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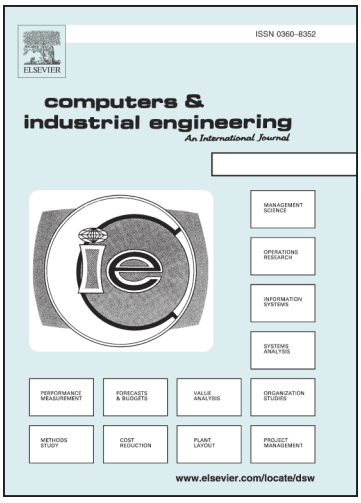

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Adopt or not: manufacturers' RFID decisions for gray marketing in a competitive environment

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Adopt or not: manufacturers' RFID decisions for gray marketing in a competitive environment

Abstract: With the global development of the e-commerce economy, gray marketing has increased sharply and caused significant impacts on manufacturers. Radio frequency identification (RFID) technology provides a new approach for gray marketing management. In this paper, we introduce RFID to track the distribution of products within the gray marketing in a competitive environment. Using a game-theoretical model, we investigate the interplay between the manufacturers' RFID adoption decisions and the third-party's gray marketing decisions and examine the impacts of competitive intensity on firms' profits and decisions. We observe that RFID narrows the scope of the third-party's gray marketing and competitive intensity plays an important role in influencing the third-party's gray marketing decisions. The third-party's gray marketing decisions depend on the RFID double effects (cost effect and punishment effect), market disparity, and competitive intensity. Despite the benefits of RFID, the manufacturer does not always adopt it. When the market disparity is sufficiently small, the manufacturer will not adopt RFID. When the market disparity is sufficiently large, the manufacturer will only adopt RFID if the RFID punishment effect is strong. We also find that increased competitive intensity decreases the third-party's incentive to engage in gray marketing. Finally, although gray marketing decreases the branded manufacturer's profits, it may also increase the competitor manufacturer's profits. Therefore, public policymakers should take into account the positive impacts of gray marketing on competitor manufacturers when they formulate policies to inhibit gray marketing. Public policies should be developed to promote the entire social welfare.

Keywords: Gray marketing, parallel importation, RFID technology, Competitive intensity, Game theory

1 Introduction

In many industries, manufacturers sell their products to customers through their distribution channels or an authorized dealer. Gray marketing, as the selling of genuine-branded products outside the manufacturer-authorized channels/dealers, engages in the competition of markets. The gray market has become increasingly widespread in a variety of industries (Autrey et al. 2014, Altug 2017). With the growth of global e-business, gray marketing has been booming around the world (Li et al. 2018). For example, in the United State, the sale of gray IT products was $40 billion and the manufacturers lost $5 billion per year (reported by KPMG). In the United Kingdom, almost 20% of sales are gray market products in the pharmaceutical industry (Kanavos et al. 2005). In Germany, more than 300,000 gray market cars were sold in 1996 for approximately $10 billion. In Malaysia, the sale of gray market mobile phones has reached nearly 70\% of the total market (Antia et al. 2004). In China, the gray market mobile phone share reached beyond the share of other handsets in 2009 (Liao and Hsieh 2013). Undoubtedly, gray marketing could cause harm to manufacturers' profits and brand image (Zhang and Feng 2018). A report by Deloitte in 2009 shows that gray marketing products in the United States cost manufacturers as much as $63 billion in sales each year (Iravani et al. 2016), and a study by KPMG in 2008 estimates lost sales of $58 billion per year in the IT industry. In addition, many other global manufacturers are facing increasing pressures from gray marketing (Ding et al. 2019).

Gray marketing has attracted much attention from global enterprises and scholars. Manufacturers, such as Mercedes-Benz and BMW, have investigated their luxury cars' gray marketing to cope with the issue since these gray market cars threaten the companies' profits within the world's largest auto market (Reuters 2015). Many other international enterprises such as Nike and Samsung are also suffering from gray marketing and have been taking countermeasures. Scholars have looked into gray marketing from different angles, such as contract perspective (Gallini and Hollis 1999), legal perspective (Hintz 1993), and marketing perspective (Ahmadi et al. 2015, Zhang 2016). These studies enrich the methods of gray marketing management. However, they fail to address the widely-existing parallel importation activities in gray marketing which are difficult to see and track. This paper attempts to fill the gap by investigating gray marketing issue with the aid of radio-frequency identification (RFID) technology, provides a promising way to improve transparency by tracking product flow.

Developments in RFID technology have endowed manufacturers with the ability to detect gray marketing activities by easily tracking product distribution. When a product is labeled with an RFID tag, manufacturers can track the distribution of their product (Nativi and Lee 2012), thereby making better decisions with the data collected from gray marketing activities. In recent years, many manufacturers, including Decathlon and Adidas, have adopted RFID technology to track product flows (Ustundag and Tanyas 2009, Kök and Shang 2014). The global sales of RFID technology are estimated to reach $40.5 billion by 2025 (Grand View Research 2017). Despite the widespread use of gray marketing and the availability of RFID technology as a promising method to tackle the gray marketing problem, previous literature offers few insights into whether and when manufacturers should adopt RFID to combat gray marketing in a competitive supply chain. It is also unclear how gray marketers decide whether to undertake

gray marketing in a competitive environment and how competitive intensity affects firms' profits and decisions. This paper aims to fulfill this research blanks by introducing RFID technology to gray marketing in a competitive supply chain.

