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Abstract: Counterfeit goods are becoming more sophisticated from shoes to infant milk powder and aircraft parts, creating problems for consumers, firms, and governments. By comparing two types of counterfeiters - deceptive, so infiltrating a licit (but complicit) distributor, or non-deceptive in an illicit channel, we provide insights into the impact of anti-counterfeiting strategies on a brand-name company, a counterfeiter, and consumers. Our analysis highlights that the effectiveness of these strategies depends critically on whether a brand-name company faces a non-deceptive or deceptive counterfeiter. For example, by improving quality, the brand-name company can improve her expected profit against a non-deceptive counterfeiter when the counterfeiter steals an insignificant amount of brand value. However, the same strategy does not work well against the deceptive counterfeiter unless high quality facilitates the seizure of deceptive counterfeits significantly. Similarly, reducing price works well in combating the non-deceptive counterfeiter, but it could be ineffective against the deceptive counterfeiter. Moreover, the strategies that improve the profit of the brand-name company may benefit the counterfeiter inadvertently and even hurt consumer welfare. Therefore, firms and governments should carefully consider a trade-off among different objectives in implementing an anti-counterfeiting strategy.

Key words: Game Theory, Global Operations Management, Supply Chain Management

1 Introduction

Trademarks, also called brands, represent the most valuable assets of many firms, requiring significant investment in research and development as well as years of efforts in maintaining high product quality and careful brand management. Famous global brands such as GE, Nike and Nestlé are popular because they offer a guarantee of quality, which is vital to consumers when they make purchasing decisions. For those goods for which the mere display of a particular brand confers prestige on their owners, such as luxury watches and fashion apparel, many consumers purchase branded goods to demonstrate that they are consumers of the particular brand. These intrinsic values of trademarks create incentives for counterfeiting.

Nowadays counterfeits have developed into a substantial threat to many industries. The OECD estimates that international trade in counterfeits could amount to $250 billion or 1.95% of world trade in 2007 (OECD 2009). If including domestically produced and consumed products, the total magnitude could be several hundred billion dollars more (OECD 2008). By 2015, the International Chamber of Commerce expects the value of counterfeit goods globally to exceed $1.7 trillion (Hargreaves 2012). The problem is no longer limited to prestigious and easy-to-manufacture products, such as designer clothing, branded sportswear, and fashion accessories. It affects nearly all product categories including items that have an impact on personal health and safety such as pharmaceuticals, food, drink, toys, medical equipment, and automotive parts (OECD 2008).

Counterfeits are broadly categorized into two types: non-deceptive and deceptive (Grossman and Shapiro 1988a). A *non-deceptive* counterfeit is the counterfeit a consumer can distinguish from the brand-name product at time of purchase. This type of counterfeits tends to be sold at a substantial discount through an unauthorized sales channel. For example, counterfeiters in the Chinese footwear industry used cheap materials to produce shoes, and they charged a small fraction of the authentic product's price to attract customers (Qian 2008). Consumers could easily tell that $10 Nike shoes sold by street vendors are counterfeits. On the contrary, a *deceptive* counterfeit is the counterfeit a consumer believes to be authentic at time of purchase even if it is, in fact, counterfeit. In order to deceive consumers, this type of counterfeit goods has to infiltrate licit supply chains. A deceptive counterfeit is usually sold at the price that is the same as or close to that of its branded product so as to deceive consumers. Although it appears to function properly at time of purchase, it lacks durability and often involves health and safety risks of consumers. Examples of deceptive counterfeits abound in both developing and developed countries. In Thailand, a Scotch whisky company suffered a significant loss due to counterfeit sales. Green and Smith (2002) report that the counterfeiters received the active cooperation of many of the licit supply chain members. The licit supply chain members were lured by the higher profits from selling counterfeits, which they could obtain for a fraction of the brand-name company's wholesale price, yet charge the same amount to consumers. In the U.S., a number of physicians and drug distributors have been prosecuted recently for the purchase or sale of non-FDA approved cancer treatments including fake Avastin. Doctors generated more profits by purchasing them at discounted price, while billing insurance, Medicare and patients at the same price they would for legitimate treatments (Imber 2014).

In order to stop or at least to reduce the incidence of counterfeits, brand-name companies are spending millions of dollars. They hire full-time employees, invest in new technologies, and redesign their products to make counterfeiting more difficult. However, the anti-counterfeiting strategies found to be useful to one product may not work for another or can even unintentionally make counterfeits flourish more in the market. For example, Chinese shoe manufacturers successfully addressed their counterfeiting issues by improving the quality of their products (Qian 2008). This is the outcome of the competition in which high-quality authentic products defeat low-quality *non-deceptive* counterfeits. However, the same strategy backfired against the Scotch whisky company mentioned above (Green and Smith 2002). At the peak of the company's sales in 1988, 42% of its premium Scotch whisky sales was stolen by *deceptive* counterfeits. High quality made the products more popular and attracted more counterfeits. After the initial attempt to combat counterfeits through quality improvement had failed, the company eventually succeeded in radically reducing the incidence of counterfeiting by establishing a system that monitors supply chains: the company focused on identifying members in its supply chain who were selling the counterfeits, facilitating seizure of counterfeits, and punishing counterfeiters.

These contrasting results illustrate a need for anti-counterfeiting strategies that are tailored to specific products. Yet, due to the limited understanding of relations between the types of counterfeits and the effectiveness of anti-counterfeiting strategies, OECD (2008) calls for research that strengthens the analysis of counterfeiting and says:

"Assessing the factors driving production and consumption of counterfeit and pirated products can generate insights into the types of products that are most likely to be infringed, . . . , and lead to more efficient and effective [anti-counterfeiting] strategies."

This paper attempts to provide such an analysis by providing insights into the following questions: (Q1) What anti-counterfeiting strategies should a brand-name company use to improve her own profit? (Q2) What is the impact of anti-counterfeiting strategies on the profit of a counterfeiter? (Q3) What is the impact of counterfeits on consumer welfare? Do consumers also benefit from the strategies that are effective in combating counterfeits?

To answer these questions, we develop a normative model of licit and illicit supply chains, in which a brand-name company competes with her potential counterfeiter. The counterfeiter in our model is either non-deceptive or deceptive, and decides the level of functional quality and wholesale price of his goods after observing the quality and price of the brand-name product. Depending on his type, the counterfeiter faces different opportunities and risks. The *non-deceptive* counterfeiter competes directly with a brand-name company for price and quality. Thus the counterfeiter has to invest in improving the quality of his goods although large investment may not lead to any return in case of getting caught by the authorities. Conversely, the *deceptive* counterfeiter may not need to invest as much in improving the quality as the non-deceptive counterfeiter (as long as he can deceive consumers successfully at time of purchase), but he has to infiltrate a licit supply chain via a legitimate distributor who sources both brand-name and counterfeit products. The legitimate distributor then faces a trade-off between a greater profit margin and a risk of getting punished for selling counterfeits.

After finding the equilibrium decisions of the counterfeiter and the distributor, we evaluate the following anti-counterfeiting strategies of which the effectiveness depends on the subsequent reaction of the strategic counterfeiter: (i) quality strategy that alters the quality of brand-name products against a counterfeiter, (ii) pricing strategy that alters the price of brand-name products against a counterfeiter, (iii) marketing campaign that educates consumers about the dangers of counterfeits, (iv) enforcement strategy that increases the chances to seize the production of counterfeits, and (v) technology strategy that makes the brand-name product more difficult to counterfeit. Our analysis highlights that the optimal strategy of the brand-name company differs depending on whether she faces the non-deceptive or deceptive counterfeiter. Although it is ideal to see the strategies that increase the profit of the brand-name company be also effective in reducing the profit of the counterfeiter and benefit consumers, our analysis shows that this is not the case for most strategies. It is therefore imperative for industries and governments to understand the type of potential counterfeiters and to carefully consider a trade-off among different objectives in implementing an anti-counterfeiting strategy.

2 Literature Review

Traditional supply chain management research is focused on licit supply chains in which members of supply chains interact with each other by exchanging goods and services legally. In this era of globalization, supply chains are no longer confined within one country as more and more companies offshore and outsource their operations to less developed countries. However, this has caused an ever-rising flood of counterfeit items coming into markets. This paper is intended to shed light on counterfeit problems in both licit and illicit supply chains and to analyze the effectiveness of anti-counterfeiting strategies.

The majority of studies on counterfeits are conceptual and descriptive. They provide frameworks for fighting counterfeiting usually based on case studies (e.g., see Staake and Fleisch (2008) for an extensive review). Marketing researchers have conducted empirical studies on counterfeits.

They mainly focus on the demand side of counterfeits, and try to answer questions such as why consumers purchase counterfeits and how to educate consumers not to purchase counterfeits. Eisend and Schuchert-Guler (2006) review this literature and conclude that further investigation is needed to develop a general framework that integrates existing results consistently. Recently, using data from Chinese shoe companies, Qian (2008) finds that brand-name companies tend to improve their product quality after the entry of non-deceptive counterfeiters.

There are only a handful of analytical studies that present prescriptive models of counterfeits. Grossman and Shapiro (1988a, 1988b) develop equilibrium models of trades between brand-name firms in a home country and low-quality producers in a foreign country. To sell their goods as counterfeits in the home market, foreign producers must pass the goods through the home-country border, hence facing the risk of confiscation. Grossman and Shapiro (1988a) analyze the consequences of deceptive counterfeits in a market where consumers cannot observe the quality of a product, and provide a welfare analysis of border inspection policy. Grossman and Shapiro (1988b) present a Cournot competition model between brand-name products and non-deceptive counterfeits given their exogenous quality levels. Because non-deceptive counterfeits can contribute positively to consumer welfare due to their lower price, the authors conclude that policies that discourage foreign counterfeiting need not improve welfare, which is consistent with our finding. Scandizzo (2001) views competition between brand-name firms and non-deceptive counterfeiters as a patent race over time. Liu et al. (2005) study the decision of an inventory manager who can source both genuine and deceptive counterfeit products. Sun et al. (2010) study a global firm's decision of outsourcing the production of its components to a foreign country, in which the firm faces a trade-off between lower labor cost and increased risk of imitation by a foreign firm. Zhang et al. (2012) analyze the case when a brand-name firm faces non-deceptive counterfeits. They show that a non-deceptive counterfeit lowers the price and profit of the brand-name product, and a brand-name firm has more incentive to improve her own quality rather than reducing that of a counterfeit.

We draw on and contribute to this stream of research by addressing the following important issues in counterfeiting problems:

(1) Strategic counterfeiters: The common assumption used in the literature is that the quality is fixed a priori. Today, thanks to outsourcing and offshoring of numerous global firms, counterfeiters benefit greatly from increasingly easy access to modern production facilities (Staake and Fleisch 2008). Moreover, consumers also demand high quality from counterfeits (e.g., Nylander 2013). Due to this change in both supply and demand sides of the counterfeit market, Schmidle (2010) notes

that today's counterfeiters come in varying levels of quality depending on their intended markets. In our model, a counterfeiter decides the functional quality and wholesale price of his product by considering a trade-off between the benefit from stealing brand value and the risk of confiscation. Our analysis shows that the effectiveness of anti-counterfeiting strategies depends critically on the strategic response of a counterfeiter to those strategies.

(2) Licit and illicit supply chains: The previous analytical papers assume that a counterfeiter is capable of selling his counterfeits directly to consumers regardless of his type. Although this is quite possible for non-deceptive counterfeits, a *deceptive* counterfeiter has to infiltrate a licit supply chain; today, very few consumers would be deceived by the counterfeits sold by street vendors or unknown websites. We take into account this fundamental difference in supply chains of non-deceptive and deceptive counterfeits, and demonstrate that an effective strategy against a non-deceptive counterfeiter may not be effective against a deceptive counterfeiter.

(3) Consumer characteristics: As consumers learn more about counterfeit problems from the media, they become more aware of the presence of counterfeits, and some even become more proactive by taking into account the likelihood of receiving *deceptive* counterfeits unknowingly when they purchase branded products from licit distributors. Our survey (presented in §3) indicates that a proportion of proactive consumers in the U.S. is substantially lower than that in China. Our analysis provides insights into how this characteristic of consumers affects the effectiveness of anti-counterfeiting strategies.

(4) Evaluation of anti-counterfeiting strategies: We evaluate the aforementioned strategies by examining their impacts on a brand-name company, a counterfeiter, and consumers. Our analysis complements Grossman and Shapiro (1988a, 1988b) for border inspection policies, and Zhang et al. (2012) for the effect of altering the quality of a brand-name good or a non-deceptive counterfeit on the profit of a brand-name firm.

Finally, we note that a counterfeiter's decision of his distribution channel is analogous to that of a legitimate firm (e.g., Xu et al. 2010), although the benefit and risk associated with each channel of counterfeits are unique as described above. Also, a research question similar to counterfeiting arises in the literature of parallel importing (or gray market) and software piracy. Parallel importing is the practice of purchasing authentic products in a lower-priced region and shipping them to a higher priced region (e.g., Hu et al. 2011 and references therein). In contrast, counterfeits are not authentic, having lower quality, and deceptive counterfeits are often sold at the same price. Software piracy can be viewed as a special case of counterfeiting, in which counterfeit products have almost the same functional quality as authentic ones but their cost of development and production is very low. Some of our results can be extended to software piracy problems; for example, consumers could be better off without piracy protection, which is consistent with Conner and Rumelt (1991).

In summary, the literature considers only one type of counterfeits with fixed quality that are sold directly to consumers. In contrast, our model captures recent changes in counterfeiting supply and demand by noting the fundamental differences between non-deceptive and deceptive counterfeits in consumers' awareness and distribution channels, and by considering counterfeiters' strategic decisions regarding price and functional quality in a market with different consumer characteristics. Our analysis provides novel insights into the effectiveness of several anti-counterfeiting strategies.

3 Model

We consider a market served by a brand-name company ('she') and her potential counterfeiter ('he'). The type of the counterfeiter is either non-deceptive or deceptive. We use subscript $i = B$ to denote the brand-name product, $i = N$ to denote the non-deceptive counterfeit, and $i = D$ to denote the deceptive counterfeit. A consumer in this market purchases at most one unit of a product. In making a purchasing decision of product i, a consumer considers his/her utility $u_i = \theta\phi_i - p_i$, where θ represents his/her taste, ϕ_i represents the quality of the product a consumer *perceives* at time of purchase, and p_i represents the retail price of the product. All consumers prefer high quality for a given price, but a consumer with a higher θ is more willing to pay to obtain a high-quality product. We assume that θ is uniformly distributed over $[0, 1]$ and that the size of the market is one. A consumer purchases a product only if the utility from purchasing the product is nonnegative in which case he/she selects a product that provides the highest utility. This is the standard vertical differentiation model, which is also used by Qian (2008) and Zhang et al. (2012). We next present our model components that capture the unique aspects of counterfeiting.

Depending on the counterfeit type, the quality of product i a consumer *perceives* at time of purchase, ϕ_i, may differ from its *real* quality q_i. (Throughout this paper, unless mentioned specifically as the perceived quality, quality refers to real quality.) For the *non-deceptive* counterfeit as well as the brand-name product, consumers know what product they are purchasing, so the perceived quality of either product is the same as its real quality; i.e., $\phi_B = q_B$ and $\phi_N = q_N$. However, for the *deceptive* counterfeit, consumers cannot distinguish it from the brand-name product at time of purchase. There are two types of consumers. First, some consumers may not consider the likelihood of purchasing counterfeits at legitimate stores, or they may not be aware of counterfeits at all. They perceive the quality of any product in the market as q_B; i.e., $\phi_B = \phi_D = q_B$. On the other hand, other consumers may be "proactive" in the sense that they take into account the likelihood of receiving deceptive counterfeits unknowingly even when purchasing products from legitimate stores. Let $\xi_s \in [0, 1]$ denote their expectation about the fraction of deceptive counterfeits in the market. Then proactive consumers perceive the quality of a product in the market as a weighted average of the quality of the brand-name product and that of the deceptive counterfeit; i.e., $\phi_B = \phi_D = (1-\xi_s)q_B + \xi_s q_D$. Let λ ($\in [0, 1]$) denote the fraction of proactive consumers in the market. In practice, λ may vary depending on the characteristic of the market. For example, our survey of 166 consumers over 4 product categories popular for deceptive counterfeits reveals that 51% of consumers in China are proactive, whereas only 4 % of consumers in the U.S. are proactive (see Table 1 and online appendix for more details). The low value of λ in the U.S. reflects the view of Rockoff and Weaver (2012), who say: "Most Americans don't question the integrity of the drugs they rely on. They view drug counterfeiting, if they are aware of it at all, as a problem for developing countries."

Table 1. Consumer Survey Results in the U.S. and China

	U.S.		China	
	Aware	Proactive	Aware	Proactive
Alcohol	14%	4%	94%	56%
Car Parts	25%	4%	54%	34%
Medical Drugs	41%	5%	86%	51%
Food, Drinks	22%	5%	90%	63%
Average	26%	4%	81%	51%

Since the counterfeit bears the trademark of the brand-name product, a consumer enjoys the brand image even when he/she purchases the counterfeit. Thus we may represent the quality of the counterfeit as $q_i = f_i + \beta q_B$ ($i = N$ or D), where f_i (> 0) is the functional quality of the counterfeit i and βq_B (where $\beta > 0$) is the brand value that the counterfeit steals from the brand-name product. The parameter β captures the following two factors. First, β captures a fraction of the brand value in the quality of the brand-name product, q_B. For example, this fraction may be high for luxury goods because a brand plays a significant role when consumers purchase such products, whereas it may be low for fast moving consumer goods because a brand is less of a concern to consumers for such goods. Second, β captures a discount factor of the original brand value for the counterfeit because the counterfeit draws only a part of the brand value from the brand-name product. Following the literature, we assume that the quality of the brand-name product is superior to that of the counterfeit; i.e., $q_B > q_N$ and $q_B > q_D$.

