On the sufficiency of regulatory enforcement in combating piracy

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Abstract:

This paper contradicts the findings of the previous literature which questions the role of regulatory enforcement in the form of monitoring in preventing piracy. In the model a regulator's choice of monitoring and a firm's investment in anti-copying technology are the regulatory and technical anti-piracy efforts. We show that the socially optimal monitoring rate can prevent piracy and there is no investment in anti-copying technology in equilibrium. If administering enforcement policies is "sufficiently" costly, then the socially optimal monitoring rate is low and there is a high level of investment in anti-copying technology which however, is not sufficient to prevent copying.

Keywords: Accommodating Strategy, Aggressive Strategy, Anti-copying Investment, Regulatory Enforcement

JEL **Classification**: K42, L11.

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1. Introduction

The existing literature focusing on the policy measures for protection against software piracy has in general questioned the role of regulatory enforcement in the form of monitoring in achieving the desired objective. In the context of commercial piracy, where copies of copyrighted material are illegally sold in the market, allowing piracy and hence, no regulatory enforcement is the optimal policy because it results in a larger market output and lower price thus leading to a higher consumer surplus and social welfare. [1] Hence, factors like lobbying by copyright holders may be necessary for regulatory enforcement to be the optimal policy which however, may not guarantee the prevention of piracy.[2] Banerjee et.al. (2008) shows that technical protection rather than regulatory enforcement may prevent piracy with certainty.

Chen et.al. (1999), Cheng et.al. (1997) and Noyelle (1990) show that lower price rather than regulatory enforcement is a better strategy to combat end-user piracy defined as copying for personal consumption. In the presence of network externalities non-protection against end-user piracy is an equilibrium.[3] Bae et.al. (2006) studies the effect of Intellectual Property Right (IPR) protection on piracy which is costly in terms of the cost of reproduction and in terms of the copied product being an inferior substitute of the legitimate product referred to as the *degradation cost*. They show that

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[1] In recent years the focus has been more on commercial piracy. The enormity of the threat is such that the US Trade Representative in its 2004 Special 301 Report, a trade sanction tailored for intellectual property trade concerns, posited that "ineffective enforcement of intellectual property rights, commercial piracy - in particular the growing problem of pirate production of optical media such as CDs, DVDs and CD-ROMs,…continue to be a global threat." Regulatory enforcement organizations like the *Strategy Targeting Organized Piracy* (STOP) was launched by the Bush administration in October 2004 to combat commercial piracy.

[2] See Banerjee 2006a and 2006b.

[3] See Shy et.al. (1999), Slive and Bernhardt (1998) for more on this issue. Takeyama (1994), Conner et.al. (1991), and Nascimento et.al. (1988) also discuss the role of network externalities on the marketing of software. Duchene et.al. (2006) show that stronger copyright protection increases the profits of firms practicing the conventional sales and marketing of physical products and lowers the profits of firms who markets its products by allowing consumers to search and sample.

if IPR protection raises degradation cost then social welfare declines in the short-run. However, if IPR protection increases reproduction cost then the effect on social welfare is ambiguous.

This paper contradicts the findings of the above cited literature and shows that it may be possible to prevent piracy through regulatory enforcement using a model that consists of a regulator, a copyright holder hereafter referred to as a monopolist, and a pirate who illegally sells copies of the monopolist's product. The regulator is responsible for detecting (hereafter, referred to as monitoring) and penalizing the illegal activities of the pirate. The monopolist chooses whether or not to invest in an anti-copying technology that may prevent copying and also chooses an output strategy that either allows or deters the pirate's entry.[4] If he invests in anti-copying technology then he also chooses the level of investment. For the purpose of exposition I will refer to them as *the anti-copying investment* and *no anti-copying investment* subgames.

For each of the subgames I determine the equilibrium entry-allowing and entry-deterring outputs, the corresponding social welfare functions and the social welfare maximizing monitoring rates. For the anti-copying investment subgame I also determine the equilibrium investment.

The equilibrium entry-deterring output strategies in both subgames are identical. This is because since entry is deterred by the output strategy it is not optimal for the monopolist to invest in anti-copying technology. In the anti-copying investment subgame the equilibrium investment corresponding to the entry-allowing output strategy is inversely related to the monitoring rate. If there is no monitoring then the equilibrium anti-copying investment prevents copying with certainty. In this case the monopolist's output is the same as that in the no-piracy situation (hereafter referred to

[4] There are evidences that suggest the development of technical methodologies that can check copyright infringement. For example, BBC (January 20, 2003) reports that the music industry has been trying out different technologies to stop the unauthorized copying of CDs.

as the monopoly outcome) and the monopolist's profit is the same as that in the no-piracy situation net of the anti-copying investment. I also show that the monopolist's profit corresponding to the equilibrium entry-allowing output strategy in the anti-copying investment subgame weakly dominates that corresponding to the equilibrium entry-allowing output strategy in the no-anti-copying subgame.

The social welfare maximizing objective of the regulator results in monitoring as the socially optimal outcome and the entry-deterring output strategy is the subgame perfect equilibrium. Hence, there is no anti-copying investment in equilibrium. The equilibrium output in this case is higher than the one that will prevail if the pirate existed in the market. If the regulator chooses not to monitor then it is optimal for the monopolist to invest in anti-copying technology and the equilibrium investment prevents copying with certainty thus restoring the monopoly outcome. Hence no monitoring is not socially optimal. Our finding differs from Park et.al. (2005) who show that the price under technical protection is lower than that under legal protection.[5]

To test for the robustness of our findings I consider a relatively general monitoring cost function. For low monitoring costs the result is the same as mentioned above. However, if monitoring is "sufficiently" costly, then the socially optimal monitoring rate is low and there is a high level of investment in anti-copying technology which however, cannot prevent copying with certainty.

This paper is organized as follows. In Sections 2 and 3 I present the model and analyse the no anti-copying investment and anti-copying investment subgames.

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[5] This is because under technical protection the user's cost of circumvention acts as the upper bound on the price. In Park et. al. (2005), both legal and technical protection prevents copying with certainty and they do not endogenize the regime which we do in our paper. . In our paper legal protection is represented by the monitoring rate which is the probability of detecting the fake-producer. Therefore, legal protection cannot guarantee the prevention of piracy with certainty. The technical protection in our paper can prevent copying with certainty only if the anti-copying investment exceeds a critical level.

Section 4 contains the welfare analysis. Here I include the analysis with the general monitoring cost function. In Section 5 I provide some discussions on possible empirical research and Section 6 contain the concluding remarks.

2. The Model

Let us consider the market for a product like software which can be copied by a pirate, and illegally sold in the market thereby competing with the monopolist, the producer of the legitimate product. The market demand for this product is characterized by a linear demand function of the form, $p(q) = a - q$, where *q* and *p* denote the quantity and the price. For computational purposes I assume, $a = 4$. I also assume an installed monopolist which allows me to avoid the fixed cost of developing the product, and the marginal cost of production is assumed to be zero. The monopoly results in the absence of piracy are $p_m^* = 2$, $q_m^* = 2$, and $\pi_m^* = 4$.

I now introduce piracy into the model. The pirate makes identical, unauthorized copies of the monopolist's product and illegally sells it in the market.[6] The regulator is responsible for monitoring and penalizing the pirate, which constitutes the legal enforcement policy. Let α be the monitoring rate which is the probability of detecting the pirate, and $c(\alpha)$ be the monitoring cost with the properties $c'(\alpha) > 0$ and $c''(\alpha) > 0$. If the pirate's illegal activities are detected which occurs with probability α then he pays an institutionally given penalty *G* to the regulator. The rationale behind this assumption is that this transfer compensates the regulator for the monitoring cost and avoids any other distributional issues. I assume $c(\alpha) = \frac{\alpha^2}{2}$ and $G = 2$ for computational purpose.[7]

[6] According to Wikipedia, "with digital technology, most modern piracy involves an exact and perfect copy of the original made from a hard copy or downloaded over the Internet".

[7] Keeping the penalty as *G* will not affect the analysis because in the social welfare analysis it will not appear since it is a transfer from the pirate to the government and hence it cancels out.

The monopolist chooses to invest or not to invest in an anti-copying technology, hereafter referred to as the anti-copying investment denoted by *T*. Let $H(T)$ be the *probability that the pirate cannot copy*. The monopolist also chooses a quantity strategy that either allows (hereafter referred to as the *accommodating* or *ac*-strategy) or deters (hereafter referred to as the *aggressive* or the *ag*-strategy) the pirate's entry.

The game played between the regulator, the monopolist and the pirate is represented in an extensive form as follows.

Stage 1: The regulator chooses a monitoring rate, α .

Stage 2: The monopolist either chooses to invest *T* or not to invest (*NT*) in anti-copying technology. He also chooses the *ac* or *ag* output strategy. Let q_m^i .denote the monopolist's output for output strategy *i*, $i \in \{ac, ag\}$. So the monopolist's strategy is the following set of pairs; $\{(T, q_m^{ac}), (T, q_m^{ag}), (NT, q_m^{ac}), (NT, q_m^{ag})\}$.

Stage 3: The pirate makes his entry decision and chooses a quantity q_p .

Let the sets $\{(NT, q_m^{ac}), (NT, q_m^{ag})\}$ and $\{(T, q_m^{ac}), (T, q_m^{ag})\}$ denote the *no anti-copying investment subgame* (*NT-subgame*) and the *anti-copying investment subgame* (*T-subgame*). Let q_m^i (q_{ma}^i), π_m^i (π_{ma}^i), π_p^i (π_{pa}^i), and CS^i (CS_a^i), $i \in \{ac, ag\}$, denote the monopolist's output, the monopolist's expected profit, the pirate's expected profit, and consumer surplus for the *NT-subgame* (*T-subgame).* The social welfare function, defined as the surplus of all agents in the model, for the *NT* and *T* subgames are, $SW^i = \pi_m^i + \pi_p^i + CS^i + \alpha G - c(\alpha)$ and $SW_a^i = \pi_{ma}^i + \pi_{pa}^i + CS_a^i + \alpha G - c(\alpha)$.

