Eco-Innovation with Opportunity of Licensing and Threat of Imitation

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Abstract

We consider the product and process innovation effort decisions a sustainable (eco) manufacturer (innovator/leader) makes in the presence of a traditional manufacturer (imitator/follower) who may procure a license or imitate innovation. While product development can be easily protected by patenting and licensing, process innovation is more difficult to protect. We find that the ignoring the potential of process imitation reduces profits for the innovating firm as the follower favors all-or-nothing imitation and many equilibrium strategies, from the leader's perspective, are to deter copycatting behavior. We also show the eco-innovator may lose its competitive advantage through licensing its product innovation; moreover, licensing may result in more imitation. Lastly, we glean further insights by characterizing the equilibrium strategies with respect to cost-related factors.

Keywords: Sustainability, Process innovation, Product development, Licensing, Imitation

1. Introduction

Eco-innovation, as defined by the European Union in its Entrepreneurship and Innovation Programme (EuropeanUnion, 2008), is "any form of innovation aiming at significant and demonstrable progress towards the goal of sustainable development. This can be achieved either by reducing the environmental impact or achieving a more efficient and responsible

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use of resources." Further, eco-innovation "will ... produce quality products with less environmental impact, whilst innovation can also include moving towards more environmentally friendly production processes and services." In addition to having government programs to promote and sustain eco-innovation, there is market demand for sustainability and environmentally friendly products driven by not only risk and regulatory compliance but also consumer awareness (Adams, 2014), companies are beginning to incorporate sustainability as a feature into their product or process innovations. For example, Zara, the Spanish company investing in "fast fashion" and the world's largest clothing retailer, committed to eliminate the release of hazardous chemicals from its manufacturing processes following intensive public pressure and signed a safety agreement after the death of 1,127 as a result of a building collapse in Bangladesh (Campbell, 2013; Greenpeace, 2012). Identifying that helping customers to reduce their carbon impact as a priority, Siemens, introduced an environmental portfolio of green products and services, which generated €32.3 billion, 43% of the company's total revenue, and cut customers' CO_2 emissions by 377 million metric tons (Siemens, 2014). Beside the goals of better non-financial (environmental, social and governance) outcomes, such eco-innovations are also driving strong financial performance in many ways through revenue enhancement and cost reduction (Bonini and Swartz, 2014; Przychodzen and Przychodzen, 2015). According to Eccles et al. (2014), highly-sustainable companies did better in both organizational processes and performance than other companies. Porter and Kramer (2006) advise that, when approached strategically, corporate social responsibility, more than just a cost or constraint, can generate opportunity, innovation, and a competitive advantage. For example, Toyota's hybrid-engine Prius was the company's early response to public concern about auto emission and later became the market leader in hybrid technology (Zapata and Nieuwenhuis, 2010).

However, as companies develop new sustainable initiatives to grow their market and market share by responding to customers' needs, they must address licensing their products and responding to copycat firms (Bhupendra and Sangle, 2016). Some firms may choose not to issue a license for their innovation in order to build a competitive advantage and stifle competition if they have the manufacturing and marketing capability to the developed technology, for example DuPont sued Monsanto over infringement of patents for producing seeds that can withstand environmental stress (Decker and Kaskey, 2011). On the other hand, firms may choose to keep their innovation a trade secret especially if the innovation is a process that may be difficult to protect (Moore and Ausley, 2004; Teece, 1986; Young, 2001). For example, in the chemical industry, including consumer products like Clorox's Green Works detergents (Glazer, 2012) and WD-40 (Bounds, 2006), process innovation is typically kept as a trade secret (Maréchal, 2013). Regardless of the way innovation is protected, patented or kept a trade secret, firms must deal with copycat products. For example, in 2012, Nike sued Adidas for patent infringement over knit-style sneakers, whose manufacturing process produces 66% less waste than traditional methods (Townsend, 2012). In the past, many companies copied and succeeded: e.g., Apple imitated others' products but made their iPod, iPhone, and iPad more appealing from both hardware and software perspectives; and fast-fashion firms grow by copying innovations from the catwalk (The Economist, 2012). The copycat followers have lower research-and-development (R&D) costs and bear less risk of market failure, which give them advantages over market pioneers (Golder and Tellis, 1993). According to Shenkar (2010a), the often overlooked and despised imitation can be more important to business growth than innovation as nearly 98% of the value generated by innovations is captured by the copycats. However, imitation is not just mindless repetition but rather requires strategic planning. Therefore, companies should smartly use it to gain a strategic edge (Shenkar, 2010b).

In this paper we consider a sustainable (eco) manufacturer that will exert effort into process and product eco-innovation. Note that as defined by the European Union (EuropeanUnion, 2008), eco-innovation may result in "more environmentally friendly production processes" in addition to new "products with less environmental impact". Given the European Union definition of eco-innovation, we say that *process eco-innovation* is any developed business or manufacturing process that is more environmentally friendly, and we say that *product eco-innovation* is any developed product that has less environmental impact, relative to what was previously available. Through the use of patents, a product eco-innovation can be protected from copycats (enforceable). On the other hand, though not impossible, it is more difficult to protect new processes from copycat competitors (unenforceable) Teece (1986).[1] Eco-innovation may result in a higher per-unit production cost for the innovating manufacturer, but result in a larger market share for the innovator. In addition to being more appealing to a marketplace, an innovating manufacturer may receive government subsidy, from programs similar to those run by the European Union, to make its product or process more sustainable, potentially resulting in increased profits. However, with the looming threat of having any developed process or product imitated, the innovative manufacturer must take these opposing forces into account before making any innovation decisions. The rival manufacturer must also consider how much of any developed process or product to copy when improving its manufacturing process or product line.

In order to better understand the opposing forces of increased market growth due to innovation and the cost of innovation and copycat products, in this paper we model the interactions between a sustainable (innovative) and a traditional (copycat) manufacturer when both need to make production, research and development effort decisions, and technology transfer decisions. In this setting, we show that the potential of copycatting can be a threat but not always, and it might be deterred. In addition, we show that the presence of copycatting results in an across the board reduction in eco-innovation of all types. We also find that licensing eco-innovation may not benefit the innovator when substantial competitive advantage can be built through new sustainable product development, and it may further induce imitation. Lastly, our numerical studies show that cost characteristics play a key role in strategic innovation and imitation, especially when more proactive strategies, like monopoly and deterrence, are considered.

In the remainder of the paper we first discuss related work in Section 2. We then present our model in Section 3, followed by our analysis in Section 4. We present numerical studies, in which we show our results graphically, in Section 5, and conclude the paper in Section 7.

[1]Personal communication with university patent officer

2. Related Work

In the extensive review by Kleindorfer et al. (2005), it is noted that sustainability has gained momentum in the field of operations management (OM) in the last three decades. Green product development and sustainable process design aim to integrate environmental and social outcomes with economic outcomes, the triple bottom lines (social, environmental, and financial), instead of trading off the three outcomes. However, as indicated by Tang and Zhou (2012), extant studies on environmental measures focus mostly on government regulations while the effect of market forces is largely ignored. With consumers becoming more conscious of environmental issues, their preferences and response as well as the resulting market competition will play a more important role in determining firms' investment in sustainability (Kikuchi-Uehara et al., 2016). Alwi et al. (2014) review a selection of papers that aim to provide guidelines on sustainable engineering and innovations. Since these works do not consider direct competition, our model complements this strain of the literature by introducing a rival who may procure a license and imitate the eco-initiatives of the innovative firm. Our modeling framework of asymmetric competition reflects the need suggested by another recent review paper (Brandenburg et al., 2014). Li et al. (2017) point out that most research separates eco-innovation into eco-process and eco-product innovation (Chang, 2011; Cuerva et al., 2014; Lin et al., 2014; Rennings and Rammer, 2011; Schiederig et al., 2012). We add to this stream of literature by proposing an analytical model as to how an eco-innovating firm best responds to the threat of imitation and providing insights into behavior that may not be directly observed through surveys or publicly available data sets.

In terms of the adoption of innovation in OM, Shane and Ulrich (2004) find most of the literature (Chen and Chang, 2010; Loch and Huberman, 1999) assumes diffusion models, which also resonate strongly with the Industrial Organization R&D stream of literature in economics (Davidson and Segerstrom, 1998). However, they mostly considered what incentives need to be given such that firms become more innovative, which in turn leads to higher social welfare. Unlike these works, we do not consider the types of incentives that should be given to stimulate economic growth over time. Instead, we assume these incentives to be exogenously given and study the dynamics between a eco-innovator and a traditional imitator in a Stackelberg setting. Specifically, we consider the R&D decisions made by the innovative leader, and subsequently the post-innovation decisions, licensing and imitation, made by the follower. Though a firm's innovation strategy can focus on product, process, or both, Arundel and Kabla (1998); Brouwer and Kleinknecht (1999) found that product innovation is more likely to be patented as infringement is easier to detect. On the other hand, patenting process innovation is less likely to enforceable and hence secrecy is a more appropriate protection mechanism for this type of innovation (Cohen et al., 2000). The spillover (externality) of innovation we consider is unidirectional, from the sustainable manufacturer to the traditional manufacturer, which is consistent with the finding by Knott et al. (2009) that spillovers have directionality and differ across firms through an empirical study in the banking industry. Work on licensing, such as that by Avagyan et al. (2014); Kamien et al. (1992); Katz and Shapiro (1987), looks at why firms license and when they should enter licensing agreements and consider external incentives, such as product diffusion. We do not consider these external incentives and only consider profit that is derived from issuing a licensing agreement. To the best of our knowledge, our work is the first considering the follower can procure part of a license and partially imitate the leader's innovations, and the leader can use patents to enhance the revenue of the innovation or deter the follower's imitation through strategic investments.

