IPR Protection and Optimal Entry Modes of Multinationals

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Abstract

The present paper develops a model to analyze the relationship between modes of entry of a Multinational Corporation (MNC) in a vertically differentiated market in a Less Developed Country (LDC) to the Intellectual Property Rights (IPR) protection policy adopted by the LDC government. The MNC has two options of entry: fragment production structure and shift assembling unit to LDC, or shift entire production to LDC with full technology transfer. The MNC incurs investment to control the copying of the original product by a commercial pirate in the two modes of entry. The results show that the optimal anti-copying investment is inversely related with the IPR protection rate chosen by the LDC government. The government may or may not monitor in equilibrium. However, government monitoring may not result in complete deterrence of piracy. Further, the MNC shifts complete production to LDC with full technology transfer if the transport-cost of sending semi-finished product from developed country to LDC is above a critical level, otherwise a fragmented mode of entry takes place with assembly-line FDI in LDC.

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I: Introduction

Mode of entry in a foreign market and protection of Intellectual Properties rights (IPR) are two important elements in the offshore business scenario. Weak IPR protection in the developing countries often results in technology diffusion/leakage thereby eroding profits of firms specially Multinational Corporations (MNCs) that are either shifting the assembly-line works to Less Developed Country (LDC) or shifting entire production unit to LDC[1]. The present paper tries to determine the optimal entry mode of an MNC to a LDC in the presence of commercial piracy and tried to link it to the optimal IPR choice of the LDC government.

We assume that an MNC can enter a vertically differentiated LDC market in two possible ways: the fragmentation mode of entry where the production process is fragmented and the assembly-line works are shifted to the LDC[2]; the complete-LDC mode of entry where the entire production process is shifted to the LDC through Foreign Direct Investment (FDI). The MNC incurs a per unit shipment-cost for transferring the semi-finished product in case of fragmentation. We assume that to deter illegal copying of its product the MNC incurs an investment (copy-protection investment) under fragmentation or complete-LDC modes of entry. The quality of the pirated product is assumed to be inferior to that of the MNC's product. The paper tries to relate the optimal entry mode of an MNC to the LDC government's welfare maximizing IPR protection rate. The model endogenously determines three important variables namely the IPR monitoring rate of the local LDC government, optimal entry mode and the copy-protection investment incurred by the MNC in response to the local government's IPR protection policy.

The issue of commercial piracy in a vertically differentiated market has been widely dealt in the works of Silve and Bernhardt (1998); Banerjee (2003); Poddar (2005); Banerjee et al. (2008); Kiema (2008); Banerjee (2011); Lu and Poddar (2012).

Banerjee et al. (2008), shows that technical protection instead of the regulatory enforcement can prevent piracy with certainty however, the model assumes original product and pirated goods are perfect substitutes. Alternatively, Banerjee (2011) in a vertically differentiated market shows that the socially optimal monitoring rate can prevent piracy and there is no investment in anti-copying technology in equilibrium if the regulatory enforcement policies are not very costly. Otherwise, the socially optimal

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[1] Business Software Alliance shows in 2010 the worldwide piracy rate was 42% as against the piracy rate of 64% in a developing economy like India. Further the commercial value of the pirated PC software in India was $2,739 million. http://globalstudy.bsa.org/2010/. Accessed on 14.5.2012.
In 2011 the global piracy rate was unchanged at 42% while the commercial value of pirated PC software in India rose to $2.93 billion. http://globalstudy.bsa.org/2011/. Accessed on 9.5.2013
[2] Recent news reveals that Multinational mobile phone company Nokia is shifting its assembly line works from Europe to Asia with plants in Europe concentrating on software-heavy aspects of the production process. http://www.indiatimes.com/mobile/nokia-to-shift-phone-assembly-to_asia-12119.html. posted on 09 Feb 2012 at 10:58:18. Accessed on 12.5.2012

monitoring rate is low and there is a high level of investment in anti-copying technology, which may not be sufficient to prevent copying. Lu and Poddar (2012) found that if the consumers' tastes are sufficiently diverse and the IPR protection is weak the original producer can profitably accommodate the pirate. In all other cases, it is profitable to deter. Further, the commercial pirate can most profitably survive by producing a pirated good of moderate quality. However, none of these studies related the optimal entry mode of the MNC to an LDC market[3], to the local government's regulatory IPR framework and the anti-copying investment of the MNC.

Thus, the present study has the unique feature that it determines the optimal entry mode of an MNC in a vertically differentiated LDC market, where LDC government endogenously chooses IPR protection policy, and the MNC incurs copy protection investment to deter the entry of a commercial pirate.

Our results show that a high IPR protection rate unambiguously reduces the copy-protection investment of the MNC. The government may or may not monitor in equilibrium. Under no-monitoring policy piracy can be deterred under complete-LDC or fragmentation mode of entry when the MNC chooses to restrict copying completely. Alternatively, when monitoring is socially optimal, a complete-LDC or fragmentation mode of entry can take place, but it may not result in the deterrence of piracy. The results have very interesting implications. The situation when the LDC government does not fight piracy, the MNC makes piracy completely impossible by itself. Taking this fact into consideration, if the LDC government chooses to monitor, it does it so inefficiently that it paves the way for the pirate to enter. The paper specifies the conditions under which all these different equilibria hold.

The rest of the paper is organized as follows: Section 2 describes the model and the sequence of the game. Section 3 develops the model and equilibrium of the MNC firm under different strategies. Section 4 gives the comparative analysis of different entry modes and optimal monitoring rate chosen by the local government. Section 5 presents a numerical analysis and Section 6 concludes the paper.

2. The Model

2.1 The Game Plan

We consider an MNC in a developed country (DC) who can fragment the production process into two stages. The MNC has the following options for production:

(1) It can fragment the production process and in the first stage, manufacturing of the core material takes place in the DC. The semi-finished good is then transported to the LDC and in the second

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[3] In this respect, we must mention some studies like *Vishwasrao* (1994), Fosfuri (2000) M*attoo, Olarreaga & Saggi* (2004) that considered the optimal entry mode of an MNC in an LDC but none of these studies discussed the outsourcing policy or fragmentation of production process or the issue of anti-copying investment incurred by MNC firms. Paper by *Long (2005)* explains why a parent company sets up a subsidiary in a low-wage economy and outsources a part of its production thus, retaining core activities like design, patent applications and marketing in the original country ('Incomplete Outsourcing') in a vertically differentiated duopoly structure. However, in this case also the issue of anti-copying investment is not addressed.

stage assembling of the core material takes place in the LDC[4]. In this case, the MNC undertakes assembly-line FDI in the LDC and transfers embodied technology.

(2) It can transfer disembodied technology and undertake the complete production in the LDC by opening up the manufacturing and assembling unit with FDI.

The options involve diffusion of technology, which leads to the possibility of the entry of the pirate. The quality of the original product is normalized to unity. The pirate produces a fake copy of quality denoted by the parameter 'q' where $0<q<1$[5], is exogenous and is a common knowledge. The probability of copying of the original product by the pirate depends upon the copy-protection investment level undertaken by the MNC and the probability that it gets detected after entry is determined by IPR protection exercised by the local government. The local LDC government as a monitoring authority extracts a penalty from the pirate if detected.

The sequential game moves in the following manner: In the first stage, the LDC government chooses an IPR protection rate. Given this rate, the MNC chooses from fragmented production or complete-LDC modes of entry. Under fragmentation and complete-LDC production, technology diffusion may cause the entry of a pirate in the market. Hence under these two cases the MNC incurs an investment to deter the entry of the pirate. Depending upon the local government's IPR protection rate, the MNC adopts either a complete copy-protection (CP) strategy, by incurring an investment that completely deters entry of the pirate or an accommodating-strategy (AC). In case of accommodating-strategy, the MNC incurs an anti-copying investment but a commercial pirate can always copy the product with a positive probability. [6] If the pirate enters and operates, the MNC acts as a price leader[7]. In case of CP-strategy the MNC acts as a monopolist. Figure 1 presents the game tree.
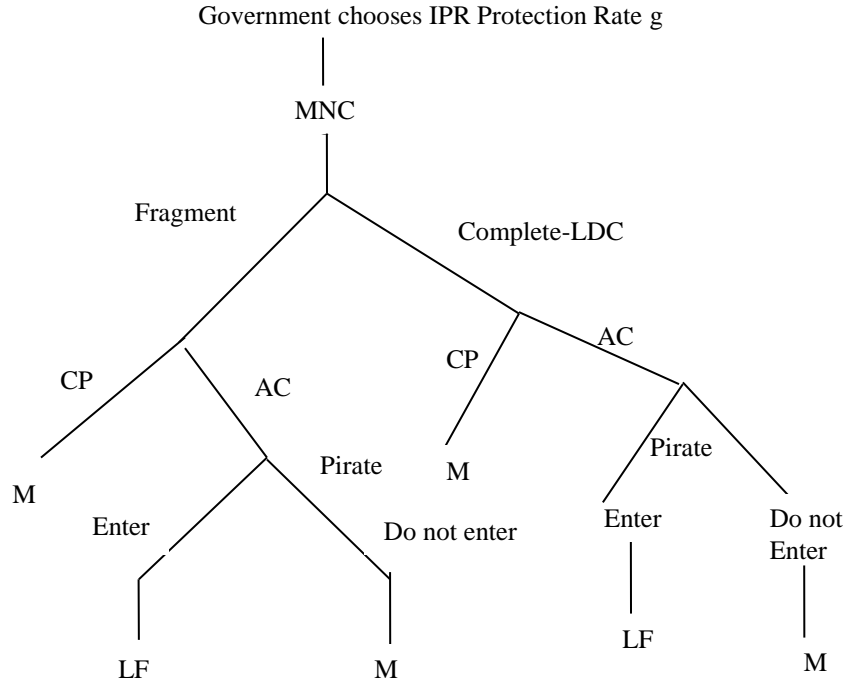
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[4] A common example of this type of production is in case of Coca Cola - one of world's leading beverage suppliers. The MNC prepares the concentrate in the United States which is then exported to different countries where the bottling units are located.
[5] This is an obvious assumption since in case of software and other information goods, the pirated product lacks user's guide and manuals and in some cases, add-on features.
[6]In the paper, complete copy-protection investment (CP-strategy) is a technology determined cost which prevents copying completely. This is in contrast to anti-copying investment (AC-strategy) which makes the task of copying difficult.
[7] The paper by Martínez-Sánchez (2007) also considered the situation where the pirate may become a price leader.

Figure 1: The Game tree

Government chooses IPR Protection Rate g

MNC

Fragment

Complete-LDC

CP

AC

AC

CP

M

Pirate

M

Pirate

Enter

Do not enter

Enter

Do not Enter

LF

LF

M

M

In all cases where the pirate does not enter a monopoly outcome (M) is observed. If the pirate enters a price leadership game is played, with the MNC as the price leader. It is denoted by LF in the game tree.

