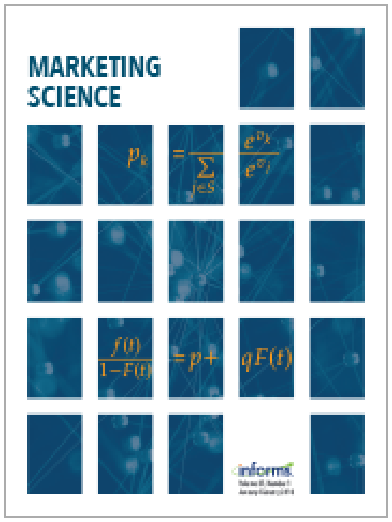

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On the Use of Overt Anti-Counterfeiting Technologies

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Abstract. Many pharmaceutical companies use overt anti-counterfeiting technologies (OACTs), such as holograms, to fight counterfeiters. An OACT is typically implemented on the drug packaging, which makes it difficult for counterfeiters to produce convincing copies and easy for patients to tell the difference between authentic and counterfeit medicines. I consider a model in which an authentic firm sells its drug at a reliable source and counterfeiters and illegitimate genuine sellers sell their drugs at a dubious source. The authentic firm chooses an OACT to combat counterfeiters. I show that there may be an inverted U-shaped relationship between the complexity of the OACT and the magnitude of counterfeit medicine purchases. The nature of this relationship is a consequence of an OACT engendering two opposing effects. On one hand, adopting an OACT imposes an entry cost on counterfeiters, causing fewer counterfeiters to enter the dubious source; as a result, the drugs at this source have a greater chance of being genuine (a *counterfeiters' entry-dampening effect*). On the other hand, more patients head to this dubious source rather than the reliable source owing to the increased chance of obtaining a genuine drug (a *patients' demand-enhancing effect*). When the selected OACT is sufficiently complex to replicate, the former effect overrides the latter and thus the problem of counterfeit purchasing is relieved. However, when the OACT is not adequately sophisticated, the latter effect more than offsets the former. This leads to an *anti-counterfeiting trap*: the use of a rudimentary OACT may beget more counterfeit purchases. This result offers an understanding to the phenomenon that despite enormous spending on the upgrading of OACTs in recent years, annual global sales of counterfeit drugs have actually risen. I also find that using an OACT may result in higher prices for both counterfeit and authentic drugs. Furthermore, I demonstrate that, at the optimum, an authentic firm may find it more profitable to employ a mediocre OACT, whereas it may not use any OACTs if its price is regulated.

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Keywords: anti-counterfeiting • overt technologies • entry • pricing • pharmaceutical industry

1. Introduction

Counterfeit goods constituted approximately 1.95% of the world trade in 2007, which translates to $250 billion, according to a report by the Organisation for Economic Co-operation and Development (2009), and continues to grow. The International Chamber of Commerce predicted that counterfeiting and piracy will drain $1.7 trillion from the global economy and put $2.5 million legitimate jobs at risk by 2015.[1] Counterfeiting infringes many industries, and one such industry is the pharmaceutical industry. The Center for Medicine in the Public Interest (2006) declares that fake medicines could be a $75-billion-a-year industry in 2010. Specifically, 10% of drugs around the world, from 1% in developed countries to 10%–30% in developing countries, might be counterfeit (World Health Organization 2006a). As an example at the firm level, the mammoth drugmaker Pfizer may suffer potential losses of its marquee drug, Viagra, of as much as hundreds of millions of dollars a year because of counterfeits (Thomas 2013).

Distinctively different from other bogus products (e.g., apparel and shoes), fake drugs not only erode brand owners' business but also perhaps, more importantly, threaten patients' health and safety. The U.S. Food and Drug Administration defines counterfeit drugs in the following statement: "Counterfeit medicine is fake medicine. It may be contaminated or contain the wrong or no active ingredient. They could have the right active ingredient but at the wrong dose. Counterfeit drugs are illegal and may be harmful to your health."[2] Fake drugs are dangerous, since they are neither produced under safe and proper manufacturing conditions nor inspected and monitored by regulatory authorities. Patients who receive counterfeit drugs are insulated from the therapeutic benefits they could get by taking genuine versions. More seriously, using fake medicines can be fatal. Bate (2012) estimates that at least

100,000 people a year lose their lives as a result of taking counterfeit drugs.

As counterfeiting has become easier and more pervasive, copyright holders have continued to increase investments to combat counterfeiters and defend their interests. As a result, the market for anti-counterfeiting technologies has flourished over the past few years and is still expanding. Global Industry Analyst (2010) projects a surge of $82.2 billion by 2015 in the global market for anti-counterfeiting technologies. Many affected companies, particularly in the pharmaceutical industry, have adopted various state-of-the-art anti-counterfeiting techniques to address alarmingly economic and social issues incurred by fake drugs. For instance, Pfizer states the following on its website:

> Pfizer has a team of experts who constantly assess new and existing technologies to identify those that will make it more difficult for those who counterfeit our medicines to make convincing copies, and for patients and healthcare providers to distinguish authentic from counterfeit Pfizer medicines.[3]

Overt anti-counterfeiting technologies (OACTs) are the most commonly used techniques in a variety of industries, including the pharmaceutical industry. The idea behind using OACTs is to make it more difficult for counterfeiters to produce convincing copies and to make it easier for consumers to distinguish between authentic and counterfeit products (World Health Organization 2007). Holograms, special packaging, security graphics, sequential product numbering, on-product marking, etc., are some of the OACTs that are used. The hologram is one such notable OACT. A majority of these techniques are generally implemented and embedded in one or more packaging components, with the exception of on-product marking (which is applied at the product level itself). Note that OACTs themselves do not bring any consumption utility to consumers but are a means for them to identify the authenticity of commodities.

According to a report by Visiongain (2012), the world market for pharmaceutical anti-counterfeiting technologies is growing fast and will hit $1.2 billion by 2015. Specifically, the market for holograms alone was about $85.5 million in 2013 and will climb to $97.9 million by 2015 (Visiongain 2013). At the firm level, for example, the pharmaceutical giant Eli Lilly has been making considerable investments, of up to $100 million in introducing new techniques to battle fraudulent peddlers (Lechleiter 2012). In the pharmaceutical industry, the hologram sticker is the most popular of many OACTs. The sticker is typically a laser-created optical image imprinted with a two- or three-dimensional company name or logo. Figure 1 presents holograms used by Pfizer for Viagra and by Eli Lilly for Cialis.

However, despite constantly adopting advanced technologies to fight the onslaught of counterfeiters, the problem of counterfeit medicine purchasing has not diminished and instead has amplified over recent years. The Center for Medicine in the Public Interest (2006) estimates a 92% increase in the revenue of the global counterfeit drug industry from 2005 to 2010, reaching $75 billion; in the meantime, the global authentic pharmaceutical market only enjoyed a 41% increase to $856 billion during the same time period (IMS Institute for Healthcare Informatics 2011). Analogously, the Pharmaceutical Security Institute reported a steep upward trend in counterfeiting incidents from 2002 to 2010, mounting from 196 to 2,054 cases.[4]

Patients might obtain counterfeit medicines from dubious sources, for example, unlicensed private sellers especially in developing countries (Björkman-Nyqvist et al. 2013) and noncredentialed online pharmacies (Bate and Hess 2010, Haiken 2013). Stated differently, counterfeiters can penetrate only dubious sources but not reliable sources, for example, hospital and retail chain pharmacies, as counterfeiters do not have the required license to sell in legitimate markets. On the other hand, pharmaceutical firms often fail to restrict dubious sellers' selling behavior and seldom operate their business in unauthorized sources.

Given that patients are able to get authentic patented and trademarked drugs from credentialed pharmacies, it would seem baffling that some of them take the risk of purchasing drugs that could be dangerous from

Figure 1. Holograms Used on Boxes of Viagra and Cialis

dubious sources. The forces that drive patients to make these risky purchases are threefold. One, the appearance of the pills and packaging of counterfeit drugs look nearly identical to that of authentic ones, making it difficult for patients to discern their falsity. Bate et al. (2011) document that 97% of fake drugs across 17 developing and midincome countries pass the visual test. Even counterfeit drugs derived from unaccredited Internet pharmacies bear the same look as that of their legitimate counterparts (U.S. Department of Justice 2012). Two, the drugs are cheaper than those at reliable sources. Bate et al. (2015) find that, on average, fake drugs are priced approximately 50% lower than their authentic counterparts in 18 low-to-middle-income countries. Three, the possibility of receiving illegitimate genuine medicines is relatively high. Bate et al. (2013) show that, for Viagra, 27 out of 35 samples from noncertified pharmacies across several countries (including Australia, Canada, China, Italy, Turkey, and the United Kingdom) are genuine. In addition, Björkman-Nyqvist et al. (2013) record that 63% of drugs from unlicensed private drug stores in Uganda are effective. There may be two conduits for the appearance of effective drugs at lower rates at unauthorized sources (gray markets).[5] First, there may be illegitimate but genuine producers, who learn drug patents, producing and selling their effective drugs at these outlets. Toscano (2011) shows that there is a significant proportion of illegal genuine drugs produced by these illegitimate producers.[6] Second, some patients might sell their unused drugs that were originally purchased from credible pharmacies (Stone 2005). Indeed, Lin and Zhang (2007) provide concrete evidence showing many leftover drugs are being sold in the illegal market. Additionally, according to Schendel and MacClure (2012), roughly one-third of the drugs dispensed from reliable sources annually in Washington—33 million containers of pills—end up as leftover medicines. Consequently, such unused drugs could be another major conduit to the sale of effective drugs at dubious sources. In sum, patients may decide to buy cheap drugs from dubious sources despite recognizing the risk of their being fake (Bate et al. 2011).[7]

The counterfeiting situation becomes more complex after pharmaceutical firms adopt OACTs. Below Moran (2013) documents a recent counterfeiting incident in which a counterfeit seller was arrested while transacting with a customer.

> People who saw Rick Hitsman in court say he looks like any other middle-aged man with gray hair and blue eyes.... He'd meet buyers at parking lots around the San Fernando Valley and sell them boxes of fake Viagra, each containing four tablets, for $10 per box. Real Viagra costs around $22 per pill, so for buyers it was quite a bargain.... Callanan, who works at Pfizer's R&D campus in Groton, Connecticut,.... She picks up two small cardboard boxes. One box contains legitimate Viagra, the other is full of fakes... they look almost identical: same size, same wide blue stripes down the left-hand side, legitimate-looking Pfizer logos and [holograms]....

Perhaps the most important takeaway from this incident is that counterfeiters can successfully replicate complicated holographic images used on the product packaging. They have acquired access to sophisticated technologies that enable them to mimic the OACTs of legitimate medicines, as confirmed by the U.S. Food and Drug Administration.[8] Take holograms, for example—some counterfeiters have produced holograms that are strikingly similar to the genuine ones and thus can suffice to fool patients (e.g., Newton et al. 2003, World Health Organization 2007). The ease of global e-commerce has meant that counterfeiters are likely to obtain the necessary production facilities for copying holograms. For example, hologram manufacturing machines can be bought from factories in China through an e-commerce platform.[9] Furthermore, counterfeiters could even learn how to falsify modern holographic technologies by following the instructions expounded explicitly in academic journal articles (e.g., Mejias-Brizuela et al. 2012).

Pharmaceutical firms have been using OACTs not only to distinguish their product from the fake one but also to impose a significant fixed production cost on counterfeiters, which would act as an entry-deterrent for them. Nevertheless, the incidents of counterfeit purchasing seem to rise, rather than fall, after the introduction of OACTs. Furthermore, it is observed that the more complex an OACT, the more purchases of counterfeit medicine are generated. That is, there exists a positive relationship between the complexity of the OACT used and the magnitude of counterfeit medicine purchases.[10] These puzzling facts prompt me to ask the question: can OACTs actually reduce the number of incidents of counterfeit medicine purchases?