3. Model

As illustrated in Figure 1 we consider a three-stage model of innovation and imitation in which a traditional manufacturer, T, and a sustainable manufacturer, S, engaging in Cournot competition within the same retail market. Thus the market-clearing price before research and development decisions is $p = m - q_S - q_T$ with a base market size, m, similar to that of Du et al. (2016); Shamir and Shin (2015); Wang and Wang (2015).

Stage 1: S determines the efforts into research and development for the sustainable pro$d$uct and pro$c$ess, I_d and I_c, at costs of $\gamma_d I_d^2$ and $\gamma_{cS} I_c^2$, respectively, similar to the quadratic

Figure 1: Pictorial representation of game dynamics

cost functions of Atasu and Subramanian (2012); Gao et al. (2016); Wang and Wang (2015)., as well as the per-unit licensing fee, λ, to charge. These innovation efforts increase S's market size by $I_d + I_c$ to $m + I_d + I_c$, and reduce T's to $m - I_d - I_c$, if there is no licensing and imitation, similar to the switching effect due to a firm violating its corporate social responsibility in Chen and Slotnick (2015); Guo et al. (2013). As noted by Haines (1964), the market response to innovation need not be linear but "a linear model is often close enough over the relevant range to the shape of the curve usually encountered to serve for practical purposes." Acemoglu and Linn (2004) found a similar linear relationship for pharmaceutical innovation. Sustainable process innovation may also increase (decrease) per-unit production cost c by βI_c for positive (negative) adjustment factor β, which is similar to that of Arora and Ceccagnoli (2006); Ceccagnoli (2005); D'Aspremont and Jacquemin (1988).

Stage 2: Given S's innovation efforts and licensing fee, T determines the fraction of the sustainable product and process innovations to license and copy from S into its business, $\theta_d \in [0, 1]$ and $\theta_c \in [0, 1]$, respectively. As new products can legally be protected using patents, the traditional manufacturer must pay a proportional licensing fee, $\theta_d \lambda$, which we discuss in greater detail shortly. On the other hand, though new processes may be patentable, identifying a process patent infringement is very difficult, which renders patenting process innovations ineffective (Peeters and van Pottelsberghe de la Potterie, 2006; Teece, 1986). Thus, we assume S does not patent nor license its newly developed processes, but all developed processes are subject to T's imitation (Ceccagnoli, 2005; D'Aspremont and Jacquemin, 1988) at a copying cost of $\theta_c \gamma_{cT} I_c$ and a unit production cost increase (or saving) $\theta_c \beta I_c$, proportional to the imitation level $\theta_c \in [0, 1]$. Similar to the negative yet prevalent cross-investments to alter a rival's demand in Arya and Mittendorf (2013) and the lobbying effort to offset the market share loss in Kraft et al.

(2013), here both licensing and imitation mitigate T's disadvantage to S's innovations, $m-(1-\theta_d)I_d$ and $m-(1-\theta_c)I_c$, respectively. That is, both S and T's market shares stay the same as m if T procures the full license and completely copies the sustainable process innovations since $m \pm (1-1)I_d \pm (1-1)I_c = m$.

Stage 3: After research and development, licensing and copying decisions are made, both manufacturers, S and T, simultaneously determine their production quantities, q_S and q_T, respectively.

Except for the seven decisions on investment, copying and production quantities, we assume the net marginal costs, γ_d, for product investments and, γ_{cS} and γ_{cT}, for process investments for S and T respectively as well as the change in production cost, β, are given and fixed. These values incorporate any government incentives or subsidies that exist for eco-innovation. Putting these parameters and decisions variables together we write the sustainable manufacturer's profit function as:

$$\Pi_S(q_S|\theta_d,\theta_c,\lambda,I_d,I_c) = [m+(1-\theta_d)I_d+(1-\theta_c)I_c-q_S-q_T]q_S+\theta_d\lambda q_T-[(c+\beta I_c)q_S+\gamma_d I_d^2+\gamma_{cS}I_c^2], \tag{1}$$

and the traditional manufacturer's profit function as:

$$\Pi_T(q_T|\theta_d,\theta_c,\lambda,I_d,I_c) = [m-(1-\theta_d)I_d-(1-\theta_c)I_c-q_S-q_T]q_T-\theta_d\lambda q_T-[(c+\theta_c\beta I_c)q_T+\theta_c\gamma_{cT}I_c^2]. \tag{2}$$

We now examine the profit function for sustainable manufacturer in greater detail. The first three terms of S's market-clearing price in (1), $m+(1-\theta_d)I_d+(1-\theta_c)I_c$, represent the effective market size after S's eco-innovation efforts (I_d, I_c), which may be offset by rival T's licensing and imitation levels $(1-\theta_d, 1-\theta_c)$. Beside the sales revenue, S may also earn extra $\theta_d\lambda q_T$ from licensing its production innovation to T. We highlight the fact that we also allow for partial licensing, as opposed to all or nothing licensing by allowing $\theta_d \in [0,1]$. We are not the first to suggest a continuum of licensing decisions as this is carried out by Mukherjee (2010) and Rockett (1990) to account for the quality of the product that is licensed, and by Bourreau et al. (2007) to model modular products, products made of a collection of components, such as a computer. As commonly used in this stream of literature (Bourreau et al., 2007; Rockett, 1990), we assume the partial licensing decisions between the two firms are made sequentially. The cost term consists of variable cost for production as well as fixed costs for product and process innovations. We note that in our model, $c+\beta I_c$, $\beta \in \mathbb{R}$, reflects the change in the unit production cost as a result of process innovation. In contrast to the R&D literature in the field of Industrial Organization, which focuses on the cost-reducing effect and thus restricts β to be negative, we allow β to take both positive and negative values to account for the fact sustainable process innovation may increase production cost, something that may be compensated by growth in market size (Nidumolu et al., 2009; Stefan and Paul, 2008). For the traditional manufacturer T, the effects of S's innovations on market share are opposite and mitigated by its licensing and imitation, which results in the licensing payment to S and imitation cost.

As both c and m are constants for ease of exposition in the remainder of the manuscript we define $a = m - c$ as in Arya and Mittendorf (2013) and rewrite (1) and (2) as:

$$\Pi_S(q_S|\theta_d, \theta_c, \lambda, I_d, I_c) = [a+(1-\theta_d)I_d+(1-\theta_c)I_c-q_S-q_T-\beta I_c]q_S+\theta_d\lambda q_T-\gamma_d I_d^2-\gamma_{cS} I_c^2 \quad (3)$$

$$\Pi_T(q_T|\theta_d, \theta_c, \lambda, I_d, I_c) = [a-(1-\theta_d)I_d-(1-\theta_c)I_c-q_S-q_T-\theta_c\beta I_c-\theta_d\lambda]q_T-\theta_c\gamma_{cT} I_c^2 \quad (4)$$

A feature of our model, is the product and process imitation fractions, θ_d and θ_c, the traditional, T, manufacturer determines. As shown in (3) and (4), these fractions have an impact on the innovation costs, market size, and licensing fees transferred between the two manufacturers. In particular, the lower the θ_d and θ_c values, the higher the differentiation between the sustainable and traditional manufacturers. Table 1 summarizes the notation used in the model.

4. Analysis

Duopoly Cases

We use backward induction to solve S's investment problem: we first find the optimal q_S and q_T, then use the updated profit function for T to solve for the optimal product licensing

Table 1: Model Notation

Symbol	Definition
I_d	Effort for sustainable product innovation
I_c	Effort for sustainable process innovation
λ	Per-unit licensing fee
θ_d	Proportion of product license to procure; $\theta_d \in [0,1]$
θ_c	Proportion of process innovation to copy; $\theta_c \in [0,1]$
q_i	Quantity sold by firm i; $i \in \{S,T\}$
γ_d	Marginal cost of product investment
γ_{ci}	Marginal cost of process investment for firm i; $i \in \{S,T\}$
β	Change of per-unit production cost
c	Unit production cost
m	Base market size
a	$= m - c$
Π_i	Firm i's profit function; $i \in \{S,T\}$

and process copying decisions, θ's, and lastly solve for S's optimal efforts, I_d and I_c, and the per unit licensing fee λ.