Either type of counterfeiter i ($= N$ or D) makes two decisions sequentially to maximize his expected profit: functional quality f_i and wholesale price w_i to a distributor. We assume that the counterfeiter makes these decisions after observing the quality q_B and price p_B of a brand-name product because counterfeiters always enter a market following a brand-name company, often after the brand-name product becomes popular. Different types of counterfeiters use different distribution channels to sell their goods as we describe next.

The *non-deceptive* counterfeiter ($i = N$) distributes his goods through an *illicit distributor*, who then decides the retail price of the non-deceptive counterfeit to consumers, p_N. In this case, consumers will choose between the brand-name product and the counterfeit. Both products carry the same brand, but they have different qualities and prices. Competition between the non-deceptive counterfeiter and the brand-name company is analogous to duopoly in a vertically differentiated market, but it is not the same because the non-deceptive counterfeit steals brand value from the brand-name product and the members of the illicit supply chain bear the risks associated with counterfeiting. The non-deceptive counterfeiter and the illicit distributor make their decisions in three sequential stages as follows. In stage 1, the non-deceptive counterfeiter chooses his functional quality $f_N \in [\underline{f}, \overline{f}]$ (where $\overline{f} > \underline{f} \geq 0$), and invest $t f_N^2$ (where $t > 0$) to develop and produce goods having f_N. The upper bound $\overline{f}$ may represent the functional quality of the brand-name product. We assume $\overline{f} < (1 - \beta) q_B$ such that $q_B > q_N$. The lower bound $\underline{f}$ may represent the minimum level of quality at which a product functions or appears to function properly. The unit production cost of the counterfeit is normalized to zero. Because it is illegal to produce counterfeits, there are some chances that the counterfeiter will be caught by the authorities. Suppose this occurs with probability $\gamma \in (0, 1)$ which captures the monitoring efforts of the government and the brand-name company on counterfeit production. In that case, the counterfeiter cannot sell his goods to the market, while getting his investment confiscated and paying a fine h_N. With probability $(1 - \gamma)$, the game proceeds to stage 2 in which the non-deceptive counterfeiter decides his wholesale price w_N to the illicit distributor. For simplicity, we represent all distributors/retailers in the illicit supply chain as one illicit distributor. In stage 3, the illicit distributor decides the retail price of the non-deceptive counterfeit to consumers, p_N. The illicit distributor has to pay a penalty of l_N if getting caught by the authorities with probability α_N.

The *deceptive* counterfeiter ($i = D$) breaks into a licit supply chain by distributing his goods through a *licit distributor*, who then sells both brand-name products and deceptive counterfeits to consumers at the same price p_B. In this case, consumers cannot distinguish deceptive counterfeits from brand-name products. Like the non-deceptive counterfeiter, in stage 1, the deceptive counterfeiter determines his functional quality $f_D \in [\underline{f}, \overline{f}]$, while facing the risk of getting his investment tf_D^2 confiscated and paying a fine h_D. In stage 2, the deceptive counterfeiter decides his wholesale price w_D to the licit distributor. In stage 3, the licit distributor determines a proportion $s \in [0, 1]$ of the deceptive counterfeit among all products he sells to consumers, and then sells all products at the price p_B. We focus on the interesting case when $s > 0$. We model the risk of the licit distributor selling deceptive counterfeits with a likelihood α_D of getting caught and a penalty l_D. Since α_D tends to increase with more counterfeits in the market, we set α_D equal to the fraction of deceptive counterfeits, s. In §7, we consider a more general case in which α_D is a function of f_D as well as s.

We make the following assumptions to simplify our analysis. First, we assume that the retail price of a brand-name product p_B is exogenous to the licit distributor in a market with *deceptive* counterfeits, and that the licit distributor earns a fixed markup $k \in [0, 1)$ from selling the brand-name product. This might be a result of the sales price maintenance that is employed in several industries such as consumer electronics, luxury brands, franchise stores and some pharmaceutical markets (e.g., Netessine and Zhang 2005). Without loss of generality, we normalize $k = 0$, implying that the licit distributor does not make a profit from selling authentic products; whereas we later show that the *deceptive* counterfeiter chooses a wholesale price w_D in equilibrium that guarantees a positive markup to the licit distributor. In online appendix, we also analyze the case where the licit distributor decides the retail price endogenously, and show that our main results are directionally true. Second, we normalize $h_N = 0$ and $l_N = 0$, while having $h_D = h > 0$ and $l_D = l > 0$. In practice, many non-deceptive counterfeiters are small workshops, and illicit distributors are usually street vendors or internet sites. Since their potential loss from seizure is small, when they get caught, they tend to close their stores temporarily and then reopen the same stores or open new ones later (e.g., Yatai Xinyang market in Shanghai, China (Naumann 2009)). In contrast, punishment on deceptive counterfeiters and licit distributors tend to be very severe. For example, the Chinese court sentenced the head of a manufacturing and distribution network for fake pills to 17 years in prison (Bennett 2010) and the U.S. court sentenced the owner of McCleod Blood and Cancer Center in Tennessee who imported illegal cancer drugs to serve 2 years and to pay \$2.6 million (Imber 2014). Third, for both types of counterfeits, we assume that the probability of counterfeits getting confiscated at the production level (γ) is independent of that at the distribution level (α_N or α_D). In the example of the Scotch whisky company, the locations of many counterfeit production facilities were unknown even when the counterfeits flooded the market (Green and

Smith 2002). The enforcement operations resulted in 56 arrests across nine Turkish cities in 2013 for producing counterfeit cancer drugs (Taylor 2014), which were conducted independently of the arrest of a Turkish drug wholesaler who smuggled those drugs into the U.S. (Whalen 2014). Table 2 summarizes our notation.

Table 2. Summary of Key Notation

Symbol	Definition
i	Brand-name product ($= B$), non-deceptive counterfeit ($= N$), deceptive counterfeit ($= D$)
θ	Taste of consumers; $\theta \sim U[0,1]$
p_i	Retail price of product i to consumers
q_i	Real quality of product i
ϕ_i	Perceived quality of product i
f_i	Functional quality of counterfeit product i; $f_i \in [\underline{f}, \overline{f}]$
π_i	Expected profit from selling product i
w_i	Wholesale price of product i to a distributor
t	Cost parameter used in the cost of developing functional quality
β	Fraction of the quality of brand-name products that counterfeits steal; $\beta \in \left(0, 1 - \overline{f}/q_B\right)$
γ	Probability that a counterfeiter's investment will be confiscated; $\gamma \in (0,1)$
l	Fine to the licit distributor if getting caught for selling deceptive counterfeits; $l > 0$
h	Fine to the deceptive counterfeiter if getting caught; $h > 0$
λ	Fraction of proactive consumers in the market; $\lambda \in [0,1]$
s	Fraction of deceptive counterfeits among all products the licit distributor sells; $s \in [0,1]$

4 Equilibrium Analysis

In this section, we present our equilibrium analysis. In §4.1 we present equilibrium, denoted by superscript *, in a market with a non-deceptive counterfeiter. In §4.2 we present equilibrium, denoted by superscript **, in a market with a deceptive counterfeiter. All proofs are provided in online appendix.

4.1 Non-Deceptive Counterfeits

In the market where non-deceptive counterfeits exist, there are three segments of consumers: (i) consumers who value the quality of a product highly and purchase the brand-name product, (ii) consumers who value the quality less and purchase the non-deceptive counterfeit, and (iii) consumers who value the quality the least and do not purchase any product. By determining the consumer who is indifferent between any two segments, we can obtain the market shares of the brand-name product and the counterfeit (see online appendix for details). Using these market shares, denoted by m_i for $i = B$ or N, we solve the game backwards to derive subgame-perfect Nash equilibrium.

In stage 3, the illicit distributor determines the retail price p_N by solving:

$$\max_{p_N}(p_N - w_N)m_N = (p_N - w_N)\left\{\frac{p_B - p_N}{(1-\beta)q_B - f_N} - \frac{p_N}{f_N + \beta q_B}\right\}.$$

One can easily obtain her optimal retail price $p_N^*(w_N, f_N) = \frac{(\beta q_B + f_N)p_B + q_B w_N}{2q_B}$. By anticipating the best response of the illicit distributor, in stages 2 and 1, the non-deceptive counterfeiter determines his wholesale price w_N and functional quality f_N, respectively, to maximize his expected profit:

$$\pi_N(w_N, f_N) = (1-\gamma)\left\{w_N\left(\frac{p_B - p_N^*}{(1-\beta)q_B - f_N} - \frac{p_N^*}{f_N + \beta q_B}\right) - tf_N^2\right\} - \gamma t f_N^2.$$

Lemma 1 *In equilibrium, the non-deceptive counterfeiter chooses wholesale price* $w_N^* = \frac{p_B(f_N^* + \beta q_B)}{2q_B}$, *and functional quality* $f_N^* = \underline{f}$ *if* $t < \frac{(1-\gamma)p_B^2}{8\{(1-\beta)q_B - f_N\}^3}$ *and* $\pi_N^*(\underline{f}) \geq \pi_N^*(\overline{f})$, *and otherwise* f_N^* *can be* $\overline{f}$ *or* $f_N^* \in (\underline{f}, \overline{f})$ *that satisfies* $\frac{\partial \pi_N^*}{\partial f_N}|_{f_N = f_N^*} = 0$. *The resulting expected profit is* $\pi_N^* = \frac{p_B^2(1-\gamma)(f_N^* + \beta q_B)}{8q_B\left\{(1-\beta)q_B - f_N^*\right\}} - t(f_N^*)^2$.

A key implication of Lemma 1 is that the non-deceptive counterfeiter may not always choose the lowest quality in contrast to the common assumption used in the literature (e.g., Grossman and Shapiro 1988a,b). In the *past*, non-deceptive counterfeits with low functional quality such as brand-name costumes, footwear and accessories dominated a counterfeit market. Their functional quality is just enough for consumers to use them, but their durability and performance are substandard. Consumers who purchase such counterfeits are those who want to enjoy the snob appeal of brands, but do not want to pay the high price of genuine goods. However, in *today*'s counterfeit markets, counterfeiters come in varying levels of quality depending on their intended markets. For example, although most of counterfeit shoes in China are of low quality, there are high-end fakes designed primarily for export, which are so sophisticated that it is difficult to distinguish the real ones from the counterfeits (Schmidle 2010). These counterfeiters usually face the least pressure from local enforcement agencies and some are likely to turn into licit competitors once intellectual property rights become more strictly enforced (Staake and Fleisch 2008). Our result is consistent with this observation of today's counterfeit markets.

4.2 Deceptive Counterfeits

In the market where deceptive counterfeits exist, both brand-name products and deceptive counterfeits are sold at price p_B. While proactive consumers with proportion λ perceive the quality of a product in the market as $(1-\xi_s)q_B + \xi_s q_D$, the rest of consumers perceive the quality of a product in the market as q_B. Similar to Grossman and Shapiro (1988a), we assume that the expectation of proactive consumers about the fraction of deceptive counterfeits in the market is rational and hence is equal, in equilibrium, to the actual fraction of counterfeits; i.e., $\xi_s = s$. These consumers may build rational expectations through repeated interactions in the marketplace (especially when they have been in the market with counterfeits for a long period of time) and through learning from the media. This notion of rational expectations equilibrium is also used in the recent operations management literature (e.g., Su and Zhang 2008, Cachon and Swinney 2009).

In this market, there are only two segments of consumers: (i) consumers who purchase products, and (ii) consumers who do not purchase any product. Among those consumers who purchase products, a fraction s of them receives deceptive counterfeits unknowingly. We solve the model backwards as follows. In stage 3, the licit distributor solves the following problem to determine s^{**}:

$$\max_{s\in[0,1]}(1-s)\left[s(p_B-w_D)\left\{1-\tfrac{\lambda p_B}{(1-s)q_B+s(f_D+\beta q_B)}-\tfrac{(1-\lambda)p_B}{q_B}\right\}\right]-sl,$$

where $(1-s)$ represents the likelihood that the distributor will not be detected for selling counterfeits and the next term in the bracket represents the distributor's profit in that case. When there is a seizure with probability s, the licit distributor does not sell any products (hence making no profits), and pays a penalty l. In stages 2 and 1, the deceptive counterfeiter decides his wholesale price w_D and functional quality f_D, respectively, to maximize his expected profit given by:

$$\pi_D(w_D,f_D)=(1-\gamma)\left[w_D s^{**}\left\{1-\tfrac{\lambda p_B}{(1-s^{**})q_B+s^{**}(f_D+\beta q_B)}-\tfrac{(1-\lambda)p_B}{q_B}\right\}-tf_D^2\right]-\gamma(tf_D^2+h).$$

Lemma 2 *(a) When no consumers are proactive (i.e., $\lambda = 0$), in equilibrium, the deceptive counterfeiter chooses wholesale price $w_D^{**} = p_B - \sqrt{\frac{lp_B}{1-\frac{p_B}{q_B}}}$ and functional quality $f_N^* = \underline{f}$, getting the expected profit of $\pi_D^{**} = \frac{1}{2}(1-\gamma)\left\{\sqrt{p_B\left(1-\frac{p_B}{q_B}\right)}-\sqrt{l}\right\}^2 - t\underline{f}^2 - \gamma h$.*
(b) When proactive consumers exist (i.e., $\lambda > 0$), there exists $\bar{t}$ (> 0) such that if $t \geq \bar{t}$, the deceptive counterfeiter chooses $f_D^{**} = \underline{f}$, and otherwise f_D^{**} can be $\overline{f}$ or $f_D^{**} \in (\underline{f}, \overline{f})$ that satisfies $\frac{\partial \pi_D^{**}}{\partial f_D}|_{f_D=f_D^{**}} = 0$. (In this case, no closed-form expressions exist for w_D^{**} and π_D^{**}.)

In the market with no proactive consumers, Lemma 2(a) shows that the deceptive counterfeiter always chooses the lowest functional quality $\underline{f}$ because improving quality does not increase counterfeit sales. Although such a counterfeit is visually identical to its brand-name product, its low quality may endanger consumers' health and safety. Typical examples are food, beverage, pharmaceuticals, and automotive spare parts (OECD 2008). It is also interesting to note that the deceptive counterfeiter's expected profit increases with $p_B\left(1-\frac{p_B}{q_B}\right)$, which is the revenue of the brand-name company without counterfeits. This is because the perceived quality and price of the deceptive counterfeit are the same as those of the brand-name product.

In the market where some consumers are proactive, although consumers cannot distinguish the deceptive counterfeit from the brand-name product, the deceptive counterfeiter can still find it optimal to improve his functional quality f_D above the minimum level $\underline{f}$. The reason is as follows. When f_D is improved, both aggregate demand for brand-name and counterfeit products and the fraction of deceptive counterfeits are increased. Thus the marginal benefit of improving functional quality is positive. If the marginal benefit exceeds the marginal cost, then the deceptive counterfeiter will choose his functional quality f_D^{**} above $\underline{f}$. In practice, some deceptive counterfeits reveal different levels of functional quality; for example, some fake drugs have the right active ingredients and they may even have the right amounts, while others may contain the wrong ingredients including toxic compounds (Israel 2014).

Having analyzed the equilibrium decisions of counterfeiters and distributors in licit and illicit supply chains, we next examine the effectiveness of anti-counterfeiting strategies: quality and pricing strategies in §5, and marketing, enforcement, and technology strategies in §6.

5 Anti-Counterfeiting Strategies: Quality and Price

We examine the effectiveness of quality and pricing strategies against the *non-deceptive* counterfeiter in §5.1, and against the *deceptive* counterfeiter in §5.2. Then we compare them in §5.3. In each of §5.1 and §5.2, we proceed our analysis as follows. First, we examine whether the brand-name company should choose higher/lower quality or price than the case with no counterfeiter in order to maximize her expected profit against the counterfeiter. We analyze quality and pricing strategies separately, while discussing the combined strategy towards the end of this section. In practice, quality may not be changed in a short period of time because it often involves a change of product design and specifications, whereas price can usually be changed more easily. Thus, when a counterfeit problem is urgent and requires immediate actions, the brand-name company may adjust the price of her product to combat counterfeits. For example, Wertheimer et al. (2003) propose reducing drug prices to make counterfeiting less profitable. In other cases, the brand-name company may not change her price due to the presence of counterfeits (Wee et al. 1995). For example, when luxury brands reduce their prices, they may damage their prestige, so many luxury brands rarely reduce prices (Bastien and Kapferer 2013). Instead, they improve the quality of their products by adding more features to combat counterfeits (Poddar et al. 2012). Given price p_B, let

q_B^m denote the optimal quality of the brand-name product with no counterfeiter in the market, and let q_B^* (resp., q_B^{**}) denote the optimal quality of the brand-name product in the presence of the non-deceptive (resp., deceptive) counterfeiter. Similarly, given quality q_B, let p_B^m denote the optimal price of the brand-name product with no counterfeiter, and let p_B^* (resp., p_B^{**}) denote the optimal price in the presence of the non-deceptive (resp., deceptive) counterfeiter. Second, knowing that the strategies of choosing q_B^* and p_B^* (resp., q_B^{**} and p_B^{**}) instead of q_B^m and p_B^m improve the expected profit of the brand-name company, we examine how these strategies affect the expected profit of the non-deceptive (resp., deceptive) counterfeiter. Finally, we investigate how those strategies affect expected consumer welfare, which is defined as follows.