To answer this question, I develop an entry game to analyze authentic pharmaceutical firm's choices of OACT and price, counterfeiters' and illegitimate genuine sellers' decisions of market entry and pricing, and patients' choice of source for the purchase of medicines. Specifically, given that an authentic firm uses an OACT, a large number of counterfeiters simultaneously make their decision on whether to enter a dubious source by incurring the cost of replicating the OACT. Then, all of the market players compete in price. Patients use the OACT as a determinant of the authenticity of the drugs, and infer the number of counterfeiters in the market based on their understanding about the difficulty of replicating the OACT. Based on their belief on the drug authenticity and observation on drug prices, patients then decide whether to buy the drugs from the reliable source or the dubious source.

This paper shows an inverted U-shaped relationship between the complexity of the OACT and the magnitude of counterfeit drug purchases. More precisely, I demonstrate that when an OACT is sufficiently sophisticated, the problem of counterfeit purchasing is relieved, but when the chosen OACT has a low level of complexity, counterfeit purchases increase. This inverted U-shaped relationship is caused by an OACT generating two countervailing effects. On one hand, it produces a *counterfeiters' entry-dampening effect*: replicating an OACT is expensive and is an effective entry barrier to counterfeiters who want to enter the dubious market, which means a reduced number of counterfeiters. This effect has been recognized in the literature (e.g., Salop 1979). On the other hand, the use of an OACT also produces a *patients' demand-enhancing effect*: more patients will be willing to make purchases from the dubious source, since there are now fewer counterfeiters and hence the chance of obtaining a genuine drug becomes higher. The latter effect is completely neglected in the extant literature.

I find that the *patients' demand-enhancing effect* more than offsets the *counterfeiters' entry-dampening effect* if the adopted OACT is not sufficiently complex, leading to more counterfeit purchases. I call this phenomenon an *anti-counterfeiting trap*—although the measures taken to fight counterfeiters have been increased, the incidents of counterfeit purchases rise, rather than fall as expected. Given this *anti-counterfeiting trap*, I question the effectiveness of using OACTs and point out that the noncomplex OACTs might be one culprit for the phenomenon of ever-increasing incidents of counterfeit purchasing. However, I show that if the selected OACT is sufficiently complex to replicate, the *counterfeiters' entry-dampening effect* overrides the *patients' demand-enhancing effect* and thus the problem of counterfeit purchasing is relieved.

Naturally, the question that I then ask is what the optimal OACT should be in order for an authentic firm to combat counterfeiters? I establish that it may be optimal for an authentic firm to adopt a mediocre OACT if the firm also prices its drugs strategically. This result explains the phenomena wherein many pharmaceutical firms do not use the most sophisticated OACTs for their brand-name drugs, as there is ample evidence to show that their adopted techniques are duplicated by many counterfeiters. That said, I demonstrate that an authentic firm at the optimum may not use any OACTs once it takes into account the *patients' demand-enhancing effect*, if it does not alter its original pricing strategy. This happens because the use of an OACT pushes more patients to buy risky drugs as it improves their chance of getting effective drugs at the dubious source. This result offers an understanding about why, typically, we do not see OACTs for the drugs whose prices are under control by regulators.

In addition, I also examine the impact of using an OACT on counterfeits' price. I find another interesting result: the price of counterfeits increases with the complexity of the OACT. The intuition is that the counterfeit entrants have an incentive to price higher as their products are much more likely to be perceived as legitimate because of the complex OACT on the product packaging. This situation means that in fact an OACT would actually result in more patients being affected by fake drugs, which not only pose a serious threat to their health but also, ironically, make them pay more. Furthermore, I look at how the use of an OACT affects authentic firm's pricing. I demonstrate that its drug price might increase with the complexity of the OACT as well. This implies that patients shopping from the reliable source also spend more, similar to those patients shopping at the dubious source. Last, I find that authentic firm's optimal choice of OACT may adversely affect the growing purchase of genuine drugs, as seen from a social planner's perspective.

The key mechanism underlying this paper is that patients draw inferences about the likelihood that the drugs at the dubious source are genuine when they see OACTs. I conduct an experiment, which lends empirical validation for this mechanism. In the experiment, the subjects evaluate the authenticity and the purchase probability of a dubious drug with or without a hologram attached on the packaging. I find that embedding a hologram on the box of a risky drug does enhance the subjects' perceptions of the drug authenticity and they indeed are more likely to buy such a drug.

The findings of this paper have significant management implications for pharmaceutical firms and policy makers. Most importantly, this article adds a word of caution to prevalent anti-counterfeiting practices about embracing OACTs, showing that the proliferation of fake drugs in the market can abate only when the chosen OACTs are sufficiently sophisticated. In using OACTs, firms and policy makers should take into account the fact that having OACTs on the product packaging can modify patients' beliefs about the authenticity of medicines sold in dubious sources, as the number of counterfeit entrants is endogenously determined by the specific OACT used. Additionally, firms should use the pricing tool as a necessary and complementary strategy to using OACTs to fight counterfeiters because it is in their best interests.

2. Related Research

Counterfeiting has caught the attention of academics since the 1980s. Grossman and Shapiro (1988a, b) classify counterfeit products into two types: deceptive versus nondeceptive. A counterfeit product is deceptive when individuals are unable to discern the authentic from the fake; a nondeceptive product can, however, be easily distinguished from a genuine one. Since the focus of this paper is pharmaceutical counterfeits, all of the counterfeits would have to be of the deceptive type, as patients would not knowingly buy fake drugs.

Many firms face a situation of dwindling revenues because of the prevalence of counterfeit products. For instance, Givon et al. (1995) estimate that software firms lose more than 80% of users to pirated copies. A limited number of studies that do cover this topic propose some strategies for brand owners to counteract counterfeiters. In terms of product strategy, Cho et al. (2015) point out the role of improved product quality in prevailing against nondeceptive counterfeiters. Qian (2014a), however, shows that this strategy could counteract both types of counterfeiters. Similarly, in terms of the pricing strategy, Cho et al. (2015) suggest that reducing the price would be effective in beating nondeceptive counterfeiters, yet Qian (2014a) demonstrates that raising prices could helpfully battle both types of counterfeiters. Another strategy to cope with deceptive counterfeiters could be to invest in enforcement (Qian 2014a). The extant literature also recommends implementing observable devices (such as holograms and special packaging) onto products as a potent strategy. Qian (2014a) points out the effectiveness of this strategy as these devices can easily isolate genuine products. Qian et al. (2015) categorize products by their quality—a searchable dimension and an experiential dimension—and suggest that firms might be more profitable if they update the searchable dimension (e.g., an appearance device) when they have a cost advantage over counterfeiters, or else enhance the experiential dimensions (e.g., a function).

This paper focuses on the use of overt techniques in anti-counterfeiting and is distinct from prior research in that it brings to light several new aspects that are especially essential for the pharmaceutical industry. First, this paper introduces the fact that there exist different sources from which patients can buy medicines—dubious sources and reliable ones; prior research (e.g., Qian 2014a, Qian et al. 2015) assumes only one type of purchase point. This assumption might be reasonable if studying nondeceptive counterfeits, as consumers can tell which product is authentic. However, when it comes to deceptive counterfeits, this assumption is flawed for two reasons: (i) in reality, patients can always get legitimate drugs from reliable sources, which are often managed by brand owners, and (ii) counterfeiters can penetrate only dubious sources, which are usually not controlled by pharmaceutical firms. Weaving this two-source arrangement into the model is important as patients' uncertainty about the authenticity of drugs is only present at dubious sources, and copyright holders generally profit only from reliable sources.

Second, the use of an OACT by firms will increase fixed entry costs for counterfeiters. Counterfeiters wishing to enter the (dubious) market have to incur a considerable fixed cost, namely, procuring expensive machines for replicating the OACT. Therefore, the assumption that counterfeiters incur only marginal costs but zero fixed costs when these technologies are utilized (Qian 2014a, Qian et al. 2015) is worth a second thought.

Third, an OACT itself does not impart any therapeutic benefits to patients.[11] Qian et al. (2015) posit that consumers derive extra utility from the appearance device implemented on a product, over and above the utility from the product itself. I argue that the authentication device cannot directly convey any benefits to consumers as they are not designed to be consumed, unlike the actual product. Instead, the only role that an OACT plays in this article is in altering the entry decision of counterfeiters, which in turn shapes patients' belief about the authenticity of drugs in dubious sources.

Last, the number of counterfeiters entering the market is endogenously determined in the model. Qian (2014a) and Qian et al. (2015) do not explicitly endogenize the number of counterfeit entrants in the market. In this paper, I derive the equilibrium counterfeiter entry, a key parameter that critically affects patients' belief about the proportion of counterfeit sellers at the dubious source. By incorporating these aspects into a new model, we can better understand how the use of an OACT influences the entry decision of counterfeiters and the source choice of patients, thereby painting a broader picture and hence allowing us to better understand the effectiveness and profitability of anti-counterfeiting practices.

On the other hand, quite a few studies also look into the bright side of counterfeiting, and assert that the presence of counterfeiters may benefit firms in different industries. Focusing on the digital industry, some analytical works show that weaker copyright protection may be good for copyright owners for various reasons, including generating positive network externality (Conner and Rumelt 1991, Shy and Thisse 1999), accelerating product diffusion (Prasad and Mahajan 2003), reducing competition (Jain 2008), increasing downstream competition (Vernik et al. 2011), and inducing reduced consumer search (Guo and Meng 2015). On the empirical side, Qian (2014b), paying attention to the fashion industry, reveals that counterfeiters are friends of legitimate companies when the advertising effect dominates the substitution effect.

Also related to this paper is a large body of literature on observational learning. Banerjee (1992) and Bikhchandani et al. (1992) examine agents' sequential decision-making process, which allows subsequent individuals to know more about an object in question. In an empirical study, Zhang (2010) shows that in the U.S. kidney market, transplant patients infer the poor quality of kidneys by observing prior refusals.

People draw inferences not only from others' choices but also from firms' policies printed on product labels. Recently, Zhang (2013) finds that consumers develop a negative quality interpretation for products when observing mandatory information disclosure about genetically modified organisms on the product's labels. This article contributes to the literature by arguing that OACTs (as one label type) can also alter individuals' perceptions about expected product quality.

The rest of the paper is organized as follows. Section 3 introduces the model setup. Section 4 presents the model analysis and the results. Section 5 reports an experiment that shows that imprinting a hologram on the box of a drug does indeed boost individuals' beliefs about the credibility of the drug, and as a consequence they respond with higher purchase likelihood for the drug. Section 6 considers several model extensions. Section 7 concludes. All of the proofs are regulated to the appendix.

3. Model Setup

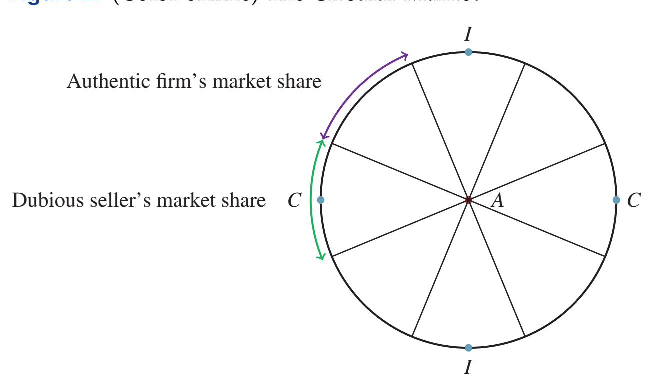
Consider a market with a unit mass of patients who are uniformly distributed on a circle of unit circumference. An authentic pharmaceutical firm (henceforth referred to simply as an authentic firm) located at the center of the circle as a reliable source sells its drugs. A large number of homogeneous counterfeiters are capable of producing fake medicines where the pills and packaging appear identical to authentic drugs, if paying a fixed cost S (>0), like the authentic firm, to purchase drug and packaging production machines. Counterfeiters can freely enter a dubious source (a gray market), which locates along the circle, and then coax patients into buying their authentic-looking fake drugs.

