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Xiong ZHANG
City University of Hong Kong

Zhiling GUO
Singapore Management University, ZHILINGGUO@smu.edu.sg

Wei Thoo YUE
City University of Hong Kong

AN ECONOMIC ANALYSIS OF THE ONLINE COUNTERFEIT MARKET AND THE IMPACT OF ANTI-COUNTERFEIT TECHNOLOGY

Xiong Zhang, Department of Information Systems, City University of Hong Kong, Hong Kong, xionzhang3@student.cityu.edu.hk

Zhiling Guo, Department of Information Systems, City University of Hong Kong, Hong Kong, zhiling.guo@cityu.edu.hk

Wei Thoo Yue, Department of Information Systems, City University of Hong Kong, Hong Kong, Wei.T.Yue@cityu.edu.hk

Abstract

Counterfeiting causes hundreds of billions dollars of losses around the world every year. Due to the growing prominence of online commerce, the seriousness of the situation could soon become much worse. Hence, reaching a clear understanding of the fundamental economic incentives behind this practice is of vital importance. In this paper, we investigate a problem within which a firm selling a counterfeit product engages in price competition with a firm that sells an authentic product to a population of heterogeneous consumers. An online intermediary acts as the facilitator of both firms' transactions and may consequently be liable for any counterfeit sales. We use a stylized model to explain the economic incentives and the equilibrium behaviors of both firms and of the intermediary. More specifically, we seek to understand the effects of anti-counterfeit technology and anti-counterfeit policies on both firms' pricing strategies and profits, as well as on the intermediary's profit, consumer surplus and social welfare. Conclusions of this paper can provide managerial implications on how to effectively handle the online counterfeit problem.

Keywords: Counterfeit product, Anti-Counterfeit technology, Online Intermediary, Market Competition.

1 INTRODUCTION

In 2007, Tiffany sued eBay, one of the largest customer to customer (C2C) e-commerce sites around the world, for not curbing the sale of fake Tiffany merchandise on its sites (Hafner, 2007). Although Tiffany eventually lost the case against eBay in New York (Hafner, 2007), Louis Vuitton, another firm that had sued eBay for the same transgression, won its case against eBay in Europe. In its defense, eBay claimed that as an online intermediary, they had not held possession of the goods or products traded on its platform and therefore should not be liable for the counterfeit sales. The central argument of both Tiffany and Louis Vuitton's, however, was that eBay had not done *enough* in preventing the illicit trades. These two cases highlight a problem that is becoming increasingly prominent in online transactions, i.e., who should be responsible for protecting consumers against sales of counterfeit products. Recent figures have shown that online counterfeit and piracy loss has reached $600 billion (IACC, 2012) and that approximately 7% of global trade involves counterfeit goods. Counterfeiting also costs U.S. businesses more than $200 billion annually, with no sign of abating. In fact, the volume of counterfeit sales is still growing at a significant rate worldwide (Quinn, 2011).

To understand the extent of the counterfeit problem, Tiffany reported that their employees bought 325 items from eBay under a test buying program initiated by the company in 2004 under which they found that 75% of the items were counterfeit (Bray, 2007). Online e-commerce sites such as eBay have subsequently increased their anti-counterfeit protection efforts. However, the following questions remain: How much of their resources should a company like eBay divert for anti-counterfeit activities? How do we determine whether these efforts are sufficient to control the sale of counterfeit products online? In this paper, we consider a problem within which two firms -- one selling authentic products and the other selling fake products -- engage in price competition using a common intermediary platform. In this case, the intermediary, which derives its profit from the sales on the platform, determines the appropriate anti-counterfeit policy. But there is an inherent conflict here. On the one hand, the intermediary has vested interests in promoting sales on its platform. On the other hand, the intermediary needs to guard against the seller's possibly illicit interests. The anti-counterfeit policy determined by the intermediary will also have a direct impact on the sellers' pricing and demand outcomes, as well as on the well-being of the consumers involved. To date, there have been no studies that examine the strategic interactions between these three players. The aim of this study is to fill this gap.

Online intermediaries today apply a variety of anti-counterfeit measures to protect themselves from the sale of counterfeit products on their platforms. The anti-counterfeit measures applied range from technological remedies such as holograms, forensic techniques and serialization (Brendelberger, 2008) to various forms of managerial intervention such as online counterfeit reporting mechanisms. For example, eBay launched the Verified Rights Owner (VeRO) program through which intellectual property holders can freely report potential counterfeit abuse and have eBay remove those suspicious items from its product list (Greek, 2009). Taobao, China's biggest C2C intermediary firm also established a third-party Internet right protection operation, which was partnered with major international brands such as Louis Vuitton and Gucci. In addition, Taobao now applies keyword and price filters to prevent sellers from posting banned items or luxury goods with incredibly low prices (Bergman, 2011).

Despite the various measures introduced by these intermediary firms, it is not clear how effective these measures are given the fact that the sale of counterfeit products continues to be reported. These efforts can sometimes produce counterproductive results as well. For instance, Coach, a marketer of luxury leather items, recently accused a customer who was selling her authentic item from Coach on eBay as a fake item and pressured eBay to remove the item from the listing for sale (Johnson, 2011). Thus, the imperfection in the current anti-counterfeit measures may introduce two kinds of problems: the first is where a fake product is offered as being authentic, and the second is where an authentic product is offered for sale as being fake.