When only brand-name products exist in the market, we can define consumer welfare as $CS_B = \int_{\frac{p_B}{q_B}}^1 (\theta q_B - p_B) d\theta$. Similarly, we can define CS_N or CS_D as consumer welfare in the market where non-deceptive or deceptive counterfeits co-exist with brand-name products, respectively, as follows:

$$CS_N = \int_{\widehat{\theta}}^{\widetilde{\theta}} (\theta q_N - p_N)\, d\theta + \int_{\widetilde{\theta}}^1 (\theta q_B - p_B) d\theta, \text{ where } \widehat{\theta} = \tfrac{p_N}{f_N + \beta q_B} \text{ and } \widetilde{\theta} = \tfrac{p_B - p_N}{(1-\beta) q_B - f_N};$$
$$CS_D = s \int_{\bar{\theta}}^1 (\theta q_D - p_B)\, d\theta + (1-s) \int_{\bar{\theta}}^1 (\theta q_B - p_B)\, d\theta, \text{ where } \bar{\theta} = \tfrac{\lambda p_B}{(1-s) q_B + s q_D} + \tfrac{(1-\lambda) p_B}{q_B}.$$

The first term of CS_N represents the surplus of those consumers who purchase the non-deceptive counterfeit, and the second term represents the surplus of those consumers who purchase the brand-name product. The first term of CS_D represents the surplus of those consumers who are cheated and receive the deceptive counterfeit, and the second term represents the surplus of those consumers who purchase and receive the brand-name product. Considering the chances that counterfeits do not reach the market due to seizure, we can further define ECS_N or ECS_D as the *expected* consumer welfare when the counterfeiter is non-deceptive or deceptive, respectively, as follows:

$$ECS_N = (1-\gamma) CS_N + \gamma CS_B \text{ and } ECS_D = (1-\gamma) CS_D + \gamma CS_B.$$

Let ECS_N^* or ECS_D^{**} denote the corresponding expected consumer welfare in equilibrium. We can show that $ECS_D^{**} < CS_B < ECS_N^*$. Intuition from this result is as follows. When non-deceptive counterfeits exist in the market, a consumer has a cheap alternative to the brand-name product. In equilibrium, the non-deceptive counterfeiter sets his price and functional quality such that he offers a higher utility to those consumers who enjoy the brand value of the brand-name product but do not appreciate its high quality or cannot afford its high price. Therefore, non-deceptive counterfeits improve consumer welfare. In contrast, when deceptive counterfeits exist, some consumers are cheated to receive low-quality deceptive counterfeits, resulting in a welfare loss. Note that we do not consider the socio-economic effects of counterfeiting on criminal activities, employment, innovation, tax revenues, and so on. If taking into account these indirect or long-term effects into account, then non-deceptive counterfeits may also decrease consumer welfare.

5.1 Non-Deceptive Counterfeits

This subsection examines the brand-name company's strategies against the *non-deceptive* counterfeiter. We first examine the brand-name company's *quality* strategy to combat the non-deceptive counterfeiter. In the following, we present the results for the case when the quality of the non-deceptive counterfeit is either low (i.e., $f_N^* = \underline{f}$) or high (i.e., $f_N^* = \overline{f}$), since the exposition of our results is much simpler in this case, while presenting the results for the case when $f_N^* \in (\underline{f}, \overline{f})$ in online appendix (which involve complex conditions for parts (a) and (c) of Proposition 1).

Proposition 1 *Suppose the quality of the non-deceptive counterfeit is either low (i.e., $f_N^* = \underline{f}$) or high (i.e., $f_N^* = \overline{f}$). Then:*

(a) To combat the non-deceptive counterfeiter, the brand-name company should choose a higher quality than that without counterfeits (i.e., $q_B^* > q_B^m$) if and only if $\beta < 1 - \left\{\frac{q_B^m - q_N^*(q_B^m)}{q_B^m}\right\}^2$.

(b) When the brand-name company chooses a higher (resp., lower) quality than that without counterfeits, the non-deceptive counterfeiter obtains a lower (resp., higher) expected profit (π_N^*).

(c) When the brand-name company chooses a higher (resp., lower) quality than that without counterfeits, the expected consumer welfare (ECS_N^*) is higher (resp., lower) unless the non-deceptive counterfeiter reduces his quality level from high to low.

We first consider the case when the non-deceptive counterfeit draws an insignificant amount of brand value from the brand-name product (i.e., $\beta < 1 - \{q_B^m - q_N^*(q_B^m)\}^2/(q_B^m)^2$). In this case, Proposition 1(a) shows that the brand-name company should set her product quality higher than q_B^m to combat the non-deceptive counterfeiter. This strategy not only improves the expected profit of the brand-name company, but also decreases the expected profit of the non-deceptive counterfeiter (Proposition 1(b)). In this case, even though the improved quality of the brand-name product also improves the quality of the non-deceptive counterfeit, the difference in quality between two competing products becomes larger because the counterfeit steals only a small part of the brand value. Consequently, the non-deceptive counterfeiter will lose its quality competition against the brand-name company. This result may explain how the shoe manufacturers mentioned in §1 successfully addressed their counterfeiting issues by improving the quality of their products. Finally, Proposition 1(c) shows that, although this strategy improves the expected profit of the

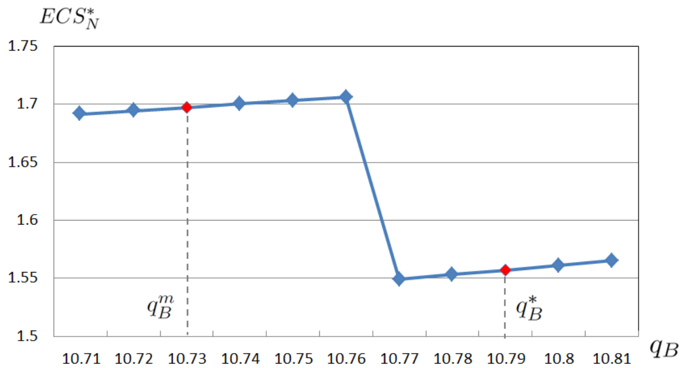

Figure 1: Expected consumer welfare as a function of the brand-name product quality when non-deceptive counterfeits are present in the market

brand-name company and reduces the expected profit of the non-deceptive counterfeiter, it does *not always* benefit consumers. This is because this strategy can lead the non-deceptive counterfeiter to lower his functional quality. In this case, consumers who purchase non-deceptive counterfeits suffer from lower functional quality, resulting a welfare loss. For example, Figure 1 illustrates that the expected consumer welfare ECS_N^* falls when the brand-name product's quality q_B is increased from $q_B^m = 10.73$ to $q_B^* = 10.79$.

Next, we consider the case when the non-deceptive counterfeit draws a significant amount of brand value from the brand-name product (i.e., $\beta > 1 - \{q_B^m - q_N^*(q_B^m)\}^2/(q_B^m)^2$). In this case, Proposition 1(a) shows it is optimal for the brand-name company to lower her product quality because the costly improvement of the brand-name product will benefit the non-deceptive counterfeiter significantly. While this strategy improves the expected profit of the brand-name company, it can help the non-deceptive counterfeiter earn higher expected profit inadvertently (Proposition 1(b)), and make consumers suffer from poor quality (Proposition 1(c)). Therefore, in this case, the brand-name company may not use this strategy to combat the non-deceptive counterfeiter.

The following proposition shows how the brand-name company can combat the non-deceptive counterfeiter through her *pricing* strategy.

Proposition 2 *(a) To combat the non-deceptive counterfeiter, the brand-name company should choose a lower price than that without counterfeits (i.e., $p_B^* < p_B^m$) for all β.*

(b) When the brand-name company chooses a lower price than that without counterfeits, the non-deceptive counterfeiter obtains a lower expected profit (π_N^*).

(c) When the brand-name company chooses a lower price than that without counterfeits, the expected

consumer welfare (ECS^*_N) is higher unless the non-deceptive counterfeiter reduces his quality level from high (i.e., $f^*_N = \overline{f}$) to low (i.e., $f^*_N = \underline{f}$) or $\frac{\partial f^*_N}{\partial p_B}$ is sufficiently high for $f^*_N \in (\underline{f}, \overline{f})$.

In contrast to the quality strategy, Proposition 2(a) shows that for any β, the brand-name company should set her price lower than p^m_B to combat the non-deceptive counterfeiter. This is because a lower price enables the brand-name company to compete better against non-deceptive counterfeits which are cheap alternatives of brand-name products. This strategy helps the brand-name company to gain more market share by inducing some consumers to switch from non-deceptive counterfeits to brand-name goods. As a result, this strategy also reduces the expected profit of the non-deceptive counterfeiter (Proposition 2(b)). We further find that the larger β is, the faster the expected profit of the non-deceptive counterfeiter will decrease. This is because the brand-name company relies more on price to compete with the non-deceptive counterfeiter when the quality levels of two products are not so distinguished due to the larger β. However, similar to the quality strategy, Proposition 2(c) shows that reducing price p_B can hurt consumers by inducing the non-deceptive counterfeiter to reduce his quality level. This strategy has been used in practice: for example, to combat rampant DVD piracy in Russia (Arvedlung 2004).

5.2 Deceptive Counterfeits

This subsection examines the brand-name company's anti-counterfeiting strategies against the *deceptive* counterfeiter. As we will show below, most effects of these strategies are monotonic when no proactive consumers exist in the market (i.e, $\lambda = 0$), whereas all effects of these strategies are non-monotonic when proactive consumers exist in the market (i.e., $\lambda > 0$). Thus, we first examine the former case analytically to establish monotonic results, and then conduct a numerical study for the latter case to show non-monotonicity. This approach will enable us to isolate the effect of λ, and to explore dominant effects of anti-counterfeiting strategies when positive λ creates non-monotonic effects. Note that the results under $\lambda = 0$ also bear some practical relevance (asymptotically) because only a small fraction of consumers may be proactive in developed countries; for example, $\lambda = 0.04$ in the U.S. in our survey results shown in Table 1.

Let us first analyze the case when no consumers are proactive. The following proposition shows, counter-intuitively, that by setting the *quality* level lower than that without counterfeits in the market, the brand-name company can improve her expected profit, reduce the expected profit of the deceptive counterfeiter, and even improve expected consumer welfare.

Proposition 3 *Consider the market in which no consumers are proactive (i.e, $\lambda = 0$).*

(a) To combat the deceptive counterfeiter, the brand-name company should choose a lower quality than that without counterfeits (i.e., $q_B^{**} < q_B^m$).

(b) When the brand-name company chooses a lower quality than that without counterfeits, the deceptive counterfeiter obtains a lower expected profit (π_D^{**}).

(c) When the brand-name company chooses a lower quality than that without counterfeits, the expected consumer welfare (ECS_D^{**}) is higher as long as the quality of deceptive counterfeits (q_D^{**}) is sufficiently low.

Proposition 3(a) states that the brand-name company should choose a lower quality level to combat the deceptive counterfeiter. Because consumers cannot distinguish deceptive counterfeits from brand-name products, this strategy reduces the perceived quality of all products in the market, and thus reduces the aggregate demand for both brand-name and counterfeit goods. However, the reduced aggregate demand discourages the licit distributor from taking the risk of selling deceptive counterfeits. The result stated in Proposition 3(a) shows that the latter (positive) effect dominates the former (negative) effect, so this strategy improves the expected profit of the brand-name company. This result highlights the importance of modeling the incentive of the licit distributor in this supply chain: Without the licit distributor, the positive effect of this strategy would not exist and therefore the result opposite to Proposition 3(a) would be obtained. Because this strategy reduces both the aggregate demand and the proportion of deceptive counterfeits sold by the licit distributor, it will also reduce the expected profit of the deceptive counterfeiter (Proposition 3(b)). More generally, even when consumers are proactive (i.e., $\lambda > 0$), we show in the proof that the expected profit of the deceptive counterfeiter increases with the quality of the brand-name product because the deceptive counterfeit gets a free ride on the brand name of the genuine product. Therefore, the brand-name company should be aware of this adverse effect when confronting a deceptive counterfeiter. For example, as the market size of the Scotch whisky company mentioned in §1 grew from 180,000 cases to 380,000 cases, the counterfeiters substantially broadened their activities and took 42% sales (Green and Smith 2002). Similarly, in the pharmaceutical industry, high-demand drugs have the most serious counterfeit problem (Bull World Health Organ 2010). Finally, contrary to our first intuition that lower quality will hurt consumers, Proposition 3(c) suggests that this strategy can improve consumer welfare. To understand this result, note that there are two opposing effects of having lower quality of brand-name products on consumer welfare: Consumers suffer from lower quality and fewer consumers buy products, but at the same time fewer consumers are deceived to buy low-quality counterfeits. Proposition 3(c) shows that when the quality of deceptive counterfeits is sufficiently low, the latter effect outweighs the former effect, benefiting consumers.

We next examine the effectiveness of the *pricing* strategy against the deceptive counterfeiter.

Proposition 4 *Consider the market in which no consumers are proactive (i.e, $\lambda = 0$).*

(a) To combat the deceptive counterfeiter, the brand-name company should choose a higher price than that without counterfeits (i.e., $p_B^{**} > p_B^m$).

(b) When the brand-name company chooses a higher price than that without counterfeits, the deceptive counterfeiter can obtain a higher or lower expected profit (π_D^{**}).

(c) When the brand-name company chooses a higher price than that without counterfeits, the expected consumer welfare (ECS_D^{**}) is higher as long as the quality of deceptive counterfeits (q_D^{**}) is sufficiently low.

With no proactive consumers in the market, Proposition 4(a) states that the brand-name company should increase her price to improve her expected profit against the deceptive counterfeiter (due to the reason similar to Proposition 3(a)). Unlike the quality strategy, however, this pricing strategy has non-monotonic impact on the expected profit of the deceptive counterfeiter (Proposition 4(b)). To understand this result, note that there are two effects of raising her price p_B : (i) it reduces the aggregate demand for brand-name and counterfeit goods; and (ii) it increases the distributor's margin from selling deceptive counterfeits. Because of the latter effect, the strategy of raising the price does not always reduce the proportion of deceptive counterfeits the licit distributor sells, nor does it always reduce the deceptive counterfeiter's market share and his expected profit. Therefore, in implementing this pricing strategy, one should carefully consider these two counterbalancing effects of raising/reducing price. In practice, we observe both instances of raising or reducing prices: Wertheimer et al. (2003) propose reducing drug prices to make counterfeiting less attractive by reducing the profit margins of fake drugs (i.e., opposite effect of (ii)), and Russia plans to raise vodka prices to put out of business makers of counterfeit alcohol (via effect (i)) although it will also affect licit companies (Reuters 2012). Finally, Proposition 4(c) suggests that this strategy can improve consumer welfare when the quality of deceptive counterfeits is sufficiently low. We can interpret this result similarly to Proposition 3(c).

Next, we analyze the case in which proactive consumers exist in the market (i.e., $\lambda > 0$). As we have mentioned earlier, this additional factor causes all the effects of the anti-counterfeiting strategies to become non-monotonic. Specifically, the brand-name company's quality q_B^{**} (resp., p_B^{**}), can be higher or lower than q_B^m without counterfeits (resp., p_B^m); furthermore, the deceptive counterfeiter's expected profit π_D^{**} and the expected consumer welfare ECS_D^{**} are non-monotonic with a change of q_B or p_B. Because the closed-form expressions of s^{**}, w_D^{**} and f_D^{**} do not exist in this case, no simple conditions can be derived analytically for monotonic results (see remarks on the proofs of Propositions 3 and 4 in online appendix). For this reason, we conduct a numerical study to compare the results under $\lambda = 0$ with those under $\lambda > 0$, and explore dominant effects. The numerical experiments are conducted with the following settings: for each of $\lambda = 0$, 0.25 or 0.5, we constructed 1024 scenarios using the following parameter values: $t \in \{0.005, 0.01, 0.015, 0.02\}$, $\beta \in \{0.1, 0.2, 0.3, 0.4\}$, $\gamma \in \{0.1, 0.2, 0.3, 0.4\}$, $l \in \{0.005, 0.01, 0.015, 0.02\}$, $c_B \in \{0.1, 0.2, 0.3, 0.4\}$, $h = 0$, $\underline{f} = 0.1$ and $\overline{f} = (1-\beta)q_B - 0.1$. The parameters are chosen so that they cover various possible scenarios. We present a summary of the results in Table 3, which reads as follows: for example, when $\lambda = 0.5$, $q_B^{**} < q_B^m$ was observed in 97.3% of 1024 scenarios, and choosing q_B^{**} reduced π_D^{**} in 97.3% of 1024 scenarios and increased ECS_D^{**} in 5.3% as compared to choosing q_B^m.

Table 3. Effects of Quality and Pricing Strategies against Deceptive Counterfeits

	Effects of Choosing q_B^{**} vs. q_B^m			Effects of Choosing p_B^{**} vs. p_B^m		
	$q_B^{**} < q_B^m$	$\pi_D^{**} \downarrow$	$ECS_D^{**} \uparrow$	$p_B^{**} > p_B^m$	$\pi_D^{**} \downarrow$	$ECS_D^{**} \uparrow$
$\lambda = 0$	1	1	0.032	1	0.097	0.016
$\lambda = 0.25$	0.961	0.961	0.052	0.989	0.398	0.048
$\lambda = 0.5$	0.973	0.973	0.053	0.984	0.454	0.039

From Table 3, we can observe the following:

(1) The results obtained under $\lambda = 0$ continue to hold in most scenarios under $\lambda > 0$. However, in some scenarios, the brand-name company finds it optimal to set $q_B^{**} > q_B^m$ or $p_B^{**} < p_B^m$. We can explain this result as follows. First, recall from our discussions above that setting lower quality q_B^{**} or higher price p_B^{**} reduces the aggregate demand for brand-name and counterfeit goods, and that the reduced aggregate demand discourages the licit distributor from taking the risk of selling counterfeits. Propositions 3(a) and 4(a) suggest that the latter (positive) effect always dominates the former (negative) effect when $\lambda = 0$. However, with proactive consumers in the market (i.e., $\lambda > 0$), the deceptive counterfeiter may improve his functional quality f_D^{**} in response to the reduced demand (see Lemma 2). This additional factor makes the licit distributor more willing to sell counterfeits, so that the positive effect does not always dominate the negative effect.

(2) In those scenarios where $q_B^{**} > q_B^m$, the strategy of setting higher quality q_B^{**} will increase the deceptive counterfeiter's expected profit π_D^{**} by making counterfeits flourish more in the market. This happens because the improved quality of the brand-name product results in an increase of the aggregate demand of brand-name and counterfeit goods, which in turn incentivizes the licit

distributor to procure more deceptive counterfeits. This may be the cause of the initial failure of the Scotch whisky company which improved her quality to combat deceptive counterfeits (see §1). Also, from the table, we confirm that the deceptive counterfeiter's expected profit is non-monotonic in price p_B for any $\lambda \geq 0$, which can be explained similarly to Proposition 4(b).