In the market, there are also numerous illegitimate genuine producers and K patients with unused drugs, both wanting to enter the dubious source to sell their effective drugs. Like counterfeiters, illegitimate genuine producers need to pay fixed costs for drug production as well. Here, the number of patients willing to sell their unused drugs is limited as they do not produce drugs themselves and their drugs are from a reliable source. Counterfeit entrants and illegal genuine sellers, as dubious sellers, symmetrically and randomly locate along the circle as in Salop (1979). The arrangement of an authentic firm and dubious sellers in such a spatially differentiated manner is for two reasons.[12] First, it reflects the fact that both types of marketers routinely situate in discrete places, and patients typically have to choose a source (reliable versus dubious) when purchasing drugs. Second, it captures the idea that the location of an authentic firm is typically stable whereas the position of a dubious seller seems changeable. The dubious sellers' instability is primarily due to the possibility of their being caught by the police if they adhere to the same place when selling unregulated drugs.

For alleviating its concern about counterfeiting, the authentic firm decides to use an OACT, which is imprinted on the product packaging, to add a significant fixed production cost to counterfeiters and enable patients to better verify the authenticity of the drug. The lump-sum cost of adopting an OACT for the authentic firm is F (>0). Higher costs mean an OACT of greater complexity. Patients are attentive to an OACT and consider buying risky drugs if and only if their pills, packaging, and OACT look like legitimate versions. As a result, under the new policy, to enter the dubious market, both counterfeiters and illegitimate genuine producers have to pay the fixed cost F for replicating the OACT such that their drugs can resemble authentic drugs.[13] This is a fact that patients are aware of. The marginal costs of the drug, packaging, and OACT production are set to zero for the authentic firm, counterfeiters, and illegitimate genuine producers. This is consistent with the fact that the marginal cost of drug production is pretty low (Bate and Boateng 2007). Marginal costs for the patients who sell their leftover drugs are also assumed to be zero for the following two reasons. First, the money that the patients paid for purchasing drugs from the reliable source is a sunk cost when they sell these drugs. Second, the unused drugs have trivial value for the patients as the drugs might be expiring soon or they may no longer be needed. Figure 2 presents a spatial setting of the circular market, which comprises the authentic firm (denoted as A), two counterfeit entrants (C), and two illegitimate genuine sellers (I).

Patients each demand one unit of the drug if the expected surplus is positive, and choose where to buy—either from the reliable source (R) or the dubious source (D)—which delivers a maximized expected surplus to them. The reliable source operated by the authentic firm always offers genuine medicines, whereas the dubious source might involve fake drugs resulting from the entry of counterfeiters. That is, the

Figure 2. (Color online) The Circular Market



dubious source consists of counterfeit sellers providing fake drugs as well as illegal genuine sellers offering genuine ones. Although a patient does not know whether a seller's drug at the dubious source is genuine or not, she will draw an inference about the authenticity of the drug on seeing an OACT on the box by forming an expectation about the number of counterfeiters entering the dubious market. Formally, I use $\mu_i \in (0,1)$, $i = R, D$, to represent patients' belief that medicine at the source i is authentic. It is clear that $\mu_R = 1$. On the other hand, $\mu_D = I/(I+N)$, where N is the number of counterfeit entrants and I is the number of sellers selling genuine drugs at the dubious source. This reflects that the chance of obtaining a fake medicine from the dubious source depends critically on the entry of counterfeiters. More precisely, the more counterfeiters entering the market, the lower the likelihood that patients will receive an effective drug.

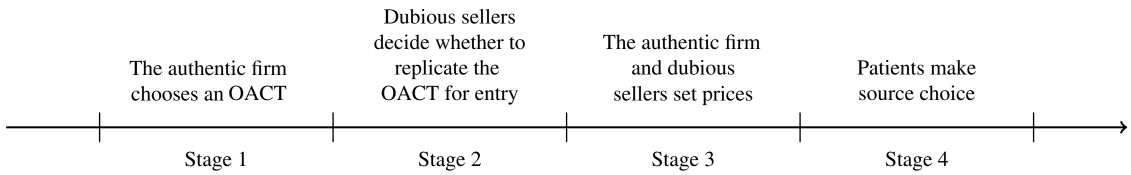
The drugs' expected quality in the two sources is $\mu_i Q - (1-\mu_i)L$. The parameter Q is a realized benefit because of receiving the right medical treatment when the purchased drug is genuine and the parameter L is an incurred loss because of being untreated when the purchased drug is counterfeit. According to the Pharmaceutical Security Institute, drugs in the genitourinary, antiinfective, and therapeutic hormones categories are the most frequently targeted by pharmaceutical counterfeiters.[14] For instance, the erectile dysfunction drug Viagra is the world's most counterfeited drug (Toscano 2011). Typically, these drugs are not life saving and so the treatment failure as a result of taking them might not be fatal. Hence, the loss L is not big enough such that patients would like to take the risk of making a purchase from the dubious source. Besides a price p_i, a patient also needs to pay a transportation cost in completing a shopping trip. Specifically, a patient incurs the cost γ if she visits the authentic firm at the reliable source as the location of the reliable sellers is routinely fixed. Note that when patients make purchases from a reliable source, some patient expenditure might be covered by insurance. This can be captured by γ, in the sense that having insurance lowers the transaction cost at the reliable source. On the other hand, a patient incurs the cost at a rate t per unit distance if she buys from a seller at the dubious source. This captures the ideas that the more dubious sellers there are at the dubious source, the easier it is for patients to trade with them and some patients may pay lower transaction costs than others because of their different locations.[15]

In addition, I also assume that these illegitimate sellers of genuine drugs are not under the authorization or surveillance by the authentic firm. This assumption makes sense. One important reason why patients seek out risky drugs at the dubious source is that there are some genuine sellers. So, if the authentic firm could fully manage these vendors, it would direct all patients to the reliable source simply by ceasing to do business with them, so as to completely dash patients' hopes of obtaining an effective drug from the dubious source. Prior to the analysis, I make two technical assumptions: (a) $Q > \gamma$, and (b) $t > K(Q+L)$. The first makes patients willing to purchase the drugs offered by the authentic firm so that the market is fully covered, in the sense that all of the patients must take a drug for medical treatment. This assumption is not unreasonable since most counterfeited drugs are not life saving ones, as illustrated before, and so their prices at the reliable source seem generally affordable by patients. Additionally, although the drugs at the dubious source are relatively cheaper than the ones at the reliable source, they are not sufficiently cheaper and so patients still need to pay a nontrivial amount of money to acquire the dubious drugs. Therefore, it is more than likely that patients can afford the reliable source's drugs if they are able to afford the dubious source's drugs. The second assumption ensures the existence of the pure strategy equilibrium, an assumption that is also used in Balasubramanian (1998).

I model the interactions among an authentic firm, counterfeiters, illegitimate genuine sellers, and patients as a sequential game. The game unfolds in four stages. Figure 3 presents the timing of the game. In the first stage, the authentic firm chooses the level of complexity of the OACT. In the second stage, counterfeiters and illegitimate genuine sellers then simultaneously decide whether to enter the dubious source by incurring a cost of replicating the OACT adopted by the authentic firm if their drugs do not resemble authentic counterparts. In the third stage, the authentic firm and all of the dubious sellers set their prices at the same time. In the fourth stage, patients make their source choice about where to purchase upon observation of the OACT and prices of drugs in both sources. In a relevant study, Ellison and Ellison (2011) structure similar timing for a parallel model where a pharmaceutical firm deters potential entrants before patent expiration. Note that the use of OACTs might be initiated by policy makers, rather than always by pharmaceutical firms. For instance, the Ministry of Health in Malaysia requires mandatory holograms for pharmaceutical companies' medicines (World Health Professions Alliance 2011). In this case, the policy maker has made the OACT choice in the first stage of the game, and its objective might be to reduce the magnitude of counterfeit purchases.

I derive the rational expectation equilibrium (REE) for the entry game, which satisfies the following characteristics.[16] First, patients' source choice is optimal, given their expectation about the number of counterfeiters and illegitimate genuine sellers entering the dubious market and their observation on drug prices. Second, authentic firm's choices of OACT and price and dubious

Figure 3. Timing of the Game



sellers' decisions of market entry and pricing are optimal, conditional on their expectation about the volume of patients willing to buy their drugs. Third, everyone's expectations are correct in equilibrium.

4. Analysis and Results

In this section, I solve the game backward. Consider the last stage where patients are making a source choice. I determine the market equilibrium, given that patients expect that N' counterfeiters have replicated the OACT and entered the dubious source together with N'' illegitimate genuine producers who also enter this source and K patients who sell their unused drugs at this source as well. Hence, the number of illegitimate genuine sellers at the dubious source I is equal to $K + N''$.

Authentic firm's use of an OACT modifies a patient's expectation about the number of counterfeiters entering the market, as an entrant's profitability depends partly on the cost of procuring the required machines to replicate the OACT. To wit, a patient infers the authenticity of the drugs in the dubious market on seeing an OACT on the product packaging. Specifically, from patients' point of view, the probability of the drugs being genuine for each seller at the dubious source is $(K + N'')/(K + N' + N'')$.

In each segment of size $1/(K + N' + N'')$, the authentic firm competes with a pair of dubious vendors. A patient in a given segment makes a purchase from either of the two sources. Specifically, a patient located at a distance x from a dubious seller derives expected utility $Q - p_R - \gamma$ and $[(K + N'')/(K + N' + N'')]Q - [1 - (K + N'')/(K + N' + N'')]L - p_D - xt$ from the reliable and the dubious source, respectively, when purchasing. A patient's expected surplus from the unreliable channel increases with a decrease in the number of counterfeit entrants; that is, it increases with the drug authenticity. The marginal patient in each segment who is indifferent between the two sources is represented by $x = (\delta + p_R + \gamma - p_D - Q)/t$, where $\delta = [(K + N'')Q - N'L]/(K + N' + N'')$.

4.1. The Impact of the Use of an OACT on Entry

I return to look at a dubious seller's pricing decision in the third stage, given that it had entered the dubious source. I first wish to establish that the equilibrium prices charged by all of the sellers at the dubious source should be identical in the model. Signaling incentives arise at the dubious source as dubious sellers privately know the quality of their drugs but patients do not. So, illegitimate genuine sellers will want to use pricing to signal their high quality. In the model, after entry, counterfeiters earn zero demand if patients were to identify their type, because no patients knowingly purchase counterfeit drugs. Therefore, counterfeiters will always mimic the price set by illegitimate genuine sellers because any deviation would reveal their drug falsity due to the price difference. As such, I can derive the perfect Bayesian equilibrium (PBE) for the pricing game among sellers. As expected, the only pricing equilibrium at the dubious source is the pooling equilibrium in which illegitimate genuine sellers and counterfeiters charge the same price. Specifically, I can adopt the strongly undefeated perfect Bayesian equilibrium (SUPBE) concept (Mailath et al. 1993) to refine the pricing equilibrium. As noted in Miklós-Thal and Zhang (2013), the SUPBE yields the high-quality seller the highest profit among all of the pooling PBEs. This property applies my setting well as it is counterfeiters that want to imitate the illegitimate genuine sellers' price, but not the reverse. In the spirit of this refinement approach, I can derive a unique pooling PBE by solving an illegitimate genuine seller's profit maximization problem, given that a counterfeiter will always mimic its pricing strategy. The pooling PBE can be sustained if patients attribute any deviation from the equilibrium decision to a counterfeiter. The following analysis focuses on the unique SUPBE outcome of the price at the dubious source.

Patients cannot distinguish between authentic and counterfeit drugs sold by all of the sellers at the dubious source as their prices are the same and the pills, packaging, and OACTs of these drugs are all authentic looking. These sellers have the same market share for the dubious market and the share for each seller is $2x$. Under the SUPBE, an illegitimate genuine seller maximizes the following profit if it had incurred the fixed costs S and F for entry, knowing that a counterfeit entrant will imitate its price:

$$\Pi_D = 2xp_D - S - F. \tag{1}$$

On the other hand, the market share for the authentic firm is $1 - 2x(K + N' + N'')$ and thus it maximizes the following profit:

$$\Pi_A = [1 - 2x(K + N' + N'')]p_R - S - F. \tag{2}$$

Differentiating Equations (1) and (2) with respect to p_D and p_R, respectively, and setting the differentials to zero yield the optimal prices for dubious sellers and the authentic firm:

$$p_D^* = \frac{t}{6(K+N'+N'')} + \frac{\delta+\gamma-Q}{3}; \tag{3}$$

$$p_R^* = \frac{t}{3(K+N'+N'')} + \frac{Q-\delta-\gamma}{3}. \tag{4}$$

I now start to derive the equilibrium number of counterfeit entrants and the equilibrium number of illegitimate genuine sellers by analyzing the second stage of the game. I first examine the entry decisions of counterfeiters. A counterfeiter enters the dubious source if it can earn nonnegative profit, namely,

$$\Pi_D^* = 2x^* p_D^* - S - F \geq 0, \tag{5}$$

where x^* is created after substituting p_D^* for p_D and p_R^* for p_R.