In this paper, we build a stylized model with the aim to understand the behaviors of sellers in an online environment where the intermediary is equipped with anti-counterfeit capability. Here, we adopt the traditional horizontal product differentiation framework to model the heterogeneous preferences of consumers when they make their purchase choice decisions between two firms that are engaged in a Bertrand type of price competition. Here, the ability of the intermediary, which is endowed with anti-counterfeit capability, could be imperfect with respect to identifying counterfeit products.

In our research, we found that there were interesting economic tradeoffs with the use of anti-counterfeit technology. Although anti-counterfeit technology helps remove counterfeit products from the market, it could also lead to a lower standard of consumer well-being because it either bars certain consumers from the consumption of some products or it subjects the whole consumer population to greater monopoly-type pricing. This outcome could lead to mixed results with respect to the level of consumer surplus. Thus, although a higher level of detection could increase the profit of the intermediary by reducing its liability for selling fake products, social welfare could suffer as a result.

The rest of the paper is organized as follows. We briefly review the existing body of literature in the next section. Sections 3 and 4 present our model. Section 5 analyzes the impact of anti-counterfeit technology's detection rate on consumer surplus, intermediary's profit and social welfare. The last section concludes our paper with discussions on the implications of this study and on the direction of future research.

2 LITERATURE REVIEW

Although counterfeit products represent a severe threat to many firms, there have been very few studies that have investigated the impact of anti-counterfeit policy on these firms. Previous studies have explored the question of why consumers buy counterfeit products. And it has been found that generally speaking consumers do understand the difference in the value of purchasing authentic versus counterfeit products. Very often product price is the main factor that lures consumers to buy counterfeit products (Penz & Stottinger, 2008; Penz, Schlegelmilch, & Stottinger, 2009). Personal preferences and attitudes have also been determined to be the critical factors that contribute to counterfeit purchases (Bian & Moutinho, 2011; Chaudhry & Stumpf, 2011).

With respect to the economic aspects of counterfeit products, previous studies have sought to examine the policy implications from the international trade perspective, where authentic products from a home country compete against foreign counterfeit products (Grossman & Shapiro, 1988a; Grossman & Shapiro, 1988b; Yao, 2005). The numerous implications of counterfeit products entering into a particular market and competing with authentic products have also been analyzed (Qian, 2006, 2008). In another study, online counterfeit frauds were found to involve products that were associated with grandiose and unrealistic claims (Jin & Kato, 2006).

With the Internet increasingly being used as the medium for product purchasing transactions, some studies have focused on the issue of how the online medium could be used to facilitate deceptive online counterfeit trades (Mavlanova et al. 2008, 2009, 2010). The remedies for this type of behaviors often inovlved some form of trust assurance services, which were embedded in the online purchases. The mechanisms involved the use of reputation protection systems, the revelation of transaction histories, etc. (Ba, Whinston & Zhang, 2003). To the best of our knowledge, little research has been conducted to gain an understanding of how the application of anti-counterfeit measures would affect the well-being of all the parties involved in an online transaction.

3 RESEARCH MODEL

Consider a situation where there are two firms, a recognized brand seller (Firm A) and a low price counterfeit seller (Firm B), within which both firms sell a specific product online through an intermediary's platform. For example, consumers who would like to purchase Calvin Klein clothes may buy from the seller of originals (with seller name Calvin Klein) on eBay or buy from a less well-

known, third party reseller on eBay who sells counterfeit Calvin Klein products at discounted prices. We assume that Firm A sells an authentic product and that Firm B sells a counterfeit product. We also assume that the marginal product cost for the firm that sells the counterfeit good is lower than that for the firm that sells an authentic product, i.e. $c_A > c_B$. Due to this cost advantage, Firm B is able to sell at a lower price, i.e., $p_A > p_B$ in equilibrium.

Assume that each consumer demands one unit of the product and derives an intrinsic value v_H (or v_L) by consuming the authentic (or the counterfeit) product. Thus, we assume $v_H > v_L$ and interpret the intrinsic value as being the consumer's willingness to pay for the product (Grossman & Shapiro, 1988a, 1988b).

In the online environment, counterfeits can easily be disguised. Here we assume that consumers know that the brand being offered by seller Firm A is the authentic product but they are not certain whether Firm B is selling the authentic product or not. Even though it is possible that Firm B's low price may reflect the offering of a counterfeit product, this lower price may still lure some consumers to make the purchase from the less reputable Firm B. Hence, the consumers' attitude toward risk and their personal preferences may affect their purchasing decisions. To model the consumers' heterogeneous preferences in the online purchasing environment, we assume that there is a continuum of potential consumers whose preference θ is uniformly distributed on the segment [0,1], where Firm A that sells the authentic product is located at 0 and Firm B that sells the counterfeit product is located at 1. The location of the consumer reflects her preference for one of the two firms. Here, the shorter distance between the consumer and Firm B, reflects the stronger attractiveness of the lower priced firm to the consumer. Following (Bockem, 1994), we denote the taste coefficient as s and show that the two firms engage in a price competition with horizontal differentiation.