(3) The expected consumer welfare ECS_D^{**} has increased in more scenarios in the market with $\lambda > 0$ than in the market with $\lambda = 0$. Similar to our explanation given in (1) above, this is because the counterfeiter may improve his functional quality f_D^{**} with proactive consumers. In general, for any $\lambda \in [0, 1]$, we can show that if an anti-counterfeiting strategy improves the average product quality in the market, then it improves the expected consumer welfare.

(4) Anti-counterfeiting strategies are *not necessarily* more effective as more consumers are proactive. We observe that the number of scenarios in which the deceptive counterfeiter's expected profit is decreased or the expected consumer welfare is increased is not necessarily monotonic in λ. For example, a change from q_B^m to q_B^{**} decreases the expected profit in all scenarios when $\lambda = 0$, in 96.1% when $\lambda = 0.25$, and in 97.3% when $\lambda = 0.5$. Similarly, we can show that more proactive consumers in the market do not necessarily benefit the brand-name company. The reason is as follows. Proactive consumers purchase products only when their expected utility is non-negative, considering the likelihood of receiving deceptive counterfeits unknowingly. As a result, with more proactive consumers, a smaller number of consumers will purchase products. This reduced aggregate demand for products discourages the licit distributor from taking the risk of selling deceptive counterfeits. Thus, depending on which of the two effects (i.e., reduced aggregate demand and reduced proportion of counterfeits) dominates, the expected profit of the brand-name company as well as her market share may increase or decrease with more proactive consumers.

5.3 Comparison

We now compare the effect of each strategy against the *non-deceptive* counterfeiter with that against the *deceptive* counterfeiter. Using the results presented in §5.1 and §5.2, we summarize in Table 4 whether the brand-name company should choose higher/lower quality or price than the case with no counterfeiter in order to maximize her expected profit, and how such anti-counterfeiting strategies affect the expected profit of the counterfeiter and the expected consumer welfare. (If a dominant effect exists for a non-monotonic case, Table 4 reports only the dominant effect.)

Table 4. Effects of Anti-Counterfeiting Strategies: Non-Deceptive vs. Deceptive

Non-Deceptive Counterfeits			Deceptive Counterfeits		
Optimal Strategy	π_N^*	ECS_N^*	Optimal Strategy	π_D^{**}	ECS_D^{**}
$q_B^* > q_B^m$ (low β)	$\downarrow$	$\uparrow$	$q_B^{**} < q_B^m$	$\downarrow$	$\uparrow$ (low q_D^{**}) or $\downarrow$ (high q_D^{**})
$q_B^* < q_B^m$ (high β)	$\uparrow$	$\downarrow$			
$p_B^* < p_B^m$	$\downarrow$	$\uparrow$	$p_B^{**} > p_B^m$	$\updownarrow$	$\uparrow$ (low q_D^{**}) or $\downarrow$ (high q_D^{**})

From Table 4, we can draw the following insights:

(1) The optimal strategy of the brand-name company (that maximizes her expected profit) differs depending on whether she faces the non-deceptive or deceptive counterfeiter. For example, reducing price is optimal against the non-deceptive counterfeiter, whereas raising price is optimal against the deceptive counterfeiter.

(2) Even when the optimal strategy of the brand-name company is the same against both types of counterfeiters, its impact on the counterfeiter's expected profit and the expected consumer welfare may not be the same. For example, when the non-deceptive counterfeit draws a significant amount of brand value (i.e., high β), setting a lower quality level than that without counterfeits improves the brand-name company's expected profit against either type of the counterfeiter. This strategy is effective against the deceptive counterfeiter (i.e., reduces π_D^{**}), but it does not work well against the non-deceptive counterfeiter (i.e., increases π_N^*). Moreover, its impact on the expected consumer welfare may not be the same across the two types of counterfeiters, either.

(3) An ideal anti-counterfeiting strategy should improve the brand-name company's expected profit, reduce the counterfeiter's expected profit, and improve the expected consumer welfare. The pricing strategy is such an ideal strategy against the non-deceptive counterfeiter. For the other cases, the brand-name company or the government should carefully consider a trade-off among those three objectives in implementing an anti-counterfeiting strategy.

Lastly, we remark on two issues in the above analysis. First, our analyses so far have examined whether the brand-name company should choose higher/lower quality or price for each type of a counterfeiter. We show in online appendix that when the brand-name company can save large costs of developing her product, the quality strategy is more profitable than the price strategy in combating either type of a counterfeiter. Second, although we have analyzed the quality and pricing strategies separately, our results have implications for the anti-counterfeiting strategy that combines both quality and pricing strategies. Consider a market with *non-deceptive* counterfeits which steal a significant amount of brand value (i.e., high β). In this case, the existence of non-deceptive counterfeits yields lower optimal quality and price of the brand-name product than those in the monopoly case (see Propositions 1(a) and 2(a)). It is well-known that an optimal price of a product in a monopoly market is increasing with the product quality. If we apply this result to a market with non-deceptive counterfeits, the reduced quality of the brand-name product lowers its optimal price even further than the optimal monopoly price. This implies that the brand-name company should choose lower quality and lower price than the monopoly quality and price, respectively. Next, consider a market with *non-deceptive* counterfeits in which β is low. In this case, Propositions 1(a) and 2(a) have shown that the existence of non-deceptive counterfeits changes the quality and price of the brand-name product in opposite directions. Because an optimal price of a product in a monopoly market is increasing with the product quality, there is a counteracting force that may affect the price in the same direction as the quality. As a result, our numerical study shows that the optimal quality and price can be higher or lower than the monopoly quality and price, respectively. However, even when it is optimal for the brand-name company to set a higher price than the monopoly price, she may not raise her price too high due to Proposition 2(a). Likewise, in a market with *deceptive* counterfeits, where the existence of counterfeits changes the quality and price of the brand-name product in opposite directions, a brand-name company may increase or decrease quality and price simultaneously. Therefore, special care needs to be taken when implementing the combined strategy.

6 Marketing, Enforcement, and Technology Strategies

In this section, we consider three other anti-counterfeiting strategies that are often used in practice. The first strategy is the marketing campaign that educates consumers about the adversity of counterfeit goods. For example, French luxury goods association Comite Colbert launched a campaign (using playful slogans such as "real ladies don't like fake") in response to the threat of the counterfeit (Wellman 2012). This strategy helps reduce the brand value the counterfeit steals from the brand-name product, i.e., reduce β. The second strategy is the direct enforcement effort to increase the chances to seize counterfeit products, γ. For example, the French police raided the clandestine workshops making Hermes counterfeit accessories, of which the surveillance was part of an investigation into the international crime ring that robs many brands (Wellman 2012). Lastly, the brand-name company may increase the technological complexity of her product to make it more difficult and expensive to counterfeit by increasing t. For example, the Scotch whisky company mentioned in §1 introduced a bottle with a special design so that the counterfeit cannot easily imitate the original product (Green and Smith 2002). In the following, we examine how reducing

β or increasing γ or t will affect firms' expected profits and expected consumer welfare.

First, let us consider the market in which the brand-name company faces the *non-deceptive* counterfeiter. It is intuitive that all three strategies will improve the expected profit of the brand-name company and reduce the expected profit of the non-deceptive counterfeiter. However, we can show that these strategies will hurt expected consumer welfare for the following reasons. The market campaign makes those consumers who purchase non-deceptive counterfeits enjoy the counterfeit brand less, resulting in a welfare loss. The enforcement strategy makes counterfeits less likely to reach the market, so consumers will suffer from less availability of non-deceptive counterfeits, which are cheaper substitutes for brand-name goods. The technology strategy makes the non-deceptive counterfeiter more reluctant to invest in quality improvement, and thus consumers will suffer from lower quality of the product. As an alternative strategy, the brand-name company may consider introducing a low-price (and low-quality) variant of the product. For example, East African Breweries launched a cut-price beer, called "Senator Keg", to help reduce the demand for illicit alcohol (The Economist 2010). This strategy may reduce the market share of the non-deceptive counterfeit because price-sensitive consumers may find such a low-price brand-name product a better alternative to the counterfeit. At the same time, this strategy may increase consumer welfare by introducing more competition into the market.

Next, we examine the effectiveness of these anti-counterfeiting strategies against the *deceptive* counterfeiter. The following proposition shows that the effectiveness of each strategy differs significantly from that against the non-deceptive counterfeiter. In online appendix, we further study how different values of λ affect the effectiveness of these strategies numerically.

Proposition 5 *Consider the market in which deceptive counterfeits exist.*
(a) (Marketing) When no consumers are proactive (i.e., $\lambda = 0$), reducing β has no impact on the profits of the brand-name company (π_B^{**}) and the deceptive counterfeiter (π_D^{**}), whereas it decreases the expected consumer welfare (ECS_D^{**}). When some consumers are proactive (i.e., $\lambda > 0$), reducing β decreases π_D^{**}, but it can increase or decrease π_B^{**} and ECS_D^{**}.
(b) (Enforcement) When $\lambda = 0$, increasing γ improves π_B^{**}, reduces π_D^{**}, and improves ECS_D^{**}. When $\lambda > 0$, increasing γ reduces π_D^{**}, but it can increase or decrease π_B^{**} and ECS_D^{**}.
(c) (Technology) When $\lambda = 0$, increasing t improves π_B^{**}, reduces π_D^{**}, and improves ECS_D^{**}. When $\lambda > 0$, increasing t reduces π_D^{**}, but it can increase or decrease π_B^{**} and ECS_D^{**}.

Proposition 5(a) suggests that special care must be taken when implementing the marketing campaign against the deceptive counterfeiter. For the case when no consumers are proactive, the marketing campaign has no impact on the firms' expected profits because consumers do not take into account the possibility of receiving counterfeits unknowingly. This result is expected. On the other hand, proactive consumers correctly expect that they will derive less utilities when receiving deceptive counterfeits unknowingly. Thus, when some consumers are proactive, the marketing campaign can reduce the expected profit of the deceptive counterfeiter by discouraging proactive consumers from purchasing products. However, it could backfire the brand-name company because proactive consumers reduce their consumption of brand-name products as well. Finally, unlike the case when no consumers are proactive, this strategy could improve expected consumer welfare when some consumers are proactive. The reason is as follows. As mentioned above, this strategy may reduce the overall demand for the authentic good and its deceptive counterfeit. As a result, although consumers enjoy the counterfeit less, fewer of them may receive low-quality deceptive counterfeits. When the latter effect outweighs the former effect, this strategy benefits consumers.

Proposition 5(b) shows that when no proactive consumers exist in the market, the enforcement strategy works well against the deceptive counterfeiter. However, contrary to a common belief, this strategy may reduce the expected profit of the brand-name company and also hurt expected consumer welfare in the market where proactive consumers exist. This result can be explained as follows. Similar to the impact of this strategy on the non-deceptive counterfeiter (discussed above), by increasing the risk of counterfeiting, this strategy makes the deceptive counterfeiter reluctant to invest in quality improvement. While the lower quality of *non-deceptive* counterfeits helps the brand-name company regain its market share in quality competition, the lower quality of *deceptive* counterfeits reduces the perceived quality of products in the market with proactive consumers, hence reducing the aggregate demand for both brand-name goods and deceptive counterfeits. In this case, consumers also suffer from the lower quality of deceptive counterfeits although fewer consumers will receive deceptive counterfeits unknowingly.

Proposition 5(c) shows that the technology strategy has the same impact as the enforcement strategy. The reason is as follows. The enforcement strategy increases the expected loss of the counterfeiter from a potential seizure. Similarly, if the brand-name product becomes more complex, then it will be more costly for a counterfeiter to imitate the brand-name product, hence reducing his expected profit from selling counterfeits. Therefore, both anti-counterfeiting strategies will reduce the incentive of the counterfeiter to develop high-quality goods.

7 Extension: Alternative Models for Counterfeiting Risks

In this section, we extend our base model to the case where the probability of counterfeits getting confiscated is a decreasing function of their functional quality. This is plausible in some situations because those consumers who have suffered from the low quality of counterfeits can report them to the authorities, which may lead to the raid of counterfeit factories or distributors. For example, soon after the infusion of fake Avastin, a lung-cancer patient became nauseous and feverish (Whalen 2014). If fake Avastin had worked as well as its genuine one, it might have been difficult to infer that Avastin the patient received was counterfeit.

Specifically, suppose that a counterfeiter will get caught by the authorities with the probability of $\gamma - \delta_1 f_i$ for $i = N$ or D, and that a licit distributor will get caught with the probability of $s - \delta_2 f_D$. We assume $\delta_1 > 0$ and $\delta_2 > 0$, so that the lower the quality of counterfeit goods, the higher the detection probabilities become. We do not consider the case where the probability of the *illicit* distributor getting caught for selling *non-deceptive* counterfeits is decreasing with the quality of non-deceptive counterfeits. Such a case is unlikely in practice because consumers already know what they purchase. Furthermore, this probability does not affect our results due to our assumption that the penalty to the illicit distributor $l_N = 0$ (see §3).

We first examine the counterfeiter's quality decision. As in Lemma 1, the non-deceptive counterfeiter chooses $f_N^* = \underline{f}$ or $f_N^* > \underline{f}$ depending on the value of t and whether $\pi_N^*(\underline{f}) \geq \pi_N^*(\overline{f})$. However, contrary to Lemma 2, the deceptive counterfeiter may choose $f_D^{**} > \underline{f}$ even without proactive consumers because high-quality counterfeits can induce the licit distributor to procure more counterfeits by reducing his probability of getting caught. These results lead to the following results regarding the effectiveness of anti-counterfeiting strategies.

Corollary 1 *Suppose the probability of a counterfeiter getting caught is $\gamma - \delta_1 f_i$ for $i = N$ or D, and the probability of a licit distributor getting caught is $s - \delta_2 f_D$, where $\delta_1 > 0$ and $\delta_2 > 0$. Then:*
(a) Proposition 1 continues to hold.
(b) Propositions 2, 3 and 4 continue to hold except that the conditions in part (c) are different.
(c) Proposition 5 continues to hold except that increasing γ or t *can increase or decrease the expected profit of the brand-name company (π_B^{**}) and the expected consumer welfare (ECS_D^{**}) when no consumers are proactive (i.e., $\lambda = 0$).*

Corollary 1 shows that the general risk model in this section affects only the impact of enforcement and technology strategies (that increase γ and t respectively) on the expected profit of the brand-name company (π_B^{**}) and the expected consumer welfare (ECS_D^{**}) when combating the *deceptive* counterfeiter. In the base model, Proposition 5 has shown that these strategies always improve π_B^{**} and ECS_D^{**} when no consumers are proactive. However, Corollary 1(c) shows that they can either increase or decrease π_B^{**} and ECS_D^{**} even when no consumers are proactive. The intuition is as follows. In the base model, when no consumers are proactive, the optimal functional quality f_D^{**} of the deceptive counterfeiter is always $\underline{f}$. However, as we have discussed above, in the extended model, $f_D^{**} > \underline{f}$ is possible even when no consumers are proactive. In this case, as the investment for quality improvement becomes more risky with higher γ or t, the deceptive counterfeiter may find it optimal to reduce f_D^{**}. This in turn increases the risk of the licit distributor selling counterfeits (through $\delta_2 f_D$) as well as his own risk of getting caught (through $\delta_1 f_D$). As a result of these two opposing effects, we find that increasing γ or t can increase or decrease f_D^{**}. When f_D^{**} is increased, it will reduce the risk of the licit distributor selling deceptive counterfeits, hence increasing the fraction of deceptive counterfeits; consequently, it could hurt the expected profit of the brand-name company, π_B^{**}. On the other hand, when f_D^{**} is decreased, consumers will suffer from the lower quality of deceptive counterfeits; thus, it could reduce the expected consumer welfare ECS_D^{**}.

Lastly, note that the probability of *deceptive* counterfeits getting confiscated in our model does not depend on the quality of the brand-name product. For example, for products such as milk, gasoline and drug, consumers cannot verify active ingredients, so higher quality of a branded good does not require a counterfeiter to spend more money in masquerading as branded products in order to deceive consumers. However, in some cases (e.g., auto spare part), quality changes might be related to the characteristics that consumers can identify when they make purchases. In such cases, it may be plausible that the quality improvement of the brand-name product makes it more difficult for the deceptive counterfeiter to masquerade as the branded product. We may model this by setting the confiscation probability of a deceptive counterfeiter as $\gamma - \delta_1^{'}(f_D - f_B)$ instead of $\gamma - \delta_1 f_D$, and by setting the confiscation probability of a licit distributor as $s - \delta_2^{'}(f_D - f_B)$ instead of $s - \delta_2 f_D$, where f_B is the functional quality of the brand-name product. In this case, if $\delta_1^{'}$ or $\delta_2^{'}$ is sufficiently large, it is possible that the optimal quality of the brand-name product q_B^{**} is higher than q_B^m in the monopoly market; i.e., the brand-name company may improve the quality so as to increase the probability of the deceptive counterfeit being detected.

8 Concluding Remarks

Today counterfeit products are being produced and consumed in virtually all economies (OECD 2008). While easy-to-manufacture goods had dominated counterfeit supply until a decade ago, there has been an alarming expansion of product categories being infringed. As a result of outsourcing and offshoring, counterfeiters have easy access to modern technology and equipment, and they are capable of producing high-quality replicas. Consumers are not easily deceived by fake goods that are sold by vendors in open markets and unknown internet sites. These changing business conditions require industry and governments to enhance their understanding of the current and potential counterfeiters and to develop strategies to limit their activities.

To aid the efforts of industry and governments to combat counterfeiting, we have developed a normative model of counterfeiting. Our model captures the recent changes in counterfeiting supply and demand that are not addressed in the previous literature. For example, the previous literature focuses on the pricing decision of a counterfeiter, assuming that the quality level of his goods is fixed, and he is capable of selling his goods, even deceptive ones, directly to consumers. In contrast, our model takes into account the strategic decisions of a counterfeiter regarding his price and functional quality; and the fundamental difference between non-deceptive and deceptive counterfeits in consumers' awareness, distribution channels, and penalty on illegal production and distribution. We have also considered the case when a fraction of consumers are proactive. Modeling these factors explicitly enables us to evaluate several anti-counterfeiting strategies against both types of counterfeiters, and to draw novel managerial insights.