As expounded in Section 1, there are two types of illegal genuine sellers—patients selling their leftover drugs acquired from reliable sources and illegitimate genuine producers making and selling effective drugs because they may have the knowledge about the drug patent. The factors that influence their entry decision are different. I then begin to examine their decision of entering the dubious source.

Patients wishing to sell their unused drugs purchased from reliable sources do not need to replicate the OACT to enter the dubious source as the authentication device already exists on their drug packaging. Therefore, they will enter the market as long as the selling price is positive. Selling can bring them some monetary benefits since, if left unsold, their drugs might expire soon and become worthless. Here, I assume that the drug supply by patients is exogenous. One can interpret this from the fact that the quantity of drugs purchased at the reliable source is primarily determined by doctors, and since patients' recovery time from illness is random, they might not make full use of the drugs in case of an early recovery.

Like counterfeiters, illegitimate genuine producers also need to replicate the OACT to enter the market because without an OACT, their drugs will not look authentic and thus patients will not buy them.[17] Assume the fixed cost of duplicating the OACT is the same for counterfeiters and illegitimate genuine producers. Suppose the fixed cost of drug and packaging production for an illegitimate genuine producer is S'. Hence, it will enter the dubious source if it can obtain nonnegative profit:

$$\Pi_D^{*\prime} = 2x^* p_D^* - S' - F \geq 0. \tag{6}$$

The cost S' should not be lower than the cost S incurred by a counterfeiter for performing the same tasks. That is, the machine manufacturing effective drugs should not be cheaper than the one producing counterfeits, since the former production technology might be on a higher level. Note that a counterfeit entrant obtains zero profit in equilibrium. Hence, when $S' > S$, an illegitimate genuine producer earns a negative profit if it enters the dubious source and thus it will not be a market entrant. As a consequence, in this case, on the supply side, there are no entrants of illegitimate genuine producers, only patients selling their unused drugs at the dubious source.

On the other hand, when $S' = S$, the effect of using an OACT by the authentic firm on entry deterrence of counterfeiters and illegitimate genuine producers is the same. Suppose the proportion of illegitimate genuine producers entering the market to the total number of entrants (counterfeiters plus illegitimate genuine producers) replicating the OACT to enter the market is $\alpha \in (0,1)$. Let me use N^e to denote the total number of such entrants. As such, in the dubious market, K patients and $N'' = \alpha N^e$ illegitimate genuine producers offer effective drugs and $N' = (1-\alpha)N^e$ counterfeiters offer fake drugs. Note that α should not be sufficiently high in the sense that acquiring and learning a drug patent can be difficult for illegitimate genuine producers. Toscano (2011) suggests that this parameter is roughly 15.6%. Hence, the chance that patients get an effective drug at the dubious source when trading with a dubious seller is rewritten as $(K+\alpha N^e)/(K+N^e)$.

The model assumes that, in equilibrium, all counterfeit entrants and illegitimate genuine entrants earn zero profit. Ideally, these entrants should obtain positive profit to make their entry to the dubious source more attractive. The model can allow this alternative specification. To see this more clearly, one can interpret S as the equilibrium reservation profit that the dubious sellers want to earn if they enter the market. A higher S means a higher equilibrium reservation profit. Following the essence of REE, patients' entry expectation should be consistent with the actual entry in equilibrium. That is, N^e has to be equal to the total number of counterfeit entrants and illegitimate genuine producers who both enter the market in equilibrium N^*. Therefore, the equilibrium number of counterfeit entrants is $N' = (1-\alpha)N^*$. Similar to Salop (1979), N^* arises by equaling $2x^* p_D^*$ to $S+F$, which is expressed in the equation below:[18]

$$N^* = \frac{t + K[2\gamma - 3\sqrt{2t(S+F)}]}{3\sqrt{2t(S+F)} + 2[(1-\alpha)(Q+L)-\gamma]}. \tag{7}$$

Proposition 1. *The equilibrium number of counterfeiters entering the dubious source is decreasing in F.*

Proposition 1 states the characteristic of the entry equilibrium. It echoes the existing market entry theory (e.g., Salop 1979): the use of an OACT (imposing a fixed cost) can decrease the number of counterfeiters entering the market. In other words, it confirms a common belief held by firms: the more sophisticated the OACT, the fewer the counterfeit entrants in the dubious market. The intuition about this result is rather direct. After the authentic firm introduces an OACT imprinted on the product packaging, a counterfeiter is less willing to enter the market as the entry cost is substantially raised—it has to order expensive equipment for replicating the new anti-counterfeiting technology. Furthermore, this low willingness to be an entrant leads to a reduced number of counterfeiters flowing into the dubious market. As expected, when F is sufficiently high such that $F \geq F'$, the entry of counterfeiters will be absent.

4.2. The Impact of the Use of an OACT on Counterfeit Purchases

Would less entry of counterfeiters result in fewer incidents of counterfeit medicine purchases? It is clear that the magnitude of fake drug purchases depends on not only the quantity of counterfeit entrants in the dubious market but also the number of patients shopping there. Specifically, the equilibrium number of counterfeit purchases (denoted as CP^*) is

$$CP^* = N'(2x^*). \tag{8}$$

The first term on the right-hand side of Equation (8) represents the number of counterfeiters entering the market and the second term in parentheses represents the market share for each dubious seller. Note that $x^* = \sqrt{(S+F)/(2t)}$ in equilibrium. Both terms are determined by the level of complexity of the OACT, which in turn affects the equilibrium counterfeiter entry. Proposition 9 and Figure 4 report the impact of the use of an OACT on the number of counterfeit purchasing incidents in equilibrium.

Proposition 2. *There is an inverted U-shaped relationship between the complexity of the OACT and the magnitude of counterfeit purchases in equilibrium*:

(1) CP^* *is increasing in* F *when* $F \leq F^*$ (*anti-counterfeiting trap*);

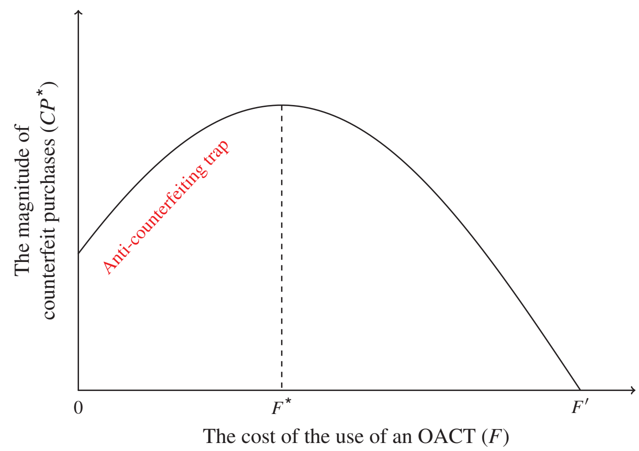
(2) CP^* *is decreasing in* F *when* $F > F^*$.

A closer look at the relationship between CP^* and F is helpful in explaining the intuition of Proposition 2. As such, I split the total derivative of CP^* from Equation (8) with respect to F into two parts:

$$\frac{\partial CP^*}{\partial F} = \underbrace{\frac{\partial N'}{\partial F}2x^*}_{\substack{\text{counterfeiters'}\\ \text{entry-dampening}\\ \text{effect}}} + \underbrace{\frac{\partial(2x^*)}{\partial F}N'}_{\substack{\text{patients'}\\ \text{demand-enhancing}\\ \text{effect}}}. \tag{9}$$

The first part is negative. This is driven by a *counterfeiters' entry-dampening effect*: the number of counterfeit sellers in the unreliable market decreases with the complexity of the OACT. This effect is rather intuitive, as the entry of fewer counterfeiters is a result of using an OACT, in that the OACT acts as an entry barrier for counterfeiters (Proposition 1). The second part is positive and is determined by a *patients' demand-enhancing effect*: the market share for a counterfeit entrant increases with the complexity of the OACT. This effect arises because more patients tend to buy drugs from the dubious source as a result of the belief that they have a higher chance of getting an effective version when there is less entry of counterfeiters in the market.

Figure 4. (Color online) The Effect of the Use of an OACT on the Magnitude of Counterfeit Purchases (a)



An experiment in Section 5 lends support to the *patients' demand-enhancing effect*. It shows that embedding a hologram on the drug packaging indeed shifts subjects' perception about the drug's authenticity as well as their willingness to buy the drug. Specifically, they perceive a dubious drug with a hologram to be more authentic, and are therefore more likely to purchase it.

Overall, combining both effects, Proposition 2 suggests that the magnitude of counterfeit purchasing incidents brought forth by launching an OACT does not change monotonically with the cost F. Interestingly, I find an *anti-counterfeiting trap*: when the chosen OACT is not adequately complex ($F \leq F^*$), the number of counterfeit purchases rises with the complexity of the OACT—although the efforts made to combat counterfeiters have been escalated, counterfeit purchasing incidents amplify, rather than dwindle as expected.[19]

While a fresh OACT can effectively deter the entry of some counterfeiters, it also leads some patients to switch from the reliable source (which would otherwise have been chosen), where they are sure to obtain genuine medicine, to the dubious source, where they might end up with a fake drug. Note that the source-switching behavior of patients is the rational response to their observations of an OACT on the product packaging as they choose the source with the objective of maximizing expected utility. In essence, CP^* depends on the number of counterfeit entrants. When the chosen OACT has a low level of complexity ($F \leq F^*$), the effectiveness in diminishing counterfeiter entry is not prominent. Hence, under this scenario the anti-counterfeiting gain from the *counterfeiters' entry-dampening effect* is outperformed by the loss from the *patients' demand-enhancing effect*. On the other hand, when the selected OACT is sufficiently sophisticated ($F > F^*$), fewer and fewer counterfeiters enter the dubious market. Under this scenario, the *counterfeiters' entry-dampening effect* would loom larger and may exceed the *patients' demand-enhancing effect* and thus the incidents of counterfeit purchases are reduced.

In short, I could say that the use of an OACT mitigates the counterfeit purchasing problem. Yet this only happens when the chosen OACT is sufficiently sophisticated such that more counterfeiters find entry unattractive. The *anti-counterfeiting trap* may offer an explanation on the estimation made by the Center for Medicine in the Public Interest (2006) that global counterfeit medicine commerce may grow 13% annually in the coming years, even though many pharmaceutical companies have constantly launched upgraded OACTs.

This finding carries significant implications for governments enacting regulations on whether to adopt OACTs to curtail the spread of fake drugs in the market. Firms are often required by law to use OACTs. For example, the Ministry of Health in Malaysia requires that all registered pharmaceutical products be labeled with a hologram security patch to fight the prevalence of unregistered counterfeit drugs (World Health Professions Alliance 2011). Hence, this result is a reminder about the effect of such interventions, and point to the dangers of policies that call for the mandatory use of low-level OACTs, since they undermine the surplus of patients; unless, of course, the OACTs are sufficiently complex such that they can deter more counterfeiter entry. That is, policy makers should only consider using the complex OACTs, not the rudimentary ones, if the objective is to reduce counterfeit purchases.

4.3. The Impact of the Use of an OACT on Dubious Drugs' Price

Having determined the equilibrium counterfeiter entry, I examine how the use of an OACT drives the equilibrium price of dubious drugs (counterfeit drugs and illegitimate genuine ones). As established earlier, both illegitimate genuine sellers and counterfeiters set the same price in the SUPBE. One belief of the equilibrium path that supports the equilibrium pooling price is that patients believe that any action different from this equilibrium price is taken by a counterfeiter. Specifically, this price can be expressed as follows:

$$p_D^* = \sqrt{\frac{t(S+F)}{2}}. \tag{10}$$

Proposition 3. *The equilibrium price of dubious drugs is increasing in F.*

The above proposition states the impact of the use of an OACT on the price of dubious drugs in equilibrium. A decrease in the number of counterfeit entrants due to the use of an OACT will improve the drug authenticity at the dubious source. As a result, patients' expectation on the quality of dubious drugs is enhanced. This in turn propels dubious sellers to charge a higher price for their drugs. This result implies that patients may spend more on dubious drugs once a pharmaceutical firm employs an OACT.