Since consumers perceive both firms as selling an authentic product, the perceived utility of buying from Firm A is $v_H - p_A - s\theta$ and the perceived utility of buying from Firm B is $v_H - p_B - s(1-\theta)$. Within this context, consumers will purchase from the firm that provides the higher utility. By solving for the inequality $v_H - p_A - s\theta > v_H - p_B - s(1-\theta)$, we have the threshold value $\theta_1 = \frac{p_B - p_A + s}{2s}$. All consumers with $\theta < \theta_1$ will purchase from Firm A. All of the remaining consumers will purchase from Firm B. Therefore, the demands for both firms are:

$$\begin{cases} D_A = \theta_1 \\ D_B = 1 - \theta_1 \end{cases} \quad (1)$$

Consumers are only able to examine the product quality after they have made the product purchase. If a consumer buys from Firm B, the realized utility is $v_L - p_B - s(1-\theta)$ since Firm B sells a counterfeit product. Two cases may arise. In the first case, some consumers who purchased from Firm B would not regret the purchase since the ex-post utility of purchasing from Firm B is still higher than the utility of purchasing from Firm A. That is, $v_H - p_A - s\theta \leq v_L - p_B - s(1-\theta)$. In the second case, some consumers would realize they could have received a higher utility had they purchased from Firm A. That is, $v_H - p_A - s\theta > v_L - p_B - s(1-\theta)$. This group of consumers who would have preferred to buy the authentic product would then complain to the intermediary. In solving for the above inequality, we have the threshold value $\theta_2 = \frac{v_H - v_L - p_A + p_B + s}{2s}$. Consumers whose preferences are within the interval $[\theta_2, 1]$ would buy the counterfeit product but would not complain afterwards. Consumers whose preferences are within the interval $[\theta_1, \theta_2]$ would buy the counterfeit product but would complain to the intermediary afterwards. The following Figure 1 shows the three market segments of consumers.

Figure 1. Consumer Segmentation.

The proportion of unsatisfied consumers in the market is $\Delta\theta = \theta_2 - \theta_1 = \frac{v_H - v_L}{2s}$. This proportion increases when the difference between the willingness to pay for an authentic product and that for the

counterfeit product becomes larger, and it decreases when consumers are more sensitive about making their preferred purchase.

The intermediary makes a profit by charging commission fees that are proportional to each firm's profit. Let $0 < t < 1$ denote the share of profit that the intermediary charges. When consumers complain about buying a fake product, the intermediary pays compensation that is proportional to the transaction price. Let $0 < l < 1$ be the proportion paid. The profit functions of both firms and of the intermediary are expressed as:

$$\begin{cases} \pi_A = (1-t)(p_A - c_A)D_A \\ \pi_B = (1-t)(p_B - c_B)D_B \\ \pi_I = t(p_A - c_A)D_A + t(p_B - c_B)D_B - lp_B\Delta\theta \end{cases} \tag{2}$$

Consumer surplus is calculated as:

$$\pi_C = \int_0^{D_A} (v_H - p_A - sx)\,dx + \int_{D_A}^{1} \big(v_L - p_B - s(1-x)\big)\,dx + lp_B\Delta\theta - (v_H - v_L)\Delta\theta \tag{3}$$

The first two terms are the consumers' net surplus from purchasing the product. The third term is the compensation that the unsatisfied consumers will receive. The last term is the welfare loss that occurs when consumers select the wrong seller (i.e., they bought from Firm B when they should have bought from Firm A).

Social welfare is made up of the profits and surpluses of all the parties involved, including the two firms, the intermediary, and the consumers:

$$\pi_S = \pi_A + \pi_B + \pi_I + \pi_C \tag{4}$$

The game structure is set up as follows. Given the intermediary's policy (t, l), the two firms that sell through the intermediary determine their prices (p_A, p_B) simultaneously. Consumers then make their purchase decisions and their demand is realized. Consumers who are not satisfied with their purchases would complain to the intermediary and receive compensation.

In solving the game problem, we get the respective optimal prices, the demand levels, and the profits of the two firms as well as the consumer and social welfare. Detailed expressions of the results are presented in Table 1 in the Appendix.

Proposition 1: *Without any anti-counterfeit effort being made by the intermediary, the firms' optimal prices would be* $p_A^* > p_B^*$ *, the optimal demands are* $D_A^* < D_B^*$*, and the optimal profits are* $\pi_A^* < \pi_B^*$.

Since $c_A > c_B$, from Table 1 we directly determine the relationship $p_A^* - p_B^* = \frac{c_A - c_B}{3} > 0$, $D_A^* - D_B^* = \frac{c_B - c_A}{3s} < 0$, and $\pi_A^* < \pi_B^*$. Not surprisingly, because the cost of the authentic product is higher, the price charged by Firm A is higher, and the demand for the counterfeit product offered by Firm B is higher than that for the authentic product because the price is lower.

The above baseline model serves as our benchmark case. In the next section, we analyze the intermediary's decision choices with respect to its anti-counterfeit measures and determine how different anti-counterfeit policies would affect the two firms' pricing strategies.