To attain the research aim, we employ a game-theoretical model of differentiated competition. The game model is very suitable for our study to investigate the interplay between manufacturers' RFID decisions and third-party's parallel importation decisions in a competitive environment. It has also been widely used in gray market research (Ahmadi and Yang 2000, Autrey et al. 2014, Shao et al. 2016, Iravani et al. 2016). The model consists of two competing manufacturers and a third-party gray marketer. One branded manufacturer sells its identical products to consumers in two separate markets. The two markets have different levels of product demand, resulting in different clearing prices of the branded manufacturer's product in the two markets. Another competitor manufacturer sells differentiated products only in the high-demand market and the third-party decides whether to divert products from the low-demand market to the high-demand market. To cope with gray marketing, the branded manufacturer must consider the RFID cost effect and decide whether to spend a marginal cost to attach an RFID tag to its products sold in the low-demand market. RFID technology detects whether the third-party is engaging in gray marketing and if so, the third-party gray marketer pays a penalty fee to the regulating institute, which is called the RFID punishment effect in the model.

Our study obtains several notable findings. Firstly, we find that the increased competitive intensity between the two manufacturers decreases the third-party's incentive to engage in gray marketing until the third-party gives up on gray marketing completely. Greater competitive intensity decreases the competitor manufacturer's profits, but can also increase the branded manufacturer's profits. Secondly, we find that in a competitive supply chain, gray marketing has different implications on the manufacturers, it decreases profits of the branded manufacturer while potentially increasing the competitor manufacturer's profits. Thirdly, RFID narrows the scope of the third-party's gray marketing. Without RFID, the third-party would undertake gray marketing as long as the marketing disparity is relatively large. However, with RFID, even if the market disparity is sufficiently large, the third-party would not able to undertake gray marketing as long as the RFID punishment effect is strong. Finally, despite the benefits of applying RFID, the manufacturer should not always adopt it. The manufacturer's decision of applying RFID would depend on the market disparity, RFID double effects, and the competitive intensity. Specifically, when the market disparity is sufficiently small, the manufacturer would not adopt RFID. When the market disparity is sufficiently large, the manufacturer would adopt RFID only when the RFID punishment effect is strong.

The above findings make several managerial contributions for manufacturers and public policymakers. For manufacturers, our findings provide conditions under which manufacturers should adopt RFID depending on the market disparity, the RFID double effects, and the competitive intensity. The findings also provide practical guidance for manufacturers to deal with gray marketing problems in a competitive supply chain. For public policymakers, our findings suggest that gray marketing is not always harmful to manufacturers in a competitive environment. It decreases the branded manufacturer's profits while increasing the competitor manufacturer's profits. Hence, public policy should encourage the adoption of RFID to

combat gray marketing and even formulate policies to directly punish the gray marketer. In the meanwhile, the positive impacts of gray marketing on the competitor manufacturer should also be envisaged. As a result, policies should be developed to promote the entire social welfare.

2 Literature Review

Our research is mainly in the nexus of three streams of literature: the literature on gray marketing, the literature on supply chain management with RFID technology, and the literature on the competitive supply chain. These three streams of literature belong to the field of supply chain management. However, there is almost no research put them together to study. This paper is the first to combine them to form a new research direction and investigate the interplay between the manufacturers' RFID adoption decisions and the third-party's gray marketing decisions in a competitive environment.

This paper is closely related to the literature on gray marketing. One stream of the literature concentrates on investigating the causes of gray marketing (Gorelick and Little 1986, Huang et al. 2004, Liao and Hsieh 2013). For example, Gorelick and Little (1986) explained the reasons for parallel importation from the view of common legal and factual defenses. They argued that the factual context reveals the policy reasons for the longstanding regulations that permit gray marketing, and consumers' attitude toward gray products is one of many important factors of gray marketing formation. Liao and Hsieh (2013) analyzed the influential factors of consumers' willingness to buy gray products. They found that consumers' attitude toward counterfeit products is positively related to their willingness to buy gray products, but the perceived risk is negatively related to their willingness to buy. Also, Huang et al. (2004) investigated the relationship between consumer attitude toward gray products and antecedents of gray marketing activities, showing that consumers form negative price-quality inferences about gray products and are risk-averse in purchasing gray products.