Given the game tree in Figure 1, the game is solved using the backward induction method. At first, the price game is solved. If the pirate enters the MNC acts as the price leader and the pirate follows, otherwise the MNC becomes the monopolist. Given copy-protection investment of the MNC and the IPR monitoring exercised by the local government, the pirate's entry decision is determined. Given the reaction function of the pirate, the MNC's choice between the CP-strategy and the AC-strategy for each entry mode is found. Next, profits under the different strategies are compared to obtain the optimal entry mode of the MNC which essentially depends on the monitoring rate chosen by the LDC government. Finally, the LDC government's optimal monitoring rate is found.

2.2: The General Assumptions

The model assumes that the product is sold and consumed solely in the LDC. The LDC government chooses a monitoring or IPR protection rate $'g'$, where $0 \leq g \leq 1$ and the cost of monitoring $c(g)$ is increasing and convex in $'g'$ that is $c'(g) > 0$ $c''(g) > 0$. Further, it is assumed that complete monitoring by government is costly such that $\underset{g \to 1}{Lt} c(g) \to \infty$

There exists a continuum of consumers indexed by θ where $\theta \in (\theta_h, \theta_l)$ and $\theta_h - \theta_l = 1$. Here θ represents the marginal willingness to pay of the consumers and follows a uniform distribution. It is

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further assumed that each consumer purchases only one unit and there is no resale market for used product. Therefore, the Utility of a consumer from purchasing one unit of the product is

$$U(\theta) = \begin{cases} (\theta - p) \text{ if he buys one unit of the original product with price p and quality 1} \\ (\theta q - p^{fake}) \text{ if he buys one unit of the pirated product with price } p^{fake} \text{ and quality q} \\ 0 \text{ if he buys none} \end{cases}$$

We assume that under accommodating-strategy, the MNC incurs an anti-copying investment but a commercial pirate can always copy the product with a positive probability. Further, for same level of anti-copying investment the probability of copying of the original product by the pirate is higher in complete-LDC mode of entry than the fragmentation mode as the former entails a full transfer of technology to LDC, whereas in fragmentation only embodied technology is transferred in the form of semi-processed product.

Given these assumptions, the behavior of the MNC and the pirate for different entry mode is analysed in Section 3.

Section 3: The Behavior of the MNC and the Pirate under Different Entry Modes.

3.1 *Fragmented Production between the DC and the LDC*

In the fragmentation mode of entry, the MNC conducts the manufacturing of core parts in its own country and completes the assembling part in the LDC. At the first stage, the MNC produces the core parts in the developed country by undertaking the sunk cost A. In the second stage, the assembling or finishing tasks are undertaken by incurring per unit variable-cost $'w'$ in the LDC. The MNC undertakes a per unit transport cost 't' for transferring the semi-finished product to the LDC where the final output level is denoted by 'y'.

This mode of entry involves possibility of the entry of a commercial pirate. As mentioned earlier the MNC can adopt two alternative strategies namely:

Complete Copy- Protection (CP) strategy – here T_{frag}^{cp} be the copy-protection investment which completely deters the entry of the pirate.

Accommodating-Strategy (AC) – here anti-copying investment (x_{frag}^{ac}) is undertaken by the MNC in such a way that the pirate can copy the product with a positive probability.

Next we determine the prices and profits under the above strategies:

The CP-strategy

The MNC enjoys monopoly profit in the CP-strategy under fragmentation mode of entry. Equation (1) defines the total cost incurred by the MNC under the CP-strategy where 'w' is the per unit

cost of assembling the semi-finished product in the LDC[8]'. 'A' and $'t'$ be the lump sum sunk cost and per unit transport cost respectively and T^{cp}_{frag} is the complete copy-protection investment.

$$c^{cp}_{frag} = wy + A + ty + T^{cp}_{frag} \tag{1}$$

The monopoly demand faced by the MNC under the CP-strategy is given as: $D^{cp}_{frag} = \theta_h - p^{cp}_{frag}$

The profit of the MNC is defined in equation (2).

$$\pi^{cp}_{frag} = \left[p^{cp}_{frag} - (w+t) \right] \left[\theta_h - p^{cp}_{frag} \right] - A - T^{cp}_{frag} \tag{2}$$

Maximizing equation (2) optimal monopoly profit, quantity and price are defined in (3).

$$\bar{\pi}^{cp}_{frag} = \left\{ \theta_h - (w+t) \right\}^2 / 4 - A - T^{cp}_{frag}, \quad \bar{y}^{cp}_{frag} = (\theta_h - w - t)/2, \quad \bar{p}^{cp}_{frag} = (\theta_h + w + t)/2 \tag{3}$$

The social-welfare under CP-strategy is equal to the difference between the net consumer-surplus and the cost of government monitoring. Equation (4) defines the social welfare.[9]

$$SW^{cp}_{frag} = \left\{ \theta_h - (w+t) \right\}^2 / 8 - c(g) \tag{4}$$

The AC-strategy

The model assumes that under the fragmentation mode of entry with AC-strategy if anti-copying investment level is 'x', then the pirate will copy the original product with probability $kh(x)$ where $'k'$ is the exogenous copying parameter. The model assumes that $0 < k < 1; 0 < h(x) < 1; h'(x) < 0; h''(x) > 0$ and $Lt_{x \to \infty} h(x) \to 0$. Thus, the probability of copying decreases with the level of anti-copying investment 'x' but complete copy-protection is not possible in this strategy. Further, we define the condition C1 in equation (5) C1[10]: $h(x)h''(x) - \left\{ h'(x) \right\}^2 > 0 \tag{5}$

Let $\quad \Delta = (h(x)h''(x) - \left\{ h'(x) \right\}^2) / h''(x) \quad$ Given C1, $\Delta > 0$ since $h''(x) > 0$

Let $'g'$ be the local government's IPR monitoring rate that gives the probability of detection of the pirate if he copies the product. Therefore $kh(x)(1-g)$ is the probability that the pirate enters the market and operates undetected and the probability that the pirate does not operate (i.e. the pirate either copies and gets detected or does not copy at all) is $\left\{ 1 - kh(x)(1-g) \right\}$. The model assumes that if the pirate operates under the AC-strategy, the MNC behaves as a price leader otherwise acts as a monopolist.

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[8] It is assumed that $w < c$ due to cheap labor in the LDC.

[9] SW^{cp}_{frag} is maximized at g=0.

[10] C1 implies that $\left| \dfrac{dh'(x)/h'(x)}{dx/x} \right| > \left| \dfrac{dh(x)/h(x)}{dx/x} \right|$, that is in absolute term, for a proportionate change in x, proportionate change in $h'(x)$ (slope) is higher than the proportionate change in h(x)(functional value). C1 along with other restrictions on h(x) implies that downward sloping h(x) is convex to origin and as x increases it becomes flatter and moves asymptotically to x-axis.

Equation (9) defines the market demand for the original and the fake products[11].

$$D_{frag}^{ac} = \theta_h - (p_{frag}^{ac} - p_{frag}^{fake})/1-q \,, \; D_{frag}^{fake} = (p_{frag}^{ac} - p_{frag}^{fake})/(1-q) - p_{frag}^{fake}/q \qquad (6).$$

The total cost incurred by the MNC under the fragmentation mode of entry with AC-strategy is defined in equation (6a) where 'w', 'A', and $'t'$ have same meaning as in equation (1) and ' x_{frag}^{ac} ' is the anti-copying investment.

$$c_{frag}^{ac} = wy + A + ty + x_{frag}^{ac} \qquad (6a).$$

Let $R_{frag}^{fake} = p_{frag}^{fake} D_{frag}^{fake}$ be the revenue earned by the pirate when he successfully operates in the market. The profit of the MNC and that of the pirate when it is operating are defined in equations (7) and (8) respectively, where the pirate incurs a one-time fixed cost of production 'F'. [12]

$$\pi_{frag}^{ac} = \left[p_{frag}^{ac} - (w+t) \right] D_{frag}^{ac} - A - x_{frag}^{ac} \qquad (7).$$

$$\pi_{frag}^{fake} = R_{frag}^{fake} - F = \left[p_{frag}^{fake} D_{frag}^{fake} - F \right] \qquad (8).$$

When the pirate chooses to enter, maximizing equation (8) the pirate's price, demand and profits are obtained as a function of the MNC's price in equation (9)

$$p_{frag}^{fake} = p_{frag}^{ac} q/2, \quad D_{frag}^{fake} = p_{frag}^{ac}/2(1-q), \quad \pi_{frag}^{fake} = (p_{frag}^{ac})^2 q/4(1-q) - F \qquad (9).$$

Given the reaction function of the pirate, the MNC's optimal price can be found maximizing equation (10). Equation (12) gives corresponding leadership profit, price, demand and consumer-surplus

$$\bar{\pi}_{frag}^{ac} = \{2\theta_h(1-q) - (w+t)(2-q)\}^2/8(1-q)(2-q) - A - x_{frag}^{ac},$$
$$\bar{p}_{frag}^{ac} = \{2\theta_h(1-q) + (w+t)(2-q)\}/2(2-q) \;\;, \bar{D}_{frag}^{ac} = \{2\theta_h(1-q) - (w+t)(2-q)\}/4(1-q)$$
$$CS_{frag}^{ac} = (2\theta_h(1-q) - (2-q)(w+t))^2/16(2-q)(1-q) \qquad (10).$$

The equilibrium values for the pirate's profit, price, demand and consumer-surplus are presented in equation (11) for $p_{frag}^{ac} = \bar{p}_{frag}^{ac}$.

$$\bar{\pi}_{frag}^{fake} = \bar{R}_{frag}^{fake} - F = q[2\theta_h(1-q) + (w+t)(2-q)]^2/16(2-q)^2(1-q) - F,$$
$$\bar{P}_{frag}^{fake} = q\{[2\theta_h(1-q) + (w+t)(2-q)]/4(2-q)\},$$
$$\bar{D}_{frag}^{fake} = \{(2\theta_h(1-q) + (w+t)(2-q))/4(2-q)(1-q)\} \qquad (11).$$
$$CS_{frag}^{fake} = q(2\theta_h(1-q) + (2-q)(w+t))^2/32(2-q)^2(1-q)$$

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[11] In this case, a consumer with $\theta = (p_{frag}^{ac} - p_{frag}^{fake})/1-q$ is indifferent between purchasing a fake product and an original product and a consumer with willingness to pay p_{frag}^{fake}/q is indifferent between purchasing a fake product to none.

[12] The variable cost of production is ignored for the sake of simplicity. In reality, it is seen in case of software and digital goods the initial set up cost is significantly high while the cost of reproduction is insignificant.
Here initial set up cost F is a sunk cost incurred by the pirate, even if he gets detected.