Given S's efforts and licensing fee (I_d, I_c, λ) as well as T's licensing and imitation levels (θ_d, θ_c), the two manufacturers' optimal quantity decisions can be determined by jointly solving the First-order Optimality Conditions (FOCs) of (3) and (4) for q_S and q_T respectively:

$$q_S(\theta_d, \theta_c, \lambda, I_d, I_c) = \frac{a}{3} + \left[(1-\theta_d)I_d + \frac{\theta_d \lambda}{3}\right] + \left[(1-\theta_c)I_c - \frac{(2-\theta_c)\beta I_c}{3}\right] \tag{5}$$

$$q_T(\theta_d, \theta_c, \lambda, I_d, I_c) = \frac{a}{3} - \left[(1-\theta_d)I_d + \frac{2\theta_d \lambda}{3}\right] - \left[(1-\theta_c)I_c - \frac{(1-2\theta_c)\beta I_c}{3}\right] \tag{6}$$

Substituting the optimal q_S and q_T back in (4) yields T's payoff function in θ_d and θ_c given S's investment levels and licensing fee:

$$\Pi_T(\theta_d, \theta_c | \lambda, I_d, I_c) = \left(\frac{a}{3} - \left[(1-\theta_d)I_d + \frac{2\theta_d \lambda}{3}\right] - \left[(1-\theta_c)I_c - \frac{(1-2\theta_c)\beta I_c}{3}\right]\right)^2 - \theta_c \gamma_{cT} I_c^2 \tag{7}$$

It can be seen from (7) that both the levels of product licensing and process imitation have impact on T's profit. With a higher level of licensing, T aims to reduce its competitive disadvantage in the marketplace to S's new sustainable product; while with a higher imitation level, T is able to reduce the negative (market-stealing) effect of S's process innovation but at a cost of exerting effort to copy the process, which may further increase the per unit production cost as well, depending on the sign of β. Continuing with our backward induction, we solve for T's optimal θ values. The optimal θ's decisions, however, can be shown to take only extreme values, i.e., 0 or 1, though they may take any value on $[0,1]$. This follows from the fact that $\Pi_T(\theta_d, \theta_c|\lambda, I_d, I_c)$ is jointly convex in θ_d and θ_c for all $\mathbb{R}^2$ (Bazaraa et al., 2006). It immediately follows that holding either θ_d or θ_c fixed, the value of the remaining free variable that maximizes $\Pi_T(\theta_d, \theta_c|\lambda, I_d, I_c)$ over $[0,1]^2$ must be either 0 or 1. Iteratively applying this observation leads to the following result.

Proposition 1.

$$(\theta_d(\lambda, I_d, I_c), \theta_c(\lambda, I_d, I_c)) = \begin{cases} (1,1) & \textit{if } I_d > \frac{2\lambda}{3} \textit{ and } I_c < \left(\frac{2a}{3} - \frac{4\lambda}{3}\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \\ (1,0) & \textit{if } I_d > \frac{2\lambda}{3} \textit{ and } I_c > \left(\frac{2a}{3} - \frac{4\lambda}{3}\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \\ (0,1) & \textit{if } I_d < \frac{2\lambda}{3} \textit{ and } I_c < \left(\frac{2a}{3} - 2I_d\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \\ (0,0) & \textit{if } I_d < \frac{2\lambda}{3} \textit{ and } I_c > \left(\frac{2a}{3} - 2I_d\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \end{cases} \tag{8}$$

All proofs can be found in the Appendix.

We find that T's licensing decision (θ_d) depends solely on the parameters related to product innovation, that is, whether the licensing cost (λ) is high or not with respect to S's effort in product differentiation through innovation (I_d): T procures the full license of S's product innovation if $\lambda < \frac{3}{2}I_d$; and does not procure the license at all otherwise. T's copying decision, however, depends on S's effort in process innovation (I_c) with respect to the change in production cost (β), marginal cost of mimicking (γ_{cT}) and λ or I_d: T tends to completely imitate S's process innovation under low innovation effort, low production cost increase (or high production cost saving), or low marginal cost of copying process innovation. We note that the licensing decision (either full or no licensing) further influences T's imitation decision as the cutoffs on I_c are decreasing in licensing fee when licensing is desired but decreasing in I_d if no licensing is preferred. Imitation decision, on the other hand, does not affect the licensing decision in any way.

Substituting (5), (6) and (8) in (3) yields four profit functions for S in λ, I_d, and I_c corresponding to each of the four (θ_d,θ_c) combinations (see (A.11) in Appendix). However, two of the four scenarios never occur:

Proposition 2. *For all λ, S's optimal product innovation effort is $I_d^* < \frac{2}{3}\lambda$. The relationship between λ and I_d^* implies $\theta_d^* = 0$.*

Proposition 2 states that regardless of the licensing fee, S will always set I_d^* such that $\theta_d^* = 0$, thus T does not have any incentive to procure the license of S's product innovation. Not licensing to the rival is the optimal decision because T always procures the full license of S's product innovation if at all, which leaves S no advantage in product differentiation but rather only the licensing fee revenue from T. Such full licensing behavior discourages S's product innovation investment, which in turn makes licensing less profitable than not licensing to T. This result is consistent with early empirical findings that for firms with complementary assets to R&D, i.e., marketing and manufacturing capability (like our firm S) are less likely to license because of high patent effectiveness of product innovations (Arora and Ceccagnoli, 2006; Teece, 1986), however unlike these studies we characterize the effect of R&D licensing (or not) on imitation. Specifically, licensing not only loses some of S's competitive advantage in differentiating its product to T, but it also makes T more likely to imitate S's process innovation (Proposition 1). For licensing to take place, $I_d > \frac{2\lambda}{3}$ implies $\left(\frac{2a}{3} - 2I_d\right) < \left(\frac{2a}{3} - \frac{4\lambda}{3}\right)$. If I_c is selected such that $I_c \in \left[\left(\frac{2a}{3} - 2I_d\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right), \left(\frac{2a}{3} - \frac{4\lambda}{3}\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right)\right]$, then copycatting would occur so S's effective market size remains the same as m and so does T's since $\theta_d = \theta_c = 1$. However, if S raises it licensing fees and does not license its product, i.e., $I_d < \frac{2\lambda}{3}$, copycatting would not occur so S's effective market size increases to $m + I_d + I_c$ while T's reduces to $m - I_d - I_c$ since $\theta_d = \theta_c = 0$.

When the option of licensing is removed, only two cases remain: copycat and no copycat (either $\theta_c = 1$ or 0 while $\theta_d^* = 0$):

$$\Pi_S^0(I_d, I_c) = \left[\frac{a}{3} + I_d + \left(1 - \frac{2\beta}{3}\right) I_c\right]^2 - \gamma_d I_d^2 - \gamma_{cS} I_c^2 \qquad \text{if } I_c \geq \bar{I}_c \tag{9}$$

$$\Pi_S^1(I_d, I_c) = \left[\frac{a}{3} + I_d - \frac{\beta}{3} I_c\right]^2 - \gamma_d I_d^2 - \gamma_{cS} I_c^2 \qquad \text{if } I_c < \bar{I}_c \tag{10}$$

where $\bar{I}_c = \left(\frac{2a}{3} - 2I_d\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right)$, and Π_S^0 corresponds to the case in which $\theta_c = 0$ while Π_S^1 represents the case of $\theta_c = 1$. The two profit functions have the following structural properties as shown in the lemma below:

Lemma 1. *Given any* I_d,

(i) $\Pi_S^0(I_d, I_c) > \Pi_S^1(I_d, I_c)$ *for all* $I_c > 0$ *if* $\beta < 3$,

(ii) $\Pi_S^0(I_d, I_c) = \Pi_S^1(I_d, I_c)$ *at* $I_c = 0$.

By bounding $\beta < 3$, which will be later shown irrelevant, Lemma 1 facilitates subsequent analysis by establishing the following structural properties: 1) if an interior solution for the no copycat case ($\theta_c = 0$) is feasible (satisfying the boundary constraint, $I_c \geq \bar{I}_c$), then it is indeed globally optimal since $\Pi_S^0(I_c^*) \geq \Pi_S^0(I_c) > \Pi_S^1(I_c),\ \forall I_c \in \mathbb{R}^+$; 2) a boundary solution ($I_c = \bar{I}_c$) in the no copycat case ($\theta_c = 0$) dominates that in the copycat case ($\theta_c = 1$) since $\Pi_S^0 > \Pi_S^1$ for all I_c including the boundary point; 3) corner solutions ($I_c = 0$) have the same objective function value in both cases, $\Pi_S^0(I_d, 0) = \Pi_S^1(I_d, 0)$; and 4) the no copycat boundary solution ($I_c = \bar{I}_c$ when $\theta_c = 0$) may be dominated by the copycat interior solution ($I_c < \bar{I}_c$ when $\theta_c = 1$). The lemma simplifies subsequent analysis by eliminating two possible solutions, the copycat boundary solution ($I_c = \bar{I}_c$) which is always dominated by the no copycat boundary solution, and the copycat corner solution ($I_c = 0$) which is equivalent to the no copycat corner solution.