Another stream of literature on gray marketing focuses on identifying solutions to cope with gray marketing (Hintz 1993, Gallini and Hollis 1999, Ahmadi et al. 2015, Zhang 2016, Iravani et al. 2016, Altug and Sahin 2019). Hintz (1993) recommended the usage of copyright laws for gray market management. Furthermore, Gallini and Hollis (1999) suggested that managers should establish a policy combining contract, tort, and antitrust law to deter gray marketing. From the marketing perspective, Ahmadi et al. (2015) examined how market conditions and product characteristics affect the manufacturer's strategy to manage gray marketing. Zhang (2016) found that offering a rebate to the consumers who purchase authorized products in the low-price market is an effective method to deter gray marketing. Besides, Iravani et al. (2016) found that demand-enhancing services can help manufacturers weaken the competition from gray marketing. In recent years, the development of information technologies (RFID, blockchain) provides new means for gray market management (Sunny et al. 2020, Liu and Li 2020), especially the rapid development and maturity of RFID technology (Gautam et al. 2017, Tu et al. 2018). However, by acknowledging the contributions of these studies to gray marketing management, little research has been conducted to examine how RFID technology helps manufacturers cope with gray marketing problems in a competitive supply chain. This paper enriches the literature on gray marketing by considering the competitive environment and introducing RFID technology.

Thus, this paper is closely related to the literature regarding supply chain management with RFID. Some

studies focus on the design of a supply chain traceability system based on RFID (Zhang et al. 2010). They integrated RFID into the supply chain to monitor product distribution, inventory records, and security. Some other studies concentrate on how RFID affects the performance of a supply chain (Ustundag and Tanyas 2009, Nativi and Lee 2012, Kök and Shang 2014, Fan et al. 2015, Choi et al. 2017, Biswal et al. 2018, Feng et al. 2018, Sim et al. 2019, Tsao et al. 2017, Cui et al. 2017). For example, Tsao et al. (2017) reported on a closed-loop supply chain network for the remanufacturing under RFID, which is required to minimize total network costs. Zhang et al. (2010) designed an information traceability system for the pork production supply chain based on RFID technology, which enables people to get logistics information precisely and systematically. Nativi and Lee (2012) analyzed the impact of RFID information-sharing strategies on the supply chain and, applied RFID to monitor in real-time the inventory information and investigated whether this real-time data can improve environmental and economic benefits. They found that the attainment of more returns significantly increases the environmental benefits. Chen et al. (2014) addressed how the application of RFID technology can get rid of misplacement problems in the supply chain, showing that an increase in RFID cost will not decrease a manufacturer's incentive when the manufacturer gets much risk from the retailer. Unlike the analytical model, Ustundag and Tanyas (2009) applied a simulation model to investigate how product value, lead time, and demand uncertainty affect the performance of the integrated RFID supply chain in terms of cost factors. In addition, Kök and Shang (2014) discussed implications on RFID investments from the perspective of reducing inventory inaccuracy. Fan et al. (2015) studied the impact of RFID on the supply chain with shrinkage and misplacement by considering RFID fixed cost and tag marginal cost in a supply chain including one supplier and one retailer. They found that the retailer is much more sensitive than the supplier to the sharing proportion of RFID fixed cost and tag marginal cost. However, we introduce RFID to a competitive channel with gray marketing and study the interplay between manufacturers' strategic adoption of RFID and third-party's endogenously gray marketing decisions. Therefore, this paper extends the application of RFID technology in supply chain management.

This research is also related to the literature on the competitive supply chain. A considerable number of studies have investigated vertical or horizontal competition in a supply chain (Choi 1991, Lee and Staelin 1997, Trivedi 1998, Fynes et al. 2005, Yao and Liu 2005, Klein et al. 2007, Almehdawe and Mantin 2010, Wu et al. 2012, Zhang et al. 2014, Hsieh et al. 2014, Li et al. 2016, Ghavamifar et al. 2018, Wang et al. 2018, Bian and Zhao 2020, Tang et al. 2020, Dai et al. 2020). For example, Choi (1991) considered a channel structure with two competing manufacturers and a common retailer and studied three non-cooperative games of different power structures between the two manufacturers and the retailer. By investigating two manufacturers selling their substitutable products through two retailers, Trivedi (1998) extended the research of Choi (1991). Similarly, Lee and Staelin (1997) also studied an industry model which is consist of two manufacturers and two retailers and analyzed the retailer product line pricing as well as competition between manufacturers and retailers. In addition, Wu et al. (2012) studied the competitive interaction in a supply chain composed of two retailers and one common supplier, which is unlike Choi (1991). In this paper, we adopt the previous model of competitive interaction in a supply chain with two manufacturers and one third-party parallel importer. We examine how the manufacturers and third-party determine their decisions in a

competitive environment.

3 Model Setup

Consider a competitive supply chain where two manufacturers (M_1 and M_2) compete in a large market H with differentiated products. The manufacturer M_1 also sells its product in a small market L, in which the clearing prices are lower (which we verify in our analysis). We assume the two markets are separate such that consumers in one market cannot purchase from the other market (Ahmadi et al. 2015). This assumption is reasonable in situations when the two markets are different countries or the manufacturer limits its retail distribution to a certain market. Due to the disparity between the two markets, the clearing price in the market H will be higher than in the market L. Under this situation, a gray marketer might undertake gray marketing by diverting products from the market L to the market H. Following Li et al. (2018) and Xiao et al. (2011), we consider a third-party gray marketer (T) who decides whether or not to undertake gray marketing activities (see Figure 1).