If the pirate does not operate the MNC enjoys monopoly profit defined in (12)

$$\pi_{frag}^{ac(m)} = \{\theta_h - (w+t)\}^2 / 4 - A - x_{frag}^{ac}, \ D_{frag}^{ac(m)} = (\theta_h - w - t)/2, \ p_{frag}^{ac(m)} = (\theta_h + w + t)/2, \ CS_{frag}^{ac(m)} = \{\theta_h - (w+t)\}^2 / 8 \qquad (12).$$

Given the equations (11) and (12) the expected profit[13] for the MNC is defined in equation (13).

$$\pi_{frag}^{ac(exp)} = \{\theta_h - (w+t)\}^2 / 4 - kh(x_{frag}^{ac})(1-g)M - A - x_{frag}^{ac} \qquad (13).$$

Where $M = \pi_{frag}^{ac(m)} - \bar{\pi}_{frag}^{ac} = \left[\{\theta_h - (w+t)\}^2 / 4 - \{2\theta_h(1-q) - (w+t)(2-q)\}^2 / 8(1-q)(2-q)\right] \qquad (13a)[14]$

The MNC maximizes the expected profit as defined in equation (13) to determine the optimal anti-copying investment ($\bar{x}_{frag}^{ac}$) which satisfies equation (14)[15]

$$- kh'(\bar{x}_{frag}^{ac})(1-g)M = 1 \qquad (14).$$

Thus, expected profit of the MNC for $x_{frag}^{ac} = \bar{x}_{frag}^{ac}$ is given as:

$$\pi_{frag}^{ac(exp)} = \{\theta_h - (w+t)\}^2 / 4 - kh(\bar{x}_{frag}^{ac})(1-g)M - A - \bar{x}_{frag}^{ac}$$

Proposition 1

In the fragmentation mode of entry, under accommodating strategy, the MNC undertakes the anti-copying investment $\bar{x}_{frag}^{ac}$, where $\bar{x}_{frag}^{ac}$ satisfies equation (16). $\bar{x}_{frag}^{ac}$ is directly related to the copying parameter 'k' and is inversely related to IPR protection rate 'g' and transport cost 't';

Proof: See Appendix 1.

Firstly, as the copying probability increases due to a rise in exogenous copying parameter 'k', the MNC chooses a higher value of anti-copying investment to make copying difficult for the pirate. [16] Secondly, Proposition 1 proves that the MNC reduces its anti-copying investment under the AC-strategy if the local LDC government's provision of IPR protection rate 'g' increases. Thus, there is substitutability between the IPR protection rate chosen by the LDC government and anti-copying investment level of the MNC. Finally, if per unit shipment-cost 't' increases, the MNC faces an increase in unit cost of production, hence profitability requires a cut in its anti-copying investment.

Let G be the penalty extracted by the LDC government if the pirate gets detected.

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[13] $\pi_{frag}^{ac(exp)} = kh(x_{frag}^{ac})(1-g)\bar{\pi}_{frag}^{ac} + \{1 - kh(x_{frag}^{ac})(1-g)\}\pi_{frag}^{ac(m)}$

[14] M is defined as the difference between the MNC's monopoly profit under the CP-strategy and the leadership profit under AC-strategy omitting the fixed cost and anti-copying investment.

[15] Second order condition requires that $h''(x) > 0$

[16] The copying probability is $prob = kh(x)$. Proposition 1 proves that $\partial \bar{x}_{frag}^{ac} / \partial k > 0$ now,

$dprob/dk = (h(x)h''(x) - \{h'(x)\}^2)/h''(x)$; $dprob/dk > 0$ when C1 holds. Thus, C1 rules out a situation where a rise in k leads to a fall in "prob".

Let $\Omega = \left[(1-g)\bar{R}^{\text{fake}}_{\text{frag}} - gG\right] = \left[(1\text{-}g)q\left[(2\theta_{\text{h}}(1-q)+(w+t)(2-q)\right]^2/16(2-q)^2(1-q)-gG\right] > 0$ (14a)[17]

The expected profit for the pirate[18] is defined in (15).

$$\pi^{fake(\exp)}_{frag} = \text{kh}(\bar{\text{x}}^{ac}_{frag})\Omega - F \tag{15}.$$

Suppose $\pi^{fake(\exp)}_{frag} = 0$ for g= g^{*}_{frag} defined in equation (16).

$$g^{*}_{frag} = \frac{\{q\left[(2\theta_{\text{h}}(1-q)+(w+t)(2-q))\right]^2/16(2-q)^2(1-q)\}-F/kh(\bar{x}^{ac}_{frag})}{\{q\left[(2\theta_{\text{h}}(1-q)+(w+t)(2-q))\right]^2/16(2-q)^2(1-q)\}+G} \tag{16}.$$

Proposition 2

i)   *The profit of the pirate as given by equation (15) increases with exogenous copying parameter 'k' and per unit shipment-cost 't', while it decreases with IPR protection rate 'g'.*

ii)   *There is a value of monitoring rate g^{*}_{frag}, such that the pirate will not operate under fragmentation if $g \in [\, g^{*}_{frag},1]$, where equation (16) defines g^{*}_{frag}.*

   Further, g^{*}_{frag} increases with 't' and 'k' but decreases with penalty level 'G'.

iii)   *For a given value of 'g', profit of the pirate unambiguously falls with 'q', the effective quality of the fake product, for $q > 2(\theta_{h} + w + t)/(6\theta_{h} + w + t)$.*

Proof: See Appendix 2.

As 'k' increases, the probability of copying rises under the AC-strategy of fragmentation mode of entry. This improves the expected profit of the pirate for a given level of x^{ac}_{frag}. However, the expected profit of the pirate falls because $\partial\bar{x}^{ac}_{frag}/\partial k > 0$ (from Proposition 1). Given these two opposite effects the profit of the pirate increases with a rise in 'k' if and only if $h(x^{ac}_{frag})h''(x^{ac}_{frag}) - \left\{h'(x^{ac}_{frag})\right\}^2 > 0$ or C1 holds.

However, an increase in the shipment-cost 't' raises the pirate's profit. As 't' increases, the MNC raises its price. This raises the demand for the pirated good. Secondly, the MNC also reduces anti-copying investment for a rise in 't'. These two combined effects improve the profit of the pirate.

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[17] Ω represents the expected profit of the pirate after the fixed costs have been paid assuming that the pirate succeeds in breaking the copy-protection of the MNC.

[18] $\pi^{fake(\exp)}_{frag} = kh(\bar{\text{x}}^{ac}_{frag})(1\text{-}g)\bar{R}^{fake}_{frag} - kh(\bar{x}^{ac}_{frag})gG - F$

Finally, an increase in the LDC government's monitoring rate $'g'$ reduces the expected profit of the pirate continuously for C1.[19]

Now for $g \geq g^*_{frag}$ the pirate does not enter the market and the MNC enjoys monopoly profit and does not undertake anti-copying investment.

A high penalty 'G' lowers the profitability of the pirate as a result of which g^*_{frag}, the critical value of monitoring rate, falls and the entry of the pirate is deterred even for a low monitoring rate. An opposite result holds for a rise in $'k'$ or $'t'$. A rise in $'t'$ or $'k'$ improves the profitability of the pirate there by increasing the critical value of monitoring rate g^*_{frag} below which the pirate can actually operate.

Finally, we observe that the expected profit of the pirate decreases with $'q'$ if $q > 2(\theta_h + w + t)/(6\theta_h + w + t)$. An increase in $'q'$ makes the fake and the original product less differentiated and raises the degree of competition between the pirate and the MNC. This induces the MNC to raise the anti-copying investment to restrict the entry of the pirate, that is, $\partial \overline{x}^{ac}_{frag} / \partial q > 0$ and the expected profit of the pirate falls. Again, as $'q'$ improves the pirate faces a rise in its demand and profit. However, the MNC being the price leader reduces the price to keep its demand base intact. So the pirate has to reduce its price, which imparts a negative impact on its profit. Given $\partial \overline{x}^{ac}_{frag} / \partial q > 0$, the price effect dominates and expected profit of the pirate unambiguously falls for $q > 2(\theta_h + w + t)/(6\theta_h + w + t)$. Otherwise, the overall effect of an increase in $'q'$ on the pirate's profit becomes ambiguous.

Proposition 3

i) The expected profit of the MNC as given by equation (15) is directly related to IPR protection rate $'g'$ and is inversely related to copying parameter $'k'$.

ii) If θ_h, the highest value of consumers' willingness to pay for the product, is sufficiently high, the expected profit of the MNC decreases with per unit shipment-cost $'t'$.

Proof: See Appendix 3.

An increase in the IPR protection rate $'g'$ raises the profit of the MNC in two ways: a higher $'g'$ reduces the probability of the entry of the pirate, thereby improving the expected profit of the MNC;

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[19] If C1 does not hold we may have a counter intuitive result that a rise in $'g'$ is actually improving the expected profit of the pirate, that is a high government monitoring is encouraging piracy.

secondly, as $'g'$ increases the MNC reduces its optimal anti-copying investment ($\bar{x}^{ac}_{frag}$) hence the expected profit of the MNC rises.

An increase in copying probability $'k'$ improves the probability of operation of the pirate in the market. Hence the expected profit of the MNC falls. The expected profit of the MNC is further reduced for an increase in total-cost as $\partial \bar{x}^{ac}_{frag} / \partial k > 0$.

Lastly, a rise in shipment-cost $'t'$ reduces the expected profit of the MNC by increasing the unit cost of production, and improves the expected profit as $\partial \bar{x}^{ac}_{frag} / \partial t < 0$. However, as optimal anti-copying investment level decreases the probability of copying of the original product rises, and expected profit gets reduced. Our result shows that if θ_h is high the negative effects on profit dominate and hence expected profit of the MNC decreases with an increase in $'t'$.

Equation (17a) defines Γ [20], the sum of net consumer-surplus (generated from original as well as pirated product) and revenue earned by the pirate when it operates in the market net off the consumer-surplus generated when the MNC operates alone.

$$\Gamma = q\left[4\theta_h^2(1-q)(1-2q) + 5(w+t)^2(2-q)^2 + 12\theta_h(1-q)(2-q)(w+t)\right] / 32(2-q)^2(1-q) \tag{17a}.$$

The expected social-welfare under the AC-strategy as defined in (18) is the sum of expected net consumer-surplus, expected profit of the pirate and net expected earning of the government.[21,22]

$$SW^{ac(exp)}_{frag} = (\theta_h - w - t)^2 / 8 + (1-g)kh(\bar{x}^{ac}_{frag})\Gamma - c(g) - F \tag{18}.$$

The LDC government maximizes equation (18) to determine the optimal value of monitoring rate.

Further, $\partial SW^{ac(exp)}_{frag} / \partial g = -k\Gamma\Delta - c'(g) < 0$ (19)

Thus social-welfare under the AC-strategy is unambiguously decreasing in $'g'$.

$$\partial SW^{ac(exp)}_{frag} / \partial k = (1-g)\Gamma\Delta > 0 \tag{20}.$$

Equation (21) is positive, given C1, where Δ is defined in (5).

---

[20] $\Gamma = CS^{ac}_{frag} + CS^{fake}_{frag} + \bar{R}^{fake}_{frag} - CS^{ac(m)}_{frag}$

[21] $SW^{ac(exp)}_{frag} = kh(\bar{x}^{ac}_{frag})(1-g)(CS^{ac}_{frag} + CS^{fake}_{frag}) + (1-kh(\bar{x}^{ac}_{frag})(1-g))CS^{mono}_{frag} + \pi^{fake(exp)}_{frag} + kh(\bar{x}^{ac}_{frag})gG - c(g)$ where

$(kh(\bar{x}^{ac}_{frag})gG - c(g))$ is the net expected earning of the government.