For S's optimal innovations, we first present the results in which T does not mimic S's process, i.e., $\theta_c = 0$ that requires $I_c \geq \bar{I}_c$, as all three types of S's solutions could be a global optimum:

Proposition 3 (No copycatting)**.** *For* $\theta_c = 0$*, S's optimal innovation decisions can be characterized as follows:*

$$(I_d^{0*}, I_c^{0*}) = \begin{cases} \left(\frac{4a}{3H^0} \cdot \gamma_{cS}, \frac{4a}{3H^0} \cdot \left(1 - \frac{2\beta}{3}\right)\gamma_d\right) & \text{if } \quad \beta < \beta_1 \quad \textit{(No copycatting)} \\ \left(I_d^{0B}, \left(\frac{2a}{3} - 2I_d^{0B}\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right)\right) & \text{if } \beta_1 \leq \beta < \beta_2 \quad \textit{(Copycat deterrence)} \\ \left(\frac{a}{3(\gamma_d - 1)}, 0\right) & \text{if } \beta_2 \leq \beta \quad \textit{(No Process Innv.)} \end{cases} \tag{11}$$

where $H^0 = 4\left[(\gamma_d - 1)\gamma_{cS} - \gamma_d\left(1 - \frac{2\beta}{3}\right)^2\right]$,

$$I_d^{0B} = \left(\frac{a}{3}\right)\left[\frac{1+4\left[\gamma_{cS}-\left(1-\frac{2\beta}{3}\right)^2\right]\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right)^2}{\gamma_d-1+4\left(1-\frac{2\beta}{3}\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right)+4\left[\gamma_{cS}-\left(1-\frac{2\beta}{3}\right)^2\right]\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right)^2}\right],$$

$\beta_1 = \frac{3}{2}\left[\frac{5}{4} - \frac{1}{4}\sqrt{1 - 8\gamma_{cT} + 16\gamma_{cS}\left(1 - \frac{2}{\gamma_d}\right)}\right]$ *and*
$\beta_2 = \min\left\{\frac{3}{2}\left[\frac{3}{2} - \frac{2+\sqrt{(\gamma_d-2)(\gamma_d-2+4\gamma_d(\gamma_{cS}-\gamma_{cT})-8\gamma_{cS})}}{2\gamma_d}\right], \frac{3}{2}\right\}$.

As noted in Proposition 3, three types of non-copycatting equilibrium could possibly occur: first, at low production cost increase from process innovation ($\beta < \beta_1$), no copycatting is the best strategy where S's optimal process innovation (denoted I_d^{0I} and I_c^{0I} where superscript $0I$ indicates interior solution satisfying FOCs, i.e., $(I_d^{0I}, I_c^{0I}) = \left(\frac{4a}{3H^0} \cdot \gamma_{cS}, \frac{4a}{3H^0} \cdot \left(1 - \frac{2\beta}{3}\right)\gamma_d\right)$) is high enough ($\geq \bar{I}_c$) that leaves T no incentive to copy; second, at a higher cost increase ($\beta_1 \leq \beta < \beta_2$), copycat-deterrence strategy should be adopted where S has to compromise by making a higher investment level ($= \bar{I}_c$) to deter T from copying as otherwise the interior optimal investment would have enticed T to completely copy the process innovation; and third, even without copycatting, no process innovation would occur if it would raise the production cost significantly ($\beta \geq \beta_2$). As noted in Lemma 1, while the first and third types of equilibrium, when attainable, are surely globally optimal, the copycat-deterrence strategy may be sub-optimal if S is better off investing in process innovation but allowing copycatting as the gain from cost-reducing innovation outweighs the loss to copycatting.

Proposition 4 (Copycatting)**.** *When copycatting is allowed, S's optimal investment decisions can be characterized as follows:*

$$(I_d^{1I}, I_c^{1I}) = \left(\frac{4a}{3H^1} \cdot \gamma_{cS},\ \frac{4a}{3H^1} \cdot \frac{-\beta\gamma_d}{3}\right) \quad \text{if } \beta_3 \leq \beta < 0 \tag{12}$$

where $H^1 = 4\left[(\gamma_d - 1)\gamma_{cS} - \gamma_d\left(\frac{\beta}{3}\right)^2\right]$ *and* β_3 *satisfies* $\Pi_S^1(I_d^{1I}, I_c^{1I}) = \Pi_S^0(I_d^{0B}, I_c^{0B})$.

We first note that for S to allow T to totally copy its process innovation and negate its advantage in differentiating itself since $(1 - \theta_c)I_c = 0$, the investment in process innovation must result in a lower production cost ($\beta < 0$). Otherwise, the costly innovation effort raises production cost yet has no positive effect on S's demand. Second, copycatting may be permitted in S's optimal strategy if the savings in production are relatively small ($\beta_3 \leq \beta < 0$) since big savings would drive S to invest more, which in turn either deters or keeps T from copying the innovation. Ultimately, if the potential savings are extremely large ($\beta \ll \beta_1$),

S's investment in process innovation could be substantial enough to totally drive T out of the market ($q_T^* < 0$) and duopolist market degenerates to a monopolist market. Before we analyze the monopoly case, we compare our copycatting and non-copycatting results to derive further insights:

Corollary 1. *If $\beta < 0$,*

(i) $I_d^{1I} < I_d^{0I}$ *and* $I_c^{1I} < I_c^{0I}$.

(ii) I_d^{1I}, I_c^{1I}, I_d^{0I} *and* I_c^{0I} *are all decreasing in* β, γ_{cS} *and* γ_d, *but independent of* γ_{cT}.

(iii) $\frac{I_d^{1I}}{I_c^{1I}} = \frac{3\gamma_{cS}}{-\beta\gamma_d}$ *and* $\frac{I_d^{0I}}{I_c^{0I}} = \frac{3\gamma_{cS}}{(3-2\beta)\gamma_d}$, *and* $\frac{I_d^{1I}}{I_c^{1I}} > \frac{I_d^{0I}}{I_c^{0I}}$.

Note that in the corollary and the following discussion, we restrict β to be negative to have $I_c^{1I} > 0$ so we can then examine the consequences of neglecting copycatting (I_c^{0I} for $\beta < 0$ is sub-optimal against the optimal I_c^{0I}). The comparative statics, however, for the non-copycatting scenario alone work for $\beta < \beta_1$. Corollary 1(i) shows that T's copycatting behavior makes S cautious about its easy-to-copy process development and thus reduces such innovation ($I_c^{1I} < I_c^{0I}$) when the threat of imitation is present. In addition, imitation may also lower protected, product, innovation ($I_d^{1I} < I_d^{0I}$), which implies that the overall innovation by S, ($I_d^{1I} + I_c^{1I}$), shrinks due to copycatting. Interestingly, such complementary effects between the two types of innovations are also observed when varying S's cost parameters (β, γ_{cS} and γ_d) as in part (ii). On the other hand, for either scenario, copycatting or not, T's cost of imitation γ_{cT} does not influence S's innovation decisions since T's copycatting decisions are all or nothing decisions. However, γ_{cT} does influence which scenario would occur as it implicitly affects β_3, the threshold in β above which copycatting behavior is observed. Though S's two distinct types of innovation react to all parameters and T's copycatting strategy in a similar fashion, the degree to which each reacts is different. As part (iii) shows within either scenario, the ratio of S's product to process innovation are increasing in its marginal process innovation cost (γ_{cS}), and decreasing in the marginal product innovation cost (γ_d) and per-unit production cost savings ($-\beta$). This is also true when examining the effect on the ratio between the two scenarios (copycatting v.s. non-copycatting) as though both innovations are negatively affected by imitation (from part (i)), copycatting discourages process innovation more and thus results in a higher product-to-process innovation ratio. However, we find that the possibility of copycatting by T increases the sensitivity to process innovation resulting in a larger ratio.