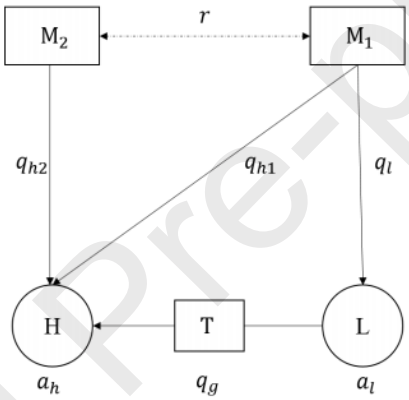

Figure 1: Competitive Supply Chain with Third-party Gray Marketing

To address gray marketing problems, the manufacturer M_1 might adopt RFID to detect unauthorized distribution by monitoring the physical locations of the products (Nativi and Lee 2012, Piramuthu and Doss 2017). By doing so, the manufacturer M_1 attaches an RFID tag to each product sold in the market L (Ustundag and Tanyas 2009, Chen et al. 2014, Tsao et al. 2017). The marginal cost of an RFID tag is C_R. We assume that $0 < C_R < a_l$ which implies that the RFID marginal cost should be too large that the firm will never adopt it. If the manufacturer detects that a gray marketer is conducting gray marketing activities, the gray marketer will be charged a penalty fee $C_P > 0$ by government regulators (Heese 2007, Fan et al. 2015). We assume that the penalty fee C_P is exogenously determined by government regulators. This assumption is reasonable since many governments have formulated laws and regulations to publish gray marketers. For instance, the Russian government has stipulated rigorous punishment for gray marketing activities. Also, the Lanham Act (15 U.S.C. 1051 et seq.) has laid out several options to punish gray marketers.

Without loss of generality, we assume that the manufacturer M_1 sells identical products in the two markets (Autrey et al. 2014). We also standardize the marginal cost of production and the cost of diverting gray products to zero, as these parameters are easy to implement in our model and do not affect our main results.

3.1 Timing Order

Following the related literature (Autrey et al. 2014, Li and Robles 2007, Autrey and Bova 2012), we present a model of quantity-based competition with a third-party gray marketer where the third- party is the Stackelberg follower. In the first stage, the manufacturer M_1 determines whether to adopt RFID technology. At the same time, the two manufacturers simultaneously choose quantities in each market (*i.e.,* q_{h1}, q_l, q_{h2}). In the second stage, the third-party determines whether to undertake gray marketing activities after observing the manufacturers' decisions. If so, the third-party also determines the quantities (*i.e.,* q_q). The timing of the game is shown in Figure 2. Backward induction is applied throughout this paper.

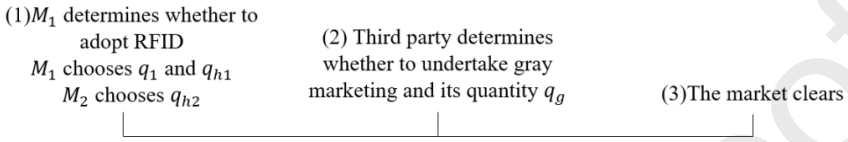

Figure 2: Timeline

3.2 Demand Structure

The linear demand structure we use is similar to Singh and Vives 1984:

$$p_i = \alpha_i - \beta_i q_i - \gamma q_j,\ i,j = 1,2,\ i \neq j\ , \tag{1}$$

where q_i are the quantities of the manufacturer M_i, and p_i are the clearing prices of the manufacturer M_i. For simplicity, we assume that $\alpha_1 = \alpha_2 = \alpha$ and $\beta_1 = \beta_2 = \beta$. Without loss of generality, we set $\alpha = a_h$ in market H and $\alpha = a_l$ in the market L, respectively. We define $a = a_h / a_l$ the market disparity between the two markets, in which $a > (\gamma + 2)/2$ so that market L prices are lower than market H prices. It also implies that a should not be too small such that the third-party will never engage in gray marketing. The parameter α represents the potential demand. In addition, we assume that $\beta = 1$ and $0 < \gamma < 1$. The parameter γ and β denote the degree of competitive intensity between the manufacturer M_1 and M_2. A larger γ represents a higher competitive intensity. These assumptions allow us to focus on the competition relationship of manufacturers.

We now formulate pricing functions in market H and market L, respectively. In market L, only the manufacturer M_1 chooses quantity q_l. Since $\alpha = a_l$ in market L, we have the following pricing function:

$$p_l = a - q_l\ . \tag{2}$$

In market H, if the third-party does not engage in gray marketing, we have the following pricing functions:

$$p_{h1} = a_h - q_{h1} - \gamma q_{h2}\ , \tag{3}$$

$$p_{h2} = a_h - \gamma q_{h1} - q_{h2}\ . \tag{4}$$

If the third-party engages in gray marketing, the total product quantities of manufacturer M_1 in market H consist of two parts: q_{h1} and q_g. Therefore, we have the following pricing functions:

$$p_{h1} = a_h - (q_g + q_{h1}) - \gamma q_{h2}\ , \tag{5}$$

$$p_{h2} = a_h - q_{h2} - \gamma (q_g + q_{h1})\ . \tag{6}$$

4 Analysis and Results

In this section, we investigate the manufacturer's RFID adoption and the third-party's gray marketing strategies. Recall that the manufacturer M_1 determines whether to adopt RFID and the third-party determines whether to undertake gray marketing, four cases occur: NN, NG, RN, and RG. In the case of NN, the manufacturer M_1 does not adopt RFID and the third-party does not undertake gray marketing. In the case of NG, the manufacturer M_1 does not adopt RFID and the third-party undertakes gray marketing. In the case of RN, the manufacturer M_1 adopts RFID and the third-party does not undertake gray marketing. In the case of RG, the manufacturer M_1 adopts RFID and the third-party undertakes gray marketing. We examine these four cases separately and derive the third-party's gray marketing decisions and the manufacturer's strategic adoption of RFID by comparing their equilibrium profits across the four cases.