[22] Interestingly, Γ may become negative for a sufficiently high θ_h and $q > \frac{1}{2}$ as proposition 2 shows that profit of the pirate decreases with q for $q > 2(\theta_h + w + t)/(6\theta_h + w + t)$.

$$\partial SW_{frag}^{ac(\exp)}/\partial t = -(\theta_h - w - t)/4 + (1-g)kh(\bar{x}_{frag}^{ac})\partial\Gamma/\partial t + (1-g)k\Gamma h'(\bar{x}_{frag}^{ac})\partial\bar{x}_{frag}^{ac}/\partial t \qquad (20a).$$

$h'(.) < 0, \partial\bar{x}_{frag}^{ac}/\partial t < 0$ and $\partial\Gamma/\partial t > 0$. Here the first and third terms are negative and only the second term is positive. Therefore $\partial SW_{frag}^{ac(\exp)}/\partial t$ is ambiguous in sign.

Equations (20) and (20a) show two interesting results. As the copying probability of the pirate rises with an increase in $'k'$, the probability that the pirate enters the market becomes high. As competition increases, the price of the original product as well as that of the fake product falls. Hence, consumers with lower willingness to pay are able to purchase the product which increases the expected social welfare. As $'t'$ is reduced, the MNC reduces its price and thereby expands its market share for a fall in unit cost of production. Thus, consumer-surplus for the buyers of the original product improves. On the other hand, the profit of the pirate and consumer-surplus for the buyers of the fake product reduce due to a fall in 't'. These opposing effects on social welfare makes $\partial SW_{frag}^{ac(\exp)}/\partial t$ ambiguous in sign. However, for a high θ_h if the first effect dominates, the social welfare will rise for a fall in $'t'$.

Comparative Study of the Copy Protection (CP) and the Accommodating (AC) Strategies under Fragmentation

Comparing (3) and (13) for $x_{frag}^{ac} = \bar{x}_{frag}^{ac}$ we find equation (21)[23]

$$\bar{\pi}_{frag}^{cp} - \pi_{frag}^{ac(\exp)} = kh(\bar{x}_{frag}^{ac})(1-g)M - (T_{frag}^{cp} - \bar{x}_{frag}^{ac}) \qquad (21).$$

Equation (22) shows that if equilibrium value of $\bar{x}_{frag}^{ac}$ is greater than or equal to T_{frag}^{cp} the AC-strategy is always dominated by the CP-strategy.

$$\partial(\bar{\pi}_{frag}^{cp} - \pi_{frag}^{ac(\exp)})/\partial g = -kh(\bar{x}_{frag}^{ac})M < 0 \qquad (22)$$

Equation (23) shows that the difference between profits under the CP and AC strategies fall with $'g'$ that is the AC-strategy becomes more profitable as $'g'$ goes up.

For $\bar{x}_{frag}^{ac} < T_{frag}^{cp}$ let us assume that there exists a value of $'g'$ say $\tilde{g}_{frag}$, such that $\bar{\pi}_{frag}^{cp} = \pi_{frag}^{ac(\exp)}$ for $x_{frag}^{ac} = \bar{x}_{frag}^{ac}$. Solving for that value of $'g'$ we get the results in equation (24) where M is defined in 15a.

$$\tilde{g}_{frag} = 1 - (T_{frag}^{cp} - \bar{x}_{frag}^{ac})/kh(\bar{x}_{frag}^{ac})M \qquad \text{where } T_{frag}^{cp} > \bar{x}_{frag}^{ac} \text{ and } M > 0. \qquad (23).$$

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[23] We assume that $\bar{\pi}_{frag}^{cp} > \pi_{frag}^{ac(\exp)}$ for g=0. Otherwise the CP-strategy is always a dominated strategy.

Proposition 4

    i)   *In the fragmented mode of entry, there is a value of monitoring rate $\tilde{g}_{frag}$ given by*

           equation (24) such that the MNC chooses the AC-strategy to the CP-strategy for

           $g \geq \tilde{g}_{frag}$

    ii) $\tilde{g}_{frag}$ *is directly related to copying probability parameter, 'k' and indirectly related to*

           per unit shipment-cost 't'.

Proof:

i) Equation (23) shows that AC-strategy becomes more profitable with an increase in $'g'$. At $\tilde{g}_{frag}$ we

have $\bar{\pi}_{frag}^{cp} = \pi_{frag}^{ac(exp)}\Big|_{\bar{x}_{frag}^{ac}}$. If 'g' increases further the AC-strategy profit will rise, and we get

$\pi_{frag}^{ac(exp)} \geq \bar{\pi}_{frag}^{cp}$ for $g \geq \tilde{g}_{frag}$. Hence follows the result.

ii) The results follow from equation (25) and (25a)

$$\partial \tilde{g}_{frag} / \partial k = (1-g)/k > 0 \tag{24}.$$

$$\partial \tilde{g}_{frag} / \partial t = -q(1-g)(w+t)/4M(1-q) < 0 \tag{24a}.$$

The profit of the MNC falls with rise in $'k'$ when it chooses the AC-strategy. So $\tilde{g}_{frag}$ increases

with a rise in $'k'$ implying that a higher rate of government monitoring is needed to induce the MNC to

choose the AC-strategy.

Alternatively as $'t'$ increases $\bar{\pi}_{frag}^{cp}$ and $\pi_{frag}^{ac(exp)}\Big|_{\bar{x}_{frag}^{ac}}$ fall due to a rise in unit cost of production.

However, profit under the AC-strategy falls at lesser proportion than that under the CP-strategy due to a

fall in $\bar{x}_{frag}^{ac}$, as $\partial \bar{x}_{frag}^{ac} / \partial t < 0$. So the AC-strategy becomes more profitable than the CP-strategy even

for a lower monitoring rate. Thus, $\tilde{g}_{frag}$ falls for an increase the shipment-cost $'t'$.

From equation (20) we observe that $\partial SW_{frag}^{ac(exp)} / \partial g < 0$ for C1. Therefore $SW_{frag}^{ac(exp)}$ is maximized

at $\tilde{g}_{frag}$ when the AC-strategy is chosen for $\tilde{g}_{frag} \leq g < g_{frag}^{*}$. Hence, depending on the value of $'g'$ in

Table 1 we summarize the strategy choice for the MNC and resultant profit and welfare level when it

considers the fragmented mode of entry.

Table 1

IPR Protection Rate(g)	MNC's profit	Social Welfare
$0 \leq g < \widetilde{g}_{frag}$	The MNC chooses the CP-strategy $$\overline{\pi}_{frag}^{cp} = \{\theta_h - (w+t)\}^2/4 - A - T_{frag}^{cp}$$	$$SW_{frag}^{cp} = \{\theta_h - (w+t)\}^2/8 - c(g)$$
$\widetilde{g}_{frag} \leq g < g_{frag}^*$	The MNC chooses the AC-strategy $$\pi_{frag}^{ac(exp)} = \{\theta_h - (w+t)\}^2/4 - kh(\overline{x}_{frag}^{ac})(1-g)M - A - \overline{x}_{frag}^{ac}$$	$$SW_{frag}^{ac(exp)} = (\theta_h - w - t)^2/8 + (1-g)kh(\overline{x}_{frag}^{ac})\Gamma - c(g) - F$$
$g_{frag}^* < g \leq 1$	The fake producer does not enter $$\pi_{frag}^{mono} = \{\theta_h - (w+t)\}^2/4 - A$$	$$SW_{frag}^{mono} = \{\theta_h - (w+t)\}^2/8 - c(g)$$

3.2 Complete Production in LDC

In this option, the MNC undertakes the complete production process in LDC with full technology transfer. As in case of fragmented production, in this mode of entry also there will be two alternative strategies to choose from, namely: Complete Copy-Protection (CP) Strategy and Accommodating (AC) Strategy.

The CP-strategy: In this case, the level of complete copy-protection investment undertaken by the MNC be T_{LDC}^{cp}. The model assumes that $T_{LDC}^{cp} > T_{frag}^{cp}$, due to full technology transfer, the copying of the original product becomes easier in complete-LDC mode of entry and the MNC needs to invest more for complete deterrence of the entry of the pirate as compared to fragmentation.

The monopoly profit of the MNC under the CP-strategy is defined in equation (26) and equation (27) defines the corresponding social welfare.

$$\overline{\pi}_{LDC}^{cp} = \{\theta_h - w\}^2/4 - A - T_{LDC}^{cp} \tag{25}$$

$$SW_{LDC}^{cp} = \{\theta_h - w\}^2/8 - c(g) \tag{26}$$

The AC-strategy – Under AC-strategy let x_{LDC}^{ac} be the level of anti-copying investment incurred by the MNC, where the probability of copying the original product is $h(x_{LDC}^{ac})$ such that $0 < h(.) < 1$, $h'(.) < 0$ and $h''(.) > 0$ and $Lt_{x \to \infty} h(x_{LDC}^{ac}) \to 0$. It implies that the copying probability is higher in the AC-strategy in complete-LDC production than the AC-strategy of fragmented production for same level of anti-copying investment (as $h(x) > kh(x)$ for $0 < k < 1$).

Optimum duopoly profit of the MNC and the pirate are defined in equation (28) and (28a) respectively.

$$\overline{\pi}_{LDC}^{ac} = \{2\theta_h(1-q) - w(2-q)\}^2/8(2-q)(1-q) - A - x_{LDC}^{ac} \tag{27}$$

$$\bar{\pi}_{LDC}^{fake} = q\{2\theta_{h}(1-q)+w(2-q)\}^{2}/16(1-q)(2-q)^{2}-F \tag{28}$$

If the pirate gets detected or fails to copy the product the MNC enjoys monopoly profit defined in equation (29).

$$\pi_{LDC}^{ac(m)} = (\theta_{h}-w)^{2}/4 - A - x_{LDC}^{ac} \tag{29}$$

The expected profit of the MNC is defined in equation (30)

$$\pi_{LDC}^{ac(exp)} = \{\theta_{h}-w\}^{2}/4 - h(x_{LDC}^{ac})(1-g)N - A - x_{LDC}^{ac} \tag{30}$$

$$\text{Where } N = \left[\{\theta_{h}-w\}^{2}/4 - \{2\theta_{h}(1-q)-w(2-q)\}^{2}/8(1-q)(2-q)\right] > 0 \tag{30a}[24]$$

The optimum value of $\bar{x}_{LDC}^{ac}$, is obtained from equation (31).

$$-h'(\bar{x}_{LDC}^{ac})(1-g)N = 1 \tag{31}$$

Proposition 5

In the AC- strategy of complete-LDC production, the anti-copying investment undertaken by the MNC ($\bar{x}_{LDC}^{ac}$) as obtained from equation 31, is inversely related to IPR protection rate 'g'.[25]

The expected profit of the pirate is defined in equation (32).

$$\pi_{LDC}^{fake(exp)} = h(\bar{x}_{LDC}^{ac})\Omega^{*}-F \tag{32}$$

$$\text{where } \Omega^{*} = \left[(1-g)q[(2\theta_{h}(1-q)+w(2-q)]^{2}/16(2-q)^{2}(1-q)-gG\right] \tag{32a}[26]$$

We define a monitoring rate $g = g_{LDC}^{*}$ in equation (33) for which $\pi_{LDC}^{fake(exp)}$ is zero.

$$g_{LDC}^{*} = \frac{q[2\theta_{h}(1-q)+w(2-q)]^{2}/16(2-q)^{2}(1-q)-F/h(\bar{x}_{LDC}^{ac})}{q[2\theta_{h}(1-q)+w(2-q)]^{2}/16(2-q)^{2}(1-q)+G} \tag{33}$$

Proposition 6[27]

i) *In the AC-strategy the profit of the pirate as defined in equation (32) always decreases with IPR protection rate 'g' and effective quality of the fake product 'q', for $q > 2(\theta_{h}+w)/(6\theta_{h}+w)$.*

ii) *There exists a value g_{LDC}^{*} defined in (33), such that the pirate does not operate for $g \in [g_{LDC}^{*},1]$, further g_{LDC}^{*} decreases with the penalty level G.*

Proposition 7[28]

In the AC-Strategy the expected profit of the MNC is directly related to IPR protection rate 'g'.