3. The equilibrium analysis of the *NT* and the *T* subgames

In the *T-subgame* the monopolist chooses the profit maximizing level of *T* as well as the output strategy. I assume that the pirate enters only if he makes positive profit. If the pirate is detected, which occurs with probability α , then he cannot sell the copied product and the monopolist is the only player in the market. The rationale behind this assumption is that the store selling pirated products is raided prior to selling.[8] If the pirate is not detected which occurs with probability $(1-\alpha)$, then both the monopolist and the pirate exists in the market.

3.1. The *NT*-subgame

Table 1 summarizes the different events and the corresponding market demands, monopolist's and pirate's profits.

Table 1: Detection, Demand and Profits (*NT*-Subgame)

Events	Market Demand	Monopolist's Profit	Pirate's Profit
Pirate enters and is detected	$p = 4 - q_m$.	$4q_m - q_m^2$	$-G = -2$
Pirate do not enter	$p = 4 - q_m$.	$4q_m - q_m^2$	0
Pirate enters and is not detected	$p = 4 - q_m - q_p$	$4q_m - q_m^2 - q_m q_p$	$4q_p - q_p^2 - q_m q_p$

Using Table 1 I determine the monopolist's and pirate's expected profit functions as shown in equation (1).

$$\begin{aligned} \pi_m(q_m, q_f; \alpha) &= (1-\alpha)(4q_m - q_m^2 - q_m q_p) + \alpha(4q_m - q_m^2), \\ \pi_p(q_m, q_f; \alpha) &= (1-\alpha)(4q_p - q_p^2 - q_m q_p) - 2\alpha. \end{aligned} \quad (1)$$

In case of the *ac*-strategy the monopolist assumes that the pirate enters the market. So it is only the monitoring rate that may prevent the pirate's entry. The results are stated in Lemma 1 and the proof is given in the Appendix.

Lemma 1: *(i) The equilibrium ac-strategy is* $q_m^{ac*} = 2$. *The pirate's equilibrium output is* $q_p^{ac*} = 1$ *and he cannot enter if* $\alpha \geq \alpha_{\max} = \frac{1}{3}$. *(ii) The monopolist's profit is*

[8] According to the UK police, a factory raid has netted pirated video games, DVDs and CDs with a street value estimated at £1 million. 30,000 of the counterfeit discs were seized from the factory in West Midlands, and there was an estimated 10,000 each of DVDs, video games and audio CDs. Along with the discs, seven PCs were seized with 35 DVD re-writers, 19 HDDs, 15 **Xbox 360** consoles and two **Wii** consoles. "Multiple" modchips were also found.. This was reported on 9.03.2009 in http://www.afterdawn.com/news/archive/16302.cfm.

$\pi_m^{ac*}(\alpha) = \begin{cases} 2(1+\alpha), & \text{for } \alpha \in [0, \alpha_{\max}), \\ 4, & \text{for } \alpha \in [\alpha_{\max}, 1]. \end{cases}$. $\pi_m^{ac*}(\alpha)$ is *linearly increasing in* α *for* $\alpha \in [0, \alpha_{max})$ *and the monopoly outcome is restored for* $\alpha \geq \alpha_{\max}$.

Table 2 lists the realised payoffs of the monopolist, the pirate and the regulator, and the consumer surplus for the different events.

Table 2: Events and Realized Equilibrium Payoffs (*NT-Subgame*)

Events / **Realized Equilibrium Payoffs**	Pirate is detected. (Probability α)	Pirate is not detected. (Probability $(1-\alpha)$)
Monopolist's Profit	4	2
Pirate's Profit	-2	1
Consumer Surplus	2	4.5
Regulator's Revenue	$2-\frac{\alpha^2}{2}$	$-\frac{\alpha^2}{2}$
Social Welfare	$6-\frac{\alpha^2}{2}$	$7.5-\frac{\alpha^2}{2}$

Using Table 2 I determine the social welfare function which is given in equation (2).

$$SW^{ac}(\alpha) = \begin{cases} \dfrac{15-3\alpha-\alpha^2}{2}, & \text{for } \alpha < \alpha_{max} \\ 6-\dfrac{\alpha^2}{2}, & \text{for } \alpha \geq \alpha_{max}. \end{cases} \tag{2}$$

From Lemma 1 we know that the pirate cannot enter if $\alpha \geq \alpha_{\max} = \frac{1}{3}$. Hence, in this range of the monitoring rate the monopoly outcome prevails and the social welfare consists of the monopoly profit and the consumer surplus net of the monitoring cost. This explains the functional form of $SW^{ac}(\alpha)$ in the range $\alpha \geq \alpha_{\max} = \frac{1}{3}$.

In case of the *ag*-strategy the monopolist strategically deters the pirate's entry by choosing a limit output such that it is not profitable for the pirate to enter the market. The result is summarized in Lemma 2 and the proof is in the Appendix.

Lemma 2: *The equilibrium ag-strategy is* $q_m^{ag*}(\alpha) = \begin{cases} 4 - 2\sqrt{\dfrac{2\alpha}{1-\alpha}}, & \text{for } \alpha \le \alpha_{max}, \\ 2, & \text{for } \alpha \ge \alpha_{max}. \end{cases}$.

The monopolist's profit is. $\pi_m^{ag*}(\alpha) = \begin{cases} \left(4 - 2\sqrt{\dfrac{2\alpha}{1-\alpha}}\right) 2\sqrt{\dfrac{2\alpha}{1-\alpha}}, & \text{for } \alpha \le \alpha_{max} \\ 4, & \text{for } \alpha \ge \alpha_{max} \end{cases}$.

$\pi_m^{ag*}(\alpha) = (4 - q_m^{ag*})q_m^{ag*}$, *for* $\alpha \in [0, \alpha_{max}]$ *is increasing and concave in* α *and the monopoly outcome is restored for* $\alpha \ge \alpha_{\max}$.

The social welfare function for the equilibrium *ag*-strategy is as follows.

$$SW^{ag}(\alpha) = \begin{cases} 4\left(4 - 2\sqrt{\dfrac{2\alpha}{1-\alpha}}\right) - \dfrac{1}{2}\left(4 - 2\sqrt{\dfrac{2\alpha}{1-\alpha}}\right)^2 - \dfrac{\alpha^2}{2}, & \text{for } \alpha \in [0, \alpha_{\max}], \\ 6 - \dfrac{\alpha^2}{2}, & \text{for } \alpha \in [\alpha_{\max}, 1]. \end{cases} \tag{3}$$

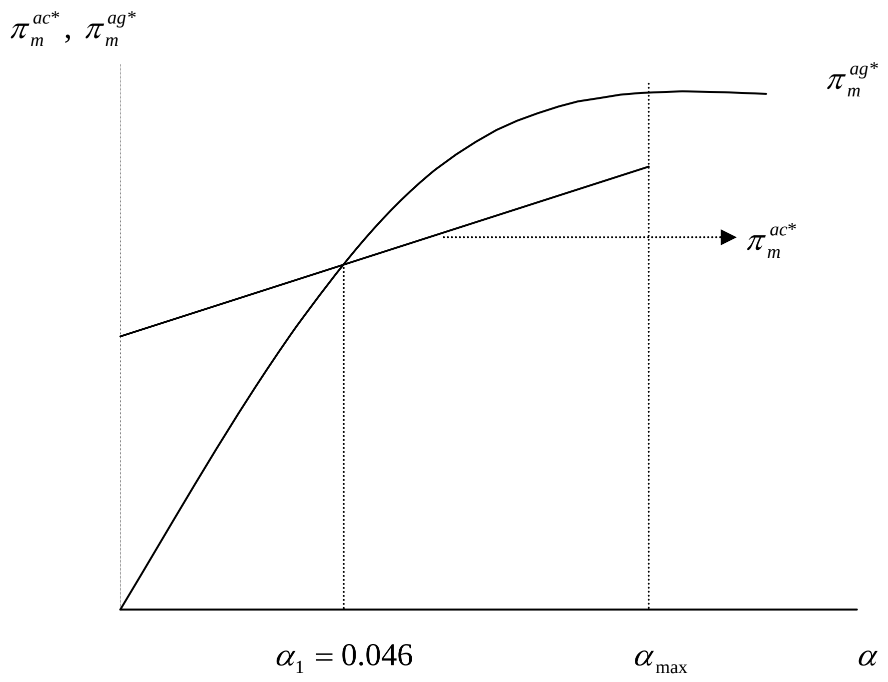
Observe that $SW^{ag}(\alpha)$ is the same as $SW^{ac}(\alpha)$ in the range $\alpha \ge \alpha_{\max} = \dfrac{1}{3}$ since the monopoly outcome is restored in this range of the monitoring rate for both *ac* and *ag* strategies.

Let us compare the properties of $\pi_m^{ac*}(\alpha)$ and $\pi_m^{ag*}(\alpha)$ with respect to α. This is summarised in Lemma 3 and diagrammatically shown in Figure 1. The proof is given in the Appendix.

Lemma 3: *In the range* $\alpha \in [0, \alpha_{\max})$, $\pi_m^{ac*}(\alpha) = \pi_m^{ag*}(\alpha)$ *at* $\alpha_1 = 0.046$. *In the range* $\alpha \in [\alpha_{\max}, 1]$ $\pi_m^{ac*}(\alpha) = \pi_m^{ag*}(\alpha) = \pi_m^*$ *and the monopoly outcome is restored.* $\pi_m^{ac*}(\alpha)$

dominates $\pi_m^{ag*}(\alpha)$ *in the range* $\alpha \in [0, \alpha_1)$ *and* $\pi_m^{ag*}(\alpha)$ *weakly dominates* $\pi_m^{ac*}(\alpha)$ *in the range* $\alpha \in [\alpha_1, \alpha_{\max}]$.