Our analysis highlights that the strategies which are effective in combating the *non-deceptive* counterfeiter may not work well against the *deceptive* counterfeiter. Moreover, even if strategies help the brand-name company improve her expected profit, they may not be effective in limiting counterfeit activities, and they can even hurt consumers. Specifically;

- To combat the non-deceptive counterfeiter, the brand-name firm should improve her quality if the non-deceptive counterfeit steals an insignificant amount of brand value, and reduce the product price. The firm, governments and regulatory bodies can use marketing campaigns, enforcement and technology strategies to reduce the counterfeiter's profit, although these strategies may hurt consumers.
- To combat the deceptive counterfeiter, the brand-name firm should lower her quality (unless high brand-name quality facilitates the seizure of deceptive counterfeits significantly), and may raise the product price although this may benefit the deceptive counterfeiter inadvertently. The firm,

governments, and regulatory bodies can use marketing campaigns, enforcement and technology strategies when there are few proactive consumers, but these strategies may hurt the brand-name firm and consumers when a significant portion of consumers is proactive.

In summary, industries and governments should understand the type of potential counterfeiters and the characteristics of consumers in order to design effective strategies to combat counterfeits. Without such understanding, anti-counterfeiting strategies could be ineffective and hurt consumers.

There are several interesting future research avenues. First, it will be interesting to consider the effect of positive or negative externality of counterfeits on brand-name products. For some product categories, counterfeits help to increase the size of user base of brand-name products, which refers to positive externality. A typical example is software piracy (Conner and Rumelt 1991). The negative externality of counterfeits refers to the negative impact of counterfeits on the value of a brand. More counterfeits in the market, less prestigious the brand becomes. Second, consumers show risk-prone or irrational behavior in some situations. For example, fraudsters use their phony pharmaceutical websites to take advantage of the recent swine-flu fears. Some consumers who are anxious for their children take risks of buying fake vaccines and bogus remedies from unknown websites (Taylor 2009). Behavioral research will help enrich our understanding of the risk attitudes of consumers. Third, it will be interesting to conduct a detailed cost-benefit analysis of anti-counterfeiting technologies such as technologies to authenticate products (e.g., NanoInk) and technologies to track and trace the movement of products (e.g., RFID). Our current model captures the role of these technologies to some degree: the former type of technologies is captured by the technology strategy (i.e., with such technologies installed, a counterfeiter needs to spend more effort to copy authentic goods) and the latter type of technologies is captured by the enforcement strategy (i.e., with RFID installed, the likelihood of seizing counterfeits increases). Finally, it will be interesting to validate our findings empirically using industry data. For example, the patent for Viagra, one of the most popular counterfeit drugs, has expired recently. As a result, many generic drugs have flooded the market, causing a price drop. It will be interesting to test how such a price drop has affected counterfeit sales. In general, it may be challenging to collect accurate data about counterfeit sales due to the illegal nature of counterfeit business. Thus, one may collect data in a market where intellectual property rights are not strictly enforced or in an online market where data are easier to collect than an offline market.

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Online Appendix

Appendix A. Proofs of Analytical Results

We use (A1) and (A2) to indicate the following assumptions: (A1) $q_B > q_N = f_N + \beta q_B$ and $q_B > q_D = f_D + \beta q_B$; (A2) $1 - \frac{p_B}{q_B} > 0$ and $1 - \frac{p_B - p_N}{q_B - q_N} > 0$ so that $m_B > 0$. We also use the following definition of expected consumer welfare introduced earlier:

$$ECS_N = (1-\gamma)CS_N + \gamma CS_B \text{ and } ECS_D = (1-\gamma)CS_D + \gamma CS_B. \tag{1}$$

Proof of Lemma 1: We first determine the market shares of the brand-name product and the counterfeit, and then solve the model backwards. The consumer who is indifferent between purchasing the brand-name product and the non-deceptive counterfeit has the taste $\widetilde{\theta} = \frac{p_B - p_N}{q_B - q_N} = \frac{p_B - p_N}{(1-\beta)q_B - f_N}$, which solves $\widetilde{\theta} q_N - p_N = \widetilde{\theta} q_B - p_B$. Similarly, the consumer who is indifferent between purchasing the non-deceptive counterfeit and not purchasing any product has the taste $\widehat{\theta} = \frac{p_N}{q_N} = \frac{p_N}{f_N + \beta q_B}$. Let m_0 denote the proportion of consumers who do not purchase any product, so that $m_B + m_N + m_0 = 1$. Then:

$$m_B = 1 - \widetilde{\theta} = 1 - \frac{p_B - p_N}{(1-\beta)q_B - f_N} \text{ and } m_N = \widetilde{\theta} - \widehat{\theta} = \frac{p_B - p_N}{(1-\beta)q_B - f_N} - \frac{p_N}{f_N + \beta q_B}. \tag{2}$$

In stage 3, the illicit distributor determines p_N by solving:

$$\max_{p_N} (p_N - w_N) m_N = (p_N - w_N) \left\{ \frac{p_B - p_N}{(1-\beta)q_B - f_N} - \frac{p_N}{f_N + \beta q_B} \right\}. \tag{3}$$

By noting that the profit of the illicit distributor in (3) is concave in p_N, one can easily obtain $p_N^*(w_N, f_N) = \frac{(\beta q_B + f_N)p_B + q_B w_N}{2q_B}$.

In stage 2, the non-deceptive counterfeiter determines w_N to maximize his expected profit given by:

$$\pi_N(w_N, f_N) = (1-\gamma) \left\{ w_N \left(\frac{p_B - p_N^*}{(1-\beta)q_B - f_N} - \frac{p_N^*}{f_N + \beta q_B} \right) - t f_N^2 \right\} - \gamma t f_N^2. \tag{4}$$

Since π_N is concave in w_N, we can easily obtain w_N^* and π_N^* respectively as follows:

$$w_N^*(f_N) = \frac{p_B(f_N + \beta q_B)}{2q_B} \text{ and } \pi_N^*(f_N) = \frac{p_B^2(1-\gamma)(f_N + \beta q_B)}{8q_B\{(1-\beta)q_B - f_N\}} - t f_N^2. \tag{5}$$

In stage 1, the non-deceptive counterfeiter decides f_N by solving $\max_{f_N \in [\underline{f}, \overline{f}]} \pi_N^*(f_N)$. From (5), we obtain $\frac{\partial^2 \pi_N^*}{\partial f_N^2} = \frac{(1-\gamma)p_B^2}{4\{(1-\beta)q_B - f_N\}^3} - 2t$, which is positive if $t < \frac{(1-\gamma)p_B^2}{8\{(1-\beta)q_B - f_N\}^3}$. Thus, if $t < \frac{(1-\gamma)p_B^2}{8\{(1-\beta)q_B - \underline{f}\}^3}$, π_N^* is convex in $f_N \in [\underline{f}, \overline{f}]$, so $f_N^* = \underline{f}$ when $\pi_N^*(\underline{f}) \geq \pi_N^*(\overline{f})$. Otherwise, f_N^* can be $\overline{f}$ or $f_N^* \in (\underline{f}, \overline{f})$ that satisfies $\frac{\partial \pi_N^*}{\partial f_N}|_{f_N = f_N^*} = 0$. A sufficient condition for $f_N^* > \underline{f}$ is $t < \frac{(1-\gamma)p_B^2}{16\underline{f}\{(1-\beta)q_B - \underline{f}\}^2}$, which can be obtained from $\frac{\partial \pi_N^*}{\partial f_N}|_{f_N = \underline{f}} = \frac{(1-\gamma)p_B^2}{8\{(1-\beta)q_B - \underline{f}\}^2} - 2t\underline{f} > 0$. □

Remark The initial investment $t f_N^2$ is considered a sunk cost in (4). Our main results continue to hold when the counterfeiter's investment has residual value but gets confiscated if getting caught. Also, whether the confiscation of investment occurs after stage 1 or stage 2 does not affect the counterfeiter's decisions. If confiscation occurs after some units are sold, $(1-\gamma)$ can be interpreted as the fraction of sales the counterfeiter has generated before confiscation.

Proof of Lemma 2: Similar to the proof of Lemma 1, we can obtain the market shares of the brand-name product and that of the deceptive counterfeit, respectively, as follows:

$$m_B = (1-s)(1-\bar{\theta}) \text{ and } m_D = s(1-\bar{\theta}), \tag{6}$$

where $1-\bar{\theta} \equiv 1-\frac{\lambda p_B}{(1-s)q_B+s(f_D+\beta q_B)}-\frac{(1-\lambda)p_B}{q_B}$ represents the aggregate demand for both brand-name and counterfeit products at price p_B.

In stage 3, the licit distributor solves the following problem to determine s:

$$\max_{s\in[0,1]} s(1-s)(p_B-w_D)\left\{1-\frac{\lambda p_B}{(1-s)q_B+s(f_D+\beta q_B)}-\frac{(1-\lambda)p_B}{q_B}\right\}-sl. \tag{7}$$

From (7), we can show that the profit of the distributor is strictly decreasing in s for $s \in [\frac{1}{2}-\epsilon, 1]$, where ϵ is a small and positive constant. Moreover, the profit given in (7) is concave in s for $s < \frac{1}{2}$. Thus, s^{**} is 0 or it satisfies the first order condition in $(0, 0.5)$.

In stage 2, the deceptive counterfeiter decides w_D to maximize his expected profit given by:

$$\pi_D(w_D, f_D) = (1-\gamma)\left[w_D s^{**}\left\{1-\frac{\lambda p_B}{(1-s^{**})q_B+s^{**}(f_D+\beta q_B)}-\frac{(1-\lambda)p_B}{q_B}\right\}-tf_D^2\right]-\gamma(tf_D^2+h). \tag{8}$$

By noting that π_D is continuous in $w_D \in [0, p_B]$, we know that the optimal wholesale price w_D^{**} always exists in $[0, p_B]$. In the case when $\lambda > 0$, the closed-form expressions for s^{**} and w_D^{**} do not exist. In the case when $\lambda = 0$, we can obtain from the first-order condition of (7) that $s^{**}(w_D, f_D) = \frac{1}{2} - \frac{lq_B}{2(p_B-w_D)(q_B-p_B)}$. By substituting s^{**} into (8) and solving $\max_{w_D\in[0,p_B]} \pi_D(w_D, f_D)$, we obtain w_D^{**} and π_D^{**} as follows:

$$w_D^{**}(f_D) = p_B - \sqrt{\frac{lp_B}{1-\frac{p_B}{q_B}}} \text{ and } \pi_D^{**}(f_D) = \frac{1}{2}(1-\gamma)\left\{\sqrt{p_B\left(1-\frac{p_B}{q_B}\right)}-\sqrt{l}\right\}^2 - tf_D^2 - \gamma h. \tag{9}$$

In stage 1, the counterfeiter decides the functional quality f_D by solving $\max_{f_D\in[\underline{f},\overline{f}]} \pi_D^{**}(f_D)$. When $\lambda = 0$, from (9), $\frac{\partial \pi_D^{**}}{\partial f_D} = -2tf_D < 0$, so $f_D^{**} = \underline{f}$. When $\lambda > 0$, we next show that $f_D^{**} = \underline{f}$ if $t \geq \bar{t}$. For any $f_D \in (\underline{f}, \overline{f}]$, $\pi_D^{**}(w_D^{**}(f_D), \underline{f}) \geq \pi_D^{**}(w_D^{**}(f_D), f_D)$ if $t \geq (1-\gamma)w_D^{**}(f_D)\{m_D^{**}(w_D^{**}(f_D), f_D) - m_D^{**}(w_D^{**}(f_D), \underline{f})\}(f_D^2 - \underline{f}^2)^{-1}$. Suppose $t \geq \bar{t} \equiv \max_{f_D\in(\underline{f},\overline{f}]}(1-\gamma)w_D^{**}(f_D)\{m_D^{**}(w_D^{**}(f_D), f_D) - m_D^{**}(w_D^{**}(f_D), \underline{f})\}(f_D^2-\underline{f}^2)^{-1}$. Then, for any $f_D \in (\underline{f}, \overline{f}]$, $\pi_D^{**}(w_D^{**}(\underline{f}), \underline{f}) \geq \pi_D^{**}(w_D^{**}(f_D), \underline{f}) \geq \pi_D^{**}(w_D^{**}(f_D), f_D)$, where the first inequality is due to the optimality of $w_D^{**}(\underline{f})$ given $\underline{f}$, and the second inequality follows from $t \geq \bar{t}$. Therefore, $f_D^{**} = \underline{f}$.

In the rest of the proof, we show $\bar{t} > 0$ in two steps: we first show that s^{**} is increasing in f_D for given w_D, and then show that the market share of the deceptive counterfeiter, $m_D^{**} = s^{**}\left\{1-\bar{\theta}(s^{**})\right\}$, is increasing in f_D for any given w_D. Then from the definition of $\bar{t}$, $\bar{t} > 0$. Let π_{LD} denote the expected profit of the licit distributor given in (7). Then

$\frac{\partial \pi_{LD}}{\partial s} = (1-2s)(p_B-w_D)\left\{1-\bar{\theta}\right\} - s(1-s)(p_B-w_D)\frac{\partial \bar{\theta}}{\partial s} - l$, and

$\frac{\partial^2 \pi_{LD}}{\partial s \partial f_D} = (2-3s)(p_B-w_D)\frac{\lambda p_B s}{\{(1-s)q_B+s(f_D+\beta q_B)\}^2} + 2s(1-s)(p_B-w_D)\frac{\lambda p_B s(q_B-f_D-\beta q_B)}{\{(1-s)q_B+s(f_D+\beta q_B)\}^3}$,

where the first term is positive because we know from §4.2 that $s^{**} < 0.5$ and $w_D \leq p_B$, and the second term is also positive according to (A1). Therefore, $\frac{\partial \pi_{LD}}{\partial s}$ is increasing in f_D. Since s^{**} satisfies $\frac{\partial \pi_{LD}}{\partial s}|_{s=s^{**}} = 0$ due to the concavity of π_{LD} with respect to s, s^{**} is increasing in f_D.

Next, we show that m_D^{**} increases as f_D increases from f_{DL} to f_{DH} for given w_D. Suppose this does not hold. Then, π_{LD} satisfies the following:

$$\pi_{LD}(s^{**}(f_{DH}), f_{DH}) = s^{**}(f_{DH})(1-s^{**}(f_{DH}))(p_B - w_D)\left\{1-\bar{\theta}(s^{**}(f_{DH}), f_{DH})\right\} - s^{**}(f_{DH})l$$
$$\leq s^{**}(f_{DL})(1-s^{**}(f_{DH}))(p_B - w_D)\left\{1-\bar{\theta}(s^{**}(f_{DL}), f_{DL})\right\} - s^{**}(f_{DH})l$$
$$< s^{**}(f_{DL})(1-s^{**}(f_{DH}))(p_B - w_D)\left\{1-\bar{\theta}(s^{**}(f_{DL}), f_{DH})\right\} - s^{**}(f_{DH})l$$
$$< s^{**}(f_{DL})(1-s^{**}(f_{DL}))(p_B - w_D)\left\{1-\bar{\theta}(s^{**}(f_{DL}), f_{DH})\right\} - s^{**}(f_{DL})l = \pi_{LD}(s^{**}(f_{DL}), f_{DH}),$$

where the first inequality follows from our premise, the second inequality follows from $\frac{\partial\bar{\theta}}{\partial f_D} = -\frac{\lambda p_B s}{\{(1-s)q_B + s(f_D+\beta q_B)\}^2} < 0$ for fixed s, and the last inequality follows from $\frac{\partial s^{**}}{\partial f_D} > 0$. However, this contradicts the condition that $s^{**}(f_{DH})$ maximizes the licit distributor's profit π_{LD} given f_{DH}. Therefore, m_D^{**} is increasing in f_D for given w_D, and $\bar{t} > 0$.

A sufficient condition for $f_D^{**} > \underline{f}$ is $t < \underline{t} \equiv \max_{f_D \in (\underline{f}, \overline{f}]} (1-\gamma)w_D^{**}(\underline{f})\{m_D^{**}(w_D^{**}(\underline{f}), f_D) - m_D^{**}(w_D^{**}(\underline{f}), \underline{f})\}(f_D^2 - \underline{f}^2)^{-1}$. We show this by contradiction. Suppose $f_D^{**} = \underline{f}$ and define $f_{\max} = \arg\max_{f_D \in (\underline{f}, \overline{f}]}(1-\gamma)w_D^{**}(\underline{f})\{m_D^{**}(w_D^{**}(\underline{f}), f_D) - m_D^{**}(w_D^{**}(\underline{f}), \underline{f})\}(f_D^2 - \underline{f}^2)^{-1}$. Then $\pi_D^{**}(w_D^{**}(f_{\max}), f_{\max}) \geq \pi_D^{**}(w_D^{**}(\underline{f}), f_{\max}) > \pi_D^{**}(w_D^{**}(\underline{f}), \underline{f})$, where the first inequality is due to the optimality of $w_D^{**}(f_{\max})$ given $f_{\max}$, and the second inequality follows from $t < \underline{t}$. However, this contradicts our premise that $f_D^{**} = \underline{f}$. Therefore, $f_D^{**} > \underline{f}$ if $t < \underline{t}$. □

Proof of Proposition 1: (a) The proof proceeds as follows: We first obtain q_B^m and q_B^*, and then derive the condition for $q_B^* > q_B^m$. When there is no counterfeiter, the expected profit of the brand-name company is given as follows:

$$\pi_B^m = (p_B - c_B)\left(1 - \frac{p_B}{q_B}\right) - t_B q_B^2, \tag{10}$$

where c_B (> 0) is the marginal cost of the brand-name product. From (10), $\frac{\partial^2 \pi_B^m}{\partial q_B^2} = -\frac{2(p_B - c_B)p_B}{q_B^3} - 2t_B < 0$, so we obtain $q_B^m = \frac{(p_B - c_B)p_B}{2t_B q_B^{m2}}$ from the first order condition. When the non-deceptive counterfeiter exists, we obtain π_B^* after substituting p_N^* and w_N^* into m_B in (2) as follows:

$$\pi_B^* = (p_B - c_B)m_B - t_B q_B^2 = (p_B - c_B)\left\{1 - \frac{(1-\gamma)p_B}{4\{(1-\beta)q_B - f_N^*\}} - \frac{(3+\gamma)p_B}{4q_B}\right\} - t_B q_B^2. \tag{11}$$

From (11), when $f_N^* = \underline{f}$ or $\overline{f}$, $\frac{\partial^2 \pi_B^*}{\partial q_B^2} = -\frac{p_B - c_B}{2}\left(\frac{p_B(1-\gamma)(1-\beta)^2}{(q_B - q_N)^3} + \frac{p_B(3+\gamma)}{q_B^3}\right) - 2t_B < 0$ due to (A1). In this case, from the first order condition of (11), $q_B^* = \frac{p_B - c_B}{2t_B}\left\{\frac{(1-\gamma)(1-\beta)p_B}{4\{(1-\beta)q_B^* - f_N^*(q_B^*)\}^2} + \frac{(3+\gamma)p_B}{4q_B^{*2}}\right\}$.