4 ANTI-COUNTERFEIT MODEL

We now consider the case where the intermediary could apply anti-counterfeit measures to monitor the sale of counterfeit products on the intermediary's platform. Many of these activities are facilitated by the application of anti-counterfeit technology. Thus, we assume that the intermediary has the necessary technology to identify counterfeit products. We use the Receiver Operating Characteristics **(**ROC) curve to represent the anti-counterfeit technology used by the intermediary. The ROC curve has been used extensively to model the detection or monitoring systems (e.g. (Cavusoglu, Mishra, & Raghunathan, 2005).

When the anti-counterfeit technology is applied, there is a reasonable probability p_d that counterfeit products will be detected. When this happens, there are two possibilities. One, the intermediary could take a pre-emptive step and take the counterfeit products off the intermediary market. Two, the intermediary could address the issue after the incident by compensating to the complaining consumers. We consider both scenarios. In addition, the technology could falsely identify authentic products as fake products with probability p_f. We further assume that there is a cost $C(p_d, p_f)$, which applies to the use of the anti-counterfeit technology. This cost depends on the chosen configuration of p_d and p_f.

When a counterfeit product is detected, we assume that the firm selling the fake products is charged a per unit penalty cost c_d. When a genuine product is wrongly detected as being counterfeit, we assume that Firm A incurs a per unit inconvenience cost c_I for the incorrect detection. The intermediary will then compensate Firm A c_f on a per unit basis for this inconvenience cost.

With the application of anti-counterfeit technology, consumer segmentation remains the same as in the baseline case shown in Figure 1. Therefore, the demand functions for both firms also remain the same as in Eq. (1).

4.1 Passive Anti-Counterfeit Reaction

Assume that Firm A will incur an inconvenience cost c_I for each product that is falsely detected as a fake product by the anti-counterfeit technology and that the intermediary agrees to compensate Firm A for the inconvenience cost. That is, $c_f = c_I$, so that the use of anti-counterfeit technology will not affect Firm A's total profit. In the case where a counterfeit product is detected, Firm B is charged with a penalty cost c_d per unit. Firm B bears this cost for selling fake products. The application of the anti-counterfeit technology will directly affect Firm B's profit.

$$\pi_A = (1-t)(p_A - c_A - c_I p_f + c_f p_f) D_A \tag{5}$$

$$\pi_B = (1-t)(p_B - c_B - c_d p_d) D_B \tag{6}$$

The resulting consumer surplus welfare is:

$$\pi_C = \int_0^{D_A} (v_H - p_A - sx)dx + \int_{D_A}^{1} (1-p_d)\big(v_L - p_B - s(1-x)\big)dx + (lp_B - v_H + v_L)(\theta_2 - \theta_1)(1-p_d) \tag{7}$$

where the last term is the unsatisfied consumers' net compensation for the welfare loss.

Similar to the result obtained in the baseline model, for those consumers who do complain, the intermediary pays compensation proportional to the transaction price. The intermediary's profit is:

$$\pi_I = t(p_A - c_A - c_I p_f + c_f p_f) D_A + t(p_B - c_B - c_d p_d) D_B + c_d p_d D_B - c_f D_A p_f - lp_B \Delta\theta (1-p_d) - C(p_d, p_f) \tag{8}$$

Note that the third term is the penalty that the intermediary collects from Firm B for the sale of the counterfeit products that the intermediary detects. The forth term is the compensation that the intermediary pays to Firm A due to the false detection of counterfeit products by the technology. The fifth term is the compensation that the intermediary pays to the unsatisfied consumers. Solving the model, the detailed results are presented in Table 2 in the Appendix. The following result shows the effects of passive anti-counterfeiting detection technology on the firms' application of optimal strategies.

Proposition 2: *An increase in the counterfeit penalty c_d and the counterfeit product detection probability p_d will lead to:*

a) an increase in the optimal prices charged by both firms;

b) an increase in the demand for authentic products and a decrease in the demand for counterfeit products, and

c) an increase in Firm A's profit and a decrease in Firm B's profit.

Comparing the firms' optimal strategies when passive anti-counterfeit technology is applied versus those without the anti-counterfeit technology, we have the following observations:

Proposition 3: *When passive anti-counterfeit technology is applied,*

a) both firms set higher prices, and the price difference between the two firms decreases;

b) the demand for authentic product increase and the demand for counterfeit product decreases;

c) Firm A's profit increases and Firm B's profit decreases.

Since $p_A^* - p_B^* = \frac{c_A - c_B - c_d p_d}{3}$, it is clear that the price difference decreases if the penalty for Firm B increases or when the counterfeit product detection probability increases. This implies that when there is less opportunity to sell fake a product (high p_d) or it is more costly to do so (high c_d), Firm B has less incentive to lower its price. Therefore, the low price strategy becomes desirable.

The fact that the demand for and profit from the sale of authentic (counterfeit) product increases (decrease) with the use of anti-counterfeit technology shows the positive effect of the technology with respect to encouraging authentic product sales.