In a nutshell, the use of an OACT might breed two adverse outcomes for patients: inducing more patients to buy fake drugs and, ironically, leading them to pay a higher price for such drugs. In other words, both the medical and pecuniary benefits of patients would be harmed after introducing an OACT.

4.4. The Impact of the Use of an OACT on Authentic Firm's Pricing

I now start to investigate the effect of using an OACT on authentic firm's price. Formally, conditional on the equilibrium entry of counterfeiters and illegitimate genuine sellers, this price is given by the following equation:

$$p_R^* = \frac{t}{2(K+N^*)} - \sqrt{\frac{t(S+F)}{2}}. \tag{11}$$

As expected, in response to the price increase at the dubious source, the authentic firm finds it more profitable to raise its price as well. This result indicates that patients may incur a pecuniary loss if they secure authentic drugs from the reliable source once the authentic firm introduces an OACT. The following proposition summarizes this result.

Proposition 4. *The equilibrium price of an authentic firm is increasing in F.*

4.5. Authentic Firm's Optimal Choice of OACT

So far I have studied the behavior of source choice of patients and market entry and pricing of dubious sellers, enabling us to see how an OACT affects the magnitude of counterfeit purchases and prices of dubious and authentic drugs. Next, I investigate the optimal decision by an authentic firm in choosing the complexity of the OACT.

Patients' demand for authentic firm's drugs at the reliable source depends on the number of dubious sellers entering the dubious source and the market share in each segment around two such sellers. Formally, this demand is $1-2x^*(N^*+K)$. As such, authentic firm's profit is captured by the following equations:

$$\Pi_A^* = \begin{cases} \left[1-\sqrt{\dfrac{2(S+F)}{t}}(K+N^*)\right]p_R^* - S - F, & F \le F'; \quad (12) \\[2ex] \dfrac{t}{2K}\left[1-\sqrt{\dfrac{2(S+F')}{t}}K\right]^2 - S - F, & F > F'. \quad (13) \end{cases}$$

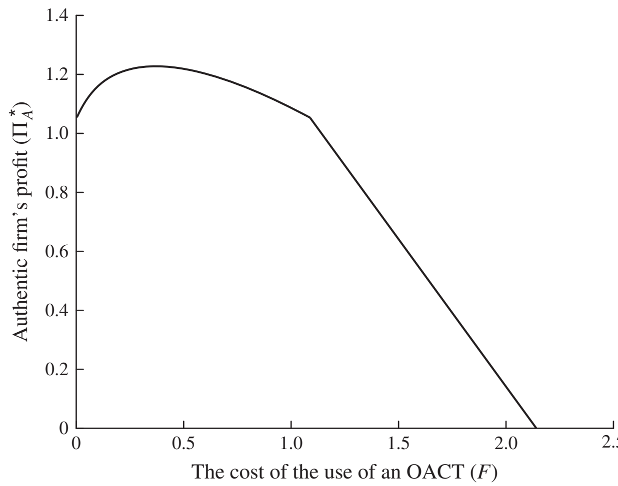
The profit takes different forms in the two segments, depending on whether there is the entry of counterfeiters. When $F \le F'$, some counterfeiters enter the market, so the authentic firm competes with both counterfeit entrants and illegitimate genuine sellers. However, when $F > F'$, counterfeit entrants are absent in the market. As a result, in this case, the authentic firm only wrestles with vendors selling genuine drugs at the dubious market. Moreover, any cost incurred owing to the use of an OACT above F' has no bearing on the price at the dubious source but only lowers profit directly. Hence, the shape of the profit is exhibited linearly, when the cost of using an OACT falls in this range. Proposition 5 formalizes the result.

Proposition 5. *The profit of an authentic firm might be nonmonotonic with F in equilibrium. Thus, it may use a mediocre OACT at the optimum if it strategically prices.*

I find that the authentic firm may benefit from the use of an OACT if it can influence price. This is because when $F \le F'$, p_R^* increases with F. As such, the firm's revenue could be higher after a more sophisticated OACT is adopted. Intuitively, by pricing strategically, the authentic firm realizes the benefit of softened competition because of decreased counterfeiter entry. Hence, in deciding the complexity of the OACT to be used, the brand owner faces a trade-off once both the benefit and cost are factored into its decision making.

As a result, when the *patients' demand-enhancing effect* is taken into account, authentic firm's best decision will be using a mediocre OACT that does not fully deter counterfeiter entry. This result explains why so many drug makers only adopt mediocre OACTs for their brand-name drugs. As can be seen from Figure 5, the profit of the authentic firm first increases but then decreases with the cost of using an OACT, prior to taking a linearly decreasing shape, where counterfeiter entry is absent. This relationship curve shows that it may be optimal for the authentic firm to choose a mediocre OACT, which will incentivize some counterfeiters to enter the dubious market.

Figure 5. The Effect of the Use of an OACT on Authentic Firm's Profit (a)



Note. The figure assumes that $S = 0.001$, $K = 1.9$, $t = 32$, $\alpha = 0.34$, $\gamma = 4.1$, $Q = 8.5$, and $L = 0.5$.

4.6. Adverse Effect of Authentic Firm's Optimal Choice of OACT

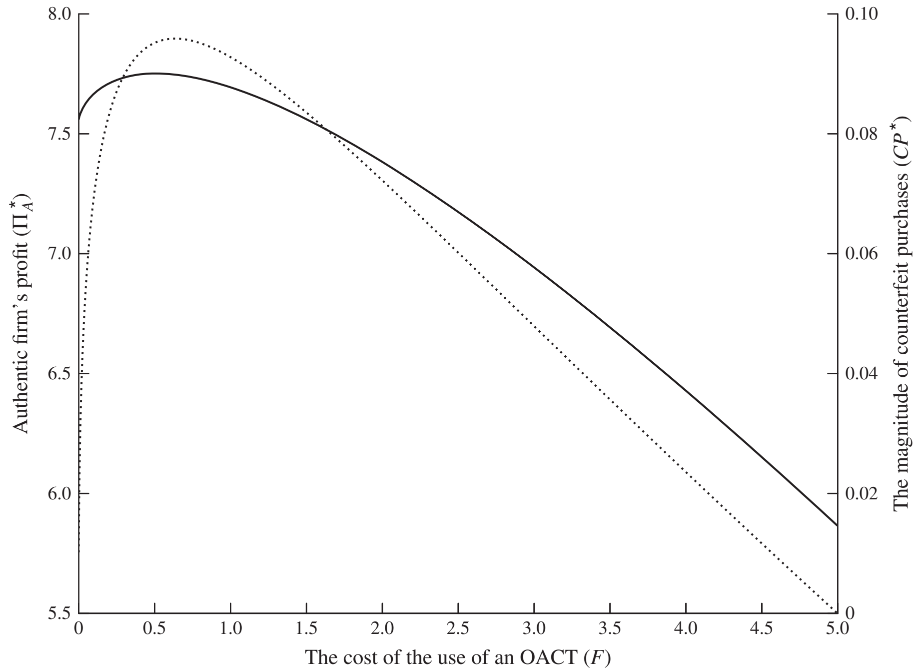
In this section, I want to highlight that the optimal choice of OACT by an authentic firm may not be the best option from a social planner's perspective. That is, having an OACT on the packaging may not encourage that more patients obtain genuine drugs and may instead intensify the problem of counterfeit purchasing. The objective of anti-counterfeiting for the authentic firm is to raise profits and so in equilibrium it may choose a mediocre OACT, as indicated in Proposition 5. However, to enhance patients' therapeutic benefits, the social planner may wish to increase the coverage of genuine drugs among patients by cutting counterfeit purchases. Ideally, this can be done if the chosen OACT is adequately complicated such that there are fewer counterfeiters entering the market, as stated in Proposition 2. Therefore, authentic firm's selection of a mediocre OACT might have an adverse effect on the social planner's objective of increasing purchases of effective drugs. In other words, the optimal OACT choice for the authentic firm may lead more patients to obtain counterfeit drugs and this outcome may not be the one the social planner pursues.

One can see this adverse effect more clearly from Figure 6. The unbroken line represents authentic firm's profit, and the dotted line represents the magnitude of counterfeit purchases. From Figure 6, we see that the optimal OACT option of the authentic firm that yields the highest profit falls on the increasing part of the curve of the magnitude of counterfeit purchases, where the entry of counterfeiters is not significantly lessened; it is not on the decreasing part of the curve, where the entry is considerably diminished. This means that, from the view of the social planner, medical benefits for patients are worse when the authentic firm uses a mediocre OACT, because of more counterfeit purchases. The following proposition formally states this result.

Proposition 6. *Authentic firm's optimal OACT choice might have an adverse effect on the social planner's objective of increasing purchases of genuine drugs.*

Based on Proposition 6, I could say that when pharmaceutical firms implement a noncomplex OACT, they may lead the way to a vicious path. When firms introduce a drug into the market, they may, after a period of time, notice some counterfeit purchases. To counter

Figure 6. Adverse Effect of Authentic Firm's Optimal OACT Choice



Note. The figure assumes that $S = 0.001$, $K = 0.55$, $t = 27$, $\alpha = 0.35$, $\gamma = 0.1$, $Q = 16.5$, and $L = 0.5$.

these fake drugs, firms will use an OACT on the product packaging. Subsequently, when they detect an increase in the number of fakes in the market, a situation that could inadvertently have been created by their dogged pursuance of these techniques, they adopt better OACTs in the hope of calming their intensifying anxieties. Eventually, even this strategy may unintentionally spur increased counterfeit purchases.

This result has significant implications for policy makers in setting regulations. First, policy makers need to regulate the use of OACTs by pharmaceutical firms to reduce the purchase of counterfeit drugs. Indeed, some countries (e.g., Malaysia) already require pharmaceutical firms to use OACTs such as holograms (World Health Professions Alliance 2011). Second, policy makers should impose the use of the more complicated OACTs so as to induce more patients to get genuine drugs. One way to reach this objective would be to reward those pharmaceutical firms if they choose more sophisticated OACTs in combating counterfeiters. This incentive might encourage firms to use more advanced OACTs to abate the magnitude of counterfeit purchases, given that patients strategically make a source choice when buying drugs.

4.7. Authentic Firm's Optimal Choice of OACT If Its Price Is Regulated

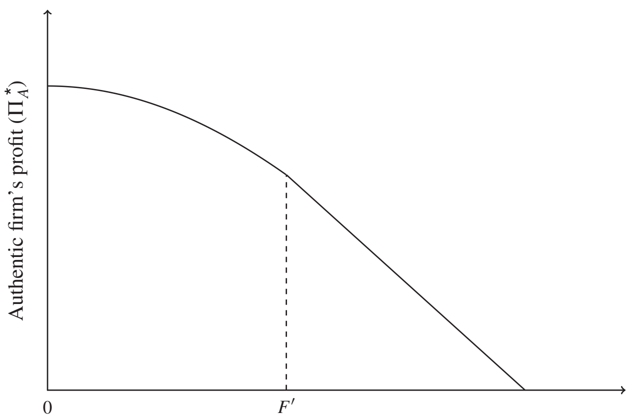
In the preceding analysis, I assume that when employing an OACT, an authentic firm does change its original price. This situation is relevant to brand-name drugs, as drugmakers are able to set their own prices. However, the situation is reversed for some drugs whose prices are controlled by regulators. Pharmaceutical firms are often limited in their pricing strategies by government restrictions on drug pricing, for example, mandatory retail prices, a price ceiling, and a price guarantee (Bate et al. 2015). In such cases, drugmakers can only rely on OACTs to fight counterfeiters. In this section, I focus my attention on whether the results under the case where the authentic firm can influence its price would change if its price is regulated.