We next show by contradiction that $q_B^* > q_B^m$ when $\beta < 1 - (\frac{q_B^m - q_N^*(q_B^m)}{q_B^m})^2$. Suppose $\beta < 1 - (\frac{q_B^m - q_N^*(q_B^m)}{q_B^m})^2$ and $q_B^* \leq q_B^m$. For $f_{NH} > f_{NL}$, from (5), we obtain $\frac{\partial \pi_N^*(f_{NH})}{\partial q_B} - \frac{\partial \pi_N^*(f_{NL})}{\partial q_B} = \frac{(\gamma-1)p_B^2(f_{NH} - f_{NL})(1-\beta)\{(1-\beta)q_B - (f_{NH}+f_{NL})/2\}}{4\{(1-\beta)q_B - f_{NH}\}^2\{(1-\beta)q_B - f_{NL}\}^2} < 0$ due to (A1), so f_N^* is decreasing in q_B. Then $q_B^* = \frac{p_B - c_B}{2t_B}\left\{\frac{(1-\gamma)(1-\beta)p_B}{4\{(1-\beta)q_B^* - f_N^*(q_B^*)\}^2} + \frac{(3+\gamma)p_B}{4q_B^{*2}}\right\} \geq \frac{p_B - c_B}{2t_B}\{\frac{(1-\gamma)(1-\beta)p_B}{4\{(1-\beta)q_B^m - f_N^*(q_B^m)\}^2} + \frac{(3+\gamma)p_B}{4q_B^{m2}}\} > \frac{(p_B - c_B)p_B}{2t_B q_B^{m2}} = q_B^m$, where the first inequality follows from $q_B^* \leq q_B^m$ and $f_N^*(q_B^*) \geq f_N^*(q_B^m)$, and the second inequality follows from $\beta < 1 - (\frac{q_B^m - q_N^*(q_B^m)}{q_B^m})^2$. Thus, there is a contradiction, so $q_B^* > q_B^m$ when $\beta < 1 - (\frac{q_B^m - q_N^*(q_B^m)}{q_B^m})^2$. The case in which $\beta \geq 1 - (\frac{q_B^m - q_N^*(q_B^m)}{q_B^m})^2$ can be shown similarly.

(b) To establish the result in the proposition, it suffices to show that π_N^* is decreasing in q_B. The

proof proceeds in two steps: We first show that π_N^* decreases in q_B for any given f_N, and then show that this result holds even when f_N^* changes with q_B. First, from (5), we obtain $\frac{\partial \pi_N^*}{\partial q_B} = \frac{(1-\gamma)p_B^2\{\beta q_B^2(\beta-1)+2q_B f_N(\beta-1)+f_N^2\}}{4q_B^2\{(1-\beta)q_B-f_N\}^2}$, which is negative by (A1) for any given f_N. Next, we consider the case in which f_N^* changes from f_{N1} to f_{N2} when q_B is increased from q_{BL} to q_{BH}. In this case, $\pi_N^*(f_{N1}, q_{BL}) \geq \pi_N^*(f_{N2}, q_{BL}) > \pi_N^*(f_{N2}, q_{BH})$, where the first inequality follows from $f_N^*(q_{BL}) = f_{N1}$ and the second inequality is due to $\frac{\partial \pi_N^*}{\partial q_B} < 0\ \forall f_N$.
(c) We first prove that ECS_N^* is increasing in q_B for given f_N, and then prove that ECS_N^* decreases when f_N^* is decreased from f_{NH} to f_{NL} for any given q_B.

To prove that ECS_N^* is increasing in q_B, it suffices to show that $\frac{\partial CS_N}{\partial q_B} > 0$ for any given f_N because $\frac{\partial CS_B}{\partial q_B} > 0$ from the definition of CS_B. Now suppose that q_B is increased from q_{BL} to q_{BH}. Then q_N is also increased from q_{NL} to q_{NH} given f_N; $\widehat{\theta}$ is decreased from $\widehat{\theta}_L$ to $\widehat{\theta}_H$; and $\widetilde{\theta}$ is decreased from $\widetilde{\theta}_L$ to $\widetilde{\theta}_H$. Using $p_N^* = \frac{3p_B q_N}{4q_B}$, we can rewrite CS_N and find $CS_N(q_{BH}) > \int_{\widehat{\theta}_L}^{\widetilde{\theta}_H}\left(\theta - \frac{3p_B}{4q_{BH}}\right)q_{NH}d\theta + \int_{\widetilde{\theta}_H}^{1}(\theta q_{BH} - p_B)d\theta > \int_{\widehat{\theta}_L}^{\widetilde{\theta}_H}\left(\theta - \frac{3p_B}{4q_{BH}}\right)q_{NH}d\theta + \int_{\widetilde{\theta}_H}^{\widetilde{\theta}_L}\left(\theta - \frac{3p_B}{4q_{BH}}\right)q_{NH}d\theta + \int_{\widetilde{\theta}_L}^{1}(\theta q_{BH} - p_B)d\theta > CS_N(q_{BL})$. The first inequality holds because $\widehat{\theta}_L > \widehat{\theta}_H$ and $\left(\theta - \frac{3p_B}{4q_{BH}}\right)q_{NH} > 0$ for $\theta \in (\widehat{\theta}_H, \widehat{\theta}_L)$. The second inequality holds because $\theta q_{BH} - p_B > \theta q_{NH} - p_N^*$ for $\theta \in (\widetilde{\theta}_H, \widetilde{\theta}_L)$. The third inequality follows from the fact that $q_{BH} > q_{BL}$ and $q_{NH} > q_{NL}$.

Next, suppose f_N^* is decreased from f_{NH} to f_{NL} for fixed q_B. Then $\widehat{\theta}$ remains the same, whereas $\widetilde{\theta}$ is decreased from $\widetilde{\theta}' \equiv \frac{p_B}{4\{(1-\beta)q_B - f_{NH}\}} + \frac{3p_B}{4q_B}$ to $\widetilde{\theta}'' \equiv \frac{p_B}{4\{(1-\beta)q_B - f_{NL}\}} + \frac{3p_B}{4q_B}$. Then,

$$ECS_N^*(f_{NH}) = (1-\gamma)\left\{\int_{\widehat{\theta}}^{\widetilde{\theta}'}\left(\theta - \frac{3p_B}{4q_B}\right)(f_{NH} + \beta q_B)d\theta + \int_{\widetilde{\theta}'}^{1}(\theta q_B - p_B)d\theta\right\} + \gamma\int_{\frac{p_B}{q_B}}^{1}(\theta q_B - p_B)d\theta$$
$$> (1-\gamma)\left\{\int_{\widehat{\theta}}^{\widetilde{\theta}''}\left(\theta - \frac{3p_B}{4q_B}\right)(f_{NL} + \beta q_B)d\theta + \int_{\widetilde{\theta}''}^{1}(\theta q_B - p_B)d\theta\right\} + \gamma\int_{\frac{p_B}{q_B}}^{1}(\theta q_B - p_B)d\theta = ECS_N^*(f_{NL}).$$

In the above, the first inequality holds because $\left(\theta - \frac{3p_B}{4q_B}\right)(f_{NH} + \beta q_B) > \theta q_B - p_B$ for $\theta \in (\widetilde{\theta}'', \widetilde{\theta}')$, and the second inequality follows from $f_{NH} > f_{NL}$. $\square$

Remark When $f_N^* \in (\underline{f}, \overline{f})$, assuming $\frac{\partial^2 f_N^*}{\partial q_B^2} \geq 0$, we can still obtain $\frac{\partial^2 \pi_B^*}{\partial q_B^2} < 0$. From the first order condition of (11), $q_B^* = \frac{p_B - c_B}{2t_B}\{\frac{(1-\gamma)(1-\beta-\partial f_N^*/\partial q_B)p_B}{4\{(1-\beta)q_B^* - f_N^*(q_B^*)\}^2} + \frac{(3+\gamma)p_B}{4q_B^{*2}}\}$. The condition for $q_B^* > q_B^m$ then becomes $\frac{(1-\gamma)(1-\beta-\partial f_N^*/\partial q_B)}{4\{(1-\beta)q_B^* - f_N^*(q_B^*)\}^2} + \frac{3+\gamma}{4q_B^{*2}} - \frac{1}{q_B^{m2}} > 0$. Unfortunately, this condition cannot be simplified further to the form like $\beta < 1 - (\frac{q_B^m - q_N^*(q_B^m)}{q_B^m})^2$ because the closed-form expressions for f_N^* and $\frac{\partial f_N^*}{\partial q_B}$ are not available. The proof for (b) does not require $f_N^* = \underline{f}$ or $\overline{f}$, so it also holds for $f_N^* \in (\underline{f}, \overline{f})$. For (c), suppose $q_B^* > q_B^m$. From (1), $\frac{\partial ECS_N^*}{\partial q_B} = [q_B^2(1-\beta)\{16(1-\beta)q_B^2 + p_B^2(\beta(15+\gamma)-16)\} + f_N^*\{p_B^2(15+\gamma) - 16q_B^2\}\{2(1-\beta)q_B - f_N^*\} + p_B^2 q_B^2(1-\gamma)\partial f_N^*/\partial q_B]\{(1-\beta)q_B - f_N^*\}^{-2}$. Then ECS_N^* is decreasing in $q_B \in [q_B^m, q_B^*]$ so that ECS_N^* is lower at q_B^* than at q_B^m if $\frac{\partial f_N^*}{\partial q_B} < -\frac{q_B^2(1-\beta)\{16(1-\beta)q_B^2 + p_B^2(\beta(15+\gamma)-16)\} + f_N^*\{p_B^2(15+\gamma)-16q_B^2\}\{2(1-\beta)q_B - f_N^*\}}{p_B^2 q_B^2(1-\gamma)\{(1-\beta)q_B - f_N^*\}^2}$.

Proof of Proposition 2: (a) From (10), $\frac{\partial^2 \pi_B^m}{\partial p_B^2} = -\frac{2}{q_B} < 0$, so we obtain $p_B^m = \frac{q_B + c_B}{2}$ from the first order condition. Next, consider the market in which the non-deceptive counterfeiter exists. When $f_N^* = \underline{f}$ or $\overline{f}$, from (11), $\frac{\partial^2 \pi_B^*}{\partial p_B^2} = -\frac{1-\gamma}{2(q_B - q_N)} - \frac{3+\gamma}{2q_B} < 0$ and $p_B^* = \frac{q_B q_D^*(1-\gamma)}{2(-4q_B + 3q_D^* + \gamma q_D^*)} + \frac{q_B + c_B}{2}$; in this

case, $p_B^* < p_B^m$ due to (A1). When $f_N^* \in (\underline{f}, \overline{f})$, we show $\frac{\partial \pi_B^*}{\partial p_B}|_{p_B=\frac{q_B+c_B}{2}} < 0$, which then results in $p_B^* < p_B^m$. From (11), we obtain $\frac{\partial \pi_B^*}{\partial p_B}|_{p_B=\frac{q_B+c_B}{2}} = \frac{(1-\gamma)\{4f_N^{*2}+4(2\beta-1)f_N^* q_B+4(\beta-1)\beta q_B^2+(c_B-q_B)(c_B+q_B)\partial f_N^*/\partial p_B\}}{16\{(1-\beta)q_B-f_N^*\}^2}$, which is negative because: $4f_N^{*2} - 4(1-2\beta)f_N^* q_B - 4(1-\beta)\beta q_B^2 - \frac{\partial f_N^*}{\partial p_B}(q_B - c_B)(q_B + c_B) < 4f_N^{*2} - 4(f_N^* - \beta q_B)f_N^* - 4f_N^* \beta q_B - \frac{\partial f_N^*}{\partial p_B}(q_B - c_B)(q_B + c_B) = -\frac{\partial f_N^*}{\partial p_B}(q_B - c_B)(q_B + c_B) \leq 0$, where the first inequality is due to (A1) and the second inequality is due to $\frac{\partial f_N^*}{\partial p_B} \geq 0$ and $q_B > p_B \geq c_B$.
(b) The proof is similar to that of Proposition 1(b), and is hence omitted.
(c) The proof for the case in which $f_N^* = \underline{f}$ or $\overline{f}$ is similar to that of Proposition 1(c). When $f_N^* \in (\underline{f}, \overline{f})$, from (1), $\frac{\partial ECS_N^*}{\partial p_B} = [-2\{(1-\beta)q_B - f_N^*\}\{16(1-\beta)q_B^2 + p_B q_B(\beta(15+\gamma)-16) + (p_B(15+\gamma) - 16q_B)f_N^*\} + p_B^2 q_B(1-\gamma)\partial f_N^*/\partial p_B]\{(1-\beta)q_B - f_N^*\}^{-2}$. Define $\kappa = \max_{p_B \in [p_B^*, p_B^m]} 2\{(1-\beta)q_B - f_N^*\}\{16(1-\beta)q_B^2 + p_B q_B(\beta(15+\gamma)-16) + (p_B(15+\gamma) - 16q_B)f_N^*\} p_B^{-2} q_B^{-1}(1-\gamma)^{-1}\{(1-\beta)q_B - f_N^*\}^{-2}$. Then ECS_N^* is increasing in $p_B \in [p_B^*, p_B^m]$ so that ECS_N^* is lower at p_B^* than at p_B^m if $\frac{\partial f_N^*}{\partial p_B} > \kappa$. □

Proof of Proposition 3: (a) When $\lambda = 0$, we obtain π_B^{**} after substituting s^{**} and w_D^{**} into m_B in (6) as follows:

$$\pi_B^{**} = (p_B - c_B)m_B - t_B q_B^2 = (p_B - c_B)\left[(1-\gamma)\left\{\frac{1}{2}(1 - \frac{p_B}{q_B}) + \frac{1}{2}\sqrt{\frac{l(1-\frac{p_B}{q_B})}{p_B}}\right\} + \gamma(1 - \frac{p_B}{q_B})\right] - t_B q_B^2. \tag{12}$$

From (12), $\frac{\partial^2 \pi_B^{**}}{\partial q_B^2} = (p_B - c_B)\{-\frac{p_B(1+\gamma)}{q_B^3} - \frac{(4q_B - 3p_B)(1-\gamma)}{8(q_B - p_B)q_B^3}\sqrt{\frac{l q_B p_B}{q_B - p_B}}\} - 2t_B < 0$ due to (A2), and $q_B^{**} = \frac{p_B - c_B}{2t_B}\left\{(1-\gamma)(\frac{p_B}{2q_B^{**2}} + \frac{1}{4q_B^{**2}}\sqrt{\frac{l p_B q_B^{**}}{q_B^{**} - p_B}}) + \frac{\gamma p_B}{q_B^{**2}}\right\}$ from the first order condition. By the same procedure in the proof of Proposition 1(a), we can prove by contradiction that $q_B^{**} < q_B^m$ if and only if $l < 4p_B(1 - \frac{p_B}{q_B^m})$. Since $s^{**} = \frac{1}{2} - \frac{1}{2}\sqrt{\frac{l}{p_B(1-\frac{p_B}{q_B})}} > 0$, we find that $l < p_B(1 - \frac{p_B}{q_B^m}) < 4p_B(1 - \frac{p_B}{q_B^m})$, so we always have $q_B^{**} < q_B^m$.
(b) To establish the result in the proposition, it suffices to show that π_D^{**} is increasing in q_B. When $\lambda = 0$, it is easy to see $\frac{\partial \pi_D^{**}}{\partial q_B} = \frac{\partial \pi_D^{**}}{\partial(1-\frac{p_B}{q_B})}\frac{p_B}{q_B^2} > 0\ \forall f_D$ from (9). Since $f_D^{**} = \underline{f}\ \forall q_B$, the result follows.
(c) When $\lambda = 0$, from (1), $\frac{\partial ECS_D^{**}}{\partial q_B} = -(1-\gamma)\left\{\frac{p_B^2}{q_B^3}s^{**} + \frac{1}{2}\left(1 - \frac{p_B^2}{q_B^2}\right)\frac{\partial s^{**}}{\partial q_B}\right\}(q_B - q_D^{**}) + \frac{1}{2}\left(1 - \frac{p_B^2}{q_B^2}\right)\{1 - (1-\gamma)s^{**}\}$. Using $\frac{\partial s^{**}}{\partial q_B} > 0$ and (A2), we prove $\frac{\partial ECS_D^{**}}{\partial q_B} < 0$ when $q_D^{**} < q_B - \frac{(1-p_B^2 q_B^{-2})\{1-(1-\gamma)s^{**}\}}{2(1-\gamma)}\{\frac{p_B^2}{q_B^3}s^{**} + \frac{1}{2}\left(1 - \frac{p_B^2}{q_B^2}\right)\frac{\partial s^{**}}{\partial q_B}\}^{-1}$ for $q_B \in [q_B^{**}, q_B^m]$. □