4.1 Case NN: Without RFID or Gray Marketing

We first analyze the case NN as a benchmark. In this case, the manufacturer M_1 does not adopt RFID and the third-party does not engage in gray marketing. The objective functions for each manufacturer are as follows:

$$\pi_{m1} = q_{h1}(a_h - q_{h1} - \gamma q_{h2}) + q_l(a_l - q_l), \tag{7}$$

$$\pi_{m2} = q_{h2}(a_h - \gamma q_{h1} - q_{h2}). \tag{8}$$

We obtain the equilibrium quantities that $q_{h1}^{*NN} = \frac{a_h}{\gamma+2}$, $q_{h2}^{*NN} = \frac{a_h}{\gamma+2}$, and $q_l^{*NN} = \frac{a_l}{2}$. The manufacturers' equilibrium profits are $\pi_{m1}^{*NN} = \frac{a_h^2}{(\gamma+2)^2} + \frac{a_l^2}{4}$ and $\pi_{m2}^{*NN} = \frac{a_h^2}{(\gamma+2)^2}$, respectively.

4.2 **Case NG: Without RFID, With Gray Marketing**

In this case, the third-party undertakes gray marketing by parallel importing products from the market *L* to market *H*. The objective functions for the manufacturers and the third-party are as follows:

$$\pi_{m1} = q_{h1}(a_h - (q_{h1} + q_g) - \gamma q_{h2}) + (q_l + q_g)(a_l - q_l), \tag{9}$$

$$\pi_{m2} = q_{h2}(a_h - \gamma(q_{h1} + q_g) - q_{h2}), \tag{10}$$

$$\pi_t = q_g(a_h - (q_{h1} + q_g) - \gamma q_{h2} - (a_l - q_l)). \tag{11}$$

We obtain equilibrium quantities for the third-party and the manufacturers sequentially. Table 1 (in Appendix) summarizes the equilibrium results.

4.3 **Case NG: Without RFID, With Gray Marketing**

In the case of RN, the manufacturer adopts RFID and the third-party does not engage in gray marketing. The manufacturer M_1 incurs a marginal cost C_R to attach an RFID tag to each product sold in market *L*. The objective functions for the manufacturers are as follows:

$$\pi_{m1} = q_{h1}(a_h - q_{h1} - \gamma q_{h2}) + q_l(a_l - q_l - C_R), \tag{12}$$

$$\pi_{m2} = q_{h2}(a_h - \gamma q_{h1} - q_{h2}). \tag{13}$$

We obtain the equilibrium quantities that $q_{h1}^{*RN} = \frac{a_h}{\gamma+2}$, $q_{h2}^{*RN} = \frac{a_h}{\gamma+2}$, and $q_l^{*NN} = \frac{a_l - C_R}{2}$. The manufacturers' equilibrium profit are $\pi_{m1}^{*RN} = \frac{a_h^2}{(\gamma+2)^2} + \frac{a_l^2}{4} - \frac{C_R^2}{4}$ and $\pi_{m2}^{*RN} = \frac{a_h^2}{(\gamma+2)^2}$, respectively.

4.4 **Case RG: With RFID and Gray Marketing**

In this case, the manufacturer adopts RFID and the third-party conduct gray marketing. The manufacturer incurs RFID's marginal cost C_R and the third-party pays the penalty fee C_P. The objective functions for the manufacturers and the third-party are as follows:

$$\pi_{m1} = q_{h1}(a_h - (q_{h1} + q_g) - \gamma q_{h2}) + (q_l + q_g)(a_l - q_l - C_R), \tag{14}$$

$$\pi_{m2} = q_{h2}(a_h - \gamma(q_{h1} + q_g) - q_{h2}), \tag{15}$$

$$\pi_t = q_g(a_h - (q_{h1} + q_g) - \gamma q_{h2} - (a_l - q_l)) - C_P. \tag{16}$$

The equilibrium quantities and profits are summarized in Table 1.

We characterize the interplay between the manufacturer's RFID adoption and the third-party's gray marketing through backward induction. First, we solve the third-party's gray marketing decisions. Then, we derive the manufacturer's strategic adoption of RFID depending on the anticipated best response from the third-party's gray marketing decisions.

Proposition 1 *The third-party's gray marketing decisions are as follows:*

(a). Without RFID,

i. When the market disparity is small (i.e., $\frac{\gamma+2}{2} < a < a_1$), the third-party will not undertake gray marketing.

ii. When the market disparity is large (i.e., $a > a_1$), the third-party will undertake gray marketing.