The findings on the impact of using an OACT on dubious sellers' entry, the magnitude of counterfeit purchases, and dubious drugs' price remain the same. This happens because no matter whether the authentic firm strategically prices its drug, the *counterfeiters' entry-dampening effect* and the *patients' demand-enhancing effect* are always present. Consequently, the same intuitions apply in reaching these results. For brevity, such parallel results and relevant analyses are not reported here.

Here, I only present one new insight, which is about a pharmaceutical firm's optimal decision on OACT selection. I find that a pharmaceutical firm is optimal by not using any OACTs in combating counterfeiters if strategic pricing is not feasible. This result sharply contrasts with the corresponding one derived under the scenario in which the drug price of a pharmaceutical firm is endogenously determined—the most profitable option is to use a mediocre OACT.

For the same reason as in Section 4.5, authentic firm's profit features two distinct forms in terms of the value of F because of the existence of counterfeit entrants in

Figure 7. The Effect of the Use of an OACT on Authentic Firm's Profit (b)



the dubious market; it is expressed in Equations (14) and (15):

$$\Pi_A^{**} = \begin{cases} [1 - 2x^{**}(K + N^{**})]p_R - S - F, & F \le F''; \quad (14) \\ (1 - 2x^{**}K)p_R - S - F, & F > F''. \quad (15) \end{cases}$$

In Equations (14) and (15), F'' is the resultant cost value when the equilibrium number of entrants of counterfeiters and illegitimate genuine producers N^{**} is equal to zero. Proposition 9 and Figure 7 give rise to the effect of the use of an OACT on authentic firm's profit and equilibrium strategy on OACT adoption, when its pricing strategy remains.

Proposition 7. *The profit of an authentic firm is decreasing in F in equilibrium and thus it may not use any OACTs at the optimum if it keeps its original price.*

Contrary to the case where the price of the authentic firm is endogenously determined, I find that the authentic firm is better off not using an OACT under the case in which the price is given ex ante. At first glance, this result is not straightforward and runs counter to prevalent practices advocating the use of OACTs in combating counterfeiters. However, the intuition becomes clearer when we take into account the fact that patients' selection of the dubious source is critically dependent on the probability of the drugs there being genuine. In principle, this probability is determined by the number of counterfeit entrants, a parameter that is undoubtedly influenced by the OACT used by a pharmaceutical firm. After applying Proposition 1, the situation of fewer counterfeit entrants induces more patients to go into the dubious market (x^{**} increases with F), and this in turn will lead to a reduced demand for a pharmaceutical firm's drugs in the reliable market. As such, the use of an OACT not only adds extra cost but also brings no benefits to a pharmaceutical firm. Therefore, when the *patients' demand-enhancing effect* is kept in mind, forgoing the use of an OACT would be optimum for the brand owner, if it sticks with the original price. This finding indicates that the massive monies used in adopting these technologies might be poorly spent. Additionally, this finding offers an understanding about the phenomena where most price-regulated drugs do not use OACTs. This result sharply contrasts the earlier finding that pharmaceutical firms may adopt mediocre OACTs if they can set the prices for their drugs, a phenomenon that is widespread in reality. Moreover, when the use of an OACT is too costly, such that $F > F''$, a pharmaceutical firm will further lose profitability despite securing revenue from patients.

Notably, an OACT introduced by an authentic firm affects counterfeiters' entry decision by forcing them to pay a fixed cost, suggesting that other types of fixed costs could easily play the same role. These fixed costs could be in the form of advanced production techniques, innovating on things such as drug colors or shapes, and would work just as well as OACTs as long as they are overtly visible to patients. Consequently, Proposition 7 suggests that if pharmaceutical firms do not implement the pricing strategy together with the OACT, they do not need to invest heavily in designing the casing of pills or tablets.

Looking at Propositions 5 and 7 together gives us a better idea of the choice of an optimal OACT for a pharmaceutical firm. Clearly, in the presence of the *patients' demand-enhancing effect*, the decision about whether to use the pricing strategy constitutes a key role in choosing an OACT. Indeed, using an OACT can convey value to the firm that sets the optimal price in response to the entry of counterfeiters. Overall, these results may help brand owners better evaluate the effectiveness of the use of OACTs so that they can make more informed anti-counterfeiting investments to defend their interests.

5. An Experiment

The central mechanism underlying this paper is that patients draw inferences about the authenticity of a risky drug by observing an OACT on its packaging. In this section, I provide an empirical assessment on this mechanism, by focusing on the question of whether attaching an OACT on the box of a drug from a dubious seller can affect individuals' perceptions about drug authenticity and their subsequent purchase propensities for such a drug.

I conduct a between-subject experiment in which a hologram is used as a representative of an OACT. Specifically, I use Eli Lilly's Cialis as the experimental drug. The experiment exogenously consists of two conditions: without-a-hologram and with-a-hologram on the drug box. Subjects in either condition are presented with the questionnaires to indicate their perceptions on the authenticity and purchase propensity of the drug on a 1-to-7 scale, with 1 being very unlikely to 7 being very likely.

The questionnaires in both conditions share a common theme in informing subjects about the danger of purchasing drugs from dubious sources:

> Patients face risks when they buy drugs from unknown drug shops, because these drug shops might sell counterfeit drugs which may pose serious threats to patients' health and safety.

In the with-a-hologram condition, the questionnaire, in addition, is verbalized to evoke the notion of the hologram:

> To make it more difficult for counterfeiters to produce convincing copies and make it easier for patients to distinguish authentic drugs from counterfeits, Eli Lilly introduced a new anti-counterfeiting technology by applying a sophisticated hologram label onto the drug box (as in the right picture in Figure 1).

The subjects are undergraduate students from a research-oriented university. A total of 52 subjects participated in the experiment, with 27 randomly assigned into the without-a-hologram condition and the other 25 into the with-a-hologram condition. Participants were unpaid but earned course credit.

Tables 1 and 2 report the experiment results. The mean perceived authenticity of the drug is 3.5185 for the without-a-hologram condition and 5.0400 for the with-a-hologram condition. In addition, the mean purchase propensity of the drug for the without-a-hologram and with-a-hologram condition are 2.4815 versus 3.9200. Both perception differences in the two conditions are statistically significant ($p = 0.0003$ versus $p = 0.0016$; two-tailed test). Moreover, the magnitudes of increases in both perceptions are great, with 43.22% in the mean drug authenticity and 58.00% in the mean purchase propensity.[20]

In a nutshell, the experiment demonstrates that implementing a hologram on the packaging of a dubious drug indeed raises an individual's perception about the authenticity of the drug, and, consequently, they are more likely to purchase it. The experiment results offer empirical support to the overarching mechanism of the paper: using an OACT impacts patient inferences.

Table 1. Perceived Authenticity

	Sample
Mean perceived authenticity under without-a-hologram	3.5185 (1.6260)
Mean perceived authenticity under with-a-hologram	5.0400 (1.1719)
t-stat	3.8436
p-value (two-tail)	0.0003
No. of observations	52

Notes. The dependent variable is perceived authenticity of the drug in a dubious source. The numbers in parentheses are the standard deviations.

Table 2. Purchase Propensity

	Sample
Mean purchase propensity under without-a-hologram	2.4815 (1.4510)
Mean purchase propensity under with-a-hologram	3.9200 (1.6563)
t-stat	3.3374
p-value (two-tail)	0.0016
No. of observations	52

Notes. The dependent variable is purchase propensity of the drug in a dubious source. The numbers in parentheses are the standard deviations.

6. Extensions

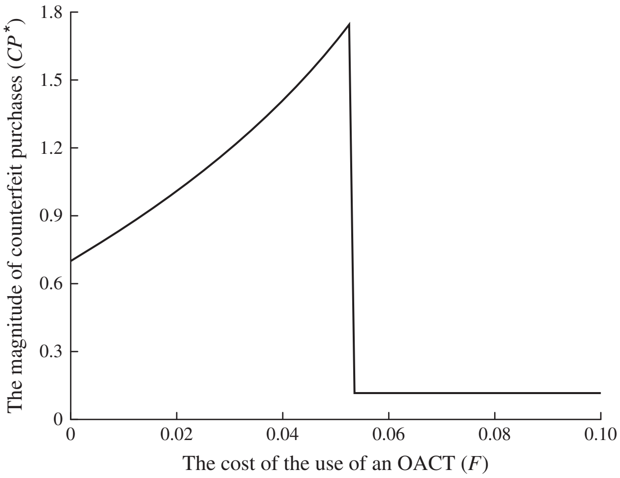
In this section, I will present several extensions for the benchmark model that has been analyzed earlier, and show the robustness of the main result.

6.1. Optimal Number of Selling Locations for Dubious Sellers

In the benchmark model, I assume that once a dubious seller enters the market, it can only occupy one location to sell its drugs. It is, however, possible for a dubious seller to operate in multiple locations after paying a fixed cost to replicate the OACT in trying to enter the market. In this section, I will study this possibility by endogenizing the number of selling locations in the market for a dubious seller.

Suppose a dubious seller who has replicated the OACT to enter the market, either a counterfeiter or an illegitimate genuine producer, chooses the same number of selling locations before the pricing stage in which a dubious seller charges the identical price at all its selling locations. Depending on the number of selling locations m, the cost of occupying multiple locations for a dubious seller is $\frac{1}{2}m^2e$. This cost form captures the idea that for a dubious seller, operating in multiple locations can be more expensive. The chance that patients can get genuine drugs at the dubious source in this case becomes $(K+N''m)/(K+N'm+N''m)$, because there are $N'm$ counterfeiters and $N''m$ illegitimate genuine producers in the market. It might turn out that a dubious seller chooses an optimal number of selling locations in equilibrium. Additionally, as both the *counterfeiters' entry-dampening effect* and the *patients' demand-enhancing effect* may remain salient as well when the number of sales locations is endogenized, we would expect that the main result of the impact of the use of an OACT on the magnitude of counterfeit purchases may continue to hold, which is illustrated in Figure 8. The following proposition formally summarizes the above conjectures.

Figure 8. The Effect of the Use of an OACT on the Magnitude of Counterfeit Purchases (b)



Note. The figure assumes that $S = 0.001$, $K = 1.9$, $t = 32$, $\alpha = 0.34$, $\gamma = 4.1$, $Q = 8.5$, $L = 0.5$, and $e = 0.002$.

Proposition 8. *The optimal number of selling locations may be m^* for a dubious seller who replicates the OACT to enter the market. In addition, the magnitude of counterfeit purchases may first increase and then decrease with the cost of using an OACT.*

6.2. The Market Is Not Fully Covered

Earlier, an assumption is made that all patients are aware of the existence of the dubious source so that the market can be fully covered by dubious sellers. In this section, I study a case wherein the market cannot be fully covered by dubious sellers, leaving them the scope to expand the market size. I follow the approach used by Balasubramanian (1998) to examine this case. A proportion β of patients, representing the market coverage, know that genuine drugs can be available not only by the authentic firm at the reliable source but also by sellers at the dubious source, and they make the source choice when purchasing drugs. This proportion is evenly distributed over the circle market. On the other hand, the rest of the patients, $1-\beta$, only know about the authentic firm at the reliable source as the only seller that offers genuine drugs, and thus they are constrained to only consider the reliable source to get drugs. The analysis for this case is similar to that in the benchmark model and thus is arranged in the appendix in a simplified manner. By intuition, the main result of the impact of the use of an OACT on the magnitude of counterfeit purchases is robust, given that both the *counterfeiters' entry-dampening effect* and the *patients' demand-enhancing effect* prevail in this case as well. Proposition 9 states the result.

Proposition 9. *When the market cannot be fully covered by dubious sellers, the magnitude of counterfeit purchases first increases and then decreases with the cost of using an OACT.*

6.3. Multiple-Unit and Repeat Purchases

As mentioned earlier, the majority of drugs that are counterfeited treat non-life-threatening, chronic conditions. Thus, patients who need these drugs may make multiple-unit purchases when trading with the drug sellers. Here, I examine this case by considering this possibility to see whether the main result of the impact of the use of an OACT on the magnitude purchases is robust. Suppose patients need to take g units of drugs in a certain period, and they purchase this amount of drugs either from the reliable source or from the dubious source. In this case, for patients, the expected utility from the reliable source and the dubious source after paying the monetary and transportation costs becomes $g(Q-p_R)-\gamma$ and $g\{[(K+N'')/(K+N'+N'')]Q-[1-(K+N'')/(K+N'+N'')]L-p_D\}-xt$, respectively, in the sense that patients need to pay more if they want to obtain more drugs to receive more therapeutic benefits. As a result, this alternative utility specification due to multiple-unit purchases does not alter the essence of the mechanism highlighted in the model. Therefore, the main result continues to hold in this case as well, which is presented in the following proposition.