Figure 1: Comparative static analysis of $\pi_m^{ac*}(\alpha)$ **and** $\pi_m^{ag*}(\alpha)$ **for *NT-subgame***



Lemma 3 shows that the single crossing property between $\pi_m^{ac*}(\alpha)$ and $\pi_m^{ag*}(\alpha)$ is satisfied in the interval $\alpha \in [0, \alpha_{\max})$. It implies that in the intervals $\alpha \in [0, \alpha_1)$ and $\alpha \in [\alpha_1, \alpha_{\max}]$ the *ac* and the *ag* strategies are dominant and weakly dominant. Hence, $SW^{ac}(\alpha)$ and $SW^{ag}(\alpha)$ are the relevant social welfare functions in the ranges $\alpha \in [0, \alpha_1)$ and $\alpha \in [\alpha_1, \alpha_{\max}]$. This is used to determine the equilibrium monitoring rate for the *NT*-subgame which is summarized in Proposition 1.

Proposition 1: $\alpha^* = \alpha^{ag*} = \alpha_1 = 0.046$ *is the unique equilibrium monitoring rate in the NT-subgame. The ag-strategy is the equilibrium and piracy is deterred.*

Proposition 1 can be proved as followed. In the range $0 \le \alpha \le \alpha_1$, $SW^{ac}(\alpha)$ is decreasing in α because $SW^{ac\,\prime}(\alpha) = \dfrac{-3-2\alpha}{2} < 0$. Hence, $\alpha^{ac*} = 0$ maximizes

$SW^{ac}(\alpha)$. For $\alpha^{ac*} = 0$, $q_m^{ac*} = 2$, $q_p^{ac*} = 1$, equilibrium price is 1, $\pi_m^{ac*} = 2$, $\pi_p^{ac*} = 1$, $CS^{ac*} = 4.5$ and $SW^{ac*} = 7.5$.

In the range $\alpha_1 < \alpha \leq \alpha_{\max}$, $SW^{ag}(\alpha)$ is decreasing in α because $SW^{ag\prime}(\alpha) < 0$. Hence $\alpha^{ag*} = \alpha_1 = 0.046$ maximizes $SW^{ag}(\alpha)$. The equilibrium limit output at $\alpha^{ag*} = \alpha_1 = 0.046$ is $q_m^{ag*} = 3.379$. The equilibrium price is 0.621, $\pi_m^{ag*} = 2.098$, $CS^{ag*} = 5.7088$, and $SW^{ag*} = 7.8068 - \frac{0.046^2}{2} = 7.8057$. Therefore, $SW^{ag*} > SW^{ac*}$.

Intuitively, the cost of choosing $\alpha^{ag*} = \alpha_1 = 0.046$ is the monitoring cost that is absent in $SW^{ac}(\alpha)$ because $\alpha^{ac*} = 0$ and the pirate's profit which is absent in $SW^{ag}(\alpha)$ since the pirate cannot enter. The benefit is the higher consumer surplus because $q_m^{ag*} = 3.379 > q_m^{ac*} + q_p^{ac*} = 3$ and higher monopolist's profit because $\pi_m^{ag*} = 2.098 > \pi_m^{ac*} = 2$. The benefit outweighs the cost resulting in $\alpha^{ag*} = \alpha_1 = 0.046$ as the equilibrium monitoring rate in the *NT-subgame*.

3.2. The T-subgame

In this section anti-copying investment is introduced. The probability function $H(T)$ is assumed to be increasing in *T*, that is, $H'(T) > 0$. The second order conditions require $H''(T) < 0$. For computational simplicity I assume $H(T) = \sqrt{T}$. At $T = 0$, $H(T) = 0$, that is copying always takes place and at $T = 1$, $H(T) = 1$ which implies that copying is prevented with certainty. Equation (4) states the possible events and the corresponding probabilities and Table 3 summarizes the market demand, the monopolist's and the pirate's profits for each of these events.

$$\begin{aligned}&\textit{Probability that the pirate copies and is detected} = \alpha(1-H(T)),\\&\textit{Probability that the pirate copies and is not detected} = (1-\alpha)(1-H(T)),\\&\textit{Probability that the pirate cannot copy} = H(T).\end{aligned} \tag{4}$$

Table 3: Copying, Detection, Demand and Profits (*T-Subgame*)

Events	Market Demand	Monopolist's Profit	Pirate's Profit
Pirate copies and is detected.	$p = 4 - q_m$.	$4q_m - q_m^2 - T$	$-G$
Pirate cannot copy.	$p = 4 - q_m$.	$4q_m - q_m^2 - T$	0
Pirate copies and is not detected.	$p = 4 - q_m - q_p$	$4q_m - q_m^2 - q_m q_p - T$	$4q_p - q_p^2 - q_m q_p$

Using Table 3 I determine the monopolist's and pirate's expected profit functions as, shown in equation (5).

$$\begin{aligned}\pi_{ma}(q_m, q_p, T, \alpha) &= (1-\alpha)(1-H(T))(4q_m - q_m^2 - q_m q_p - T)\\&\quad + (H(T) + \alpha(1-H(T)))(4q_m - q_m^2 - T),\\\pi_{pa}(q_m, q_p, T, \alpha) &= (1-H(T))((1-\alpha)(4q_p - q_p^2 - q_m q_p) - \alpha G).\end{aligned} \tag{5}$$

The pirate's reaction function remains as $q_p = \dfrac{4-q_m}{2}$ because he can enter only if he can copy which occurs with probability $(1-H(T))$. The results for the equilibrium *ac*-strategy is summarised in Lemma 4 and the proof is given in the Appendix. Table 4 summarizes the events and the equilibrium realized payoffs.

Lemma 4: *(i) The equilibrium ac-strategy is* $q_{ma}^{ac*} = 2$. *The pirate's output is* $q_{pa}^{ac*} = 1$ *and he cannot enter if* $\alpha \geq \alpha_{\max} = \dfrac{1}{3}$. *(ii) The equilibrium anti-copying investment is* $T^{ac*} = \begin{cases}(1-\alpha)^2, \textit{if } 0 \leq \alpha < \alpha_{max},\\ 0, \quad \textit{if } \alpha \geq \alpha_{max}.\end{cases}$ $T^{ac*} = (1-\alpha)^2$ *is decreasing in the monitoring rate till* $\alpha < \alpha_{\max} = \dfrac{1}{3}$. *Copying is prevented with certainty at* $\alpha = 0$ *when* $T^{ac*} = 1$.

(iii) The monopolist's profit is $\pi_{ma}^{ac*}(\alpha) = \begin{cases} 3+\alpha^2, & if\ 0 \le \alpha < \alpha_{max}, \\ 4, & if\ \ \alpha \ge \alpha_{max}. \end{cases}$ $\pi_{m}^{ac*}(\alpha)$ *is increasing in* α *for* $\alpha < \alpha_{\max}$ *and the monopoly outcome is restored for* $\alpha \ge \alpha_{\max}$.

Table 4: Events and Realized Equilibrium Payoffs (*T-Subgame*)

Events / Realized Equilibrium Payoffs	Pirate cannot copy. (Probability $H(T^{ac*})$)	Pirate copies and is detected. (Probability $\alpha(1-H(T^{ac*}))$)	Pirate copies and is not detected. (Probability $(1-\alpha)(1-H(T^{ac*}))$)
π_{ma}^{ac*}	$4-T^{ac*}$	$4-T^{ac*}$	$2-T^{ac*}$
π_{pa}^{ac*}	0	-2	1
Consumer Surplus	2	2	4.5
Regulator's Revenue	$-\frac{\alpha^2}{2}$	$2-\frac{\alpha^2}{2}$	$-\frac{\alpha^2}{2}$
Social Welfare	$6-\frac{\alpha^2}{2}-T^{ac*}$	$6-\frac{\alpha^2}{2}-T^{ac*}$	$7.5-\frac{\alpha^2}{2}-T^{ac*}$

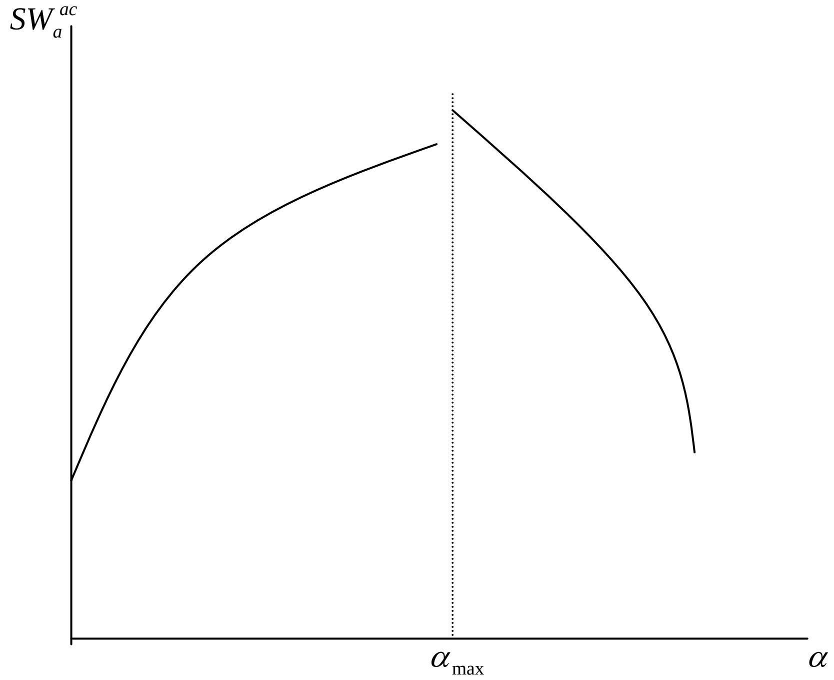
Table 4 is used to derive the social welfare function for the equilibrium *ac*-strategy as given in equation (6).

$$SW_a^{ac}(\alpha) = \begin{cases} 5+3.5\alpha-3\alpha^2, & for\ \alpha < \alpha_{max}, \\ 6-\frac{\alpha^2}{2}, & for\ \alpha \ge \alpha_{max}. \end{cases} \tag{6}$$

Since the monopoly results are restored for $\alpha \ge \alpha_{\max}$ the social welfare function in this range of the monitoring rate is the sum of the monopoly profit and the consumer surplus net of the monitoring cost. Lemma 5 states some of the important properties of $SW_a^{ac}(\alpha)$ which is diagrammatically represented in Figure 2 and the proof is in the Appendix.