4.2 Pre-emptive Anti-Counterfeit Reaction

In this case, we assume that the intermediary could pre-empt the situation and take the products off the intermediary market when counterfeit products are detected. Such a policy would have two effects. First, those consumers who would otherwise prefer to purchase counterfeit products would now choose to purchase from the Firm A that sells authentic product. Second, the number of consumers who would otherwise complain to the intermediary would be reduced due to the reduced number of incidents.

With the application of anti-counterfeit technology, the realized demand for Firm B's products becomes $(1 - p_d)D_B$ and the lost demand from Firm B ($p_d D_B$) will go to Firm A. Without complicating our analysis, note that here we assume perfect competition such that all consumers who originally preferred to buy from Firm B can also afford to purchase from Firm A. Here D_B is the demand function of Firm B in the baseline case, as shown in Eq. (1). Accordingly, the profit of Firm A will be:

$$\pi_A{}' = (1 - t)(p_A - c_A)[D_A + p_d D_B] \tag{9}$$

where D_A is the demand function for Firm A in the baseline case, as shown in Eq. (1). Firm B's profit function is:

$$\pi_B' = (1 - t)(p_B - c_B - c_d p_d)D_B \tag{10}$$

Similarly, we can express the intermediary's profit function as:

$$\pi_I' = t(p_A - c_A)[D_A + p_d D_B] + t(p_B - c_B - c_d p_d)D_B - l p_B \Delta\theta(1 - p_d) + c_d p_d D_B - c_f D_A p_f - C(p_d, p_f) \tag{11}$$

The consumer surplus is:

$$\pi_C{}' = \int_0^{D_A} (v_H - p_A - sx)\, dx + \int_{D_A}^1 \left[p_d(v_H - p_A - sx) + (1 - p_d)\big(v_L - p_B - s(1 - x)\big)\right] dx + (1 - p_d)\Delta\theta[l p_B - (v_H - v_L)] \tag{12}$$

The optimal solutions are presented in Table 3 in the Appendix. The following result shows the effects of pre-emptive anti-counterfeiting detection technology on the firm's optimal strategies.

Proposition 4: *An increase in the counterfeit penalty c_d and the counterfeit product detection probability p_d will lead to:*

a) an increase in the optimal prices being paid by both firms;

b) an increase in the demand for authentic product and a decrease in the demand for counterfeit product, and

c) an increase in Firm A's profit and a decrease in Firm B's profit.

In comparing the firms' optimal pricing strategies with the pre-emptive anti-counterfeit policy versus that with the passive policy, we make the following observations:

Proposition 5: *When anti-counterfeit technology is applied,*

a) both firms' prices under the pre-emptive anti-counterfeit policy are higher than those under the passive anti-counterfeit policy, and

b) the price difference between the two firms under the pre-emptive anti-counterfeit policy is larger than that under the passive anti-counterfeit policy.

5 IMPACT ANALYSIS OF DETECTION RATE

We next illustrate the impact of the detection rate on the consumers' welfare, the intermediary's profit and social welfare well-being under three scenarios: the baseline case where no anti-counterfeit technology is used, the case with passive anti-counterfeit policy and the case with pre-emptive anti-counterfeit policy.

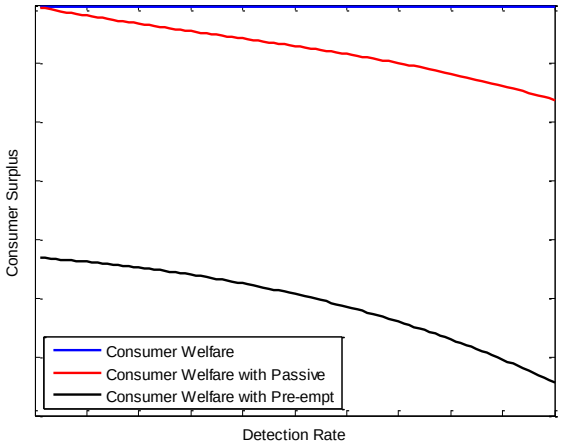

Figure 2 Consumer Surplus over Detection Rate

Interestingly, with the use of anti-counterfeit technology, consumer welfare decreases as the detection rate increases. This is because under the passive anti-counterfeit policy, a portion of the consumers who would otherwise prefer to purchase a counterfeit product are unable to buy from Firm B. This effectively causes such consumers to leave the market and results in a reduced level of consumer well-being. Under the pre-emptive anti-counterfeit policy, although all consumers eventually have the option to buy from Firm A, the elimination of Firm B's product from the market essentially provides Firm A with a monopoly that makes it possible for Firm A to charge a higher price. Both cases, then, lead to lower consumer welfare. Moreover, the pre-emptive anti-counterfeit policy has an even greater negative effect on consumer welfare than the passive anti-counterfeit policy.