Proposition 10. *When patients make multiple-unit purchases, the magnitude of counterfeit purchases first increases and then decreases with the cost of using an OACT.*

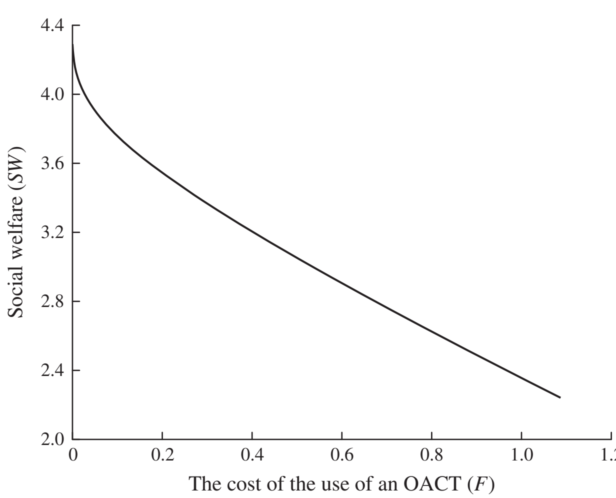
It is also possible that patients may not purchase multiple units of drugs in one period, and instead purchase them over several periods. Thus, the model should also consider repeat purchases, and can accommodate this market characteristic to some extent. The model assumes that dubious sellers, including counterfeiters and illegitimate genuine sellers, randomly locate themselves around the circle. The manner of random location for dubious sellers captures the idea that the position of a dubious seller is changeable. This is because, unlike an authentic firm, dubious sellers typically do not have a physical store to sell unregulated drugs, as this activity is a serious violation of the law. The dubious sellers' instability is primarily due to the possibility of their being caught by the police if they situate themselves in the same place. One reason they could be caught is if patients who purchase the ineffective drugs may report their locations to the police. Another incentive to alter the selling positions constantly is that sticking with the same selling place may enable the police to identify their illegal selling behavior easily. In some developing countries, such as China, even unregulated fruit sellers, who engage in relatively petty violations, change their selling places frequently to avoid drawing attention from urban management officers. This rationale can be supported by reality as we rarely find dubious sellers operating their business out of the same location. Hence, in a period when repeated purchases occur, all dubious sellers are likely to alter their positions. As such, in a multiperiod model in which counterfeiters incur a fixed cost of replicating the OACT for market entry only in the first period, the patients' chances of obtaining a genuine drug at the dubious source when they trade with a different dubious seller in a later period remains the same. Therefore, the essence of the main result continues to hold in this case.

6.4. The Impact of the Use of an OACT on Social Welfare

Next, I will study how the use of an OACT affects social welfare. Recall that counterfeiters and illegitimate genuine producers make zero profit in equilibrium. Note that patients who sell their unused drugs at the dubious source seriously violate the law. So, the social welfare in this paper consists of the following two components. One is the profit that the authentic firm earns and the other is the surplus that patients obtain. Formally, the social welfare SW can be written as $SW = \Pi_A^* + [1-2x^*(K+N^*)](Q-p_R^*-\gamma)+2x^*(K+N^*)\{[(K+\alpha N^*)/(K+N^*)]Q - \{[(1-\alpha)N^*]/(K+N^*)\}L - p_D^*\} - (K+N^*)tx^{*2}$. Proposition 11 and Figure 9 show that the social welfare decreases with the cost of using an OACT. This result is driven by the possibility that patients may receive less surplus after the authentic firm adopts an OACT because they may in turn pay higher prices for the drugs from both the reliable and dubious sources because of softened competition by the effect of entry deterrence.

Proposition 11. *The social welfare may decrease with the cost of using an OACT.*

Figure 9. The Impact of the Use of an OACT on Social Welfare



Notes. The figure assumes that $S = 0.001$, $K = 1.9$, $t = 32$, $\alpha = 0.34$, $\gamma = 4.1$, $Q = 8.5$, and $L = 0.5$.

7. Conclusion

Drugmakers have been using OACTs to create hurdles for counterfeiters in making counterfeits and infiltrating the market, and to assist patients to better verify the authenticity of drugs. However, evidence suggests that the magnitude of counterfeit purchasing incidents has not dwindled but in fact has amplified: annual sales of fake medicines have risen, rather than declined, in recent years.

I argue that the use of insufficiently sophisticated OACTs might be one culprit for this upward trend. Patients infer the authenticity of a dubious drug on seeing the OACT on the product packaging. A pharmaceutical firm's choice in using an OACT means that a number of counterfeiters, who are unable to take on the large fixed cost of producing these complex OACTs, drop out of the dubious market, thus raising the possibility of procuring a genuine drug in this dubious market. Hence, more patients choose to shop from this market (a *patients' demand-enhancing effect*) thanks to the increase in the drug authenticity (a *counterfeiters' entry-dampening effect*). As it turns out, the former effect overrides the latter when the chosen OACT is inadequately advanced. This points to the existence of an *anti-counterfeiting trap*. That is, a rudimentary OACT used by a pharmaceutical firm could lead to more counterfeit purchases.

Yet having said that, I show that a sufficiently complex OACT is able to ease the counterfeit purchasing problem, demonstrating that choosing an appropriately pitched OACT is pivotal for raising patients' therapeutic benefits. The perils of the use of an OACT for patients might not be confined to the situation ensuing from the *anti-counterfeiting trap*. This paper finds that the use of an OACT can push up the price of dubious drugs, meaning that patients may spend more on fake drugs. The use of an OACT also hurts patients who receive authentic drugs from a reliable source as the drug price of a pharmaceutical firm is also set higher when launching an OACT. Regarding the effect of the use of an OACT on a pharmaceutical firm's profit, I show that a pharmaceutical firm would be better-off choosing a mediocre OACT, whereas it would be worse off introducing an OACT if its drug price is not strategically set. In addition, I demonstrate that a mediocre OACT for an authentic firm may give rise to an unfavorable outcome from a policy-maker's perspective, as this choice may enable fewer patients to get genuine drugs.

In general, the core mechanism of this paper can be applied to markets where there are two types of sources, reliable versus dubious, for consumers to choose when making purchases, and dubious sellers can only enter the dubious source to operate their business. Additionally, another important feature in these markets is that counterfeits bring no value to consumers. That is, once consumers can identify the authenticity of products, they will not consider purchasing counterfeit products. Therefore, the model of this paper can study other products that can be categorized under health (e.g., alcohol, cosmetics, and food) or safety (e.g., bike helmet and fire extinguisher) as fake products in these categories may be injurious to consumers. Indeed, counterfeiting is also a serious concern for firms offering these products, even though the use of OACTs is pervasive in these product categories. For instance, cosmetics counterfeiting has greatly increased in recent years even though companies spent more money in adopting OACTs.[21] In another example, the food and beverages industries have also seen a sharp rise in counterfeit products recently despite more efforts in using OACTs.[22] Hence, the results of this paper have wider applicability when it comes to studying anti-counterfeiting by using OACTs for such products as well. In summary, I suggest that when thinking about anti-counterfeiting tactics, firms and policy makers take into consideration their impact on consumer inferences so that better decisions are made.

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Appendix

Proof of Proposition 1

From Equation (7), it is easy to see that $\partial N^*/\partial F < 0$. □

Proof of Proposition 2

Recall that $x^* = (\delta + p_R^* + \gamma - p_D^* - Q)/t$. Plugging p_D^* in Equation (2) and p_R^* in Equation (3) into this equation yield $x^* = (1/t)\{t/[6(K+N^e)] + (\delta+\gamma-Q)/3\}$. As in equilibrium $2x^* p_D^* = S+F$, I have $t/[6(K+N^e)] + (\delta+\gamma-Q)/3 = \sqrt{2t(S+F)}$. Hence, $N^* = \{t + K[2\gamma - 3\sqrt{2t(S+F)}]\}/\{3\sqrt{2t(S+F)} + 2[(1-\alpha)\cdot(Q+L)-\gamma]\}$ and $x^* = \sqrt{(S+F)/(2t)}$. Then, the equilibrium number of counterfeit purchases is

$$CP^* = N'(2x^*) = (1-\alpha)N^*\sqrt{\frac{2(S+F)}{t}}. \tag{A.1}$$

Let w represent $\sqrt{2t(S+F)}$. Then, inserting N^* into Equation (A.1) and differentiating it in both sides with respect to m yield

$$\frac{\partial CP^*}{\partial w} = \frac{-(1-\alpha)\{9Kw^2 + 12K[(1-\alpha)(Q+L)-\gamma]w - 2(t+2\gamma K)[(1-\alpha)(Q+L)-\gamma]\}}{t\{3w + 2[(1-\alpha)(Q+L)-\gamma]\}^2}. \tag{A.2}$$

Therefore, CP^* first increases and then decreases with F, because $(1-\alpha)(Q+L)-\gamma > 0$ if $Q > \gamma$ and α is not sufficiently large. The *counterfeiters' entry-dampening effect* is negative because of Proposition 1 and the *patients' demand-enhancing effect* is positive because $\partial x^*/\partial F > 0$. Note that F^* is the positive solution solving $\partial CP^*/\partial w = 0$. Moreover, to make it possible for the authentic firm to trade with patients, I assume that $x^* < 1/(2(K+N^*))$ holds, which reduces to $t > 2(S+F)\cdot(K+N^*)^2$. □

Proof of Proposition 3

From Equation (10), it can be readily verified that $\partial p_D^*/\partial F > 0$. Note that a seller at the dubious source has no incentive to undercut its neighboring sellers, because $p_D^* - t/(K+N^*)$ is strictly negative. This makes the derived pure strategy equilibrium sustainable. □

Proof of Proposition 4

Substituting N^* in Equation (7) for N^e, p_R^* in Equation (4) can be expressed by Equation (11). Then differentiating p_R^* with respect to w, I have

$$\frac{\partial p_R^*}{\partial w} = \frac{t - K(1-\alpha)(Q+L)}{t + 2K(1-\alpha)(Q+L)}. \tag{A.3}$$

Hence, $\partial p_R^*/\partial w > 0$ if $t > K(Q+L)$. □

Proof of Proposition 5

In Equations (12) and (13), $F' = (t+2\gamma K)^2/(18tK^2) - S$, which solves $N^* = 0$. The revenue of the authentic firm could be increasing in F because its price might be increasing in F. In addition, it is easy to see that when $F > F'$, authentic firm's profit is decreasing in F. Hence, when using an OACT, the authentic firm needs to balance the gain in revenue and the loss in cost, thereby leading to that it may optimally choose a mediocre OACT in equilibrium. □

Proof of Proposition 6

This is immediately from Propositions 2 and 5. □

Proof of Proposition 7

Similar to the above analysis, I can derive the equilibrium number of entrants of counterfeiters and illegitimate genuine producers $N^{**} = \{K[p_R + \gamma - \sqrt{2t(S+F)}]\}/[\sqrt{2t(S+F)} + (1-\alpha)(Q+L-\gamma) - p_R - \gamma]$ and the market share for each dubious seller is $x^{**} = x^* = \sqrt{(S+F)/(2t)}$. Then, the profit of the authentic firm can be written as Equations (14) and (15). Recall that F'' is the value beyond which there will be no counterfeit entrants. Formally, $F'' = (p_R+\gamma)^2/(2t) - S$ solving

$N^{**} = 0$. From Equation (14), given that $Q - p_R - \gamma > 0$ and α is not sufficiently large, when $F \le F''$,

$$\frac{\partial \Pi_A^{**}}{\partial w} = -\frac{p_R K(1-\alpha)(Q+L)[(1-\alpha)(Q+L) - p_R - \gamma]}{t[w + (1-\alpha)(Q+L) - p_R - \gamma]^2} - \frac{w}{t} < 0. \tag{A.4}$$