Lemma 5: $SW_a^{ac}(\alpha)$ *is increasing and concave in* α *for* $\alpha < \alpha_{\max} = \frac{1}{3}$ *and decreasing in* α *for* $\alpha \ge \alpha_{\max} = \frac{1}{3}$. $\alpha_a^{ac*} = \alpha_{\max}$ *maximizes* $SW_a^{ac}(\alpha)$.

Figure 2: Properties of the SW function for the ac-strategy in the T-subgame



The equilibrium *ag-strategy* is the same as that in the *NT-subgame* analysed in Section 3.1. This is because the monopolist deters the pirate's entry using the limit output strategy; hence, it is not optimal to make any further anti-copying investment to prevent copying. Therefore, the equilibrium anti-copying investment is zero, that is $T^{ag*} = 0$. So the result is identical to that stated in Lemma 2 and the social welfare function, SW_a^{ag}, is identical to SW^{ag} as given in equation (3) which is decreasing in the monitoring rate.

Figure 3 represents the comparison of the comparative static analysis of π_{ma}^{ac*} and π_{ma}^{ag*} with respect to α. This will be used to determine the equilibrium monitoring rate for the *T-subgame*. Equating $\pi_{ma}^{ac*}(\alpha) = \pi_{ma}^{ag*}(\alpha)$ yields $\alpha_2 = 0.112364$.

Figure 3: Comparative static analysis of monopolist's profit for the T- subgame

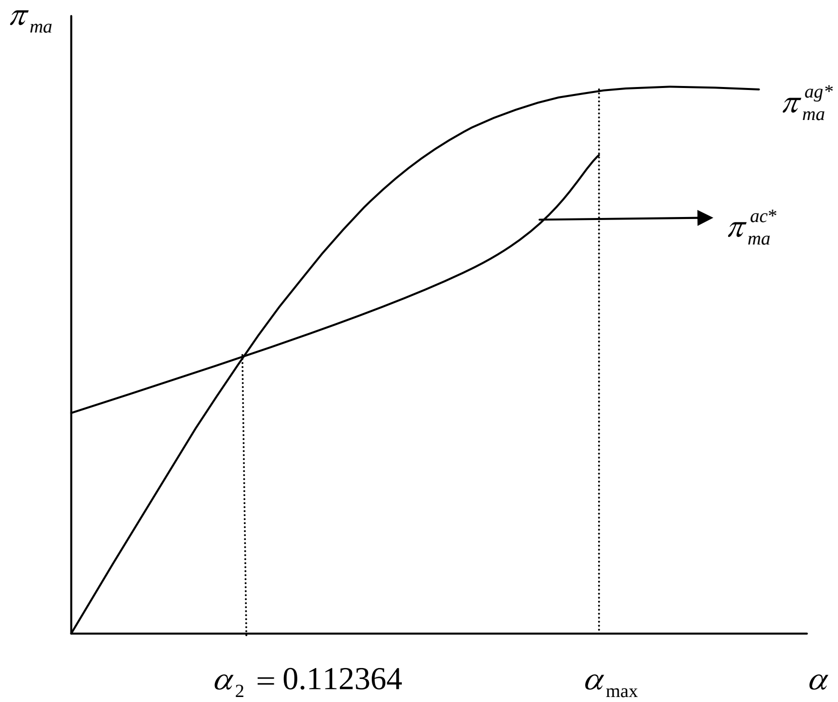


Figure 3 shows that for $\alpha < \alpha_2$ the *ac*-strategy dominates the *ag*-strategy because in this range of the monitoring rate $\pi_{ma}^{ac*} > \pi_{ma}^{ag*}$. So from equation (5) we get $SW_a^{ac}(\alpha) = 5 + 3.5\alpha - 3\alpha^2$ as the relevant social welfare function in the range $\alpha < \alpha_2$. From Lemma 5 we know that this social welfare function is increasing in the monitoring rate. Hence, $\alpha_a^{ac*} \cong \alpha_2 = 0.112364$.

For $\alpha \geq \alpha_2$ the *ag*-strategy weakly dominates the *ac*-strategy because $\pi_{ma}^{ac*} \leq \pi_{ma}^{ag*}$. So for $\alpha \geq \alpha_2$, SW_a^{ag} is the relevant social welfare function which is decreasing in the monitoring rate. Therefore, $\alpha_a^{ag*} = \alpha_2 = 0.112364$.

Let α_a^* be the equilibrium monitoring rate for the *T*-subgame. The results are summarized in Proposition 2 and the proof is given in the appendix.

Proposition 2: $\alpha_a^* = \alpha_a^{ag*} = \alpha_2 = 0.112364$ *is the equilibrium monitoring rate in the T-subgame. The ag-strategy is the equilibrium in this subgame, hence piracy is deterred and there is no anti-copying investment in equilibrium.*

The upward sloping property of $SW_a^{ac}(\alpha)$ with respect to α is the driving force behind this result. A change in the monitoring rate has a direct effect on $SW_a^{ac}(\alpha)$ and an indirect effect via the anti-copying investment which in equilibrium is inversely related to the monitoring rate. We explain the upward sloping property of $SW_a^{ac}(\alpha)$ by explaining the direct and the indirect effects on the various components of the social welfare function.

One, an increase in the monitoring rate reduces the possibility of the pirate's entry thereby reducing the consumer surplus since the total output shrinks. However, the corresponding decrease in the equilibrium anti-copying investment increases the possibility of copying thereby raising the consumer surplus. Since $CS_a^{ac\prime}(\alpha) = 2.5\alpha - 2.5\alpha^2 > 0,\ for\ \alpha < \alpha_{max}$ it implies that the indirect effect dominates the direct effect on consumer surplus. Hence, consumer surplus is increasing in the monitoring rate.

Two, an increase in the monitoring rate reduces the likelihood of pirate's entry thereby increasing the monopolist's equilibrium profit. An increase in the monitoring rate reduces the monopolist's equilibrium anti-copying investment which further increases the monopolist's profit.

Three, starting from a zero monitoring situation in which case the optimal anti-copying investment prevents copying with certainty, because $T^{ac*} = (1-\alpha)^2$, an increase in the monitoring rate initially increases the pirate's profit because it increases the possibility of copying. But beyond the critical level, $\alpha = \frac{1}{6}$ (which we get by differentiating $\pi_{pa}^{ac*}(\alpha) = \alpha(1-3\alpha)$ with respect to α and equating it to 0), the pirate's profit is decreasing in the monitoring rate because the chances of getting detected increases which outweighs the gain from the increased possibility of copying.

The positive overall effect of an increase in the monitoring rate dominates the negative effect which occurs only via the pirate's profit in the range $\frac{1}{3} \geq \alpha \geq \frac{1}{6}$ resulting in an upward sloping $SW_a^{ac}(\alpha)$. Thus $\alpha_a^{ac*} = \alpha_{\max}$ maximizes $SW_a^{ac}(\alpha)$. Banerjee et.al. (2008) assumes that $SW_a^{ac}(\alpha)$ is such that $\alpha_a^{ac*} \in [0, \alpha_2)$ and avoids the possibility that $SW_a^{ac}(\alpha)$ can be upward sloping. This explains the difference in the results.

Now $SW_a^{ac}(\alpha_a^{ac*} = \alpha_{\max}) = SW_a^{ag}(\alpha_{\max})$ because

$SW_a^{ac}(\alpha) = SW_a^{ag}(\alpha) = 6 - \frac{\alpha^2}{2}$ for $\alpha \geq \alpha_{\max}$ as seen from equations (3) and (6).

Since SW_a^{ag} is decreasing in the monitoring rate, hence,

$SW_a^{ag}(\ \alpha_a^{ag*} = 0.112364) > SW_a^{ac}(\alpha_a^{ac*} = \alpha_{\max}) = SW_a^{ag}(\alpha_{\max})$. Therefore,

$\alpha_a^{ag*} = 0.112364$ is the equilibrium monitoring rate in the *T-subgame*.

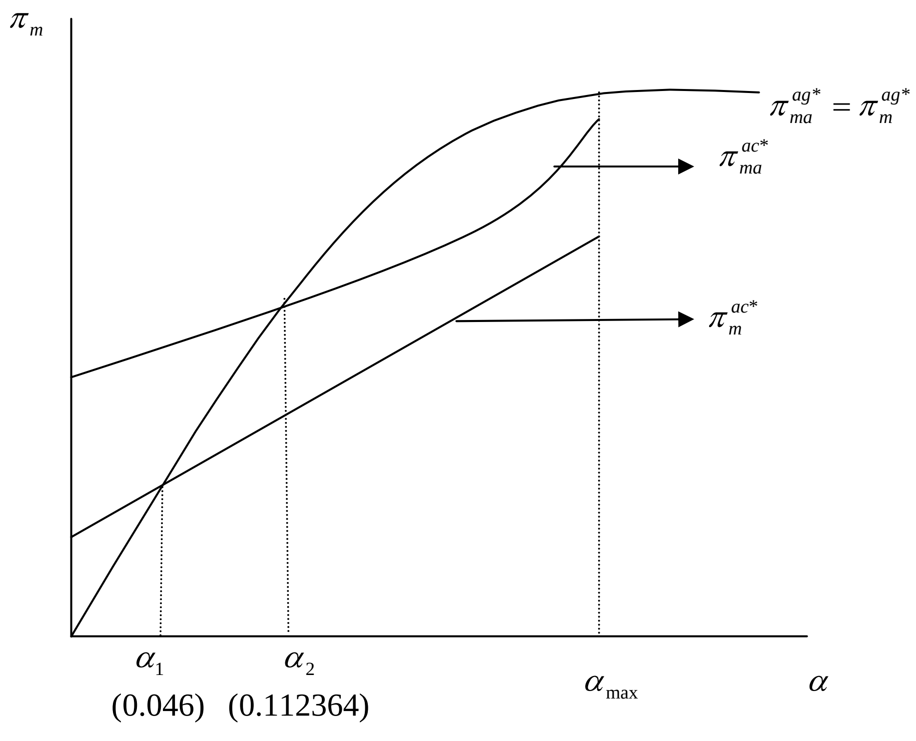
4. Is there a need for anti-copying investment?