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[24] N has same interpretation as that of M defined in (15a) for $t = 0$ and $k = 1$

[25] Proof is same as that of Proposition 1, where t=0 and k=1

[26] Ω^{*} has same interpretation as of Ω defined in (16a) for $t = 0$ and $k = 1$

[27] Proof is same as that of Proposition 2, where t=0 and k=1

[28] Proof is same as that of Proposition 3, where t=0 and k=1

Given $\Gamma^* = q\left[4\theta_h^2(1-q)(1-2q) + 5w^2(2-q)^2 + 12\theta_h w(1-q)(2-q)\right]/32(2-q)^2(1-q)$ [29] the social welfare in

the complete-LDC production is defined in equation (34):

$$SW_{LDC}^{ac(exp)} = (\theta_h - w)^2/8 + (1-g)h(\bar{x}_{LDC}^{ac})\Gamma^* - c(g) - F \tag{34}$$

$$\partial SW_{frag}^{ac(exp)}/\partial g = -\Gamma^*\Delta - c'(g) < 0 \qquad (\text{given C1}) \tag{35}$$

Comparative Study of the CP and the AC Strategies under Complete-LDC production

Comparing the equations (26) and (30) we find equation (35a).

$$\left.\bar{\pi}_{LDC}^{cp} - \pi_{LDC}^{ac(exp)}\right|_{\bar{x}_{LDC}^{ac}} = h(\bar{x}_{LDC}^{ac})(1-g)N - (T_{LDC}^{cp} - \bar{x}_{LDC}^{ac}) \tag{35a}$$

We define a critical value of monitoring rate $\tilde{g}_{LDC}$ in equation (36) such that $\bar{\pi}_{LDC}^{cp} = \pi_{LDC}^{ac(exp)}$.

$$\tilde{g}_{LDC} = 1 - (T_{LDC}^{cp} - \bar{x}_{LDC}^{ac})/h(\bar{x}_{LDC}^{ac})N \quad \text{where } T_{frag}^{cp} > \bar{x}_{frag}^{ac} \text{ and } N > 0. \tag{36}$$

We conclude that under complete-LDC mode of entry the MNC chooses the AC-strategy to the CP-

strategy for $g \geq \tilde{g}_{LDC}$ as $\bar{\pi}_{LDC}^{cp} \leq \pi_{LDC}^{ac(exp)}$ and $\partial(\bar{\pi}_{LDC}^{cp} - \pi_{LDC}^{ac(exp)})/\partial g < 0$

Finally, given equations (34) and (35) social welfare in the AC-strategy under complete-LDC

production is maximized at g= $\tilde{g}_{LDC}$ where the AC-strategy is chosen for $\tilde{g}_{LDC} \leq g \leq g_{LDC}^*$. In Table 2

we summarize the strategy choice for the MNC and resultant profit and social welfare level for various

values of 'g' when its chooses to produce completely in the LDC.

Table 2

IPR Protection Rate(g)	MNC's profit	Social Welfare
$0 \leq g < \tilde{g}_{LDC}$	The MNC chooses the CP-strategy $\bar{\pi}_{LDC}^{cp} = \{\theta_h - w\}^2/4 - A - T_{LDC}^{cp}$	$SW_{LDC}^{cp} = \{\theta_h - w\}^2/8 - c(g)$
$\tilde{g}_{LDC} \leq g < g_{LDC}^*$	The MNC chooses the AC-strategy $\pi_{LDC}^{ac(exp)} = \{\theta_h - w\}^2/4 - h(\bar{x}_{LDC}^{ac})(1-g)N - A - \bar{x}_{LDC}^{ac}$	$SW_{LDC}^{ac(exp)} = (\theta_h - w)^2/8$ $+ (1-g)h(\bar{x}_{LDC}^{ac})\Gamma^* - c(g) - F$
$g_{LDC}^* \leq g \leq 1$.	The fake producer does not enter $\pi_{LDC}^{mono} = \{\theta - w\}^2/4 - A$.	$SW_{LDC}^{mono} = \{\theta_h - w\}^2/8 - c(g)$

Section 4 gives the choice of optimal monitoring rate and possible entry modes.

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[29] $\Gamma*$ has same interpretation as of Γ defined in (18a) for $t = 0$ and $k = 1$

Section 4 : Choice of Optimal Monitoring Rate and Possible Entry Modes

This section presents an analysis to determine the sub-game perfect Nash equilibrium (SPNE) solution of the model. Let g_{opt} be the optimal monitoring rate chosen by the government.

The possible sub-game perfect Nash equilibrium solutions are summarized as follows:

Equilibrium 1

The monitoring rate $g_{opt} = \tilde{g}_{frag}$, induces fragmented production structure, with the AC-strategy as a sub-game perfect Nash equilibrium if

$$\pi_{frag}^{ac(\exp)}\Big|_{g=\tilde{g}_{frag}} = \overline{\pi}_{frag}^{cp} > \overline{\pi}_{LDC}^{cp} \quad \text{and} \quad SW_{frag}^{ac(\exp)}\Big|_{g=\tilde{g}_{frag}} > SW_{frag}^{cp}\Big|_{g=0} \quad \text{and} \quad \pi_{frag}^{fake(\exp)} > 0$$

Proof: It can be shown that $\tilde{g}_{frag} < \tilde{g}_{LDC}$.[30] If the LDC government chooses $\tilde{g}_{frag}$, the MNC has two options: it can either choose AC-strategy under fragmentation mode of entry or the CP-strategy under complete-LDC mode of entry. If $\pi_{frag}^{ac(\exp)}\Big|_{g=\tilde{g}_{frag}} = \overline{\pi}_{frag}^{cp} > \overline{\pi}_{LDC}^{cp}$, then the MNC will always choose the

AC-strategy with fragmentation mode of entry. The government will choose monitoring rate $g_{opt} = \tilde{g}_{frag}$,

if $SW_{frag}^{ac(\exp)}\Big|_{g=\tilde{g}_{frag}} > SW_{frag}^{cp}\Big|_{g=0}$ where $SW_{frag}^{ac(exp)}$ is maximized at $g_{opt} = \tilde{g}_{frag}$ and $\pi_{frag}^{fake(\exp)} > 0$ (Hence Proved).

Equilibrium 1a.

The non-monitoring or $g_{opt}=0$, induces fragmented production structure, with the CP-strategy as a sub-game perfect Nash equilibrium if $\overline{\pi}_{frag}^{cp} > \overline{\pi}_{LDC}^{cp}$ and $SW_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{frag}} < SW_{frag}^{cp}\Big|_{g=0}$.

Proof: If $\overline{\pi}_{frag}^{cp} > \overline{\pi}_{LDC}^{cp}$ the government chooses $g_{opt}=0$ for $SW_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{frag}} < SW_{frag}^{cp}\Big|_{g=0}$. In this

case, non-monitoring induces a SPNE with firms choosing fragmentation mode of entry with the CP-strategy with complete deterrence of the entry of the pirate. (Hence Proved).

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[30] $d\tilde{g}_{frag} = (\partial \tilde{g}_{frag} / \partial t)dt + (\partial \tilde{g}_{frag} / \partial k)dk$. Proposition 4 proves that $\partial \tilde{g}_{frag} / \partial k > 0$ and $\partial \tilde{g}_{frag} / \partial t < 0$ and $dt < 0$ and $dk > 0$ therefore $d\tilde{g}_{frag} > 0$ which implies that $\tilde{g}_{frag} < \tilde{g}_{LDC}$

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Equilibrium 2

The monitoring rate $g_{opt} = \tilde{g}_{LDC}$, *induces complete-LDC production structure, with the AC-strategy as a sub-game perfect Nash equilibrium if* $\bar{\pi}_{frag}^{cp} < \bar{\pi}_{LDC}^{cp}$, $\bar{\pi}_{LDC}^{cp} = \pi_{LDC}^{ac(exp)}\Big|_{g=\tilde{g}_{LDC}} > \pi_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{LDC}}$,
$SW_{LDC}^{ac}\Big|_{g=\tilde{g}_{LDC}} > SW_{LDC}^{cp}\Big|_{g=0}$ *and* $\pi_{LDC}^{fake(exp)} > 0$.[31]

Proof: In this case for, $g_{opt} = \tilde{g}_{LDC}$ the MNC either chooses complete-LDC mode of entry with the AC-strategy or can deviate to fragmented mode of entry as $\tilde{g}_{frag} < \tilde{g}_{LDC}$. This deviation is not feasible if $\bar{\pi}_{LDC}^{cp} = \pi_{LDC}^{ac(exp)}\Big|_{g=\tilde{g}_{LDC}} > \pi_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{LDC}}$ and $\bar{\pi}_{frag}^{cp} < \bar{\pi}_{LDC}^{cp}$. Further if $g_{opt} = \tilde{g}_{LDC}$ maximizes social welfare under complete-LDC mode of entry with AC-strategy (with $SW_{LDC}^{ac}\Big|_{g=\tilde{g}_{LDC}} > SW_{LDC}^{cp}\Big|_{g=0}$) and the pirate earns a positive profit, then none of the agents has any incentive to deviate. So $g_{opt} = \tilde{g}_{LDC}$ induces an SPNE under the above conditions. (Hence proved).

Equilibrium 3

The non-monitoring or $g_{opt} = 0$, *induces complete-LDC production structure, with the CP-strategy as the sub-game perfect Nash equilibrium if* $\bar{\pi}_{LDC}^{cp} > \bar{\pi}_{frag}^{cp}$ *and* $\pi_{LDC}^{ac(exp)}\Big|_{g=\tilde{g}_{LDC}} < \pi_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{LDC}}$.