(b). With RFID,

i. When the market disparity is small (i.e., $\frac{\gamma+2}{2} < a < a_1$), the third-party will not undertake gray marketing.

ii. When the market disparity is moderate (i.e., $a_1 < a < a_2$), the third-party will undertake gray marketing if and only if penalty fee and RFID's marginal cost are both low (i.e., $0 < C_P < \tilde{C}_P$, $0 < C_R < C_{R1}$).

iii. When the market disparity is large (i.e., $a > a_2$), the third-party will undertake gray marketing if and only if the penalty is low (i.e., $0 < C_P < \tilde{C}_P$).

Proposition 1 illustrates the third-party's strategic decisions on whether to engage in gray marketing. Without RFID, the third-party will engage in gray marketing only when the market disparity is large. However, with RFID technology application, the third-party may not engage in gray marketing even when the market disparity is large. For instance, when the market disparity is moderate, the third-party will not undertake gray marketing if bearing either a high penalty fee or a high RFID's marginal cost. Even when the market disparity is sufficiently large, the third-parity will not undertake gray marketing if the penalty fee is high. The reasons are as follows.

In the absence of RFID. The market disparity between market *H* and *L* leads to the price difference between the two markets (*i.e.,* $p_{h1}^{*NN} > p_l^{*NN}$, $p_{h1}^{*NG} > p_l^{*NG}$). A large market disparity will result in a huge price difference between the two markets (*i.e.,* $\frac{p_{h1}^{*NN} - p_l^{*NN}}{a} > 0$, $\frac{p_{h1}^{*NG} - p_l^{*NG}}{a} > 0$). Therefore, when the market disparity is large, it will be profitable for the third-party to undertake gray marketing, even though by doing

so, the competition between the manufacturers in market *H* will become fiercer. However, when the market disparity is small, the price difference will be low. The third-party engages in gray marketing will intensify the competition and thereby make it unprofitable.

In the presence of RFID. In addition to taking market disparity into account, the third-party also takes the RFID's marginal cost and the penalty fee as endogenous decision variables. When the market disparity is small, the third-party will not undertake gray marketing as well. Remarkably, when the market disparity is moderate, the third-party will not undertake gray marketing if either the penalty fee or the RFID's marginal cost is high. This is different from that of result a(ii). The reasons are as follows. The RFID's marginal cost increases the clearing price in market *L* (notice from Equations (12) and (14)). Thus, a high marginal cost of RFID will compress the price gap between markets, which will make it unprofitable for the third-party to undertake gray marketing. Furthermore, as the third-party will be charged with a penalty fee under the monitoring of RFID, this penalty fee reduces the third-party's profits directly. If the penalty fee is high, the third-party will have no incentive to undertake gray marketing. Therefore, the third-party will undertake gray marketing only when it does not incur a high cost (i.e., either the penalty fee or RFID's marginal cost). Finally, when the market disparity is large enough, the third-party will undertake gray marketing as long as the penalty fee is low. This is different from that of result b(ii). In this situation, the price difference will be large enough. Although a high RFID's marginal cost will reduce the price difference, it still will be profitable for the third-party to engage in gray marketing as long as the penalty fee is low. Since the penalty fee directly reduces the third-party's profits, a high penalty fee will prevent the third-party from undertaking gray marketing even when the market disparity is sufficiently large.

Generally, Proposition 1 suggests two notable insights: (1) RFID has a significant impact on third-party's gray marketing decisions, which narrows the scope of gray marketing; (2) since the boundaries $\tilde{C}_P$ and C_{R1} are the functions of parameter γ and a, the third-party endogenously makes gray marketing decisions which depends on the competitive intensity, the market disparity, and the presence of RFID. To further explore the impact of competitive intensity on the third-party's gray marketing decisions, we examine how parameter γ affects the third-party's profits in Remark 1.

Proposition 2

(a). $0 < C_P < \tilde{C}_P$

i. When the market disparity is small (i.e., $\frac{\gamma+2}{2} < a < a_1$*),* M_1 *will not adopt RFID.*

ii. When the market disparity is moderate (i.e., $a_1 < a < a_2$*), the manufacturer* M_1 *will adopt RFID if and only if the RFID's marginal cost is moderate (i.e.,* $C_{R1} < C_R < C_{R2}$*).*

iii. When the market disparity is large (i.e., $a > a_2$*), the manufacturer* M_1 *will not adopt RFID.*

(b). If the penalty fee is large $C_P > \tilde{C}_P$

i. When the market disparity is small (i.e., $\frac{\gamma+2}{2} < a < a_1$*),* M_1 *will not adopt RFID.*

ii. When the market disparity is moderate (i.e., $a_1 < a < a_2$*), the manufacturer* M_1 *will adopt RFID if and only if the RFID's marginal cost is low (i.e.,* $0 < C_R < C_{R1}$*)..*

iii. When the market disparity is large (i.e., $a > a_2$*), the manufacturer* M_1 *will adopt RFID.*