Monopoly Cases

In the case of monopoly, S's profit function can be rewritten by removing q_T, θ_d, λ, and θ_c in (3):

$$\Pi_S^M(q_S|I_d, I_c) = (a + I_d + I_c - q_S - \beta I_c)q_S - \gamma_d I_d^2 - \gamma_{cS} I_c^2 \tag{13}$$

The analysis of monopolistic setting is analogous to that under the duopolistic environment, and takes into account the two boundary scenarios, to deter either copycat entry or non-copycat entry. We summarize the monopolistic results below:

Proposition 5 (Monopoly)**.** *For the monopolistic S, its optimal investment decisions can be characterized as follows:*

$$(I_d^{M*}, I_c^{M*}) = \begin{cases} \left(\frac{a\gamma_{cS}}{H^M}, \frac{a\gamma_d(1-\beta)}{H^M}\right) & \text{if } \beta_0 \le \beta < \beta_4 \quad \text{(Monopoly)} \\ \left(I_d^{M1}, \frac{a-3I_d^{M1}}{\beta+3\sqrt{\gamma_{cT}}}\right) & \text{if } \beta_4 \le \beta < \beta_5 \quad \text{(Copycat-entry deterrence)} \\ \left(I_d^{M0}, \frac{a-3I_d^{M0}}{3-\beta}\right) & \text{if } \beta_5 \le \beta < \beta_6 \quad \text{(Noncopycat-entry deterrence)} \end{cases} \tag{14}$$

where $H^M = 4\gamma_d\gamma_{cS} - \gamma_{cS} - \gamma_d(1-\beta)^2$, $I_d^{M1} = \frac{(3\sqrt{\gamma_{cT}}+1)(3\sqrt{\gamma_{cT}}-3+4\beta)+12\gamma_{cS}}{4\gamma_d(\beta+3\sqrt{\gamma_{cT}})^2+36\gamma_{cS}-(3\sqrt{\gamma_{cT}}-3+4\beta)^2}$, $I_d^{M0} = a \cdot \frac{(2-\beta)\beta+3\gamma_{cS}}{(3-\beta)^2\gamma_d+9\gamma_{cS}-\beta^2}$, $\beta_0 = 1 - \sqrt{\frac{(4\gamma_d-1)\gamma_{cS}}{\gamma_d}}$, $\beta_4 = 1 - \left(\frac{4\gamma_{cS}}{1+3\sqrt{\gamma_{cT}}}\right)\left(\frac{\gamma_d-1}{\gamma_d}\right)$, $\beta_5 = \frac{3-3\sqrt{\gamma_{cT}}}{2}$, *and* $\beta_6 = \frac{7}{4} - \frac{\sqrt{\gamma_d(\gamma_d+24\gamma_{cS}(\gamma_d-2))}}{4\gamma_d}$.

It is first noted that monopolistic cases occur only at low and negative β's, i.e., cost-reducing process innovation. The monopolistic cutoffs β_4, β_5, or β_6 are much smaller, in absolute value terms, than the duopolistic cutoffs β_1, β_2, or β_3. When β is extremely low (between β_0 and β_4), the interior monopolistic investments are significant to keep T from entering the market. At a higher β ($\beta_4 < \beta < \beta_5$), S loses some of its monopoly power as it will not invest as much, which may give T the opportunity to copy its process innovation and enter the market if not deterred by S through entry-deterrence investment strategy; on the other hand, for even higher β ($\beta_5 < \beta < \beta_6$), S needs only to deter T's entry with no copying intention as copycatting is too costly for T. Lastly, for sufficiently high cost increase, deterring the entry of T can be costly to S so duopolistic outcomes will prevail as shown in earlier analysis.

Analysis Summary

We summarize the monopolistic and duopolistic equilibrium in Table 2. We note from the

Condition	Equilibrium
$\beta_0 \leq \beta < \beta_4$	Monopoly
$\beta_4 \leq \beta < \beta_5$	Copycat Entry Deterrence
$\beta_5 \leq \beta < \beta_6$	Non-copycat Entry Deterrence
$\beta_6 \leq \beta < \beta_1$	No Copycat Duopoly
$\beta_1 \leq \beta < \min\{\beta_2, \beta_3\}$	Copycat Deterrence Duopoly
$\beta_3 \leq \beta < 0$	Copycat Duopoly
$\max\{0, \beta_2\} \leq \beta$	No Investment Duopoly

Table 2: A summary of the equilibrium.

table that if not considered by an innovator, copycatting may lead to reduced profits, but not in all cases. When β, the post-innovation production cost change, is sufficiently low (between β_0 and β_4), as a monopolist the innovator need not consider copycatting. However, when β is just a little higher, $\beta \in [\beta_4, \beta_5)$, copycatting must be taken into account to deter the entry of an imitator. Interestingly, as β further increases to $[\beta_5, \beta_1)$, the impact of copycatting needs not to be considered again since the optimal strategies are to deter or compete with non-copycat entrant. These non-contiguous regions of β mean that an innovating firm should be wary of copycat firms, but not always and imitation may be deterred.

Thus far, we categorize the equilibrium types based on the post-innovation production cost change, β. However, since the β cutoffs at which the equilibrium type changes are functions of other investment parameters, γ_d, γ_{cS} and γ_{cT}, we further examine the interaction among these factors and how they jointly affect the equilibrium outcome in the numerical section.

5. Numerical Studies

Having completed the analysis of the duopolistic game between S and T as well as the monopolistic analysis for S, in this section we use numerical studies to further explore how S should strategically invest in response to its process-related costs (γ_{cS} and β), marginal product vs. process innovation costs (γ_d and γ_{cS}), and T's vs. S's marginal process innovation cost (γ_{cT} and γ_{cS}). We would like to note and leave out the discussion of product-related innovation decision as it has been shown analytically that S should never issue licenses for its product innovation to T (Property 2). Henceforth, we focus our discussion only on the process-related decisions.

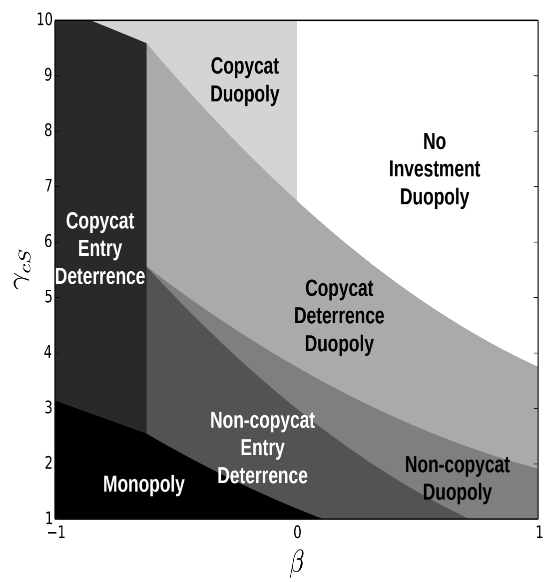
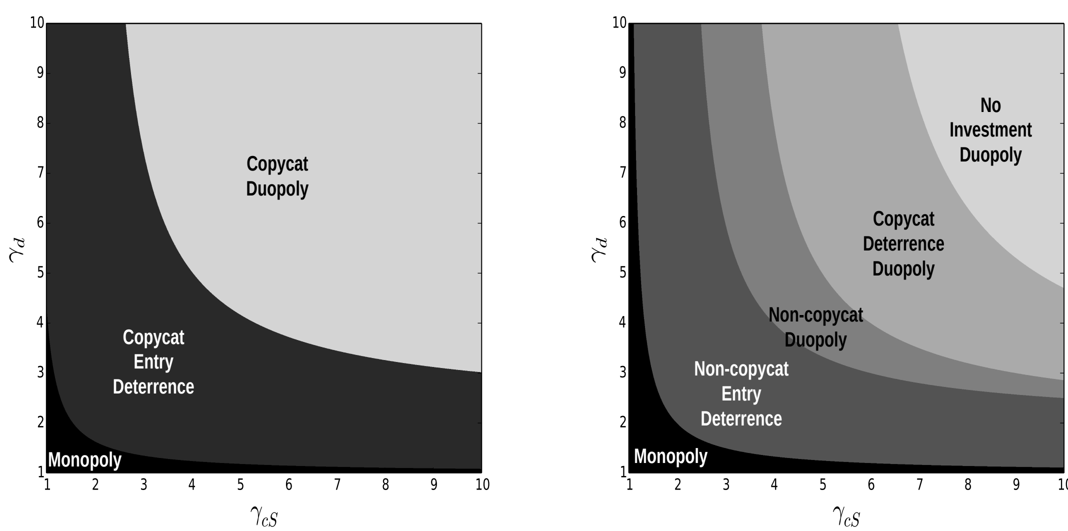


Figure 2: Equilibrium in S's process innovation cost and production cost change

Let $\gamma_d = 6$ and $\gamma_{cT} = 2$, Figure 2 first confirms the earlier analytical results regarding how the process investment decision is affected by the production cost change ($-1 \leq \beta \leq 1$ where a negative value corresponds to production cost reduction): for instance, when faced with intermediate marginal cost for process innovation ($4 \leq \gamma_{cS} \leq 5$), the duopolistic outcomes would transit from non-copycat, copycat deterrence, to no investment as β increases (Proposition 3); for high marginal cost ($\gamma_{cS} \geq 7$), it may be too costly to deter T from copying the innovation so allowing copycatting may still prove beneficial if sufficient production cost savings can be made (Proposition 4); for either low marginal innovation cost or high production cost saving (small γ_{cS} or β), as Proposition 5 depicts, monopolistic outcomes prevail. It is worth noting that in terms of monopolistic deterrence strategies, the monopolist S would have to exert more effort to deter copycat entry when β is low (< -0.7) and non-copycat entry when β takes values in the middle of the considered range. Interestingly, though S's two process-related factors, γ_{cS} and β, are mostly substitutes in determining the optimal strategy (the same equilibrium type remains when one parameter increases while the other decreases for the most part of Figure 2), T's entry decision is mainly influenced by the production cost change (β) as seen from the two straight vertical β cutoffs of the copycat entry deterrence and copycat equilibrium types (at $\beta = .65$ and $\beta = 0$, respectively).