Proof: If $\bar{\pi}_{LDC}^{cp} > \bar{\pi}_{frag}^{cp}$ and $\pi_{LDC}^{ac(exp)}\Big|_{g=\tilde{g}_{LDC}} < \pi_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{LDC}}$, the government cannot maximise welfare by choosing $g_{opt} = \tilde{g}_{LDC}$ as for $\tilde{g}_{LDC}$ deviation to fragmentation mode of entry is profitable for the MNC. Hence, under this condition $g_{opt} = 0$ will induce SPNE with the MNC choosing the CP-strategy under LDC mode of entry with complete deterrence of piracy.

The nature of equilibrium will depend on the parameter configurations of the model. We define a critical value of transport cost $'t'$ given as t^* in equation (37) such that at $t = t^*$, profit of the MNC under the CP-strategy for fragmentation and complete-LDC modes of entry are equal, that is, $\bar{\pi}_{frag}^{cp} = \bar{\pi}_{LDC}^{cp}$

$$t^* = (\theta_h - w) - \sqrt{(\theta_h - w)^2 - 4(T_{LDC}^{cp} - T_{frag}^{cp})} \tag{37}.$$

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[31] In this case we have assumed that $\tilde{g}_{LDC} < g_{frag}^*$, so that the MNC chooses the AC-strategy under fragmentation for $g = \tilde{g}_{LDC}$. Otherwise if $\tilde{g}_{LDC} > g_{frag}^*$, MNC enjoys monopoly profit at $g = \tilde{g}_{LDC}$ and Equilibrium 2 will induce a SPNE if $\pi_{LDC}^{ac(exp)}\Big|_{g=\tilde{g}_{LDC}} > \pi_{frag}^{mono}$

Thus, for $t < t*$ we have $\overset{cp}{\pi_{\text{frag}}} > \overset{cp}{\pi_{\text{LDC}}}$ and vice versa.

We define a locus (LL) of $'k'$ and $'t'$ combinations along which $\pi_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{\text{LDC}}} = \bar{\pi}_{LDC}^{cp}$, where the slope of the locus as defined below is negative given Proposition 3:[32]

$$\frac{dk}{dt}\Big|_{LL} = -\frac{\partial \pi_{frag}^{ac(exp)}/\partial t}{\partial \pi_{frag}^{ac(exp)}/\partial k} < 0$$

As $\partial \pi_{\text{frag}}^{ac(exp)}/\partial t < 0$ (for θ_h sufficiently high) and $\partial \pi_{\text{frag}}^{ac(exp)}/\partial k < 0$. [33]

Thus, for $'k'$ and $'t'$ combinations lying above the locus we have $\pi_{\text{frag}}^{ac(exp)}\Big|_{g=\tilde{g}_{\text{LDC}}} < \overset{cp}{\pi_{\text{LDC}}}$ as high $'k'$ and $'t'$ reduce the fragmented profit of the MNC under the AC-strategy and vice versa. The (LL) locus is shown in Figure 2.

Proposition 8

There exists a value of shipment-cost $t*$ defined in equation (37), such that

i) *For $t \leq t*$, either Equilibrium 1 or Equilibrium 1a will be the optimal solution.*

ii) *For $t > t*$ and t and k combinations lying above the LL locus Equilibrium 2 will be the optimal solution.*

iii) *For $t > t*$ and t and k combinations lying below the locus LL Equilibrium 3 will be the optimal solution.*

Proof: i) $t \leq t* \Rightarrow \bar{\pi}_{LDC}^{cp} \leq \bar{\pi}_{frag}^{cp}$. Under this configuration, if $SW_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{frag}} < SW_{frag}^{cp}\Big|_{g=0}$, Equilibrium 1a becomes the optimal solution as none has any incentive to deviate. Alternatively for $SW_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{frag}} \geq SW_{frag}^{cp}\Big|_{g=0}$ Equilibrium 1 becomes optimal solution and the MNC does not have any incentive to deviate for $\pi_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{frag}} = \bar{\pi}_{frag}^{cp} > \bar{\pi}_{LDC}^{cp}$

ii) $t > t* \Rightarrow \bar{\pi}_{LDC}^{cp} > \bar{\pi}_{frag}^{cp}$ or $\pi_{LDC}^{ac(exp)}\Big|_{g=\tilde{g}_{\text{LDC}}} = \bar{\pi}_{LDC}^{cp} \geq \bar{\pi}_{frag}^{cp}$

Along LL locus $\pi_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{\text{LDC}}} = \bar{\pi}_{LDC}^{cp} = \pi_{LDC}^{ac(exp)}\Big|_{g=\tilde{g}_{\text{LDC}}}$, if $'k'$ and $'t'$ combinations lie above the LL locus, then $\pi_{LDC}^{ac(exp)}\Big|_{g=\tilde{g}_{\text{LDC}}} > \pi_{frag}^{ac(exp)}\Big|_{g=\tilde{g}_{\text{LDC}}}$ and Equilibrium 2 will be the solution for

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[32] LL schedule will cut t axis for k=0 at $t_1* = (\theta_h - w) - \sqrt{(\theta_h - w)^2 - 4T_{LDC}^{cp}}$.

[33] It can be shown that $d^2k/dt^2\Big|_{LL} > 0$

$$SW^{ac}_{LDC}\Big|_{g=\tilde{g}_{LDC}} > SW^{cp}_{LDC}\Big|_{g=0} \text{ and } \pi^{fake(exp)}_{LDC} > 0.$$

iii)   For $t > t*$ and $'k'$ and $'t'$ combinations lying below the LL locus, at $\tilde{g}_{LDC}$ the MNC will always move to the fragmented mode of entry as $\pi^{ac(exp)}_{LDC}\Big|_{g=\tilde{g}_{LDC}} < \pi^{ac(exp)}_{frag}\Big|_{g=\tilde{g}_{LDC}}$. So the only possible solution of the model will be as defined by Equilibrium 3 where $g_{opt}=0$ and complete-LDC mode of entry with the CP-strategy is chosen.

In Figure 2 we illustrate the equilibrium choices for different $'k'$ and $'t'$ combinations.
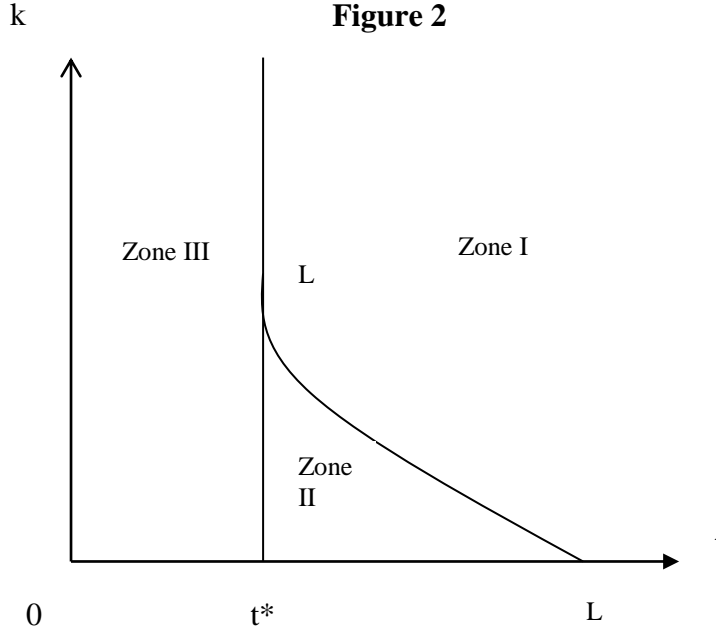

Figure 2

Figure 2 defines three zones for different equilibrium configurations. In Zone I, $'t' > t*$ and $'t'$ and $'k'$ combinations lying above the LL locus, $\pi^{ac(exp)}_{LDC}\Big|_{g=\tilde{g}_{LDC}} = \pi^{cp}_{LDC} \geq \pi^{cp}_{frag}$ and $\pi^{ac(exp)}_{LDC}\Big|_{g=\tilde{g}_{LDC}} > \pi^{ac(exp)}_{frag}\Big|_{g=\tilde{g}_{LDC}}$ government chooses $g = \tilde{g}_{LDC}$ for $SW^{ac}_{LDC}\Big|_{g=\tilde{g}_{LDC}} \geq SW^{cp}_{LDC}\Big|_{g=0}$.(Equilibrium 2)

In Zone II, $'t' > t*$ but $'t'$ and $'k'$ combinations lying below the LL locus $\overline{\pi}^{cp}_{LDC} \geq \overline{\pi}^{cp}_{frag}$ but $\pi^{ac(exp)}_{LDC}\Big|_{g=\tilde{g}_{LDC}} < \pi^{ac(exp)}_{frag}\Big|_{g=\tilde{g}_{LDC}}$, government chooses g=0 or non-monitoring.(Equilibrium 3)

In Zone III for $'t' \leq t*$, $\overline{\pi}^{cp}_{LDC} \leq \overline{\pi}^{cp}_{frag}$. Government chooses g=0   if $SW^{ac(exp)}_{frag}\Big|_{g=\tilde{g}_{frag}} < SW^{cp}_{frag}\Big|_{g=0}$,otherwise government chooses $g = \tilde{g}_{frag}$ (Equilibrium 1 or 1a)

From equation (37) it is found that $\partial t*/\partial\theta_h < 0$. It implies that as θ_h (the highest value of willingness to pay for the product) increases $t*$ falls. Thus, the MNC chooses complete-LDC production

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for lower values of shipment-cost because a rise in θ_h improves the relative profitability of this mode through an increase in the willingness to pay for the product of an average consumer[34].

Alternatively, $\partial t * / \partial w > 0$, that is, if per unit assembling cost increases in LDC, the MNC prefers to choose fragmentation mode of entry than the complete-LDC as the former involves lower probability of copying of the product.

Finally, $\partial t * / \partial (T_{LDC}^{cp} - T_{frag}^{cp}) > 0$ implies that if $(T_{LDC}^{cp} - T_{frag}^{cp})$ falls, the MNC prefers to choose the complete-LDC mode of entry to the fragmentation. This has a policy implication too. Suppose the local LDC government provides some additional incentive, apart from monitoring, to the MNC under complete-LDC mode of entry, so that the $(T_{LDC}^{cp} - T_{frag}^{cp})$ is reduced, then $t *$ will fall and areas under Zone 1 and Zone II will expand. This will improve the possibility of complete transfer of technology to LDC.