$p_l^{*RN} - p_l^{*NN} = \frac{C_R}{2}$

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Proposition **3**

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5 Implications of Competition Intensity

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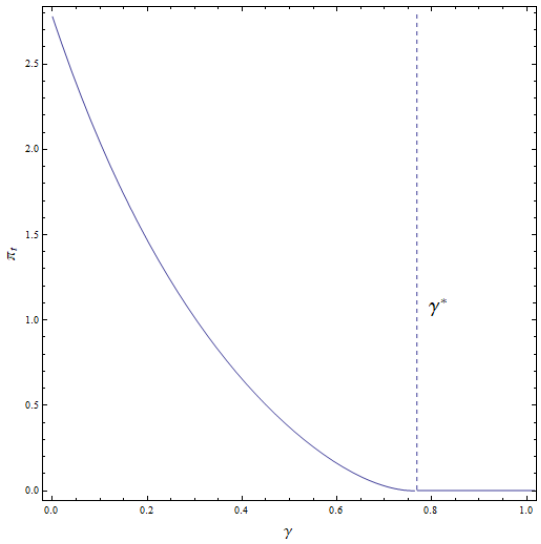
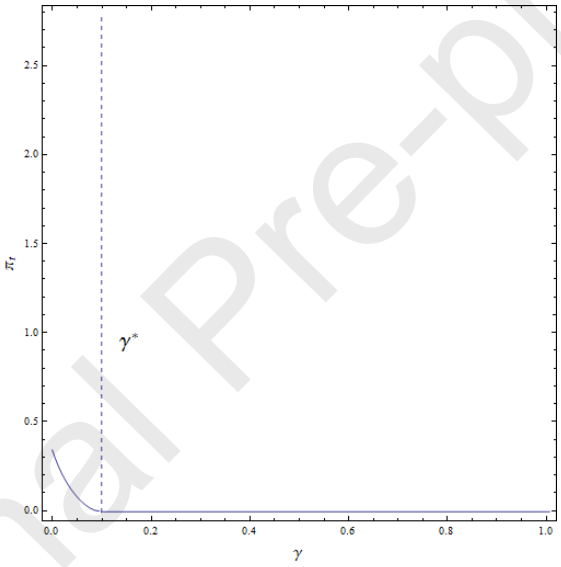
Remark 1