Propositions 1 and 2 show that the equilibrium monitoring rates in the *NT* and *T-subgames*, are $\alpha^* = \alpha^{ag*} = \alpha_1 = 0.046$ and $\alpha_a^* = \alpha_a^{ag*} = \alpha_2 = 0.112364$. In both cases piracy is deterred in equilibrium because the *ag*-strategy is the equilibrium. The result for the socially optimal monitoring rate is summarized in Proposition 3 and the proof is discussed in the main text.

Proposition 3: $\alpha_a^* = \alpha_a^{ag*} = \alpha_2 = 0.112364$ *is the socially optimal monitoring rate and piracy is deterred in equilibrium because the ag-strategy is the subgame perfect equilibrium. There is no anti-copying investment in equilibrium.*

The proof follows from the properties of $\pi_m^{ac*}(\alpha) = 2(1+\alpha)$ and $\pi_{ma}^{ac*}(\alpha) = 3+\alpha^2$. The former is steeper and has a smaller intercept than the latter and the two intersects at $\alpha = 1$ which is outside the range of α for which these two profit functions hold, which is, $\alpha \in \left[0, \alpha_{\max} = \frac{1}{3}\right)$. Thus in this range of the monitoring rate $\pi_{ma}^{ac*}(\alpha) = 3+\alpha^2$ is higher than $\pi_m^{ac*}(\alpha) = 2(1+\alpha)$. This is diagrammatically represented in Figure 4 which is a combination of the Figures 1 and 3.

Figure 4: Comparison of π_m^{ac*}, π_{ma}^{ac*} and $\pi_{ma}^{ag*} = \pi_m^{ag*}$.



From Figure 4 we see that π_{ma}^{ac*} dominates π_{m}^{ac*} in the range $\alpha \in \left[0, \alpha_{\max} = \frac{1}{3}\right)$.

That is, the introduction of the anti-copying investment allows the monopolist to enjoy a higher profit level for each monitoring rate compared to the no anti-copying investment situation. This is because in the former case the likelihood of pirate's entry is lower compared to the latter because both monitoring and anti-copying investment are there to prevent piracy. Consequently, the intersection between π_{ma}^{ac*} and $\pi_{ma}^{ag*} = \pi_{m}^{ag*}$ is at a higher monitoring rate than that between π_{m}^{ac*} and $\pi_{ma}^{ag*} = \pi_{m}^{ag*}$.

Hence the choice is between $\alpha^{ag*} = \alpha_1 = 0.046$ and $\alpha_a^{ag*} = \alpha_2 = 0.112364$. If the regulator chooses $\alpha^* = \alpha^{ag*} = \alpha_1 = 0.046$ then from Figure 4 we see that the monopolist will choose the strategy (T, q_m^{ac}) because at $\alpha_1 = 0.046$ $\pi_{ma}^{ac*} > \pi_{ma}^{ag*} = \pi_{m}^{ag*}$. If the regulator chooses $\alpha_a^* = \alpha_a^{ag*} = \alpha_2 = 0.112364$ then from Figure 4 we see that the *ag*-strategy weakly dominates the strategy (T, q_m^{ac}) and $\alpha_a^* = \alpha_a^{ag*} = \alpha_2 = 0.112364$ maximizes $SW_a^{ag}(\alpha)$. Hence, it is socially optimal. There is no anti-copying investment in equilibrium because the *ag*-strategy is the subgame perfect equilibrium and piracy is deterred.

4.1. Social welfare analysis with a general monitoring cost function

There are two direct costs involved in the anti-piracy measures. One is the monitoring cost to the regulator and the other is the monopolist's investment in anti-copying technology. So to understand how does the monitoring cost relative to the anti-copying investment matters in driving the result mentioned in Proposition 3 let us consider a monitoring cost of the form $c(\alpha) = x\alpha^2, x > 0$.

The social welfare functions for the *ac* and *ag* strategies in the *NT-subgame* are,

$$SW^{ac}(x,\alpha) = 7.5 - 1.5\alpha - x\alpha^2,$$
$$SW^{ag}(x,\alpha) = 4\left(4 - 2\sqrt{\frac{2\alpha}{1-\alpha}}\right) - \frac{1}{2}\left(4 - 2\sqrt{\frac{2\alpha}{1-\alpha}}\right)^2 - x\alpha^2. \quad (7)$$

Both social welfare functions are decreasing in the monitoring rate hence $\alpha^{ac*} = 0$ and $\alpha^{ag*} = 0.046$. The maximum values of the social welfare functions are,

$$SW^{ac}(x; \alpha^{ac*} = 0) = 7.5$$
$$SW^{ag}(x; \alpha^{ag*} = 0.046) = 7.95178198 - 0.002116\,x \quad (8)$$

Now $SW^{ac}(x; \alpha^{ac*} = 0) \leq SW^{ag}(x; \alpha^{ag*} = 0.046)$ if $x \leq 213.5075519$.

Let us now consider the *T-subgame*. The social welfare functions for the *ac* and *ag* strategies are,

$$SW_a^{ac}(x,\alpha) = 5 + 3.5\alpha - (2.5 + x)\alpha^2,$$
$$SW_a^{ag}(x,\alpha) = 4\left(4 - 2\sqrt{\frac{2\alpha}{1-\alpha}}\right) - \frac{1}{2}\left(4 - 2\sqrt{\frac{2\alpha}{1-\alpha}}\right)^2 - x\alpha^2. \quad (9)$$

$SW_a^{ag}(\alpha)$ remains decreasing in α, hence, $\alpha_a^{ag*} = \alpha_2 = 0.112364$. Therefore,

$$SW_a^{ag}(x; \alpha_a^{ag*} = 0.112364) = 7.873412 - 0.012626\,x. \quad (10)$$

This is linearly decreasing in *x* with $SW_a^{ag}(x = 0; \alpha_a^{ag*} = 0.112364) = 7.873412$ and $SW_a^{ag}(x = 623.58720; \alpha_a^{ag*} = 0.112364) = 0$.

Solving $SW_a^{ac\,\prime}(x; \alpha_a^{ac}) = 0$ yields $\alpha_a^{ac*} = \frac{3.5}{5+2x}$. The condition $\alpha_a^{ac*} = \frac{3.5}{5+2x} < \alpha_{\max} = \frac{1}{3}$ holds if *x* satisfies the inequality $x > 2.75$. The relevance of this condition is the fact that $SW_a^{ac}(x,\alpha) = 5 + 3.5\alpha - (2.5 + x)\alpha^2$ is defined for $\alpha < \alpha_{\max} = \frac{1}{3}$. The value of $SW_a^{ac}(x,\alpha)$ at $\alpha_a^{ac*} = \frac{3.5}{5+2x}$ is

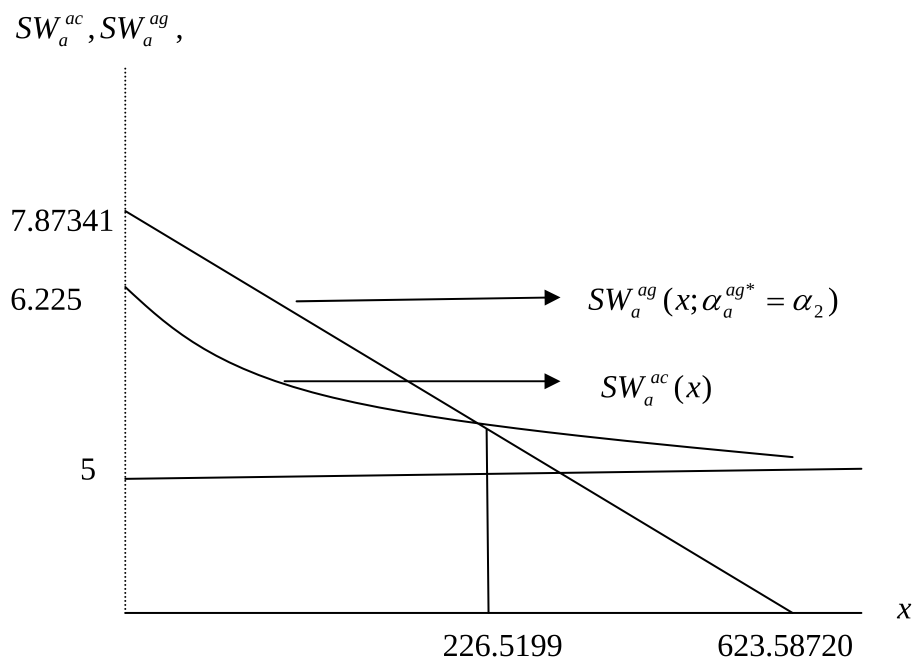
$$SW_a^{ac}(x;\alpha_a^{ac*}) = 5 + \frac{12.25}{2(5+2x)}. \tag{11}$$

$SW_a^{ac}(x;\alpha_a^{ac*})$ is decreasing in *x*, $SW_a^{ac}(x=0) = 6.225$, and

$Limit\ x \to \infty, SW_a^{ac}(x) \to 5$.