Remark When $\lambda > 0$, both $q_B^{**} < q_B^m$ and $q_B^{**} > q_B^m$ are possible as shown in Table 3. The condition for $q_B^{**} < q_B^m$ is $t_B > \frac{(p_B - c_B)}{2q_B^m}[\frac{\gamma p_B}{q_B^{m2}} - (1-\gamma)\{1 - \frac{(1-\lambda)p_B}{q_B^m} - \frac{\lambda p_B}{(1-s^{**}(q_B^m))q_B^m + s^{**}(q_B^m)(\beta q_B^m + f_D^{**}(q_B^m))}\}\frac{\partial s^{**}}{\partial q_B} + (1-\gamma)(1 - s^{**}(q_B^m))\{\frac{(1-\lambda)p_B}{q_B^{m2}} + \lambda p_B(1 + s^{**}(q_B^m)(\beta - 1 + \frac{\partial f_D^{**}}{\partial q_B}) + (f_D^{**}(q_B^m) + \beta q_B^m - q_B^m)\frac{\partial s^{**}}{\partial q_B})((1 - s^{**}(q_B^m))q_B^m + s^{**}(q_B^m)(\beta q_B^m + f_D^{**}(q_B^m)))^{-2}\}]$, which can be obtained from $\frac{\partial \pi_B^{**}}{\partial q_B}|_{q_B = q_B^m} < 0$. In this case, π_D^{**} is increasing in q_B as in the case when $\lambda = 0$ shown in the proof of Proposition 3(b). The proof follows the same procedure as in that of Lemma 2, so we provide a sketch of the proof here. For given w_D and f_D, we can show that s^{**} and m_D^{**} are increasing in q_B. Then when q_B is increased from q_{BL} to q_{BH}, the following inequalities hold in equilibrium: $\pi_D^{**}(w_D^{**}(q_{BH}), f_D^{**}(q_{BH}), q_{BH}) \geq \pi_D^{**}(w_D^{**}(q_{BL}), f_D^{**}(q_{BL}), q_{BH}) > \pi_D^{**}(w_D^{**}(q_{BL}), f_D^{**}(q_{BL}), q_{BL})$. Finally, when $\lambda > 0$, the condition for $\frac{\partial ECS_D^{**}}{\partial q_B} < 0$ given in the proof of Proposition 3(c) is modified to the following: $q_D^{**}\{2\bar{\theta}s^{**}\frac{\partial\bar{\theta}}{\partial q_B}+(1-\bar{\theta}^2)\frac{\partial s^{**}}{\partial q_B}\} < \frac{\gamma}{1-\gamma}\left(1-\frac{p_B^2}{q_B^2}\right)+2\left\{p_B-\bar{\theta}q_B(1-s^{**})\right\}\frac{\partial\bar{\theta}}{\partial q_B}+(1-\bar{\theta}^2)\left\{1-\left(1-\beta-\frac{\partial f_D^{**}}{\partial q_B}\right)s^{**}-q_B\frac{\partial s^{**}}{\partial q_B}\right\}$. Unfortunately, this condition cannot be simplified further since the closed-form expressions of s^{**} and f_D^{**} do not exist. The non-monotonicity of ECS_D^{**} is shown in Table 3.

Proof of Proposition 4: (a) From (12), $\frac{\partial^2\pi_B^{**}}{\partial p_B^2} = -\frac{1+\gamma}{q_B} - \frac{1-\gamma}{2p_B^2}\sqrt{\frac{lq_B}{(q_B-p_B)p_B}}\left\{c_B+\frac{q_B(p_B-c_B)}{4(q_B-p_B)}\right\} < 0$, and $\frac{\partial\pi_B^{**}}{\partial p_B}|_{p_B=\frac{q_B+c_B}{2}} = \frac{c_B(1-\gamma)}{2(c_B+q_B)}\sqrt{\frac{l(q_B-c_B)}{q_B(c_B+q_B)}} > 0$ due to $q_B > p_B \geq c_B$ by (A2). Therefore, by the concavity of π_B^{**}, $p_B^{**} > p_B^m$.

(b) The non-monotonicity of π_D^{**} with respect to p_B is shown in Table 3.

(c) When $\lambda = 0$, from (1), $\frac{\partial ECS_D^{**}}{\partial p_B} = (1-\gamma)[\frac{s^{**}p_B}{q_B}\left(1-\frac{q_D^{**}}{q_B}\right)+\left(1-\frac{p_B}{q_B}\right)\{\frac{1}{2}\left(1+\frac{p_B}{q_B}\right)\frac{\partial s^{**}}{\partial p_B}(q_D^{**}-q_B)-1\}] + \gamma(\frac{p_B}{q_B}-1)$. Using $\frac{\partial s^{**}}{\partial p_B} < 0$ and (A2), we prove $\frac{\partial ECS_D^{**}}{\partial p_B} > 0$ when $q_D^{**} < q_B - \frac{q_B-p_B}{1-\gamma}\{\frac{p_B}{q_B}s^{**} - \frac{1}{2}\left(1+\frac{p_B}{q_B}\right)(q_B-p_B)\frac{\partial s^{**}}{\partial p_B}\}^{-1}$ for $p_B \in [p_B^m, p_B^{**}]$. □

Remark When $\lambda > 0$, both $p_B^{**} > p_B^m$ and $p_B^{**} < p_B^m$ are possible as shown in Table 3. The condition for $p_B^{**} > p_B^m$ is $\gamma(1-\frac{p_B^m}{q_B}) + (1-\gamma)(1-s^{**}(p_B^m))Y + (p_B-c_B)[-\frac{\gamma}{q_B} - (1-\gamma)Y\frac{\partial s^{**}}{\partial p_B} + (1-\gamma)(1-s^{**}(p_B^m))\{\frac{Y-1}{p_B^m} + \frac{\lambda p_B^m\{s^{**}(p_B^m)\frac{\partial f_D^{**}}{\partial p_B}+(f_D^{**}(p_B^m)+\beta q_B-q_B)\frac{\partial s^{**}}{\partial p_B}\}}{\{(1-s^{**}(p_B^m))q_B+s^{**}(p_B^m)(\beta q_B+f_D^{**}(p_B^m))\}^2}\}] > 0$, where $Y = 1-\frac{(1-\lambda)p_B^m}{q_B} - \frac{\lambda p_B^m}{(1-s^{**}(p_B^m))q_B+s^{**}(p_B^m)(\beta q_B+f_D^{**}(p_B^m))}$. This can be obtained from $\frac{\partial\pi_B^{**}}{\partial p_B}|_{p_B=p_B^m} > 0$. The condition for $\frac{\partial ECS_D^{**}}{\partial p_B} > 0$ given in the proof of Proposition 4(c) is modified to the following: $q_D^{**}\left\{\bar{\theta}s^{**}\frac{\partial\bar{\theta}}{\partial p_B} - \frac{1-\bar{\theta}^2}{2}\frac{\partial s^{**}}{\partial p_B}\right\} < \frac{\gamma}{1-\gamma}\left(\frac{p_B}{q_B}-1\right)+\left\{p_B-\bar{\theta}q_B(1-s^{**})\right\}\frac{\partial\bar{\theta}}{\partial p_B}+\frac{1-\bar{\theta}^2}{2}\left\{s^{**}\frac{\partial q_D^{**}}{\partial p_B}-q_B\frac{\partial s^{**}}{\partial p_B}\right\}-1+\bar{\theta}$. Unfortunately, this condition cannot be simplified further since the closed-form expressions of s^{**} and f_D^{**} do not exist. The non-monotonicity of ECS_D^{**} is established in Table 3.

Proof of Proposition 5: When $\lambda = 0$, we observe from (12) that π_B^{**} does not change with β, and that π_B^{**} is increasing in γ and t. When $\lambda > 0$, similar to the proof of Lemma 2, we can show that the aggregate demand, $(1-\bar{\theta})$, for the brand-name product and the deceptive counterfeit is increasing in β and decreasing in γ and t, and that the fraction of the brand-name product, $(1-s^{**})$, is decreasing in β and increasing in γ and t. The non-monotonicity of π_B^{**} is shown in our numerical experiments presented in online appendix B. The proofs for π_D^{**} and ECS_D^{**} are similar to those of Proposition 3(b)-(c), and hence are omitted. □

Proof of Corollary 1: When the *non-deceptive* counterfeiter exists in the market, it is easy to see that the price decisions of the illicit distributor and the counterfeiter in stages 3 and 2, respectively, are unchanged. In stage 1, the counterfeiter chooses his optimal functional quality f_N^* to maximize his expected profit, which is modified from (5) as follows: $\pi_N^*(f_N) = \frac{p_B^2(1-\gamma+\delta_1 f_N)(f_N+\beta q_B)}{8q_B\{(1-\beta)q_B-f_N\}} - tf_N^2$. Similar to Lemma 1, we can show that $f_N^* = \underline{f}$, $\overline{f}$ or $f_N^* \in (\underline{f}, \overline{f})$ that satisfies $\frac{\partial\pi_N^*}{\partial f_N}|_{f_N=f_N^*} = 0$, depending on the value of t and whether $\pi_N^*(\underline{f}) \geq \pi_N^*(\overline{f})$. When the *deceptive* counterfeiter exists in the market, in stage 3, the licit distributor chooses its optimal fraction s^{**} of counterfeits by solving the following problem (which is modified from (7)):

$$\max_{s\in[0,1]} s\{1-s+\delta_2 f_D\}(p_B-w_D)\left\{1-\frac{\lambda p_B}{(1-s)q_B+sq_D}-\frac{(1-\lambda)p_B}{q_B}\right\}-(s-\delta_2 f_D)l. \tag{13}$$

In stages 2 and 1, the counterfeiter decides w_D and f_D, respectively, to maximize his expected profit given by: $\pi_D(w_D, f_D) = w_D s^{**}(1-\gamma+\delta_1 f_D)\left\{1 - \frac{\lambda p_B}{(1-s^{**})q_B + s^{**}(f_D+\beta q_B)} - \frac{(1-\lambda)p_B}{q_B}\right\} - t f_D^2 - \gamma h$. When $\lambda = 0$, by following the procedure similar to that in the base model, we obtain the closed-form expressions of s^{**} and w^{**} as follows: $s^{**} = \frac{1+\delta_2 f_D}{2} - \frac{l q_B}{2(p_B - w_D)(q_B - p_B)}$ and $w_D^{**} = p_B - \sqrt{\frac{l p_B}{(1-\frac{p_B}{q_B})(1+\delta_2 f_D)}}$. When $\lambda > 0$, similar to the base model, we can show the existence of s^{**}, w^{**} and f_D^{**}, but their closed-form expressions are not available.

(a) Suppose $f_N^* = \underline{f}$ or $\overline{f}$. We can obtain $\frac{\partial \pi_B^*}{\partial q_B}$ by replacing γ in the base model with $\gamma - \delta_1 f_N^*$. To show that Proposition 1(a) continues to hold, we need to prove that f_N^* is decreasing in q_B. For $f_{NH} > f_{NL}$, $\frac{\partial \pi_N^*(f_{NH})}{\partial q_B} - \frac{\partial \pi_N^*(f_{NL})}{\partial q_B}$ can be expressed as follows:

$$-\frac{p_B^2(1-\gamma+\delta_1 f_{NH})\{q_B(\beta q_B+f_{NH})(1-\beta)+f_{NH}(q_B-\beta q_B-f_{NH})\}}{8q_B^2\{(1-\beta)q_B-f_{NH}\}^2}+\frac{p_B^2(1-\gamma+\delta_1 f_{NL})\{q_B(\beta q_B+f_{NL})(1-\beta)+f_{NL}(q_B-\beta q_B-f_{NL})\}}{8q_B^2\{(1-\beta)q_B-f_{NL}\}^2}$$

$$< (1-\gamma+\delta_1 f_{NH})\left[-\frac{p_B^2\{q_B(\beta q_B+f_{NH})(1-\beta)+f_{NH}(q_B-\beta q_B-f_{NH})\}}{8q_B^2\{(1-\beta)q_B-f_{NH}\}^2}+\frac{p_B^2\{q_B(\beta q_B+f_{NL})(1-\beta)+f_{NL}(q_B-\beta q_B-f_{NL})\}}{8q_B^2\{(1-\beta)q_B-f_{NL}\}^2}\right]$$

$$= -\frac{(1-\gamma+\delta_1 f_{NH})p_B^2(f_{NH}-f_{NL})(1-\beta)\{(1-\beta)q_B-(f_{NH}+f_{NL})/2\}}{4\{(1-\beta)q_B-f_{NH}\}^2\{(1-\beta)q_B-f_{NL}\}^2},$$

which is negative due to (A1). Then, following the same procedure as in the proof of Proposition 1(a), we can show $q_B^* > q_B^m$ if and only if $\beta < 1 - \left\{\frac{q_B^m - q_N^*(q_B^m)}{q_B^m}\right\}^2$. For Proposition 1(b), when f_N is given, $\frac{\partial \pi_N^*}{\partial q_B} = \frac{(1-\gamma+\delta_1 f_N)p_B^2\left\{\beta q_B^2(\beta-1)+2q_B f_N(\beta-1)+f_N^2\right\}}{4q_B^2\{(1-\beta)q_B-f_N\}^2} < 0$ due to (A1). When f_N^* changes from f_{N1} to f_{N2} as q_B is increased from q_{BL} to q_{BH}, $\pi_N^*(f_{N1}, q_{BL}) \geq \pi_N^*(f_{N2}, q_{BL}) > \pi_N^*(f_{N2}, q_{BH})$, where the first inequality follows from $f_N^*(q_{BL}) = f_{N1}$ and the second inequality is due to $\frac{\partial \pi_N^*}{\partial q_B} < 0\ \forall f_N$. For Proposition 1(c), to prove that ECS_N^* is increasing in q_B, it suffices to show that $\frac{\partial CS_N}{\partial q_B} > 0$. Since $\frac{\partial CS_N}{\partial q_B}$ does not depend on γ when f_N is given, Proposition 1(c) continues to hold.

(b) We can show that the proof for Proposition 2 also applies to the case with $\gamma - \delta_1 f_N$ similarly to Proposition 1, except part (c) when $f_N^* \in (\underline{f}, \overline{f})$. With the extension, $\frac{\partial ECS_N^*}{\partial p_B} = \{(1-\beta)q_B - f_N^*\}^{-2}$ $[p_B^2 \frac{\partial f_N^*}{\partial p_B}\{-\delta_1 f_N^*(2\beta q_B - 2q_B + f_N^*) - q_B((\beta-1)\beta\delta_1 q_B + \gamma - 1)\} - 2((\beta-1)q_B + f_N^*)\{f_N^* p_B(\beta\delta_1 q_B - \gamma - 15 + \delta_1 f_N^* + \frac{16 q_B}{p_B}) + q_B(16(\beta-1)q_B - p_B\beta(\gamma+15) + 16p_B)\}]$. Define $\kappa = \max_{p_B \in [p_B^*, p_B^m]} 2p_B^{-2}((\beta-1)q_B + f_N^*)\{f_N^* p_B(\beta\delta_1 q_B - \gamma - 15 + \delta_1 f_N^* + \frac{16 q_B}{p_B}) + q_B(16(\beta-1)q_B - p_B\beta(\gamma+15) + 16p_B)\}\{-\delta_1 f_N^*(2\beta q_B - 2q_B + f_N^*) - q_B((\beta-1)\beta\delta_1 q_B + \gamma - 1)\}^{-1}$. Then ECS_N^* is increasing in $p_B \in [p_B^*, p_B^m]$ so that ECS_N^* is lower at p_B^* than at p_B^m if $\frac{\partial f_N^*}{\partial p_B} > \kappa$.

To show that Proposition 3(a) continues to hold, when $\lambda = 0$, we can prove by contradiction that $q_B^{**} < q_B^m$ if and only if $(1+\delta_2 f_D)l < 4p_B(1-\frac{p_B}{q_B^m})$ by the same procedure as in the proof of Proposition 1(a). Since $s^{**} = \frac{1+\delta_2 f_D}{2} - \frac{1}{2}\sqrt{\frac{l(1+\delta_2 f_D)}{p_B(1-\frac{p_B}{q_B})}} > 0$, we obtain $l < p_B(1-\frac{p_B}{q_B^m})(1+\delta_2 f_D) < \frac{4p_B}{1+\delta_2 f_D}(1-\frac{p_B}{q_B^m})$, so $q_B^{**} < q_B^m$ always holds. For Proposition 4(a), $\frac{\partial \pi_B^{**}}{\partial p_B}|_{p_B = \frac{q_B + c_B}{2}} = \frac{c_B(1-\gamma+\delta_1 f_D)}{2(c_B+q_B)}\sqrt{\frac{l(q_B-c_B)(1+\delta_2 f_D)}{q_B(c_B+q_B)}} > 0$, so $p_B^{**} > p_B^m$. For Propositions 3(b) and 4(b), we can show that, with the extension, s^{**} and m_D^{**} are increasing in q_B and decreasing in p_B for given w_D and f_D. Then, when q_B is increased from q_{BL} to q_{BH}, the following inequalities hold in equilibrium: $\pi_D^{**}(w_D^{**}(q_{BH}), f_D^{**}(q_{BH}), q_{BH}) \geq \pi_D^{**}(w_D^{**}(q_{BL}), f_D^{**}(q_{BL}), q_{BH}) > \pi_D^{**}(w_D^{**}(q_{BL}), f_D^{**}(q_{BL}), q_{BL})$. Similarly, when p_B is decreased from

p_{BH} to p_{BL}, the following inequalities hold in equilibrium: $\pi_D^{**}(w_D^{**}(p_{BL}), f_D^{**}(p_{BL}), p_{BL}) \geq \pi_D^{**}(w_D^{**}(p_{BH}), f_D^{**}(p_{BH}), p_{BL}) > \pi_D^{**}(w_D^{**}(p_{BH}), f_D^{**}(p_{BH}), p_{BH})$. Propositions 3(c) and 4(c) can be shown similarly to Proposition 2(c).
(c) The proofs of π_D^{**} and ECS_D^{**} are similar to those of Proposition 3(b)-(c). When $\lambda = 0$, the non-monotonicity of π_B^{**} or ECS_D^{**} with respect to γ can be shown numerically as follows. Set $q_B = 1$, $p_B = 0.5$, $t = 0.01$, $c_B = 0.01$, $\beta = 0.1$, $l = 0.02$, $h = 0$ and $\delta_1 = \delta_2 = 0.1$. As γ increases from 0.2 to 0.3, π_B^{**} increases from 0.174 to 0.181 and ECS_D^{**} increases from 0.070 to 0.076. As γ increases from 0.3 to 0.4, π_B^{**} decreases from 0.181 to 0.173 and ECS_D^{**} decreases from 0.070 to 0.069. The non-monotonicity of π_B^{**} or ECS_D^{**} with respect to t can be shown similarly. □

The following corollary examines when the quality strategy is more profitable than the pricing strategy for the brand-name company.