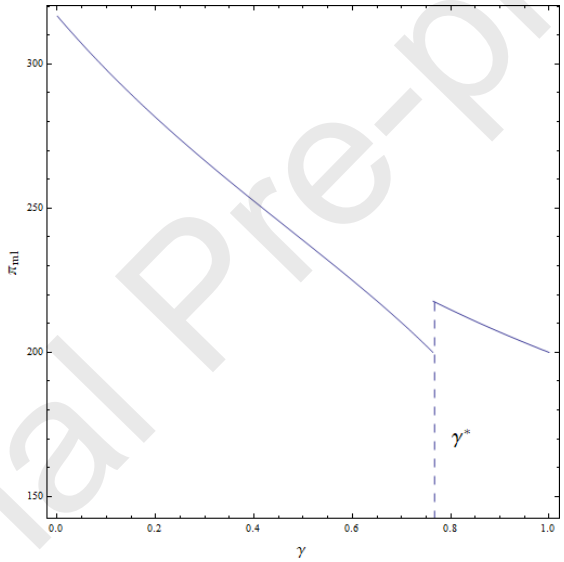


$a_h = 30$ $a_l = 20$

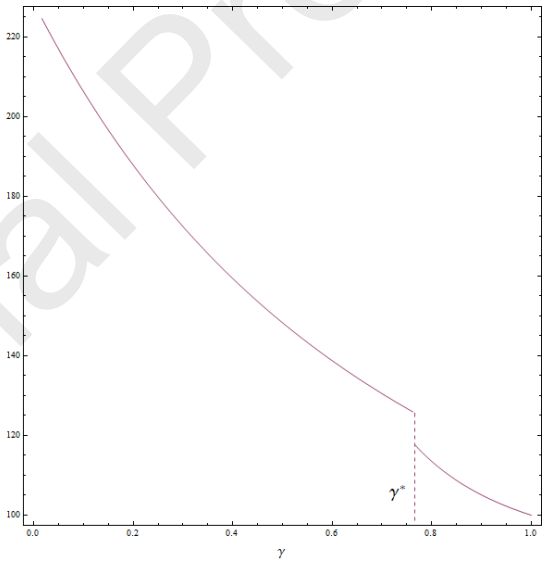


$a_h = 30$ $a_l = 20$ $C_P = 2$

Remark 2



Remark 3



6 Managerial Insights

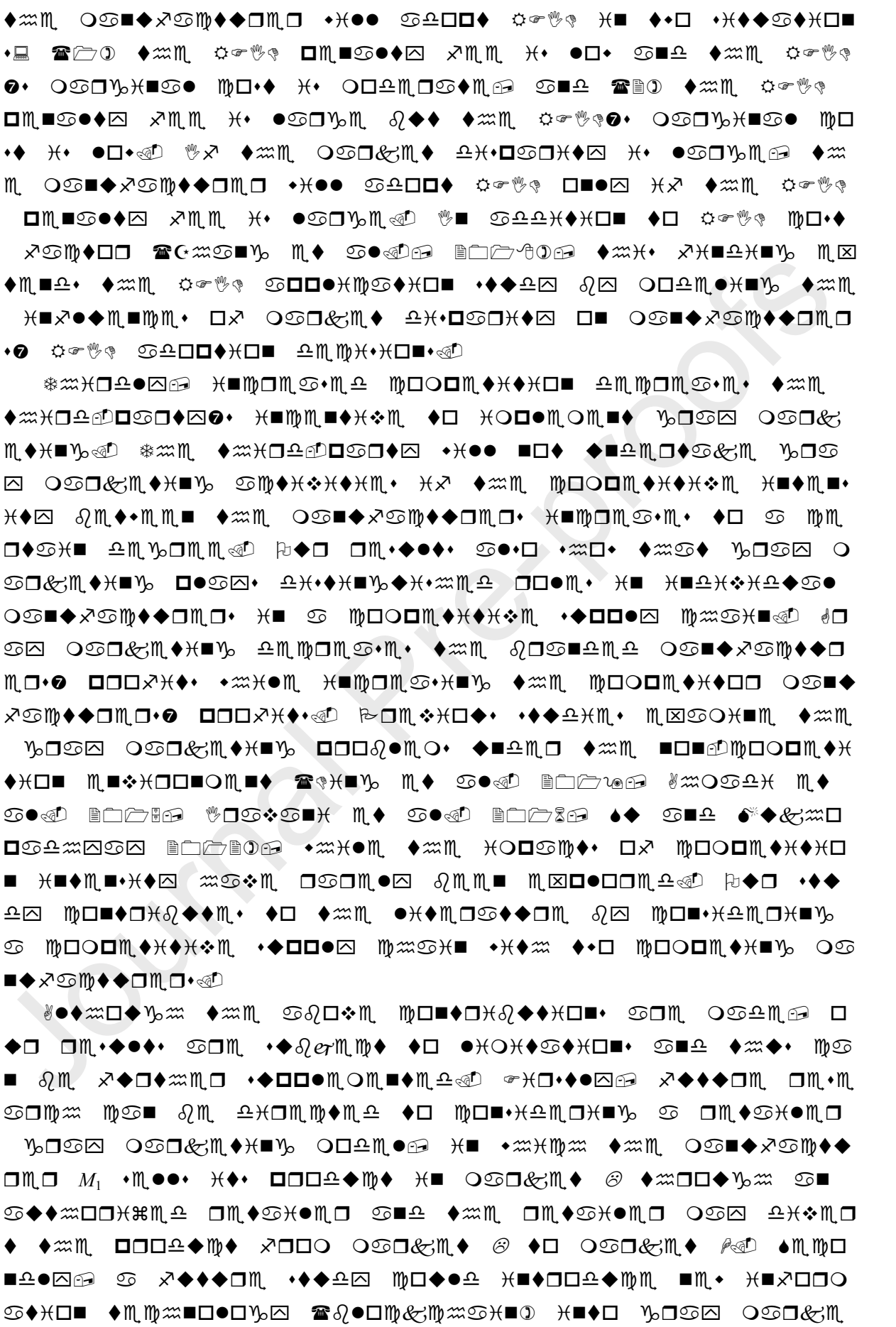
ke on a decreasing trend. However, when the competitive intensity increases to a certain degree, the third-party will completely halt its gray marketing activities. Under such competition, we advise the third-party not to engage in gray marketing.

How does competitive intensity affect profits? For the manufacturer M_1, our analysis shows that competitive intensity may increase its profits under certain conditions. As the competition becomes aggressive, the manufacturer M_1's profits will decrease at first, then gradually increase before continuing to decrease. The reason for a sudden increase is due to the third-party abandoning gray marketing when the competitive intensity increased to a certain degree. For the manufacturer M_2 and the third-party, their profits always decrease with the increase of competitive intensity.

How does gray marketing affect the manufacturers' profits in a competitive supply chain? Gray marketing is not always harmful to manufacturers. Our analysis shows that gray marketing is harmful to the manufacturer M_1 but may be beneficial to the manufacturer M_2, informing that gray marketing leads to different effects on manufacturers in a competitive supply chain. Specifically, gray marketing harms the branded manufacturer but may benefit its competitors. This finding offers managerial insight to government regulators. On the one hand, the regulators should formulate policies to protect branded manufacturers' interests in gray marketing. On the other hand, the regulators should also envisage and well handle the positive effect of gray marketing on competitor manufacturers so that the entire social welfare can be promoted.

7 Conclusion

The increasingly fierce market competition h



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CRediT author statement

Long Ding: Conceptualization, Methodology, Writing- Original draft preparation.
Bin Hu: Data curation, Supervision.
Hongping Yuan: Writing- Reviewing and Editing,

Highlights:

- We introduce RFID into gray marketing in a competitive environment.
- We study the interplay between RFID adoption and gray marketing decisions.
- We examine the impact of competition intensity on manufacturers' profit.
- We investigate how competition intensity affects gray marketing decisions.