We next explore the tradeoff between S's two innovation costs, γ_d vs. γ_{cS}. To isolate the effect of β on process innovation, we assume $\beta = 0$ so that there is no production cost change.



(a) $\beta = 0 < \beta_5$ (with $\gamma_{cT} = 0.5$) (b) $\beta = 0 \geq \beta_5$ (with $\gamma_{cT} = 3$)

Figure 3: Equilibrium in S's marginal product and process innovation cost

As is clear from Figure 3, whether T copies S's innovation depends on its marginal process innovation cost γ_{cT}, which in turn determines if $\beta > \beta_5$. When the cost for copying is relatively cheap (Figure 3(a)), we find T has the incentive to enter the market even though it would not save any production costs ($\beta = 0$) but negates the loss of market to S ($\theta_c = 1$); on the other hand, T has no interest in copying S's process if the process innovation cost is high (Figure 3(b)). In both cases, however, the equilibrium regions are nearly symmetric to S's two marginal innovation costs, γ_d and γ_{cS}. This implies that with no effect on production cost changes, the two costs are close substitutes to each other. Lastly, we examine the relative process development costs between S and T.

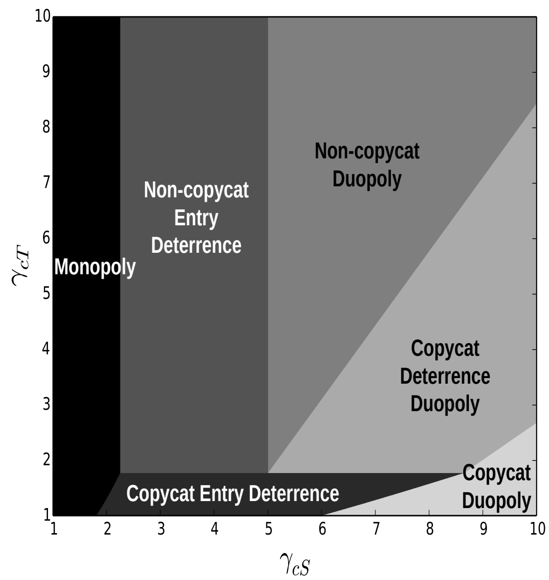


Figure 4: Equilibrium in T's and S's marginal process innovation costs ($\gamma_d = -0.5$ and $\beta = -0.5$)

Since γ_{cS} is the true innovation cost while γ_{cT} is the copying cost, it may be reasonable to assume $\gamma_{cS} \geq \gamma_{cT}$ and therefore we only focus on the lower-right triangle of Figure 4. It is notable that when the cost is high for S to innovate while low for T to copy, S has no choices but to let T copy which offsets some of its savings from production cost reduction because of negative β (the upper-right corner would be "no process innovation" if $\beta > 0$). On the other hand, when the costs are relatively the same for both the innovator and copycat (45-degree diagonal line), then S should be more aggressive and leave T no incentive to copy.

6. Discussion

In this section we discuss some managerial takeaways from our work as well as some natural extensions one may consider of the proposed model.

6.1. Summary of Results and Implications

Copycatting behavior may be a threat but not always, and it might be deterred. We show that though mostly overlooked in the literature of innovation, imitation like licensing should be of strategic importance for both the eco-innovator and traditional imitator as copycat-related equilibria are fairly commonly observed (Figures 2-4). This finding is consistent with earlier empirical and case studies that find that most value of innovation is captured by the copycats (Shenkar, 2010a). Our results suggest that not only should the traditional firm imitate strategically (Proposition 1), the sustainable firm should also take rival's potential imitation behavior into consideration before carrying out any innovations (Propositions 4 and 5). However, the threat of imitation may not always be credible, and imitation might be deterred through strategic innovation management (Table 2 and Figure 2). In addition, we find that imitation leads to an across the board reduction in innovation (Corollary 1). One potential takeaway from this is that a regulatory body may want to provide additional incentives for innovation in order to curtail the threat of innovation imitation. Specifically, when eco-innovation can lead to cost savings, the innovator may tolerate imitation (Proposition 4). For example, Apple was among the first companies, but the only smartphone maker, to start the Conflict-Free Smelter Program (CFSP) (Conflict-Free-Sourcing-Initiative, 2016),[2] which benefits late participants from the smartphone industry. Compared to regular member companies like Samsung, that pay only small membership fees, an initiator like Apple had to provide substantial initial funding. However, joint efforts with large firms from other industries (like GE, HP, Intel and Microsoft) saves Apple tremendous amount of money when engaging in auditing tasks of shared suppliers, with firms via the CFSP.

[2] The CFSP program was started in the wake of the Dodd-Frank Reform Act to ensure manufacturers used conflict-free materials. The program shares supply chain auditing costs across multiple industries to ensure compliance with the act.

Licensing eco-innovation may do more harm than good to the innovator and further induce imitation of its unprotected, process, innovation. Though many companies, including start-up and mature firms, use licensing extensively to generate revenue and recoup development cost from their innovations, we show that licensing sustainable product innovation deprives the sustainable manufacturer of the competitive advantage in product differentiation, and licensing is always undercompensated from the appropriated rents (Proposition 2). Our finding is in line with the empirical and case studies (Arora and Ceccagnoli, 2006; Teece, 1986) that licensing is not recommended if the innovator possesses complementary manufacturing and marketing assets. In addition, by incorporating two distinct types of innovations and the possibility of a copycat, our results extend earlier studies by understanding the effect of holding back licensing on a rival's copycatting behavior. We show that holding all else equal, not licensing patented innovation to build a differentiated product and thus stronger brand also helps reduce the possibility of copycatting (Proposition 1). In fact, Siemens in their 2015 Annual Report stated that their R&D activities lead to innovative and sustainable solutions that safeguard their competitiveness by holding 56,200 granted patents worldwide (Kaeser and Busch, 2015). Our results suggest Siemens should keep most patents themselves and not license to direct competitors in order to sustain the leadership in eco-innovations and discourage potential imitators.

In summary, our analytical and numerical results illustrate that the optimal (equilibrium) innovation strategy is sensitive to various cost-related factors, including per unit production cost change, marginal product and process innovation costs, and marginal imitation cost (Table 2 and Figures 2-4). No single factor dominates the others and there exist strong interactions among factors that jointly determine the optimal innovation strategy. It is also important to highlight that innovation should not be treated equally and independently as we show enforceable, patents, and unenforceable, trade secret, innovation efforts have opposing impacts on a competitor's copycat decisions (Propositions 3-5). All of these factors must be balanced carefully by an innovating firm, and the type of innovation, product (enforceable) or process (unenforceable), must also be distinguished in developing its eco-innovation strategy. When used properly, a proactive strategy may keep the follower from imitating eco-innovation, or even deter the entrance altogether and thus give the leader monopolistic power.

6.2. Model Limitations and Future Work

In the presented work, the marginal innovation costs have incorporated any government incentives, which are all set a priori. A natural extension to the presented work is to include the government as third player in the game, interested in driving an entire industry sector to adopt sustainable manufacturing practices. Though in the presented work a government can perform sensitivity analysis given any set of incentives, finding the equilibrium incentives is of importance to see how sustainable innovations can benefit society as a whole. In addition, we assumed that the production cost and market size are the same for both the sustainable and traditional firms, referred to as symmetric production costs. In a preliminary exploration, we note that even with asymmetric production costs, a traditional firm will still choose all or nothing licensing and copying decisions. However, imitation is more likely to occur when the production cost is lower for the traditional firm, which puts its sustainable rival in an even more disadvantageous position relative to the symmetric case. In the future, further exploring model parameter asymmetry between the two firms may be of interest to allow better understanding to the best decisions for both firms. Further, we would also like to incorporate consumer response to different products, for example some customers may prefer traditional products as opposed to sustainable products. Considering a heterogeneous set of customers, it is interesting to determine if there are settings in which it is optimal to offer both sustainable and traditional products, regardless of government incentives. Also, it may be insightful to study how competition affects the equilibrium outcome, such as an oligopoly settings where multiple innovators and imitators coexist and may collaborate in innovations. These market structure extensions may bridge the findings to those of the diffusion models which assume some pooled innovation spillovers. Lastly, another possible reason to take copycatting seriously is that it may be required to make an impactful innovation, as discussed by Steve Jobs regarding the impactful Apple Macintosh:

"Picasso had a saying, he said, 'Good artists copy. Great artists steal.' And we have always been shameless about stealing great ideas." (Jobs, 1994)

7. Conclusion

While most extant R&D literature in operations management focuses on cost-reducing innovation, many companies these days invest in costly innovations that do not necessarily reduce production cost but rather aim to increase its competitive advantage to traditional manufacturers in the marketplace. However, though most product innovations can be protected by a patent and may generate additional revenue for firms through licensing, process innovations, on the other hand, may be subject to the threat of imitation due to the difficulty of proving infringement. In this paper, we considered a sustainable manufacturer's decisions in product and process innovations, followed by a traditional manufacturer's decisions whether to procure the license and/or copy the innovations. We think that our results are of use to not only managers, as discussed in Section 6, but we also make a contribution to the sustainable innovation literature by incorporating the impact of various innovation effort types on the optimal licensing the copying decisions by each firm.

