_r^2 = \frac{\alpha_r - w\beta + \varepsilon_r\lambda r + \gamma p_d^2}{2\beta - \varepsilon_r^2} + w \quad (6)$$

$$v^2 = \frac{2\beta\lambda r + \varepsilon_r(\alpha_r - \beta w + \gamma p_d^2)}{2\beta - \varepsilon_r^2} \quad (7)$$

$$p_d^2 = \frac{2\beta(1 - \alpha_r) + \varepsilon_r(\alpha_r - (\beta + \gamma)w - \varepsilon_r) - w(\gamma^2 + \beta(\gamma + 2\beta)) + \lambda r(2\beta(1 - \varepsilon_r) + \gamma\varepsilon_r)}{2\beta(2\beta - \varepsilon_r^2) + 2\gamma\varepsilon_r^2 - 2\varepsilon_r\gamma - 2\gamma^2} \quad (8)$$

3.3 Scenario 3

Lemma 3. *π_r^3 on p_r^3 , v, and z and π_d^3 on p_d^3 are jointly concave functions.*

Proof. The Hessian matrix for π_r^3 is calculated as $H = \begin{pmatrix} -2\beta & \varepsilon_r & \mu f \\ \varepsilon_r & -1 & 0 \\ \mu f & 0 & -1 \end{pmatrix}$ that is negative definite. Thus, π_r^3 in Equation (3) is jointly concave in p_r^3 , v^3, and z^3 . Hence, by setting $\partial\pi_r^3/\partial p_r = 0$, $\partial\pi_r^3/\partial v = 0$, and $\partial\pi_r^3/\partial z = 0$, the unique optimal set (p_r^3, v^3, z^3) is obtained. Now, after substituting Equations (9), (10), and (11) in Equation (3), the second derivative of π_d^3 in Equation (3) with respect to p_d^3 is $-2\beta - \frac{-2\varepsilon_r^2\gamma + 2\varepsilon_r\gamma + 2\gamma^2}{\varepsilon_r^2 + f^2\mu^2 - 2\beta} < 0$.

Theorem 3. *Under scenario 3, the equilibrium solutions of the two retailers are:*

$$p_r^3 = \alpha_r - \mu f + k\mu f^2 - \varepsilon_r \lambda r + \beta w + \gamma p_d^3 - w(\varepsilon_r^2 + \mu^2 f^2)/\varepsilon_r^2 - 2\beta + (\mu f)^2 \quad (9)$$

$$v^3 = \lambda r(\mu f)^2 + \varepsilon_r(\alpha_r + \beta w + \gamma p_d^3 + \mu f - k\mu f^2) + 2\beta\lambda r/\varepsilon_r^2 - 2\beta + (\mu f)^2 \quad (10)$$

$$z^3 = -f(2\beta k + \alpha_r \mu - k\varepsilon_r^2 - f\mu^2 + \gamma\mu p_d^3 - \beta\mu w + \varepsilon_r \mu\lambda r)/\varepsilon_r^2 - 2\beta + (\mu f)^2 \quad (11)$$

$$p_d^3 = \frac{(\mu f)^2(1-\alpha_r+\lambda r(1-\varepsilon_r)+w(\beta+\gamma))+(\alpha_r+\beta w-\gamma w-\mu f)(\varepsilon_r)+2\beta(1-\alpha\_r+\beta w)+\varepsilon\_r\text{^}2\,(\mu f-1) + \mu f^2(k\varepsilon_r(1-\varepsilon_r)+\gamma)+\lambda r(\varepsilon_r\gamma-2\beta\varepsilon_r+2\beta)}{2(\beta\varepsilon_r^2-\varepsilon_r^2\gamma+\varepsilon_r\gamma+\beta(\mu f)^2-2\beta^2+\gamma^2)} \quad (12)$$

4 Numerical example

In this section, due to the complexity of equations and optimal solutions, we use a numerical example to compare the optimal solutions in three scenarios. Following Zhang, Chen [15] and Li, Li [4], the parameters are setting as $\alpha_r = 0.6$, $\beta = 0.5$, $\gamma = 0.1$, $\mu = 0.2$, $w = 0.6$, $\varepsilon_r = 0.5$, $\theta = 0.02$, $\omega = 0.005$, $\lambda = 0.008$, $r = 0.5$ and $k = 2$.