Equating $SW_a^{ac}(x;\alpha_a^{ac*})$ as given in equation (11) to $SW_a^{ag}(x;\alpha_a^{ag*})$ in equation (10) yields $x = 226.5199$. In Figure 5 we provide a diagrammatic representation of the properties of $SW_a^{ag}(x;\alpha_a^{ag*} = 0.112364)$ and $SW_a^{ac}(x;\alpha_a^{ac*})$.

Figure 5: SW functions with alternative cost functions for the T-subgame



From the above analysis we observe that there are three ranges of *x*. Since *x* is a cost parameter these ranges are defined in terms of monitoring cost as follows:

(i) $x \leq 213.5075519$ is defined as the "*low monitoring cost*" range;

(ii) $213.5075519 < x \leq 226.5199$ is defined as "*moderate monitoring cost*" range;

(iii) $x > 226.5199$ is defined as "*high monitoring cost*" range.

Lemma 6 summarizes the relationship between the equilibrium monitoring rates and *x* in the *NT* and *T* subgames. This will be used to determine the socially optimal monitoring rate and the subgame perfect equilibrium for the different ranges of *x*. The proof of Lemma 6 is given in the Appendix.

Lemma 6: *(ia) In the NT-subgame,* $\alpha^{ac*} = 0$ *is the equilibrium monitoring rate if* $x > 213.5075519$ *resulting in the ac-strategy as the equilibrium and there is piracy.*

(ib) If $x \leq 213.5075519$ *,* $\alpha^{ag*} = 0.046$ *is the equilibrium monitoring rate in the NT-subgame resulting in the ag-strategy as the equilibrium and there is no piracy.*

(iia) In the T-subgame $\alpha_a^{ac*} = \frac{3.5}{5 + 2x}$ *is the equilibrium monitoring rate, if* $x > 226.5199$ *resulting in the ac-strategy as the equilibrium with positive anti-copying investment which cannot prevent copying with certainty.*

(iib) If $x \leq 226.5199$ *then* $\alpha_a^{ag*} = 0.112364$ *is the equilibrium monitoring rate in the T-subgame resulting in the ag-strategy as the equilibrium. There is no anti-copying investment and no piracy in equilibrium.*

Lemma 6 allows us to list the equilibrium monitoring rates and the corresponding equilibrium output strategy for the *NT* and *T* subgames for the different monitoring cost ranges. This is given in Table 5.

Table 5: Monitoring cost ranges, equilibrium monitoring rates and strategies

Monitoring cost ranges	***NT-subgame***		***T-subgame***	
	Equilibrium Monitoring Rate	Equilibrium Output Strategy	Equilibrium Monitoring Rate	Equilibrium Output Strategy
Low monitoring cost range	$\alpha^{ag*} = 0.046$	*ag*-strategy	$\alpha_a^{ag*} = 0.112364$	*ag*-strategy
Moderate monitoring cost range	$\alpha^{ac*} = 0$	*ac*-strategy	$\alpha_a^{ag*} = 0.112364$	*ac*-strategy
High monitoring cost range	$\alpha^{ac*} = 0$	*ac*-strategy	$\alpha_a^{ac*} = \dfrac{3.5}{5+2x}$	*ac*-strategy

We now use Table 5 to determine the socially optimal monitoring rates for the different monitoring cost ranges. The result is summarized in Proposition 4. We discuss the proof in the main text because it is instructive.

Proposition 4: *(i) In the low and moderate monitoring cost ranges* $\alpha_a^* = \alpha_a^{ag*} = \alpha_2 = 0.112364$ *is the socially optimal monitoring rate. The ag-strategy is the subgame perfect equilibrium. There is no anti-copying investment in equilibrium and piracy is deterred.*

(ii) In the high monitoring cost range $\alpha_a^{ac*} = \dfrac{3.5}{5+2x}$ *is the socially optimal monitoring rate. The ac-strategy with* $T^{ac*} = 1 - \alpha_a^{ac*}$ *is the subgame perfect equilibrium. There is positive anti-copying investment in equilibrium but prevention of copying and piracy are not guaranteed.*

The proof for the low and moderate monitoring cost ranges is the same as Proposition 3. Let us discuss the proof for the high monitoring cost range. In this case the choice is between $\alpha^{ac*} = 0$ and $\alpha_a^{ac*} = \dfrac{3.5}{5+2x}$ as seen from Table 5. Suppose the regulator chooses $\alpha^{ac*} = 0$. Then from Figure 4 we observe that the monopolist will choose the *ac*-strategy with anti-copying investment where $T^{ac*} = 1$. This will prevent copying with certainty and restore the monopoly outcome net of the anti-copying investment, $T^{ac*} = 1$. However, $\alpha_a^{ac*} = \frac{3.5}{5+2x}$ is the equilibrium monitoring rate for the *T*-subgame. Hence, $\alpha_a^{ac*} = \frac{3.5}{5+2x}$ is the socially optimal monitoring rate.

Since, the socially optimal monitoring rate is $\alpha_a^{ac*} = \frac{3.5}{5+2x}$, there is no finite *x* for which $\alpha_a^{ac*} = 0$. This implies that $T^{ac*} = 1-\alpha_a^{ac*} < 1$ that is, the optimal anti-copying investment cannot prevent copying with certainty.

Thus the analysis with a general monitoring cost function shows that “very” high anti-copying investment and low monitoring rate is the equilibrium only when the monitoring cost is sufficiently high. In other cases regulatory enforcement through monitoring succeeds in preventing piracy with no anti-copying investment in equilibrium.

5. Discussion on empirical research

In this section I provide some discussion on possible empirical research on the relationship between piracy, regulatory enforcement and technology adoption for protection against software piracy. I suggest an outline of an empirical model and discuss some issues regarding data on regulatory enforcement and technology adoption.

This paper brings together regulatory (legal) enforcement and technology adoption by a firm as anti-piracy measures. The theory suggests that piracy (*PR*) depends on the price of the legitimate software (p_m), level of investment on anti-copying technology (*T*), the level of regulatory enforcement *Z* (which is the same as the monitoring rate α in the theoretical model) and other variables represented by the vector X_1 to be discussed later in this section. However, the price and the anti-copying investment depend on the level of regulatory enforcement. Hence, the specification of an empirical model following the theory analysed in the previous sections may take the following form.

$$PR = f(p_m(Z), T(Z), Z, X) \quad (12)$$

The model outlined in equation (12) requires estimation of $p_m = p_m(Z)$ and $T = T(Z)$ along with the estimation of equation (12). So the system of equations that needs to be estimated are,

$$\begin{aligned} PR &= \beta_0 + \beta_1 p_m + \beta_2 T + \beta_3 Z + \beta_4 X_1 + \varepsilon, \\ p_m &= \gamma_0 + \gamma_1 Z + \gamma_2 X_2 + \eta, \\ T &= \delta_0 + \delta_1 Z + \delta_2 X_3 + \mu. \end{aligned} \quad (13)$$

X_2 and X_3 are vectors of exogenous variables affecting p_m and *T*.

From the theoretical analysis in the previous sections we know that the price and the anti-copying investment are positively and inversely related to the monitoring rate captured by the regulatory enforcement variable (Z). So the hypotheses to be tested following these theoretical results can be as follows.

Hypothesis 1: Price of software is positively related to the regulatory enforcement variable *Z*, that is, $H_O : \gamma_1 > 0$.

Hypothesis 2: Level of adoption of technology for protection against piracy is negatively related to the level of regulatory enforcement *Z*, that is, $H_O : \delta_1 < 0$.

The regulatory enforcement variable Z has a direct effect on piracy and indirect effects via the price and the technology variables. The reduced form of the system of equations in (13) is,

$$\begin{aligned} PR &= (\beta_0 + \beta_1\gamma_0 + \beta_2\delta_0) + (\beta_1\gamma_1 + \beta_2\delta_1 + \beta_3)Z + \beta_4 X_1 + \beta_1\gamma_2 X_2 \\ &\quad + \beta_2\delta_2 X_3 + (\beta_1\eta + \beta_2\mu + \varepsilon) \\ &= \phi_0 + \phi_1 Z + \phi_2 X_1 + \phi_3 X_2 + \phi_4 X_3 + \omega. \end{aligned} \tag{14}$$

So the hypotheses to be tested following the theoretical results from Proposition 3 can be as follows.

Hypothesis 3: Regulatory enforcement has a significant negative effect on piracy, that is, $H_O : \phi_1 < 0.$

The existing empirical literature, which is relatively few, addresses the effect of legal variables on piracy and the effect of technology adoption on piracy separately. That is, one strand of literature analyses the effectiveness of legal variables in countering piracy and the other strand only considers the impact of technology adoption on piracy. To the best of our knowledge there is no empirical research that jointly addresses the two issues. Such an analysis requires information on regulatory enforcement at the country level and firm level data on investment in anti-copying technology adoption.

Let us begin with a possible data analysis on regulatory enforcement. A suitable proxy for regulatory enforcement is the strength of a country's Intellectual Property Right (IPR) that requires creation of an index. In a recent paper Andrés (2006) constructs an index measuring the IPR strength based on *membership in international treaties* and *enforcement provisions*.

Membership in international treaties reflects a country's degree of toleration of the violation of IPR and it includes; (i) the Berne convention for the protection of artistic and literary works (1886), (ii) the World Intellectual Property Organization Copyright Treaty (WIPO,1996), (iii) the Agreement on Trade-Related Aspects of Intellectual Property Rights (Trips, 1994). The *enforcement provisions* category encompasses the dual task of prevention of infringement and prosecution of criminal offences. Hence, this category consists of the following provisions; (i) border measures, (ii) ex-parte civil search orders, and (iii) remedies.[9] One can also include Corruption Perception Index where the ranking follows a reverse order implying that a lower ranked country will mean that the regulatory structure is weakly enforced and there is non-compliance of law including the ones related IPR.