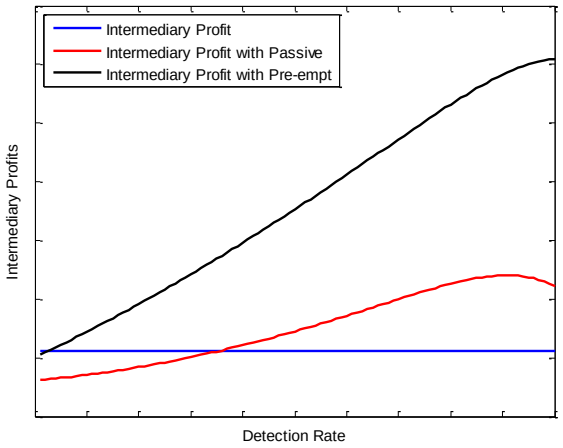

Figure 3 Intermediary's Profit over Detection Rate

Thus, with the application of anti-counterfeit technology, the intermediary's profit could be either higher or lower depending on the cost of implementing the anti-counterfeit measures. For example, when the cost of anti-counterfeit technology, penalties and inconvenience is reasonable, the use of anti-counterfeit technology allows the intermediary to derive higher profit through the more accurate detection of counterfeit products. In other words, because of the higher rate of detection, the pre-emptive policy could generate higher profit for the intermediary. Overall, a higher level of detection could also reduce the intermediary's liability for selling fake products. However, this would result in lower consumer surplus. We also observe that when the anti-counterfeit measures cannot accurately detect fake products (as is the case with a low detection rate), it is better to adopt a more conservative strategy, i.e., take a passive anti-counterfeit approach to addressing the counterfeit problem.

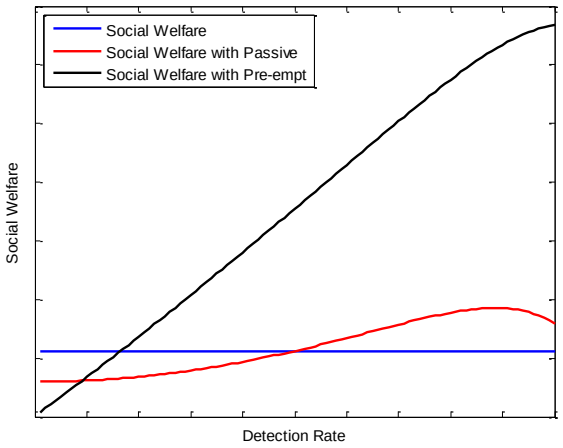

Figure 4 Social Welfare over Detection Rate

The implications of social welfare vary for each of the four parties identified in our model. Although the use of anti-counterfeit technology obviously will benefit the profit margin of Firm A and harm that of Firm B, its effect on the intermediary involves tradeoffs. In addition to the investment cost associated with the technology implementation, the intermediary incurs an additional expense in the form of the lost opportunity for profit sharing with Firm B due to the elimination of counterfeit product sales.

6 CONCLUSION

The problem of the increasing prominence of the online sale of counterfeit products warrants more attention from both market practitioners and academics. In this paper, we study the overall strategies

to be applied and the welfare implications for the parties involved in the online counterfeit market. We found that even without the use of anti-counterfeit technology product prices will serve as an indicator of product authenticity. Thus, the firms selling authentic products and those selling counterfeit products will basically self-segregate. Moreover, the use of anti-counterfeit technology results in there being a smaller price difference between the two firms' products and masks the differences between the authentic and the counterfeit products. This outcome does not necessary lead to a higher state of social welfare for all concerned. It is especially true when the cost of applying the anti-counterfeit technology is high.

We also studied how two different policies differed with respect to the detection of counterfeit products. We showed that both policies led to a state of lower consumer welfare. The decrease in consumer welfare was either because those consumers who preferred counterfeit products cannot buy from Firm B (under the firm's passive anti-counterfeit policy), or because the use of anti-counterfeit technology gave Firm A a near monopoly market with the power to extract more consumer surplus (under its pre-emptive anti-counterfeit policy). The pre-emptive policy would thus benefit Firm A more than the passive policy. However, it is less clear which policy would lead to higher social well-being. In fact, the use of anti-counterfeit measures could lead to either lower or higher social well-being than as in the baseline case. Hence, the issue of the social welfare implication involves more complicated tradeoffs that call for further analyses.

Our model has the following limitations: (1) we assume that there is a fixed cost for the anti-counterfeit system. In reality, the cost of an anti-counterfeit system depends on its detection performance. (2) Product quality can also be considered as a variable rather than a constant. In our future research, we will consider these issues.

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8 APPENDIX

	Firm A	Firm B
Price	$p_A^* = \frac{3s + 2c_A + c_B}{3}$	$p_B^* = \frac{3s + 2c_B + c_A}{3}$
Demand	$D_A^* = \frac{c_B - c_A + 3s}{6s}$	$D_B^* = \frac{c_A - c_B + 3s}{6s}$
Profit	$\pi_A^* = \frac{(1-t)}{18s}(3s + c_B - c_A)^2$	$\pi_B^* = \frac{(1-t)}{18s}(3s + c_A - c_B)^2$
Intermediary profit	$\pi_I^* = \frac{t}{18s}(3s + c_B - c_A)^2 + \frac{t}{18s}(3s + c_A - c_B)^2 - \frac{l(3s + 2c_B + c_A)(v_H - v_L)}{6s}$	
Consumer welfare	$\pi_C^* = \frac{1}{18s}(3v_H - 3s - c_B - 2c_A)(3s + c_B - c_A) - s\left(\frac{c_B - c_A + 3s}{6s}\right)^2 + \frac{1}{18s}(3v_L - 6s - 2c_B - c_A)(3s + c_A - c_B) + \frac{1}{2}s - \frac{(v_H - v_L)^2}{2s} + \frac{l(3s + 2c_B + c_A)(v_H - v_L)}{6s}$	
Social welfare	$\pi_s^* = \frac{1}{18s}(3s + c_B - c_A)^2 + \frac{1}{18s}(3s + c_A - c_B)^2 + \frac{1}{18s}(3v_H - 3s - c_B - 2c_A)(3s + c_B - c_A) + \frac{1}{18s}(3v_L - 6s - 2c_B - c_A)(3s + c_A - c_B) - \frac{(v_H - v_L)^2}{2s} - s\left(\frac{c_B - c_A + 3s}{6s}\right)^2 + \frac{1}{2}s$	