Figure 1 shows that a higher webrooming effect coefficient will increase the equilibrium retail prices in both online and offline channels. The reason behind this is that the impact of webrooming increases the number of potential customers and thus increases market demand. Therefore, both retailers increase retail prices to obtain more profit. With the increase of webrooming effect, the slope of offline retailer price increase is higher than the slope of e-tailer price increase, which shows that offline retailer benefits more from virtual reality without any payment for virtual reality with increased demand and consequently rising prices.

Figure 2 indicates that a higher webrooming effect coefficient increases the profits of both retailers. This suggests that although providing virtual reality may lead to webrooming behavior and reduces e-tailer's demand, it is not always harmful to the e-tailer and, as we can see in the Figure 2, always increases the profitability of both retailers.

Figure 3 illustrates the changes of virtual reality investment and return function with respect to virtual reality effect coefficient and sensitivity of returns quantity with respect to virtual reality investment. The higher the sensitivity of the return function on the virtual reality investment and the higher the webrooming effect coefficient, the greater the e-tailer investing on virtual reality, and the return function decreases. Therefore, in answer to question 4, we can say that with the increase of e-tailer's investment on virtual reality, customers become fully aware of the product, and the number of returned products decreases.

Figure 4 shows that increasing the sensitivity of product demand to the cybersecurity level leads to increasing the cybersecurity level and decreasing the virtual reality investment. The reason for this is that as demand sensitivity to cybersecurity level increases, the e-tailer decides to focus more on cybersecurity instead of increasing their investment on virtual reality. That is, increase investment on cybersecurity by reducing investment on virtual reality.