Section 5: Numerical Analysis

In this section we present a simple numerical analysis to determine the SPNE equilibrium solution of the model using the following functional forms:

$h(x) = 1/x$ for $x > 1$
$\quad\quad = 1$ if $x = 0$

$c(g) = g^2/2$

The results of numerical analysis has been are summarized in Table 3 for different parameter values[35]

<div align="center">Table 3: Summarized Results of Numerical Analysis</div>

| Parameters	$t *$	Shipment-cost $'t'$	Profits, Social Welfare, g_{opt}	SPNE
CASE 1: $A=0$, $\theta_h = 4$, $q=.5$, $w=.4$, $k=.7$ $T_{frag}^{cp}=1.75$ $T_{LDC}^{cp}=2$ $G=.25$ $F=.15$ (See Figure 3a, 3b and 3c)	0.141677	$0 < t \le .031$	$\overline{\pi}_{frag}^{cp} > \overline{\pi}_{LDC}^{cp}$, $SW_{frag}^{ac(exp)}\big|_{g=\tilde{g}_{frag}} < SW_{frag}^{cp}\big|_{g=0}$ $g_{opt}=0$	Fragmentation mode of entry with the CP-strategy. The pirate does not enter (Equilibrium 1a)
		$.031 < t \le .141677$	$\pi_{frag}^{ac(exp)}\big|_{g=\tilde{g}_{frag}} = \overline{\pi}_{frag}^{cp} > \overline{\pi}_{LDC}^{cp}$, $SW_{frag}^{ac(exp)}\big|_{g=\tilde{g}_{frag}} > SW_{frag}^{cp}\big|_{g=0}$ $g_{opt} = \tilde{g}_{frag}$, $\pi_{frag}^{fake(exp)} > 0$ for relevant value g.	Fragmentation mode of entry with the AC-strategy. The pirate may enter. (Equilibrium 1)
		$.141677 < t \le .194$.[36]	$\overline{\pi}_{LDC}^{cp} > \overline{\pi}_{frag}^{cp}$ and $SW_{LDC}^{ac}\big|_{g=\tilde{g}_{LDC}} < SW_{LDC}^{cp}\big|_{g=0}$ $\pi_{LDC}^{ac(exp)}\big|_{g=\tilde{g}_{LDC}} < \pi_{frag}^{ac(exp)}\big|_{g=\tilde{g}_{LDC}}$, $g_{opt}=0$	LDC mode of entry with the CP-strategy. The pirate does not enter. (Equilibrium 3)

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[34] $E(\theta) = (2\theta_h - 1)/2$

[35] Data set generated for numerical analysis is available with the authors on request.

[36] This value of t is obtained from LL locus for k=.7

		t>.194	$\overline{\pi}_{LDC}^{cp} > \overline{\pi}_{frag}^{cp}$ and $\pi_{LDC}^{ac(exp)}\big|_{g=\tilde{g}LDC} > \pi_{frag}^{ac(exp)}\big|_{g=\tilde{g}LDC}$ $SW_{LDC}^{ac}\big|_{g=\tilde{g}LDC} \geq SW_{LDC}^{cp}$ Thus, $g_{opt} = \tilde{g}_{LDC}$ $\pi_{LDC}^{fake(exp)} > 0$ for relevant value g.	LDC mode of entry with the AC-strategy and the pirate may operate in the market. (Equilibrium 2)
CASE II: *A=0,* $\theta_h = 4$ *q=.95,* *w=.4, k=.7* T_{frag}^{cp} *=1.75* T_{LDC}^{cp} *=2* *G=.25 F=.15*	0.141677	$. \; 0 < t \leq .141677$	$\overline{\pi}_{frag}^{cp} > \overline{\pi}_{LDC}^{cp} > 0$ and $\pi_{frag}^{fake(exp)} < 0$, g_{opt}=0	Fragmentation mode of entry with the CP-strategy. (Equilibrium 1a).
		t>.141677	$0 < \overline{\pi}_{frag}^{cp} < \overline{\pi}_{LDC}^{cp}$ and $\pi_{LDC}^{fake(exp)} < 0$, g_{opt}=0	Complete-LDC mode of entry with CP-strategy. (Equilibrium 3).

Table 3 presents the possible SPNE of the model for two sets of parameter values. LL locus corresponding to case I is presented in Figure 3a. The results summarized under Case I, depict all possible equilibrium configurations for different range of values of $'t'$ as presented in Proposition 8. Figure 3a shows that conditions under which equilibrium 1 or 1a take place and Figure 3b shows the possible existence of equilibrium 2 and equilibrium 3.

Figure 3a
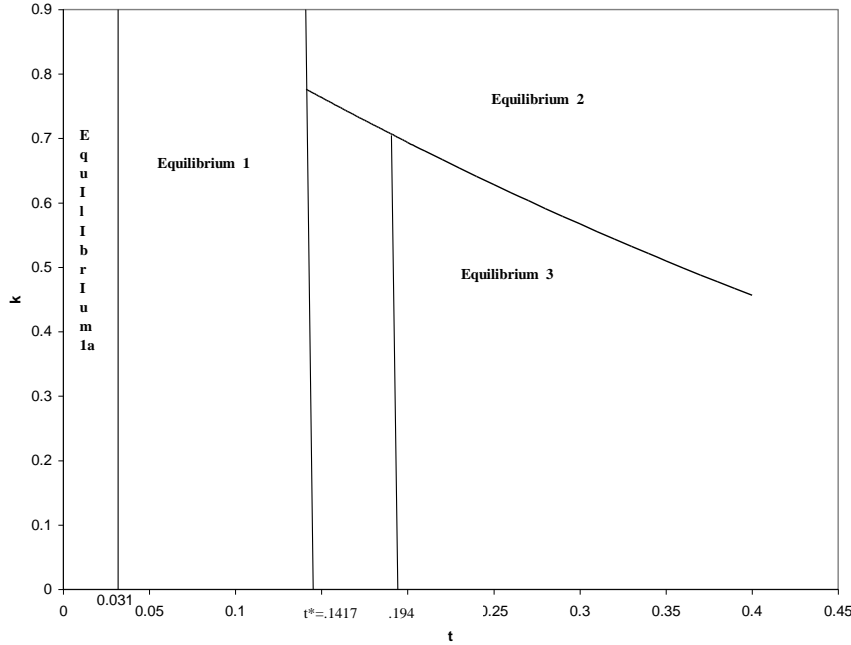
LL Locus for A=0, $\theta_h = 4$ q=.5, w=.4, T_{frag}^{cp}=1.75, T_{LDC}^{cp}=2, G=.25 and F=.15
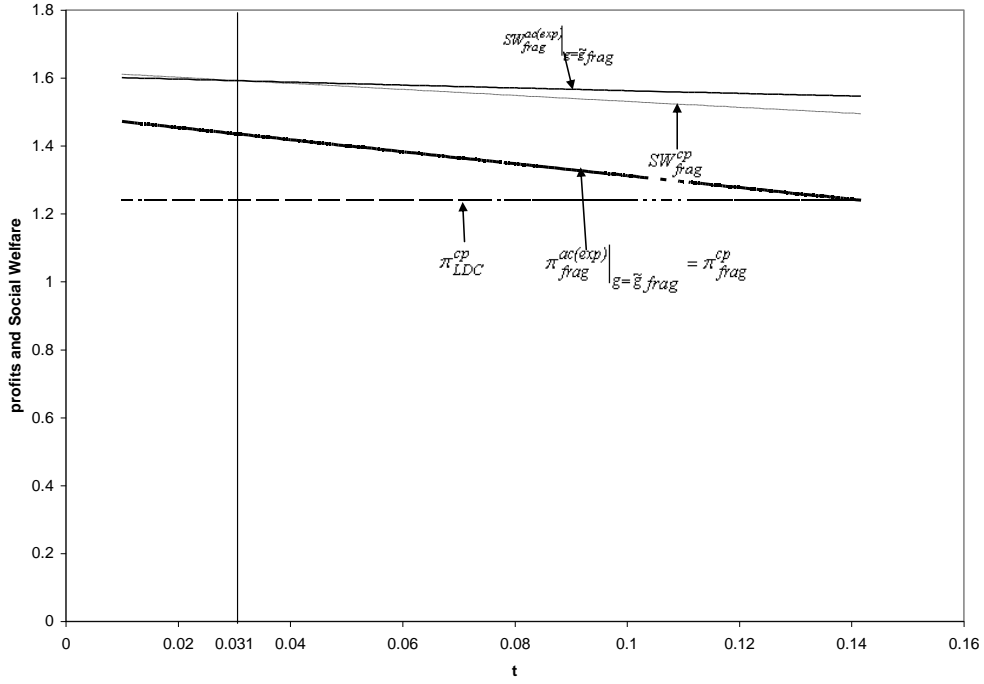
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Figure 3b

Figure 3b shows that for $0 < t \le .031$ $\left. SW_{frag}^{ac(exp)} \right|_{g=\widetilde{g}\,frag} < SW_{frag}^{cp}$ and equilibrium 1a occurs. For $.031 < t \le .141677$

$\left. SW_{frag}^{ac(exp)} \right|_{g=\widetilde{g}\,frag} > SW_{frag}^{cp}$ and Equilibrium 1 occurs.
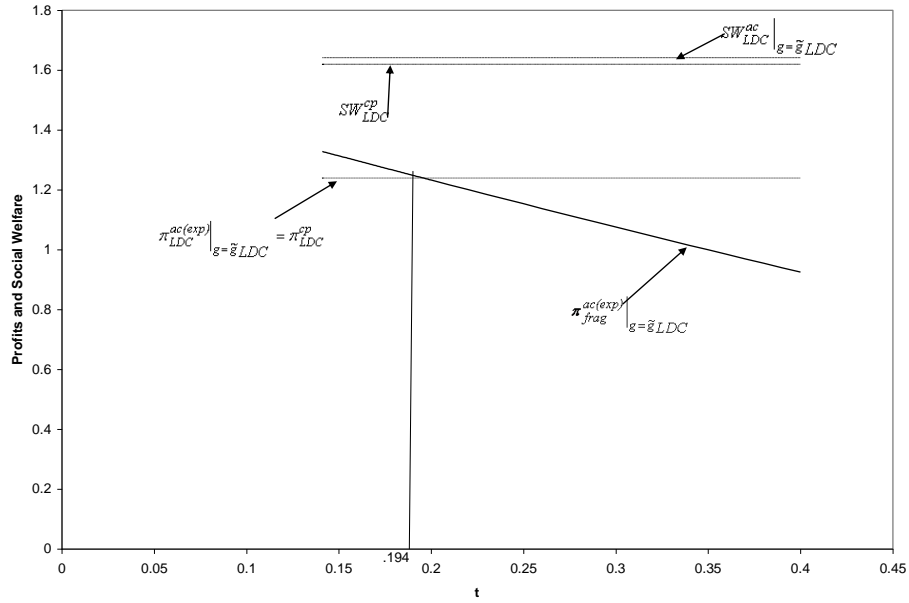
Figure 3c

Figure 3c shows that for $.141677 < t < .194$ $\left. SW_{LDC}^{ac} \right|_{g=\widetilde{g}_{LDC}} > SW_{LDC}^{cp}$ but $\left. \pi_{LDC}^{ac(exp)} \right|_{g=\widetilde{g}_{LDC}} < \left. \pi_{frag}^{ac(exp)} \right|_{g=\widetilde{g}_{LDC}}$. So Equilibrium 3

occurs. However for t>.194 $\left. \pi_{LDC}^{ac(exp)} \right|_{g=\widetilde{g}LDC} > \left. \pi_{frag}^{ac(exp)} \right|_{g=\widetilde{g}LDC}$ Equilibrium 2 occurs.