Table 1: Optimal Solutions without Anti-Counterfeiting Technology

	Firm A	Firm B
Price	$p_A^* = \frac{3s + 2c_A + c_B + c_d p_d}{3}$	$p_B^* = \frac{3s + c_A + 2c_B + 2c_d p_d}{3}$
Demand	$D_A^* = \frac{c_B - c_A + 3s + c_d p_d}{6s}$	$D_B^* = \frac{c_A - c_B + 3s - c_d p_d}{6s}$
Profit	$\pi_A^* = \frac{(1-t)}{18s}(3s + c_B - c_A + c_d p_d)^2$	$\pi_B^* = \frac{(1-t)}{18s}(3s + c_A - c_B - c_d p_d)^2$
Intermediary profit	$\pi_I^* = \frac{t}{18s}(3s + c_B - c_A + c_d p_d)^2 + \frac{t}{18s}(3s + c_A - c_B - c_d p_d)^2 - \frac{l(3s + c_A + 2c_B + 2c_d p_d)(v_H - v_L)(1 - p_d)}{6s} - c_f\left(\frac{-c_A + c_B + c_d p_d + 3s}{6s}\right)p_f - C(p_d, p_f) + c_d p_d\left(\frac{c_A - c_B + 3s - c_d p_d}{6s}\right)$	
Consumer welfare	$\pi_C^* = \frac{1}{18s}(3v_H - 3s - c_B - 2c_A - c_d p_d)(3s + c_B - c_A + c_d p_d) - \frac{1}{2}s\left(\frac{c_B - c_A + 3s + c_d p_d}{6s}\right)^2 + \frac{1}{18s}(3v_L - 6s - 2c_B - c_A - 2c_d p_d)(3s + c_A - c_B - c_d p_d)(1 - p_d) + \frac{1}{2}s(1 - p_d) - \frac{1}{2}s(1 - p_d)\left(\frac{c_B - c_A + 3s + c_d p_d}{6s}\right)^2 + \frac{1}{6s}(l(3s + 2c_B + c_A + 2c_d p_d) - 3v_H + 3v_L)(v_H - v_L)(1 - p_d)$	
Social welfare	$\pi_s^* = \frac{1}{18s}(3s + c_B - c_A + c_d p_d)^2 + \frac{1}{18s}(3s + c_A - c_B - c_d p_d)^2 + \frac{1}{18s}(3v_H - 3s - c_B - 2c_A - c_d p_d)(3s + c_B - c_A + c_d p_d) + \frac{1}{18s}(3v_L - 6s - 2c_B - c_A - 2c_d p_d)(3s + c_A - c_B - c_d p_d)(1 - p_d) - \frac{(v_H - v_L)^2}{2s}(1 - p_d) - C(p_d, p_f) - c_f\left(\frac{-c_A + c_B + c_d p_d + 3s}{6s}\right)p_f + c_d p_d\left(\frac{c_A - c_B + 3s - c_d p_d}{6s}\right) - \frac{1}{2}s\left(\frac{c_B - c_A + 3s + c_d p_d}{6s}\right)^2 + \frac{1}{2}s(1 - p_d) - \frac{1}{2}s(1 - p_d)\left(\frac{c_B - c_A + 3s + c_d p_d}{6s}\right)^2$	

Table 2: Optimal Solutions with Passive Anti-Counterfeit Technology

	Firm A	Firm B
Price	$p_A^* = \frac{2c_A + c_B + \frac{3 + p_d}{1 - p_d}s + c_d p_d}{3}$	$p_B^* = \frac{c_A + 2c_B + \frac{3 - p_d}{1 - p_d}s + 2c_d p_d}{3}$
Demand	$D_A^* = \frac{1}{6s}\left(\left(-c_A + c_B - \frac{2p_d}{1 - p_d}s + c_d p_d\right)(1 - p_d) + 3s(1 + p_d)\right)$	$D_B^* = \frac{1}{6s}\left(-\left(-c_A + c_B - \frac{2p_d}{1 - p_d}s + c_d p_d\right)(1 - p_d) + 3s(1 - p_d)\right)$