When $F > F''$, $x^{**} = \sqrt{(S+F'')/(2t)}$. From Equation (15), $\partial\Pi_A^{**}/\partial w < 0$ as well in this case. □

Proof of Proposition 8

The analysis on pricing is similar to that in the benchmark model. Here, I only present the analysis on deriving the optimal number of selling locations for a dubious seller and showing the robustness of the main result. The profit of a dubious seller can be written as $2m/t\{t/[6(K+Nm)] + \{3(K+Nm)\gamma - [2K + (3-\alpha)Nm]Q - (1-\alpha)NmL\}/[3(K+Nm)]\}^2 - 1/2m^2e - S - F$. Differentiating the profit with respect to m and setting this differential equal to zero, m can be written as the function of N. Then inserting m^* back into this profit and setting the profit equal to zero, the equilibrium number of dubious sellers N^1 can be determined. Subsequently, the optimal number of selling locations for a dubious seller m^* is derived by substituting N with N^1 in the function mentioned earlier. As a result, the magnitude of counterfeit purchases is $CP^1 = (1-\alpha)N^1\sqrt{[2m^*(S+F+1/2m^{*2}e)]/t}$. Then, the main result of the impact of the use of an OACT on the magnitude of counterfeit purchases may remain the same as that of the benchmark model. □

Proof of Proposition 9

The profits of a dubious seller and the authentic firm can be written as $2\beta x p_D - S - F$ and $[1 - 2\beta x(K + N' + N'')]p_R - S - F$, respectively. Note that, to make the case nontrivial, it is assumed that the authentic firm does not want to sell exclusively to the patients who are aware of genuine drugs being available only at the reliable source, but wish to sell to all patients who may or may not know the existence of the dubious source. This assumption is satisfied when the authentic firm makes a higher profit in the latter scenario. Then, following a similar analysis to the benchmark model, I can derive the equilibrium number of dubious entrants consisting of counterfeiters and illegitimate genuine producers, which is $N^2 = \{t + (1-\beta)K[2\gamma - 3\sqrt{2t(S+F)}]\}/\{(1-\beta)\{3\sqrt{2t(S+F)} + 2[(1-\alpha)(Q+L) - \gamma]\}\}$. As a result, similar to the proof of Proposition 2, it can be readily verified that the magnitude of counterfeit purchases first increases and then decreases with the cost of the use of an OACT. □

Proof of Proposition 10

Similar to the analysis in the benchmark model, the equilibrium number of dubious entrants that is composed of counterfeiters and illegitimate genuine producers can be derived as $N^3 = \{(t/g) + K[(2\gamma/g) - 3\sqrt{2t(S+F)}]\}/\{3\sqrt{2t(S+F)} + 2[(1-\alpha)\cdot(Q+L) - (\gamma/g)]\}$. Then, similar to the proof of Proposition 2, one can easily see that the main result of the impact of the use of an OACT on the magnitude of counterfeit purchases remains. □

Endnotes

[1] See http://www.iccwbo.org/advocacy-codes-and-rules/bascap/ (accessed April 8, 2016).

[2] See http://www.fda.gov/Drugs/ResourcesForYou/Consumers/BuyingUsingMedicineSafely/CounterfeitMedicine/ (accessed April 8, 2016).

[3] See http://www.pfizer.com/products/counterfeit (accessed April 8, 2016).

[4] An incident is specified as "a discrete event triggered by the discovery of counterfeit, illegally diverted or stolen pharmaceuticals." Incidents differ in magnitude, scale, and time frame. See http://www.psi-inc.org/incidentTrends.cfm (accessed April 8, 2016).

[5] There are some works investigating such gray market phenomena for other product categories (e.g., Ahmadi and Yang 2000, Xiao et al. 2011, Autrey et al. 2014).

[6] Illegitimate genuine producers might be an important channel that provides effective drugs at the dubious source. For total clarity, in the introduction, I use the definition of counterfeit medicine from the FDA to define a counterfeit drug. From this definition, one can see that unlike authentic drugs, counterfeit drugs are ineffective because they have the wrong ingredients. Hence, counterfeiters in the paper are those producers who illegally produce ineffective drugs. Another widely used definition of counterfeit medicine is from the World Health Organization, which defines counterfeit medicine more broadly: "A counterfeit medicine is one which is deliberately and fraudulently mislabelled with respect to identity and/or source. Counterfeiting can apply to both branded and generic products and counterfeit products may include products with the correct ingredients or with the wrong ingredients, without active ingredients, with insufficient (inadequate quantities) of ingredient(s) or with fake packaging." Based on this definition, some counterfeit drugs produced by counterfeiters could have the correct ingredients found in the authentic versions. In the paper, I refer to these counterfeiters as illegitimate genuine producers because they illegally produce counterfeits that contain the right ingredients. Toscano (2011) shows that counterfeit drugs containing the right ingredients make up 15.6% of all counterfeit drugs, a significant figure.

[7] Note that medicine is different from other product categories (such as luxury goods), in that individuals will never buy the drugs that are detected as counterfeits, no matter how low the prices are, but may knowingly buy cheaper bogus luxury products to signal their social status (Wilcox et al. 2009, Han et al. 2010).

[8] See http://www.fda.gov/drugs/drugsafety/ucm180899.htm (accessed April 8, 2016).

[9] It should be noted that holograms (especially for new generations) do involve advanced production techniques. As such, counterfeit producers are unlikely to acquire exactly the same hologram machines used by brand owners, because of their limited ability to locate and patronize manufacturers who can supply such machines. As a result, the machines ordered online might not help counterfeiters to duplicate holograms perfectly—all of the elements they contain should be exactly the same as those of genuine ones, including less visible elements. Even so, counterfeiters would be able to produce copies that may sufficiently confuse patients with ordinary machines. Hence, the replicas could be simplified versions of genuine counterparts, in the sense that they lack some integral parts of the original holograms, which play no visual role, or only a trivial one. This explains why pharmaceutical experts can tell the falsity of copied holograms by using some professional apparatuses while patients cannot.

[10] Admittedly, this information is at the aggregate level for all of the drugs, not for a specific drug. As such, it may not necessarily imply a causal relationship between the level of complexity of the OACT and the magnitude of counterfeit purchases.

[11] The results do not change if it is assumed that patients can obtain additional consumption utility from an OACT.

[12] See Heal (1980), Balasubramanian (1998), and Jerath et al. (2016) for models that are structurally related to the model setup, but with different concentrations.

[13] Salop (1979) and Sutton (1991) employ a similar approach to studying a firm's market entry decision with an exogenous fixed cost.

[14] See http://www.psi-inc.org/therapeuticCategories.cfm (accessed April 8, 2016).

[15] Low income is one important factor in some patients buying dubious drugs at the dubious source. Low-income patients are hence more willing to purchase dubious drugs than high-income patients. Although the model does not directly consider this income impact, the results can be explained by income heterogeneity among patients to some extent. The model assumes that patients incur different transportation costs when buying drugs, as the authentic firm and dubious sellers typically sell the drugs in different places. This difference in cost varies across countries too: the problem of counterfeit drug purchasing is more prevalent in developing countries than developed countries (World Health Organization 2006b). This disparity could be primarily because patients in developing countries have greater access to dubious drugs than those in developed countries as the former markets have more dubious sellers than the latter ones because of weak law enforcement (World Health Organization 2006a). Therefore, a patient's ease of purchasing dubious drugs may play an important role in modeling the patient's choice of source, as different patients have different ease of access. In this case, for better understanding the appropriateness of the model, one can interpret transportation cost as the ease with which individuals make purchases (Balasubramanian 1998). Ideally, the patients who choose to buy the dubious drugs rather than the reliable drugs might be those who find that trading with a dubious seller is easier. As illustrated in a real example of purchasing the dubious Viagra in Section 1, the process of purchasing from a dubious seller may take a patient some time as she needs to first communicate with the seller to set up a trading place, and then must travel there to make the trade. This implies that such patients may have plenty of time to set up a deal with dubious sellers. Hence, their opportunity cost of time (transportation cost) is low (Balasubramanian 1998). A low opportunity cost in terms of time might well signal a low income on the part of the patient (Nichols et al. 1971, Ratchford 1982). Explained thus, the model can capture the income effect on a patient's choice of source to some extent, in the sense that some patients want to take a chance on the cheaper drugs at the dubious source because their income level is low.

[16] The notion of the REE is that the economic outcomes are consistent with people's expectations (Muth 1961). The rational expectation assumption is a standard assumption in analytical study and this equilibrium concept has been applied in many works, for example, Lal and Matutes (1994), Lal and Rao (1997), Rao and Syam (2001), Amaldoss and Jain (2005), and Jerath et al. (2010). Ideally, patients should be aware of the newly adopted OACTs, as such adoption will have no use if they know nothing about them. By intuition, given that patients have this in mind, introducing an OACT will have an impact on their inferences about the authenticity of the drugs at the dubious source as this influences counterfeiter entry. This intuition, to some extent, can also be justified from the results of the experiment: embedding a hologram on the box of a risky drug enhances the subjects' perceptions of the drug's authenticity and they indeed are more likely to buy such a drug. Therefore, the REE fits the current research, in that it captures the thought that when patients go to an unauthorized market, they have no knowledge about which seller offers genuine drugs and which seller offers counterfeit ones. Thus, their purchase decision is based on their belief about the drug authenticity—the proportion of vendors selling counterfeits among the total vendors. Their belief varies with the number of counterfeit entrants, which is affected by entry cost.

[17] One may think that illegitimate genuine producers could not replicate the OACT and offer drugs with different appearances in the dubious market. However, in reality, we rarely see such cases. This need to replicate the authentic drug's packaging might be because for patients, the risk of buying such drugs is extremely high as there may be many counterfeit entrants offering drugs with the same appearances because of easier replication.

[18] Iyer and Katona (2016) use a similar method in studying an entry game, in which the number of agents as content contributors for social communication is an outcome of discrete choices.

[19] One can see that removing the fixed cost of production S from the model will not change the paper's key insight: there is an inverted U-shaped relationship between the complexity of the OACT and the magnitude of counterfeit purchases. However, if this fixed cost is not considered, the shape of this relationship seems to be inaccurate in capturing reality. Note that the number of counterfeit purchases depends on the number of counterfeit entrants and the market demand for each. When an OACT is not used to combat counterfeiters and the fixed cost S is zero, we would expect that the number of counterfeit entrants should be sufficiently large so that no patients would take a chance on dubious drugs as they may very likely obtain a counterfeit drug as a result. One can see this more clearly from the demand for each dubious seller. In this case, the magnitude of counterfeit purchases is zero. In reality, this magnitude is not insignificant, resulting in pharmaceutical firms adopting OACTs for combating counterfeiters. Therefore, to better capture the reality of measuring the magnitude of counterfeit purchases, the fixed cost of production S might be added in the model.

[20] The results of the experiment are an outcome of a signaling effect, but, essentially, this signaling effect is from an entry deterring effect. The only difference in the two conditions of the experiment is whether a hologram that is difficult to replicate for counterfeiters is found on the packaging of the dubious drug or not. Intuitively, to encourage individuals to buy dubious drugs, dubious sellers need to include the authentic firm's hologram on their own packaging to pass them off as genuine. However, this signaling comes from the effect of deterring counterfeiter entry, if we think that using an OACT can affect counterfeiters' entry decisions, a point that is illustrated during the experiment. Therefore, the results from the experiment are an outcome of the entry deterring effect. In addition, the objective of conducting this experiment is to show that using an OACT can have an impact on patients' inferences about the authenticity of dubious drugs. The paper provides an angle to understand this impact.

[21] See https://www.bloomberg.com/features/2017-counterfeit-makeup/ and https://www.alliedmarketresearch.com/anti-counterfeit-pharmaceuticals-and-cosmetics-packaging-market (accessed July 15, 2017).

[22] See https://www.europol.europa.eu/newsroom/news/largest-ever-seizures-of-fake-food-and-drink-in-interpol-europol-operation and https://www.alliedmarketresearch.com/anti-counterfeit-packaging-food-beverages-market (accessed July 15, 2017).

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