Most of the empirical literature seems to be mildly affirmative with respect to the impact of IPR protection on piracy. However, the studies vary significantly in terms of the countries studied, the period of analysis, measure of IPR protection, and sets of explanatory variables. Andrés (2006) shows that copyright software protection is significantly related to piracy. Park (2001) and Ronkainen et.al. (2001) suggests that a country's membership in any international convention may signal that its national law recognizes intellectual property right protection (IPR) and hence such membership may influence the level of the violation of IPR in such a country. Papadopoulos (2003) uses the same measurement for the strength of IPR protection but includes an index of property rights as a proxy for copyright enforcement and shows that piracy decreases with the strengthening of IPR protection. In the context of audio software industry Burke (1996) measures IPR strength by using membership in international treaties and duration of membership (e.g., Berne 1887, Rome 1961,

[9] For more on creating an index based on membership in international treaties and enforcement provisions see Andrés (2006). Border measures refer to acts where the copyright holder may file an application to customs to suspend entry of pirated goods. Ex-parte civil search orders refers to a legal search procedure conducted upon application by the copyright holder where the latter alleges an infringement of a right like TRIPs. Such searches can be conducted without prior notice filed a court. Remedies include legal measure like seizure and destruction of infringing copies, materials and equipment used for copying.

Geneva Phonogram 1971) and shows that there may be no association between IPR protection and piracy.

Let us now discuss the technology adoption aspect. Such a study requires firm level data on investment on technology adoption for protection against piracy. However, to the best of my knowledge such data is not available and hence data needs to be collected using a survey. Stolpe (2000) collected data on technology adoption from a survey of 1600 German software publishers of which 378 responded. He subdivided the data on the basis of the type of software and the export markets served. The types of software included operating systems, operating tools, standard applications, industry specific applications, individually tailored and other software. The export markets considered in the paper are German speaking countries, European Union, other Europe, US and Canada, Japan and other markets.[10]

Stolpe (2000) shows that the degree of adoption of technology protection by publishers depend on the type of the product. For example, industry specific business applications and software with a large network externality adopt hardware keys, which is the most secured form of protection. Another factor influencing technology adoption by publishers is the export of software to countries where protection strategies relying on registration requirements and legal action are difficult to implement. This finding is consistent with the theoretical results for the high monitoring cost range mentioned in Proposition 4 where there is low level of monitoring rate and a high level of anti-copying investment.

The vector X_1 in equation (13) may consist of variables like GDP, share of software production in GDP, share of software in trade, trade restrictions, Gini ratio to capture the effect of income inequality, and other socio-economic variables like civil

[10] See Stolpe (2000) for more on the methodology.

liberty and democracy. Piquero and Piquero (2006) suggest that more democratic countries including those with strong political and civil liberties have lower piracy rates.

Thus an empirical research on regulatory enforcement and technology adoption to prevent piracy requires a merger of the above mentioned two strands of the empirical literature on piracy. Alternatively, one can also use laboratory based experimental methodology which can be especially useful given the problem of the unavailability of data at the firm level on investment on technology to prevent piracy.

The experimental methodology can be designed as random groups of three players in the role of a regulator, a copyright holder and a pirate. There need to be two treatments, one with only regulatory enforcement and the other with regulatory enforcement and technology adoption. The reason for having the two treatments is to compare the level of regulatory enforcements in the two cases and whether the findings are consistent with the theory. Numbers for the experiment can be generated from the theoretical model presented in this paper.

The decision variable of the regulator can consist of a discrete set of monitoring rates and the corresponding level of social welfare. A random generator will decide whether the pirate is detected or not given a choice of the monitoring rate. The monopolist can choose whether to allow or deter the pirate's entry. In the treatment with technology adoption he will also have to choose the level of anti-copying investment based on which the random generator will decide whether copying is successful or not. In each of the two treatments the pirate's choice variable will consist of whether to enter or not to enter the market. Such an experiment will allow us to study the decision making process of the three players, whether the theoretical predictions hold and may also throw some light on the behavioural aspect of the decision making process. It may also be worthwhile to consider treatments with and without contextual terms like pirate, regulator, copying and so on to see whether such terminologies do play a role in the decision making process.

6. Conclusion

This paper contradicts the literature that questions the role of regulatory enforcement in achieving its objective of protection against piracy. I considered a model where the government chooses a monitoring strategy that represents the regulatory enforcement policy. The monopolist decides either to invest or not to invest in an anti-copying technology and also chooses an output strategy that either allows or deters a pirate's entry.

I showed that regulatory enforcement may be successful in protecting piracy. The socially optimal monitoring rate results in the monopolist's choice of entry-deterring output strategy with no investment in the anti-copying technology as the subgame perfect equilibrium.

Using a general monitoring cost function I showed that if monitoring is sufficiently costly, then there is a low level of regulatory enforcement in equilibrium and a high level of investment in anti-copying technology. However, the level of monitoring cannot prevent piracy with certainty and the level of anti-copying investment is not sufficient to prevent copying with certainty. Some discussions on possible future empirical research that brings together the issues of regulatory enforcement and technology adoption for protection against piracy were also discussed.

This paper assumes an installed monopolist, that is, the issue of innovation is avoided and treated as a sunk cost. The existing literature that includes innovation provides mixed result with respect to the impact of piracy on innovation and the role of enforcement policies. Jaisingh (2009) shows that stricter regulatory enforcement policies raise the legitimate product quality which can be used as a measure of innovation. Qiu (2006) shows that only “customized software” is developed under weak copyright protection. Both “customized” and “packaged” software are developed under strong copyright protection. On the contrary, Novos and Waldman (1984) considers the price-quality combination that allows copying and show that a sufficient condition is needed to sustain the common claim that increases in copyright protection decreases the social welfare loss due to underproduction.

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Appendix

Proof of Lemma 1: The first order conditions yield the equilibrium *ac*-strategy to be $q_m^{ac*}=2$. The pirate's equilibrium output and profit is $q_p^{ac*}=1$ and $\pi_p^{ac*}=1-3\alpha$. The pirate's profit is monotonically decreasing in the monitoring rate and he cannot enter if $\alpha\geq\alpha_{\max}=\frac{1}{3}$. So for $\alpha\geq\alpha_{\max}$ the monopoly results hold. *Q.E.D*

The consumer surplus is $CS^{ac}(\alpha)=\begin{cases}\frac{9-5\alpha}{2}, & for\ \alpha<\alpha_{max}\\ 2, & for\ \alpha\geq\alpha_{max}\end{cases}$.

Proof of Lemma 2: . Substituting the pirate's reaction function is $q_p=\frac{4-q_m}{2}$ in its expected profit function and equating it to zero yields $q_m^{ag}(\alpha)=4-2\sqrt{\frac{2\alpha}{1-\alpha}}$ which is decreasing in α. At $\alpha=\alpha_{\max}=\frac{1}{3}$, $q_m^{ag}(\alpha)=2$ which is the monopoly output. So for $\alpha\geq\alpha_{\max}$ the output remains at $q_m^{ag}(\alpha)=2$. So the equilibrium *ag*-strategy is

$q_m^{ag*}(\alpha)=\begin{cases}4-2\sqrt{\frac{2\alpha}{1-\alpha}}, & for\ \alpha\leq\alpha_{max},\\ 2, & for\ \alpha\geq\alpha_{max}.\end{cases}$ The monopolist's profit is

$$\pi_m^{ag*}(\alpha)=\begin{cases}\left(4-2\sqrt{\frac{2\alpha}{1-\alpha}}\right)2\sqrt{\frac{2\alpha}{1-\alpha}}, & for\ \alpha\leq\alpha_{max}\\ 4, & for\ \alpha\geq\alpha_{max}\end{cases}.$$

$\pi_m^{ag*}(\alpha)=\left(a-2\sqrt{\frac{\alpha G}{1-\alpha}}\right)2\sqrt{\frac{\alpha G}{1-\alpha}},\ for\ \alpha\leq\alpha_{max}$ is increasing in α and reaches its maximal value which is the monopoly profit level at $\alpha=\alpha_{\max}$. The second order derivative of $\pi_m^{ag*}(\alpha)$ with respect to α is negative implying that $\pi_m^{ag*}(\alpha)$ is increasing and concave in α. *Q.E.D.*

The consumer surplus is $CS^{ag}(\alpha)=\begin{cases}\frac{1}{2}\left(4-2\sqrt{\frac{2\alpha}{1-\alpha}}\right)^2, & for\ \alpha \le \alpha_{max}\\ 2, & for\ \alpha \ge \alpha_{max}\end{cases}$.

Proof of Lemma 3: The intuitive proof of Lemma 3 is as follows. Since $\pi_m^{ac*}(\alpha=0)=2$ and $\pi_m^{ag*}(\alpha=0)=0$ and the monopoly result for both strategies are restored at $\alpha=\alpha_{\max}=\frac{1}{3}$, there exists an $\alpha=\alpha_1=0.046$ where $0<\alpha_1<\alpha_{\max}$ at which $\pi_m^{ac*}(\alpha_1)=\pi_m^{ag*}(\alpha_1)$. This implies that $\pi_m^{ac*}(\alpha)>\pi_m^{ag*}(\alpha)$ in the range $0\le\alpha<\alpha_1$, and therefore the *ac*-strategy is dominant in this range of the monitoring rate. $\pi_m^{ag*}(\alpha)\ge\pi_m^{ac*}(\alpha)$ in the range $\alpha_1\le\alpha\le\alpha_{\max}$ and therefore, the *ag*-strategy is weakly dominant in this range of the monitoring rate. *Q.E.D.*

Proof of Lemma 4: Substituting the pirate's reaction function in the monopolist's expected profit function and maximizing it with respect to q_m and *T* yields $q_{ma}^{ac*}=2$ and $T^{ac*}=(1-\alpha)^2$. The pirate's equilibrium quantity if he enters is $q_{pa}^{ac*}=1$. The pirate's expected equilibrium profit is $\pi_{pa}^{ac*}(\alpha)=(1-H(T^{ac*}))(1-3\alpha)$. The pirate cannot enter if either $H(T^{ac*})=1$ or $\alpha=\alpha_{\max}=\frac{1}{3}$. If $\alpha\ge\alpha_{\max}=\frac{1}{3}$ then the pirate cannot enter even if he can copy. So for $\alpha\ge\alpha_{\max}=\frac{1}{3}$ the equilibrium anti-copying investment is $T^{ac*}=0$. So the complete characterisation of the equilibrium anti-copying investment and the monopolist's and pirate's profit are as follows.