Profit	$\pi_A^* = \frac{(1-t)}{18s}\Big(-c_A + c_B + \frac{3+p_d}{1-p_d}s + c_d p_d\Big)\Bigg(\Big(-c_A + c_B - \frac{2p_d}{1-p_d}s + c_d p_d\Big)(1-p_d) + 3s(1+p_d)\Bigg)$	$\pi_B^* = \frac{(1-t)}{18s}\Big(c_A - c_B + \frac{3-p_d}{1-p_d}s - c_d p_d\Big)^2$
Intermediary profit	$\pi_I^* = \frac{t}{18s}\Big(-c_A + c_B + \frac{3+p_d}{1-p_d}s + c_d p_d\Big)\Bigg(\Big(-c_A + c_B - \frac{2p_d}{1-p_d}s + c_d p_d\Big)(1-p_d) + 3s(1+p_d)\Bigg) + \frac{t}{18s}\Big(c_A - c_B + \frac{3-p_d}{1-p_d}s - c_d p_d\Big)^2 - \frac{l}{6s}\Big(c_A + 2c_B + \frac{3-p_d}{1-p_d}s + 2c_d p_d\Big)(v_H - v_L)(1-p_d) - \frac{c_f p_f}{6s}\Big(-c_A + c_B - \frac{3-5p_d}{1-p_d}s + c_d p_d\Big) - C(p_d, p_f) + \frac{c_d p_d}{6s}\Bigg(-\Big(-c_A + c_B - \frac{2p_d}{1-p_d}s + c_d p_d\Big)(1-p_d) + 3s(1-p_d)\Bigg)$	
Consumer welfare	$\pi_C^* = \frac{1}{18s}\Big(3v_H - 2c_A - c_B - \frac{3+p_d}{1-p_d}s - c_d p_d\Big)\Big(-c_A + c_B + \frac{3-5p_d}{1-p_d}s + c_d p_d\Big) - \frac{1}{2}s\left(\frac{-c_A + c_B + \frac{3-5p_d}{1-p_d}s + c_d p_d}{6s}\right)^2 + \frac{1}{18s}\Big[p_d\Big(3v_H - 2c_A - c_B - \frac{3+p_d}{1-p_d}s - c_d p_d\Big) + (1-p_d)\Big(3v_L - c_A - 2c_B - \frac{6-4p_d}{1-p_d}s - 2c_d p_d\Big)\Big]\Big(c_A - c_B + \frac{3-p_d}{1-p_d}s - c_d p_d\Big) - \frac{1}{2}p_d s + \frac{1}{2}p_d s\left(\frac{-c_A + c_B + \frac{3-5p_d}{1-p_d}s + c_d p_d}{6s}\right)^2 + \frac{1}{2}(1-p_d)s - \frac{1}{2}(1-p_d)s\left(\frac{-c_A + c_B + \frac{3-5p_d}{1-p_d}s + c_d p_d}{6s}\right)^2 + \frac{l}{6s}\Big(c_A + 2c_B + \frac{3-p_d}{1-p_d}s + 2c_d p_d\Big)(v_H - v_L)(1-p_d) - (1-p_d)\frac{(v_H - v_L)^2}{2s}$	
Social welfare	$\pi_s^* = \frac{1}{18s}\Big(-c_A + c_B + \frac{3+p_d}{1-p_d}s + c_d p_d\Big)\Bigg(\Big(-c_A + c_B - \frac{2p_d}{1-p_d}s + c_d p_d\Big)(1-p_d) + 3s(1+p_d)\Bigg) + \frac{1}{18s}\Big(c_A - c_B + \frac{3-p_d}{1-p_d}s - c_d p_d\Big)^2 + \frac{1}{18s}\Big(3v_H - 2c_A - c_B - \frac{3+p_d}{1-p_d}s - c_d p_d\Big)\Big(-c_A + c_B + \frac{3-5p_d}{1-p_d}s + c_d p_d\Big) - \frac{1}{2}s\left(\frac{-c_A + c_B + \frac{3-5p_d}{1-p_d}s + c_d p_d}{6s}\right)^2 + \frac{1}{18s}\Big[p_d\Big(3v_H - 2c_A - c_B - \frac{3+p_d}{1-p_d}s - c_d p_d\Big) + (1-p_d)\Big(3v_L - c_A - 2c_B - \frac{6-4p_d}{1-p_d}s - 2c_d p_d\Big)\Big]\Big(c_A - c_B + \frac{3-p_d}{1-p_d}s - c_d p_d\Big) - \frac{1}{2}p_d s + \frac{1}{2}p_d s\left(\frac{-c_A + c_B + \frac{3-5p_d}{1-p_d}s + c_d p_d}{6s}\right)^2 + \frac{1}{2}(1-p_d)s - \frac{1}{2}(1-p_d)s\left(\frac{-c_A + c_B + \frac{3-5p_d}{1-p_d}s + c_d p_d}{6s}\right)^2 - \frac{c_f p_f}{6s}\Big(-c_A + c_B - \frac{3-5p_d}{1-p_d}s + c_d p_d\Big) - C(p_d, p_f) + \frac{c_d p_d}{6s}\Bigg(-\Big(-c_A + c_B - \frac{2p_d}{1-p_d}s + c_d p_d\Big)(1-p_d) + 3s(1-p_d)\Bigg) - (1-p_d)\frac{(v_H - v_L)^2}{2s}$	

Table 3: Optimal Solutions with Pre-empt Anti-Counterfeit Technology