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Appendix. Proofs

Proof of Proposition 1. Since $\frac{\partial^2 \Pi_T}{\partial \theta_d^2} \geq 0$, $\frac{\partial^2 \Pi_T}{\partial \theta_c^2} \geq 0$ and $|\nabla^2 \Pi_T| = 0$ where

$$\nabla^2 \Pi_T(\theta_d, \theta_c | \lambda, I_d, I_c) = \begin{bmatrix} 2\left(I_d - \frac{2\lambda}{3}\right)^2 & 2\left(I_d - \frac{2\lambda}{3}\right)\left(I_c - \frac{2\beta I_c}{3}\right) \\ 2\left(I_d - \frac{2\lambda}{3}\right)\left(I_c - \frac{2\beta I_c}{3}\right) & 2\left(I_c - \frac{2\beta I_c}{3}\right)^2 \end{bmatrix} \quad \text{(A.1)}$$

Π_T is positive semi-definite, which implies corner optimal solutions: $\theta_d = \{0, 1\}$ and $\theta_c = \{0, 1\}$. That is, T either fully licenses the new product innovation or not licenses at all, and same is true regarding whether to copy the process innovation or not. The corresponding profit function for each corner solution are as follows:

$$\Pi_T(\theta_d = 1, \theta_c = 1|\lambda, I_d, I_c) = \left(\frac{a}{3} - \left[\frac{2\lambda}{3}\right] - \left[\frac{\beta I_c}{3}\right]\right)^2 - \gamma_{cT} I_c^2 \tag{A.2}$$

$$\Pi_T(\theta_d = 1, \theta_c = 0|\lambda, I_d, I_c) = \left(\frac{a}{3} - \left[\frac{2\lambda}{3}\right] - \left[I_c - \frac{\beta I_c}{3}\right]\right)^2 \tag{A.3}$$

$$\Pi_T(\theta_d = 0, \theta_c = 1|\lambda, I_d, I_c) = \left(\frac{a}{3} - [I_d] - \left[\frac{\beta I_c}{3}\right]\right)^2 - \gamma_{cT} I_c^2 \tag{A.4}$$

$$\Pi_T(\theta_d = 0, \theta_c = 0|\lambda, I_d, I_c) = \left(\frac{a}{3} - [I_d] - \left[I_c - \frac{\beta I_c}{3}\right]\right)^2 \tag{A.5}$$

To derive the conditions for each solution, we compare the gain/loss when T switches from $\theta_d = 1$ to $\theta_d = 0$ and from $\theta_c = 1$ to $\theta_c = 0$:

$$\Pi_T(1,1) - \Pi_T(0,1) = \left(I_d - \frac{2\lambda}{3}\right)\left(\frac{2a}{3} - \left[\frac{2\lambda}{3}\right] - [I_d] - 2\left[\frac{\beta I_c}{3}\right]\right) \tag{A.6}$$

$$\Pi_T(1,0) - \Pi_T(0,0) = \left(I_d - \frac{2\lambda}{3}\right)\left(\frac{2a}{3} - \left[\frac{2\lambda}{3}\right] - [I_d] - 2\left[I_c - \frac{\beta I_c}{3}\right]\right) \tag{A.7}$$

$$\Pi_T(1,1) - \Pi_T(1,0) = \left(I_c - \frac{2\beta I_c}{3}\right)\left(\frac{2a}{3} - \frac{4\lambda}{3} - I_c\right) - \gamma_{cT} I_c^2 \tag{A.8}$$

$$\Pi_T(0,1) - \Pi_T(0,0) = \left(I_c - \frac{2\beta I_c}{3}\right)\left(\frac{2a}{3} - 2I_d - I_c\right) - \gamma_{cT} I_c^2 \tag{A.9}$$

The differences can then be used to derive bounds on I_d and I_c for T's optimal decisions, θ_d and θ_c.

$$(\theta_d, \theta_c) = \begin{cases} (1,1) & \text{if } I_d > \frac{2\lambda}{3} \text{ and } I_c < \left(\frac{2a}{3} - \frac{4\lambda}{3}\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \\ (1,0) & \text{if } I_d > \frac{2\lambda}{3} \text{ and } I_c > \left(\frac{2a}{3} - \frac{4\lambda}{3}\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \\ (0,1) & \text{if } I_d < \frac{2\lambda}{3} \text{ and } I_c < \left(\frac{2a}{3} - 2I_d\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \\ (0,0) & \text{if } I_d < \frac{2\lambda}{3} \text{ and } I_c > \left(\frac{2a}{3} - 2I_d\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \end{cases} \tag{A.10}$$

Here all we are doing is for each of the components of (8), we solve for a pair of equations (A.6)-(A.9) being > 0 or < 0. For example, for (1,1) being optimal, implies that (A.6) > 0 and (A.8) > 0 solving these equations we have the condition on (1,1) For (1,0) being optimal, we have (A.7) > 0 and (A.8) < 0, etc. □

Proof of Proposition 2.

$$\Pi_S(\lambda, I_d, I_c) = \begin{cases} \left(\frac{a+\lambda-\beta I_c}{3}\right)^2 + \lambda\left(\frac{a-2\lambda-\beta I_c}{3}\right) - \gamma_d I_d^2 - \gamma_{cS} I_c^2 \\ \qquad \text{if } I_d > \frac{2\lambda}{3} \text{ and } I_c < \left(\frac{2a}{3} - \frac{4\lambda}{3}\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \\ \\ \left(\frac{a+\lambda+3I_c-2\beta I_c}{3}\right)^2 + \lambda\left(\frac{a-2\lambda-3I_c+\beta I_c}{3}\right) - \gamma_d I_d^2 - \gamma_{cS} I_c^2 \\ \qquad \text{if } I_d > \frac{2\lambda}{3} \text{ and } I_c > \left(\frac{2a}{3} - \frac{4\lambda}{3}\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \\ \\ \left(\frac{a+3I_d-\beta I_c}{3}\right)^2 - \gamma_d I_d^2 - \gamma_{cS} I_c^2 \\ \qquad \text{if } I_d < \frac{2\lambda}{3} \text{ and } I_c < \left(\frac{2a}{3} - 2I_d\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \\ \\ \left(\frac{a+3I_d+3I_c-2\beta I_c}{3}\right)^2 - \gamma_d I_d^2 - \gamma_{cS} I_c^2 \\ \qquad \text{if } I_d < \frac{2\lambda}{3} \text{ and } I_c > \left(\frac{2a}{3} - 2I_d\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) \end{cases} \tag{A.11}$$

For the first two cases of (A.11) in which $\theta_d = 1$,

$$\frac{\partial \Pi_S(\lambda, I_d, I_c)}{\partial I_d} = -2\gamma_d I_d \leq 0 \tag{A.12}$$

This implies S would never invest more than $\frac{2\lambda}{3}$ in product innovation so $\theta_d = 0$ and T would never license the product at all ($\lambda = 0$ or could be any number since it is irrelevant). □

Proof of Lemma 1. $\Pi_S^0(I_d, I_c) - \Pi_S^1(I_d, I_c) = \left(1 - \frac{\beta}{3}\right) I_c \left[\left(\frac{a}{3} + I_d + \left(1 - \frac{2\beta}{3}\right) I_c\right) + \left(\frac{a}{3} + I_d - \frac{\beta}{3} I_c\right)\right] > 0$ iff (if and only if) $\beta < 3$ since the two terms in the square brackets represent quantities (non-negative) in the associated cases ($\theta_c = 0$ and $\theta_c = 1$). $\Pi_S^0(I_d, I_c) - \Pi_S^1(I_d, I_c) = 0$ if $I_c = 0$. □

Proof of Proposition 3.

$$\nabla \Pi_S(I_d, I_c) = \begin{bmatrix} \frac{2a}{3} - 2(\gamma_d - 1) I_d + 2\left(1 - \frac{2\beta}{3}\right) I_c \\ \frac{2a}{3}\left(1 - \frac{2\beta}{3}\right) + 2\left(1 - \frac{2\beta}{3}\right) I_d + 2\left(1 - \frac{2\beta}{3}\right)^2 I_c - 2\gamma_{cS} I_c \end{bmatrix} \tag{A.13}$$

$$\nabla^2 \Pi_S(I_d, I_c) = \begin{bmatrix} -2(\gamma_d - 1) & 2\left(1 - \frac{2\beta}{3}\right) \\ 2\left(1 - \frac{2\beta}{3}\right) & -2\left[\gamma_{cS} - \left(1 - \frac{2\beta}{3}\right)^2\right] \end{bmatrix} \tag{A.14}$$