In Case II, Table 3 we have increased only the value of 'q', while keeping the values for all other parameters unchanged as in Case I. As 'q' is increased, we observe that the profit of the pirate becomes strictly negative for $g = \tilde{g}_{frag}$ under fragmentation mode of entry and for $g = \tilde{g}_{LDC}$ under complete-LDC mode of entry, but positive for g=0 under both modes of entry[37]. Thus, only possible equilibrium configurations are either Equilibrium 1a (if $t < t^*$) or Equilibrium 3 *(if $t \geq t^*$)* when LDC government chooses non-monitoring and the entry of the pirate is completely deterred.

Section 6: Conclusion

Our model relates the mode of entry of an MNC in a vertically differentiated LDC market to the IPR regime of the economy and tries to find out the sub-game perfect Nash equilibrium level of monitoring rate exercised by the LDC government under different environments where the MNC incurs copy protection investment to deter the entry of a pirate.

The MNC in our model originates in an IPR protected developed country. It manufactures a product which can be suitably fragmented. The MNC can develop the technology-oriented intermediate-good in the developed country and finish it in the LDC. The sequential game proceeds in the following way: In the first stage, the local LDC government chooses the level of IPR protection. Given the IPR level the MNC chooses from the two options of entry namely fragmented mode of entry and complete-LDC mode of entry. It is assumed that embodied technology transfer takes place in the fragmented mode of entry whereas full technology transfer takes place only in the complete-LDC mode of entry. Further, in these two options there is a possibility that a pirate can copy the original product. Given the possibility of the entry of the pirate the MNC has two options to control the unauthorized reproduction of its goods. It can fully prevent the entry of the pirate by incurring a complete copy protection investment (CP-strategy) or it can undertake an anti-copying investment for which copying of the original product by the pirate is always possible with a positive probability (AC-strategy) when the pirate incurs a fixed cost. After observing the IPR rate of the government and the MNC's strategy choice the pirate takes the entry decision. It is assumed that quality of the pirated good is inferior to that of the original product. If the pirate enters the MNC acts as a price leader otherwise he acts as a monopolist.

The results show that the local government can induce complete-LDC mode of entry with full technology transfer only if the shipment-cost of transferring the intermediate product to LDC in the fragmentation mode is above a critical level. Under complete-LDC mode of entry, monitoring is socially

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[37] The results follow from Proposition 2 ($\partial \pi_{frag}^{fake\,(exp)} / \partial g < 0$ and $\partial \pi_{frag}^{fake\,(exp)} / \partial q < 0$ for $q > 2(\theta_h + w + t)/(6\theta_h + w + t) = 0.4$) and from Proposition 6($\partial \pi_{LDC}^{fake\,(exp)} / \partial g < 0$ and $\partial \pi_{LDC}^{fake\,(exp)} / \partial q < 0$ for $q > 2(\theta_h + w)/(6\theta_h + w) = 0.36$).

optimal if probability of copying in the fragmented production is relatively high. However, government monitoring induces the MNC to adopt the AC-strategy and complete deterrence of piracy is not possible. Alternatively, if the shipment-cost is above the critical level but the copying probability is relatively low under fragmentation, non-monitoring is socially optimal and the MNC chooses the CP-strategy that results in full deterrence of piracy. Similarly, for a low shipment-cost when fragmentation is optimal, non-monitoring leads to complete deterrence of piracy as the MNC adopts CP-strategy, whereas government monitoring induces the MNC to choose AC-strategy and the pirate can enter the market. Hence we observe that non-monitoring induces the MNC to deter piracy completely by itself whereas if government monitors it chooses AC-strategy where the pirate always has a chance of entry. This result reveals the fact that whenever the LDC government chooses to monitor the pirate it monitors so inefficiently that the pirate has a good chance of both breaking the MNC's technical protection schemes and not getting caught by the government. Intuitively, this means that when monitoring is socially optimal the LDC government wants the pirate to enter the market.

Further, a low shipment-cost induce the MNC to choose complete-LDC mode of entry if the willingness to pay for the product of an average consumer increases, the wage rate in LDC falls or the difference between complete copy protection investment for complete-LDC or fragmentation modes of entry falls. It is also observed that a certain degree of product differentiation is needed for profitable operation of the pirate.

The paper also runs a numerical analysis to validate the results. The results of numerical analysis show that if the quality difference between the original and the pirated product is very low, non-monitoring becomes the optimal solution irrespective of the mode of entry of the MNC in the market.

Thus, the paper explains the link between the optimal mode of entry and technology transfer in an LDC with the IPR policy of the LDC government.

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Appendix 1

Proof of Proposition 1

Proof: Differentiating Equation.(16) with respect to $'g'$, $'t'$ and $'k'$ respectively

$$\partial \overline{x}_{frag}^{ac} / \partial g = h'(\overline{x}_{frag}^{ac}) / h''(\overline{x}_{frag}^{ac})(1-g) < 0$$

$$\partial \overline{x}_{frag}^{ac} / \partial t = h'(\overline{x}_{frag}^{ac})(w+t)q / 4(1-q)h''(\overline{x}_{frag}^{ac})M < 0$$

$$\partial \overline{x}_{frag}^{ac} / \partial k = -h'(\overline{x}_{frag}^{ac}) / kh''(\overline{x}_{frag}^{ac}) > 0 \quad \because h'(\overline{x}_{frag}^{ac}) < 0 \text{ and } h''(\overline{x}_{frag}^{ac}) > 0, M > 0$$

Hence Proposition 1 is proved.

Appendix 2

Proof of Proposition 2

Proof: i) Differentiating Equation (17) with respect to $'k'$, $'t'$,$'g'$ we get

$$\partial \pi_{frag}^{fake(\exp)} / \partial k = \Delta \Omega > 0 \ \because \Delta > 0, \Omega > 0$$

$$\partial \pi_{frag}^{fake(\exp)} / \partial t = k(1-g)h(\overline{x}_{frag}^{ac})q[2\theta_h(1-q)+(w+t)(2-q)]/8(1-q)(2-q)+kh'(\overline{x}_{frag}^{ac})\partial \overline{x}_{frag}^{ac} / \partial t \ \Omega > 0$$

$$\because \partial \overline{x}_{frag}^{ac} / \partial t < 0 \text{ and } h'(\overline{x}_{frag}^{ac}) < 0 \text{ and } \Omega > 0$$

$\partial \pi_{frag}^{fake(exp)} / \partial g = -q\left[2\theta_h(1-q)+(w+t)(2-q)\right]^2 / 16(1-q)(2-q)^2 \left\{k\Delta - kG\left[h(\bar{x}_{frag}^{ac})+h'(\bar{x}_{frag}^{ac})^2 g / h''(\bar{x}_{frag}^{ac})(1-g)\right] \right\}<0$

which follows from C1 defined in Equation (5) and $h'(\bar{x}_{frag}^{ac})<0, h''(\bar{x}_{frag}^{ac})>0$.

ii)) As $\pi_{frag}^{fake(exp)} \leq 0$ for $g \in [g_{frag}^*,1]$ the pirate does not enter.

Differentiating Equation(18) with respect to 'G', $'t'$ and $'k'$ respectively we get

$\partial g_{frag}^* / \partial G = -\left[\{q\{2\theta_h(1-q)+(w+t)(2-q)\}^2 / 16(2-q)^2(1-q)\} - F / kh(\bar{x}_{frag}^{ac}) \right] / B < 0$

$\partial g_{frag}^* / \partial t = \left[\left\{q\{\theta_h(1-q)+(w+t)(2-q)\}/8(1-q)(2-q) \right\}\left\{G + \dfrac{F}{kh(\bar{x}_{frag}^{ac})} \right\}\right] / B^2 + \dfrac{Fh'(\bar{x}_{frag}^{ac})}{Bkh(\bar{x}_{frag}^{ac})^2}\partial \bar{x}_{frag}^{ac}/\partial t > 0$

The first term in the R.H.S is positive while in the 2nd term $\partial \bar{x}_{frag}^{ac}/\partial t <0$ and $h'(\bar{x}_{frag}^{ac})<0$ by assumption.

$\partial g_{frag}^* / \partial k = F\Delta/(kh(\bar{x}_{frag}^{ac}))^2 B > 0$

$\because h'(\bar{x}_{frag}^{ac})<0, \partial \bar{x}_{frag}^{ac}/\partial k > 0, B = q\{2\theta_h(1-q)+(w+t)(2-q)\}/16(2-q)^2(1-q)+G$

iii) Finally differentiating Equation (17) with respect to 'q' we get

$\partial \pi_{frag}^{fake(exp)} / \partial q = kh(\bar{x}_{frag}^{ac})(1-g)\dfrac{[2\theta_h(1-3q)+(w+t)(2-q)][2\theta_h(1-q)+(w+t)(2-q)]}{16(1-q)(2-q)^3}+kh'(\bar{x}_{frag}^{ac})\Omega\partial\bar{x}_{frag}^{ac}/\partial q$

$= kh(\bar{x}_{frag}^{ac})(1-g)\dfrac{[2(\theta_h+w+t)-q(6\theta_h+w+t)][2\theta_h(1-q)+(w+t)(2-q)]}{16(1-q)(2-q)^3}++kh'(\bar{x}_{frag}^{ac})\Omega\partial\bar{x}_{frag}^{ac}/\partial q < 0$

if $q > 2(\theta_h+w+t)/(6\theta_h+w+t)$ where $6\theta_h+w+t > 2(\theta_h+w+t)$ for $\theta_h > w+t$

$\partial\bar{x}_{frag}^{ac}/\partial q = -h'(\bar{x}_{frag}^{ac})\partial M /\partial q / h''(\bar{x}_{frag}^{ac})M > 0$ & $\partial M/\partial q > 0$

Hence Proposition 2 is proved.

Appendix 3

Proof of Proposition 3

Proof:

i) Differentiating equation. (15) with respect to $'k'$, and $'g'$ for $x_{frag}^{ac} = \bar{x}_{frag}^{ac}$ we get

$\partial \pi_{frag}^{ac(exp)} / \partial k = h'(\bar{x}_{frag}^{ac}) / kh''(\bar{x}_{frag}^{ac})-(1-g)M\Delta < 0 \because h'(\bar{x}_{frag}^{ac})<0$ and $\Delta > 0$.

$\partial \pi_{frag}^{ac(exp)} / \partial g = -h'(\bar{x}_{frag}^{ac}) / h''(\bar{x}_{frag}^{ac})(1-g)+kM\Delta > 0$

$as\ M > 0, h'(\bar{x}_{frag}^{ac})<0, h''(\bar{x}_{frag}^{ac})>0$ and $\Delta > 0$

ii) Differentiating equation (15) with respect to 't' for $x_{frag}^{ac} = \bar{x}_{frag}^{ac}$ we have

$\partial \pi_{frag}^{ac(exp)} / \partial t = -\theta_h / 2+(w+t)\left[1+\{kh(\bar{x}_{frag}^{ac})q(1-g)\}/2(1-q)\right]/2$

If θ_h is sufficiently large then $\partial \pi_{frag}^{ac(exp)} / \partial t < 0$

Hence Proposition 3 is proved.