$T^{ac*}=\begin{cases}(1-\alpha)^2, & if\ 0\le\alpha<\alpha_{max},\\ 0, & if\ \alpha\ge\alpha_{max}.\end{cases}$, $\pi_{ma}^{ac*}(\alpha)=\begin{cases}3+\alpha^2, & if\ 0\le\alpha<\alpha_{max},\\ 4, & at\ \alpha=\alpha_{max}.\end{cases}$ and

$\pi_{pa}^{ac*}(\alpha) = \begin{cases} \alpha(1-3\alpha), \; if \; 0 \le \alpha < \alpha_{max}, \\ 0, \qquad\qquad at \;\; \alpha = \alpha_{max}. \end{cases}$. $T^{ac*} = (1-\alpha)^2$ is decreasing in the

monitoring rate till $\alpha < \alpha_{\max} = \frac{1}{3}$. If $\alpha = 0$ then $T^{ac*} = 1$ and copying is prevented

with certainty in which case the monopolist's profit net of the anti-copying investment

is $\pi_{ma}^{ac*}(\alpha) = 3$. The monopolist's profit is increasing at an increasing rate till

$\alpha < \alpha_{\max} = \frac{1}{3}$. For $\alpha \ge \alpha_{\max}$ the monopoly results are restored. *Q.E.D.*

The consumer surplus is $CS_a^{ac}(\alpha) = \begin{cases} 2 + 2.5\alpha - 2.5\alpha^2, \; for \; \alpha < \alpha_{max}, \\ 2, \qquad\qquad\qquad for \; \alpha \ge \alpha_{max}. \end{cases}$.

Proof of Lemma 5: $SW_a^{ac}(\alpha)$ is increasing in α till $\alpha < \alpha_{\max} = \frac{1}{3}$ because

$SW_a^{ac\,\prime}(\alpha) = 3.5 - 6\alpha > 0$ and $SW_a^{ac\,\prime\prime}(\alpha) = -6 < 0$ for $\alpha < \alpha_{\max} = \frac{1}{3}$. For

$\alpha \ge \alpha_{\max} = \frac{1}{3}$, $SW_a^{ac\,\prime}(\alpha) = -\alpha < 0$. So $SW_a^{ac}(\alpha)$ attains its maximum either at

$\alpha_a^{ac*} = \alpha_{\max}$ or at $\alpha_a^{ac*} = \alpha_{\max} - \varepsilon$ where $\varepsilon > 0$ and as small as possible. Suppose

the latter holds that is, $SW_a^{ac}(\alpha_{\max}) < SW_a^{ac}(\alpha_{\max} - \varepsilon)$. Then there must be a

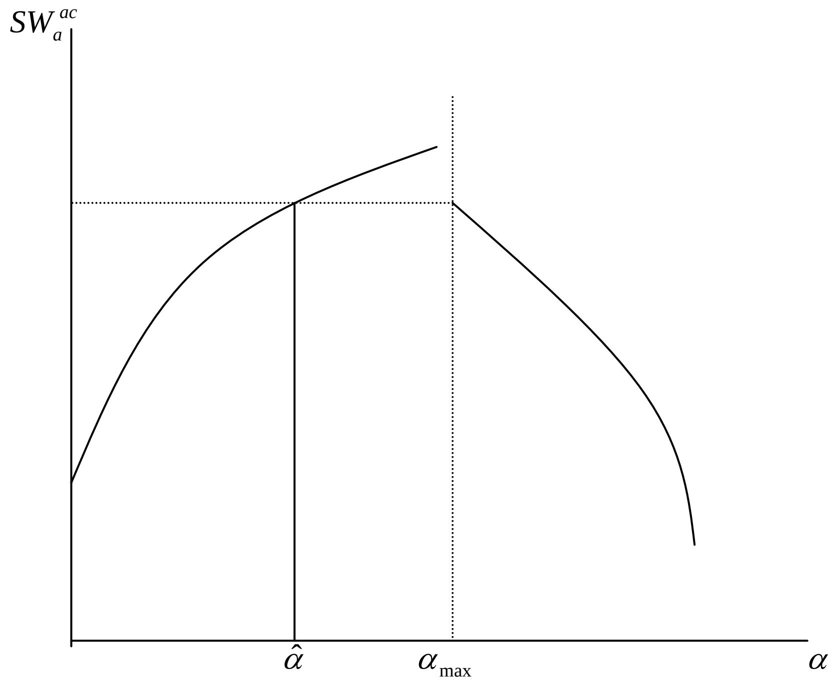
monitoring rate say $\hat{\alpha}$ in the interval $\alpha < \alpha_{\max} = \frac{1}{3}$ such that

$SW_a^{ac}(\alpha_{\max}) = SW_a^{ac}(\hat{\alpha})$. Now, $SW_a^{ac}(\alpha_{max} = \frac{1}{3}) = \frac{107}{18}$. Solving for

$SW_a^{ac}(\hat{\alpha}) = 5 + 3.5\hat{\alpha} - 3\hat{\alpha}^2 = \frac{107}{18}$ yields $\hat{\alpha} = \frac{63 \pm 17.234}{108}$. Both values of $\hat{\alpha}$

exceeds $\alpha_{\max} = \frac{1}{3}$. Hence the contradiction and therefore, $\alpha_a^{ac*} = \alpha_{\max}$. *Q.E.D*

Figure A1: Diagrammatic representation of the proof of Lemma 5



Proof of Proposition 2: In the range $\alpha \in [0, \alpha_2)$ $SW_a^{ac}(\alpha) = 5 + 3.5\alpha - 3\alpha^2$ is the relevant social welfare function. From Lemma 5 we know that

$SW_a^{ac\prime}(\alpha) = 3.5 - 6\alpha > 0$ in the range $\alpha \in [0, \alpha_2)$. Hence, $\alpha_a^{ac*} \cong \alpha_2 = 0.112364$.

In the range $\alpha \in [\alpha_2, \alpha_{\max}]$, SW_a^{ag} is the relevant social welfare function. Since,

$SW_a^{ag\prime}(\alpha) < 0$, hence, $\alpha_a^{ag*} = \alpha_2 = 0.112364$.

Proof of Lemma 6: (i) Equating the two equations in (8) yields $x = 213.5075519$.

The equilibrium monitoring rate for the *NT-subgame* is $\alpha^{ac*} = 0$ for

$x > 213.5075519$ and the ac-strategy is the equilibrium strategy. This is because

$SW^{ag}(x; \alpha^{ag*} = 0.046)$ is decreasing in *x*. $\alpha^{ag*} = 0.046$ is the equilibrium

monitoring rate if $x \leq 213.5075519$.

(ii) For α_a^{ac*} to be the equilibrium monitoring rate in the *T-subgame* the following

two conditions must be satisfied.

C.1. $\alpha_a^{ac*} \in [0, \alpha_2)$ [11] and,

C.2. $SW_a^{ac}(\alpha_a^{ac*}) > SW_a^{ag}(\alpha_a^{ag*} = \alpha_2 = 0.112364)$. Equating

$SW_a^{ag}(x; \alpha_a^{ag*} = 0.112364) = 7.951782 - 0.002116\,x$ and

$SW_a^{ac}(x) = 5 + \dfrac{12.25}{2(5+2x)}$ yields $x = 226.5199$. Substituting this in

$\alpha_a^{ac*} = \dfrac{3.5}{5+2x}$ gives $\alpha_a^{ac*} = 0.00764$. So condition C.1. is satisfied. Both

$SW_a^{ag}(x; \alpha_a^{ag*} = 0.112364)$ and $SW_a^{ac}(x)$ are monotonically decreasing in *x*. Also

$SW_a^{ag}(x = 0; \alpha_a^{ag*} = 0.112364) = 7.951782 > SW_a^{ac}(x = 0) = 6.225$ and the

minimum values of the social welfare functions for $x > 0$ are

$SW_a^{ag}(x = 623.58720; \alpha_a^{ag*} = 0.112364) = 0$ and $Limit\ x \to \infty, SW_a^{ac}(x) \to 5$.

As a result of these properties of the social welfare functions the single crossing property is satisfied at $x = 226.5199$ So for $x > 226.5199$,

$SW_a^{ag}(x; \alpha_a^{ag*} = 0.112364) < SW_a^{ac}(x)$. Since conditions C.1 and C.2 are satisfied when $x > 226.5199$, consequently, the equilibrium monitoring rate is $\alpha_a^{*} = \alpha_a^{ac*}$.

Therefore, the ac-strategy is the equilibrium and there is positive anti-copying investment in equilibrium. *Q.E.D.*

[11] Suppose $\alpha_a^{ac*} > \alpha_2 = 0.112364$ and we know that $\alpha_a^{ag*} = 0.112364$. If the regulator chooses $\alpha_a^{*} = \alpha_a^{ac*}$ then the monopolist will choose the *ag*-strategy because it is the dominant strategy. But $\alpha_a^{ag*} = 0.112364$ maximizes $SW_a^{ag}(\alpha)$. So for the possibility to have $\alpha_a^{*} = \alpha_a^{ac*}$ *x* must be such that $\alpha_a^{ac*} \in [0, \alpha_2)$.