Corollary 2 *Suppose that the brand-name company needs to invest $t_B q_B^2$ for developing and setting up facilities to produce a product with quality q_B. Then:*
(a) Consider the market in which a non-deceptive counterfeit with $f_N^* = \underline{f}$ or $\overline{f}$ exists. There exists $\underline{t}_N$ such that if $t_B > \underline{t}_N$ and $\beta \geq 1 - \left\{\frac{q_B^m - q_N^*(q_B^m)}{q_B^m}\right\}^2$, the brand-name company is more profitable when setting quality q_B^* ($< q_B^m$) than setting price p_B^* ($< p_B^m$); and if $t_B > \underline{t}_N$ and $\beta < 1 - \left\{\frac{q_B^m - q_N^*(q_B^m)}{q_B^m}\right\}^2$, the brand-name company is less profitable when setting quality q_B^* ($> q_B^m$) than setting price p_B^* ($< p_B^m$).
(b) Consider the market in which a deceptive counterfeit exists and there are no proactive consumers with $\lambda = 0$. There exists $\underline{t}_D$ such that if $t_B > \underline{t}_D$, the brand-name company is more profitable when setting quality q_B^{**} ($< q_B^m$) than setting price p_B^* ($> p_B^m$).

Proof of Corollary 2: (a) When non-deceptive counterfeits are in the market and $\beta \geq 1 - \left\{\frac{q_B^m - q_N^*(q_B^m)}{q_B^m}\right\}^2$, we know from Propositions 1 and 2 that $q_B^m > q_B^*$ and $p_B^m < p_B^*$. To determine which strategy is more profitable, we compare $-\frac{\partial \pi_B^*}{\partial q_B}$ and $\frac{\partial \pi_B^*}{\partial p_B}$. For given q_B and p_B, from (11), $\frac{\partial \pi_B^*}{\partial p_B} - (-\frac{\partial \pi_B^*}{\partial q_B}) = 1 - \frac{(3+\gamma)p_B}{4q_B} - \frac{(1-\gamma)p_B}{4(q_B - \beta q_B - f_N^*)} - \frac{(p_B - c_B)\{4q_B - (3+\gamma)(f_N^* + \beta q_B)\}}{4q_B(q_B - \beta q_B - f_N^*)} - \frac{p_B(p_B - c_B)}{4}\left\{\frac{3+\gamma}{q_B^2} + \frac{(1-\beta)(1-\gamma)}{(q_B - \beta q_B - f_N^*)^2}\right\} - 2q_B t_B$, which is decreasing in t_B. Thus, if t_B is sufficiently large, $\frac{\partial \pi_B^*}{\partial p_B} < (-\frac{\partial \pi_B^*}{\partial q_B})$ so that changing quality from q_B^m to q_B^* is more profitable than changing price from p_B^m to p_B^*. The proofs for $\beta < 1 - \left\{\frac{q_B^m - q_N^*(q_B^m)}{q_B^m}\right\}^2$ and for (b) are similar to that for (a), and are hence omitted. □

Appendix B. Numerical Experiments

This section contains our numerical study that examines the effectiveness of the marketing campaign, the enforcement strategy and the technology strategy against the *deceptive* counterfeiter. Similar to the numerical study presented in §5.2, we have constructed 1024 scenarios for $\lambda = 0, 0.25$ or 0.5, using the following parameter values: $t \in \{0.005, 0.01, 0.015, 0.02\}$, $\beta \in \{0.1, 0.2, 0.3, 0.4\}$, $\gamma \in \{0.1, 0.2, 0.3, 0.4\}$, $l \in \{0.005, 0.01, 0.015, 0.02\}$, $c_B \in \{0.005, 0.01, 0.015, 0.02\}$, $h = 0$, $\underline{f} = 0.1$ and $\overline{f} = (1-\beta)q_B - 0.01$. (q_B, p_B) is fixed at (q_B^m, p_B^m). We omit the result for increasing t because its effect is essentially the same as increasing γ. We computed the difference in firms' expected profits and expected consumer welfare associated with the adjacent values of β or γ for a fixed set of other parameter values. There are 3 increments of β or γ for a set of 256 possible values of other parameters, so there are 768 scenarios for which we can examine the direction of changes with a decrease of β or an increase of γ. The results are summarized in Table 5, which reads as follows: for example, when $\lambda = 0.5$, reducing β increased π_B^{**} in 33.1% of 768 scenarios, decreased π_D^{**} in all scenarios, and increased ECS_D^{**} in 13.9% of 768 scenarios.

Table 5. Effects of Marketing and Enforcement Strategies against Deceptive Counterfeits

	Effects of Reducing β			Effects of Increasing γ		
	$\pi_B^{**} \uparrow$	$\pi_D^{**} \downarrow$	$ECS_D^{**} \uparrow$	$\pi_B^{**} \uparrow$	$\pi_D^{**} \downarrow$	$ECS_D^{**} \uparrow$
$\lambda = 0$	no change	no change	0	1	1	1
$\lambda = 0.25$	0.374	1	0.260	1	1	0.952
$\lambda = 0.5$	0.331	1	0.139	0.990	1	0.927

Table 5 confirms the results stated in Proposition 5. In addition, similar to the quality and pricing strategies discussed in §5.2, these strategies are not necessarily more effective as more consumers are proactive with higher λ.

Appendix C. Extension: Price Decision of Licit Distributor

When the *deceptive* counterfeiter is in the market, suppose that the licit distributor decides on the retail price p_B, while the brand-name company instead decides the wholesale price w_B to the licit distributor. The rest of the decisions remain the same as in the base model as follows. After observing the quality q_B and wholesale price w_B of the brand-name product, the deceptive counterfeiter decides his functional quality f_D and wholesale price w_D in stages 1 and 2, respectively. In stage 3, the licit distributor decides a fraction of deceptive counterfeits s, and then decides the retail price p_B. We consider two cases that differ in how the licit distributor determines p_B: (1) the distributor chooses the retail price that maximizes his expected profit from selling both brand-name and counterfeit goods; and (2) the distributor chooses the optimal retail price as if he does not sell the deceptive counterfeit, for fear that consumers or third parties may identify the deceptive counterfeit from a lower retail price than the price of authentic goods. The second case reflects the fact that a deceptive counterfeit is usually sold at the same price or close to that of its branded product so as to deceive consumers (see §1 and §3).

In the first case, the licit distributor solves the following problem in stage 3 to determine p_B:

$$\max_{p_B} (1-s)\{p_B - sw_D - (1-s)w_B\}\left\{1 - \frac{\lambda p_B}{(1-s)q_B + s(f_D+\beta q_B)} - \frac{(1-\lambda)p_B}{q_B}\right\} - sl.$$

We can verify that the distributor' profit is concave in p_B, and obtain $p_B^{**} = \frac{sw_D+(1-s)w_B}{2} + \frac{1}{2}\{\frac{\lambda}{(1-s)q_B+s(f_D+\beta q_B)} + \frac{1-\lambda}{q_B}\}^{-1}$. Since $w_D < w_B$ and $f_D + \beta q_B < q_B$, the distributor charges a lower retail price p_B^{**} when the fraction of counterfeits s is larger or the fraction of proactive consumers λ is larger. To find the optimal fraction s^{**}, the licit distributor solves the following problem which is obtained by substituting p_B^{**} into the distributor's profit:

$\max_s \frac{1}{4}(1-s)\left\{\frac{\lambda}{(1-s)q_B+s(f_D+\beta q_B)}+\frac{1-\lambda}{q_B}\right\}\left[sw_D+(1-s)w_B-\left\{\frac{\lambda}{(1-s)q_B+s(f_D+\beta q_B)}+\frac{1-\lambda}{q_B}\right\}^{-1}\right]^2-sl.$

Due to complexity, however, it is not possible to find the closed-form expression of s^{**}. Although the part of our analysis in the base model does not rely on its closed-form expression, the impact of any anti-counterfeiting strategy on s^{**} becomes prohibitively complex to obtain any analytical result. Thus we conduct extensive numerical experiments to examine the effects of anti-counterfeiting strategies. We use the same parameters in Table 6 as in Table 5. For each case with $\lambda = 0$ and $\lambda = 0.5$, there are 1024 scenarios in which we can investigate the anti-counterfeiting strategies that change quality or price from the case with no counterfeiter to the optimal levels. On the other hand, similar to Table 5, there are 768 scenarios for which we can examine the anti-counterfeiting strategies that reduce β or increase γ. Table 6 can be read similarly to Table 5.

Table 6. Effects of Anti-counterfeiting Strategies in the Extended Model

	$\lambda = 0$			$\lambda = 0.5$		
	$\pi_B^{**}\uparrow$	$\pi_D^{**}\downarrow$	$ECS_D^{**}\uparrow$	$\pi_B^{**}\uparrow$	$\pi_D^{**}\downarrow$	$ECS_D^{**}\uparrow$
$q_B^m \to q_B^{**}$	1	0.320	0.672	1	0.998	0.647
$w_B^m \to w_B^{**}$	1	0.508	0.805	1	0.998	0.647
$\beta\downarrow$	no change	no change	0	0.135	1	0.135
$\gamma\uparrow$	1	1	1	0.779	1	0.798

Table 6 shows that the effects of anti-counterfeiting strategies remain directionally true in this extended model. For example, as the price changes from w_B^m to w_B^{**}, π_D^{**} and ECS_D^{**} can increase or decrease; this is consistent with Proposition 4. Also, as stated in Proposition 5, when $\lambda = 0$, reducing β has no impact on π_B^{**} and π_D^{**}, but decreases ECS_D^{**}, whereas increasing γ reduces π_D^{**} and increases π_B^{**} as well as ECS_D^{**}; when $\lambda > 0$, reducing β or increasing γ decreases π_D^{**}, but it can increase or decrease π_B^{**} and ECS_D^{**}. One notable exception is that when $\lambda = 0$, changing q_B^m to q_B^{**} can increase π_D^{**} although it always decreases π_D^{**} in the base model. This happens because of the additional lever the licit distributor has (i.e., determining p_B as well as s): in response to the change of q_B, the distributor can increase the aggregate demand for both brand-name and counterfeit goods by reducing p_B. As a result, we find that the distributor may increase or decrease s^{**} in response to this strategy, which thus creates a non-monotonic effect on π_D^{**}.

In the second case, the licit distributor chooses p_B to maximize $(p_B - w_B)\left(1-\frac{p_B}{q_B}\right)$. We obtain the optimal retail price: $p_B^{**} = \frac{w_B+q_B}{2}$. Different from the first case, p_B^{**} does not depend on the fraction of counterfeits s or the fraction of proactive consumers λ. To find the optimal fraction s^{**}, the licit distributor solves the following problem:

$$\max_s \frac{(1-s)}{2}\left\{\frac{w_B+q_B}{2}-sw_D-(1-s)w_B\right\}\left\{2-\frac{\lambda(w_B+q_B)}{(1-s)q_B+s(f_D+\beta q_B)}-\frac{(1-\lambda)(w_B+q_B)}{q_B}\right\}-sl.$$

In the case when $\lambda = 0$, we can obtain from the first-order condition that $s^{**} = \frac{1}{2}-\frac{(q_B-w_B)^2+4lq_B}{4(w_B-w_D)(q_B-w_B)}$. By substituting s^{**} into (8) and solving $\max_{w_D} \pi_D(w_D, f_D)$, we obtain w_D^{**} and the corresponding

expected profit of the deceptive counterfeiter π_D^{**} as follows:
$w_D^{**} = w_B - \sqrt{\frac{w_B[(q_B-w_B)^2+4lq_B]}{2(q_B-w_B)}}$ and $\pi_D^{**} = (1-\gamma)w_D\left\{\frac{1}{2} - \sqrt{\frac{(q_B-w_B)^2+4lq_B}{8w_B(q_B-w_B)}}\right\}(\frac{1}{2} - \frac{w_B}{2q_B}) - tf_D^2 - \gamma h.$
From w_D^{**} and π_D^{**}, we can verify that several insights from the base model continue to hold. For example, as the risk of the licit distributor selling counterfeits increases with l, the deceptive counterfeiter has to reduce his price w_D^{**} to compensate for the increased risk, resulting in a decrease in his expected profit π_D^{**}. Also, the deceptive counterfeiter always chooses the lower bound $\underline{f}$ for his functional quality in the market with no proactive consumers. The following corollary shows that the main results from the base model continue to hold in this case.

Corollary 3 *Suppose the licit distributor decides the retail price p_B as if he does not sell the deceptive counterfeit. Then there exists $\underline{l}$ such that if $l > \underline{l}$, Propositions 3 and 4 continue to hold except that the conditions in part (c) are different.*

Proof: When the deceptive counterfeiter exists in the market with $\lambda = 0$, we obtain the following π_B^{**} after substituting s^{**} and w_D^{**} into m_B in (6):

$$\pi_B^{**} = (w_B - c_B)\left(\frac{1}{2} - \frac{w_B}{2q_B}\right)\left[(1-\gamma)\left\{\frac{1}{2} + \sqrt{\frac{(q_B-w_B)^2+4lq_B}{8w_B(q_B-w_B)}}\right\} + \gamma\right] - t_B q_B^2.$$

From the first order condition, $q_B^{**} = \frac{w_B(w_B-c_B)}{4t_Bq_B^2}\left\{\frac{1}{4}(1-\gamma)(2 + \sqrt{\frac{2[(q_B-w_B)^2+4lq_B]}{w_B(q_B-w_B)}}) + \gamma\right\}$
$+\frac{(1-\gamma)(w_B-c_B)[(q_B-w_B)^2-4lq_B]}{16t_Bq_B\sqrt{2w_B(q_B-w_B)[(q_B-w_B)^2+4lq_B]}}$, which is decreasing in l if l is sufficiently large. On the other hand, $q_B^m = \frac{w_B(w_B-c_B)}{4t_Bq_B^2}$, which does not depend on l. Thus, there exists $\underline{l}$ such that if $l > \underline{l}$, we have $q_B^{**} < q_B^m$. The proof of p_B^{**} is similar and hence omitted. To establish the result in Proposition 3(b), it suffices to show that π_D^{**} is increasing in q_B. In the expression of π_D^{**} above, $(\frac{1}{2} - \frac{w_B}{2q_B})$ is increasing in q_B and $\{\frac{1}{2} - \sqrt{\frac{(q_B-w_B)^2+4lq_B}{8w_B(q_B-w_B)}}\}$ is increasing in q_B if l is sufficiently large. Therefore, there exists $\underline{l}$ such that if $l > \underline{l}$, π_D^{**} is increasing in q_B. The non-monotonicity of π_D^{**} (with respect to p_B) and ECS_D^{**} are shown in Table 7. □

Corollary 3 shows that our main results in the base model continue to hold as long as the licit distributor faces a significant penalty if getting caught by the authorities, which is true in most countries (see §3). The intuition is that in such a case, the counterfeiter offers a low wholesale price to the distributor to compensate for the high risk so that the distributor's margin from selling the counterfeit is high. As a result, the quality strategy discussed in Proposition 3, which reduces the aggregate demand, still discourages the licit distributor from taking the risk of selling the counterfeit and results in a lower s^{**} in this case. Similarly, the pricing strategy discussed in Proposition 4 leads to the same behavior of the distributor because it still reduces the aggregate demand and increases the distributor's margin from selling the counterfeit.

When $\lambda > 0$, the closed-form expressions of s^{**}, w_D^{**} and f_D^{**} do not exist. We conduct a numerical study similar to the first case using the same set of parameters. A summary of the results is presented in Table 7. Comparing Table 7 with Table 6, we can verify that the dominant effects are the same in both cases. Therefore, the effects of anti-counterfeiting strategies remain directionally true in all cases.

Table 7. Effects of Anti-counterfeiting Strategies in the Extended Model

	$\lambda = 0$			$\lambda = 0.5$		
	$\pi_B^{**} \uparrow$	$\pi_D^{**} \downarrow$	$ECS_D^{**} \uparrow$	$\pi_B^{**} \uparrow$	$\pi_D^{**} \downarrow$	$ECS_D^{**} \uparrow$
$q_B^m \to q_B^{**}$	1	0.500	0.688	1	0.990	0.730
$w_B^m \to w_B^{**}$	1	0.523	0.676	1	0.990	0.730
$\beta \downarrow$	no change	no change	0	0.500	1	0.500
$\gamma \uparrow$	1	1	1	0.645	1	0.656

Appendix D. Details of Consumer Survey

Respondents of our survey are college students and faculty with ages from 18 to 50. The number of respondents is 86 in the U.S., and it is 80 in China. Two questions were asked in the questionnaire: (1) Are you aware of the sale of counterfeits in each of the above product categories; and (2) For each product category in which you are aware of the sale of counterfeits, do you take into account the risk of getting a counterfeit and therefore discount the value of the product when you purchase a brand-name product at a full price in a legal store? Those customers who answered yes to (1) are considered "Aware", and those customers who answered yes to both (1) and (2) are considered "Proactive." The absolute numbers may be escalated because respondents may be reminded of counterfeits by the questionnaire. Our survey indicates that being "aware" of the existence of counterfeits differs from being "proactive." One may explain such difference from cognitive psychology (e.g., Bendoly et al. 2010, Goldsmith and Amir 2010, and references therein); for example, it may be due to a positive-outcome "bias" or "wishful thinking" caused by overestimating the probability of good things happening.

Additional References

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