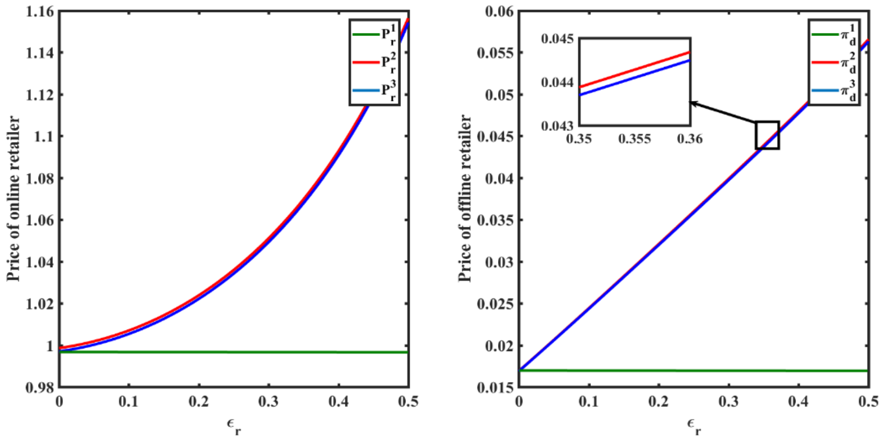

Fig. 1. Optimal prices comparison

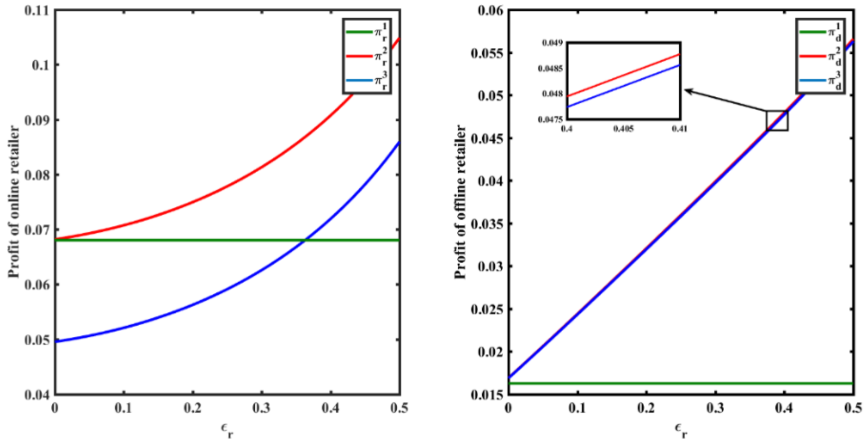

Fig. 2. Equilibrium profits comparison

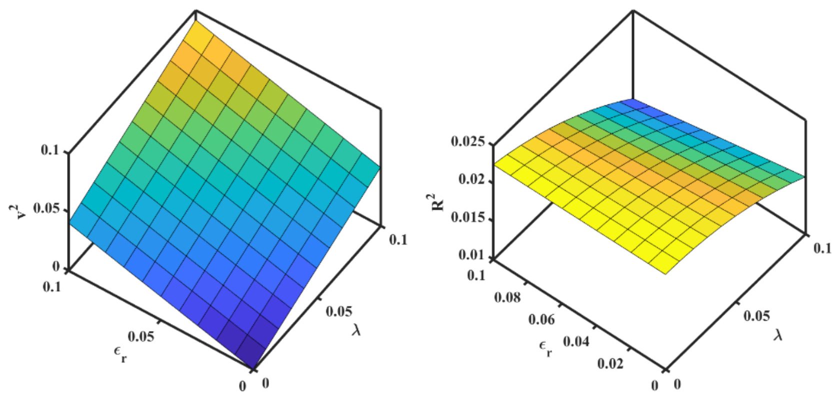

Fig. 3. The effect of ε_r and λ on virtual reality investment and return function

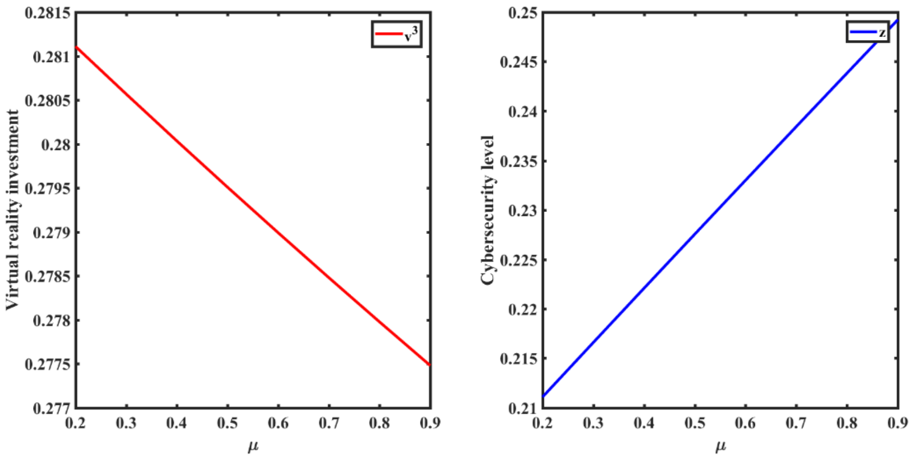

Fig. 4. The effect of μ on virtual reality investment and cybersecurity level

5 Summary

Today, increasing use of Internet leads to increasing the number of e-tailers in all over the world. Especially after Covid 19, e-commerce became more important. With the increasing importance of e-commerce and the increase in the number of e-tailers, issues such as reviewing and testing the product before buying online, and the security of customer information when buying online have been considered by managers. Virtual reality is an interesting tool for e-tailers to inform the customer about the specification of the product before purchasing. Although the e-tailers can use virtual reality to attract customers, but it can lead to webrooming behavior. This paper considers two online and offline retailers and investigates the optimal solutions of each retailer under three scenarios. The main purpose of this paper is to investigate the effect of virtual reality on equilibrium solutions and product return rate in the presence of webrooming behavior and cyber-attacks. The results are presented in numerical example section and show that the virtual reality service will increase the retail prices and profits of both retailers. This result is consistent with findings that are mentioned in [4, 15]. Also, providing the virtual reality will reduce the number of product retuned. For future works, it is worthwhile to examine different power structures and different competition of retailers. Also, considering nonlinear demand function could improve the model.

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