To ensure S's profit function is negative definite, it requires the following SOCs (Second-order Optimality Conditions): $\gamma_d > 1$ and $H^0 \equiv |\nabla^2 \Pi_S^0| = 4\left[(\gamma_d - 1)\gamma_{cS} - \gamma_d\left(1 - \frac{2\beta}{3}\right)^2\right] > 0 \implies \gamma_{cS} > \left(1 - \frac{2\beta}{3}\right)^2 \left(\frac{\gamma_d}{\gamma_d - 1}\right)$. Jointly solving for the FOCs yields the optimal interior solution:

$$I_d^{0I} = \frac{4a}{3H^0} \cdot \gamma_{cS} \tag{A.15}$$

$$I_c^{0I} = \frac{4a}{3H^0} \cdot \left(1 - \frac{2\beta}{3}\right)\gamma_d \tag{A.16}$$

where the superscript ^{0I} indicates Interior solution for the case of $\theta_c = 0$. Note that $I_c^{0I} > 0$ iff $\beta < \frac{3}{2}$; otherwise, if $\beta > \frac{3}{2}$, then this results in a corner

$$I_d^{0C} = \frac{a}{3(\gamma_d - 1)} \tag{A.17}$$

$$I_c^{0C} = 0 \tag{A.18}$$

In addition, for feasibility, I_d^{0I} and I_c^{0I} must satisfy the condition for which $\theta_c = 0$, i.e., $I_c > \bar{I}_c$, which yields the following condition: $\beta < \frac{3}{2}\left[\frac{5}{4} - \frac{1}{4}\sqrt{1 - 8\gamma_{cT} + 16\gamma_{cS}\left(1 - \frac{2}{\gamma_d}\right)}\right] \equiv \beta_1$. If such inequality condition does not hold, then boundary solution prevails, i.e., $I_c = \bar{I}_c = \left(\frac{2a}{3} - 2I_d\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right)$. Substituting such I_c back in the profit function and solving for I_d results in

$$I_d^{0B} = \left(\frac{a}{3}\right)\left[\frac{1 + 4\left[\gamma_{cS} - \left(1 - \frac{2\beta}{3}\right)^2\right]\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right)^2}{\gamma_d - 1 + 4\left(1 - \frac{2\beta}{3}\right)\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right) + 4\left[\gamma_{cS} - \left(1 - \frac{2\beta}{3}\right)^2\right]\left(\frac{1-\frac{2\beta}{3}}{1-\frac{2\beta}{3}+\gamma_{cT}}\right)^2}\right] \tag{A.19}$$

$$I_c^{0B} = \left(\frac{2a}{3} - 2I_d^{0B}\right)\left(\frac{1 - \frac{2\beta}{3}}{1 - \frac{2\beta}{3} + \gamma_{cT}}\right) \tag{A.20}$$

For $\beta \geq \beta_1$, to ensure that the boundary solution outperforms the corner solution, it further requires $\Pi_S^0(I_d^{0B}, I_c^{0B}) > \Pi_S^0(I_d^{0C}, 0)$ which leads to the following condition $\beta < \min\left\{\frac{3}{2}\left[\frac{3}{2} - \frac{2+\sqrt{(\gamma_d-2)(\gamma_d-2+4\gamma_d(\gamma_{cS}-\gamma_{cT})-8\gamma_{cS})}}{2\gamma_d}\right], \frac{3}{2}\right\} \equiv \beta_2$.

□

Proof of Proposition 4.

$$\nabla\Pi_S(I_d, I_c) = \begin{bmatrix} \frac{2a}{3} - 2(\gamma_d - 1)I_d - \frac{2\beta I_c}{3} \\ -\frac{2\beta a}{9} - \frac{2\beta I_d}{3} + \frac{2\beta^2 I_c}{9} - 2\gamma_{cS} I_c \end{bmatrix} \tag{A.21}$$

$$\nabla^2\Pi_S(I_d, I_c) = \begin{bmatrix} -2(\gamma_d - 1) & -\frac{2\beta}{3} \\ -\frac{2\beta}{3} & -2\left(\gamma_{cS} - \frac{\beta^2}{9}\right) \end{bmatrix} \tag{A.22}$$

To ensure S's profit function is negative definite, it requires the following SOCs: $\gamma_d > 1$,

$H^1 \equiv |\nabla^2 \Pi_S^1| = 4\left[(\gamma_d - 1)\gamma_{cS} - \gamma_d\left(\frac{\beta}{3}\right)^2\right] > 0 \Longrightarrow \gamma_{cS} > \frac{\beta^2\gamma_d}{9(\gamma_d-1)}$ Jointly solving for the FOCs yields the optimal solutions:

$$I_d^{1I} = \frac{4a}{3H^1} \cdot \gamma_{cS} \quad (A.23)$$

$$I_c^{1I} = \frac{4a}{3H^1} \cdot \frac{-\beta\gamma_d}{3} \quad (A.24)$$

Note that $I_c^{1I} > 0$ iff $\beta < 0$, and for copycatting ($\theta_c = 1$) to be the optimal solution, it requires $\Pi_S^1(I_d^{1I}, I_c^{1I}) \geq \Pi_S^0(I_d^{0B}, I_c^{0B})$ which leads to $\beta \geq \beta_3$ where β_3 solves $\Pi_S^1(I_d^{1I}, I_c^{1I}) = \Pi_S^0(I_d^{0B}, I_c^{0B})$. □

Proof of Corollary 1. (i) $I_d^{1I} = \frac{a\gamma_{cS}}{3\cdot\left[(\gamma_d-1)\gamma_{cS}-\gamma_d\left(\frac{-\beta}{3}\right)^2\right]} < I_d^{0I} = \frac{a\gamma_{cS}}{3\cdot\left[(\gamma_d-1)\gamma_{cS}-\gamma_d\left(1-\frac{2\beta}{3}\right)^2\right]}$ and $I_c^{1I} = \frac{a\left(\frac{-\beta}{3}\right)\gamma_d}{3\cdot\left[(\gamma_d-1)\gamma_{cS}-\gamma_d\left(\frac{-\beta}{3}\right)^2\right]} < I_c^{0I} = \frac{a\left(1-\frac{2\beta}{3}\right)\gamma_d}{3\cdot\left[(\gamma_d-1)\gamma_{cS}-\gamma_d\left(1-\frac{2\beta}{3}\right)^2\right]}$ if $\frac{-\beta}{3} < \left(1 - \frac{2\beta}{3}\right)$, which is true when $\beta < 0$.

(ii) After rearrangements, $I_d^{1I} = \frac{a/3}{\gamma_d\left[1-\frac{1}{\gamma_{cS}}\left(\frac{-\beta}{3}\right)^2\right]-1}$, $I_d^{0I} = \frac{a/3}{\gamma_d\left[1-\frac{1}{\gamma_{cS}}\left(1-\frac{2\beta}{3}\right)^2\right]-1}$, $I_d^{0I} = \frac{\left(\frac{a}{3}\right)\left(\frac{-\beta}{3}\right)}{\gamma_{cS}\left(1-\frac{1}{\gamma_d}\right)-\left(\frac{-\beta}{3}\right)^2}$ and $I_c^{0I} = \frac{\left(\frac{a}{3}\right)\left(1-\frac{2\beta}{3}\right)}{\gamma_{cS}\left(1-\frac{1}{\gamma_d}\right)-\left(1-\frac{2\beta}{3}\right)^2}$ are clearly all decreasing in β (for negative β), γ_{cS} and γ_d, but independent of γ_{cT}.

(iii) The first part follows directly by dividing I_d with I_c in Propositions 4 and 3 respectively; the second part holds if $-\beta < 3 - 2\beta$, which is true when $\beta < 0$.

□

Proof of Proposition 5. For S to drive T out of the market, the individual rationality (IR) conditions on (7), $\Pi_T(\theta_c | I_d^M, I_c^M) \leq 0$, must hold under the duopolistic setting (q_S^* and q_T^* as characterized in (5) and (6) respectively).

$$\Pi_T(\theta_c | I_d^M, I_c^M) = \left(\frac{a}{3} - I_d^M - \left[(1-\theta_c)I_c^M - \frac{(1-2\theta_c)\beta I_c^M}{3}\right]\right)^2 - \theta_c\gamma_{cT}(I_c^M)^2 \leq 0 \quad (A.25)$$

which leads to the following two conditions:

For $\theta_c = 1$ (copying entry deterrence): $I_c^M \geq \frac{a-3I_d^M}{\beta+3\sqrt{\gamma_{cT}}} \equiv \bar{I}_c^{M1}$.

For $\theta_c = 0$ (non-copying entry deterrence): $I_c^M \geq \frac{a-3I_d^M}{3-\beta} \equiv \bar{I}_c^{M0}$.

Note that $\bar{I}_c^{M1} > \bar{I}_c^{M0}$ iff $\beta < \frac{3}{2}\left(1 - \sqrt{\gamma_{cT}}\right) \equiv \beta_5$. Therefore, to deter T's entry whether copying or not, S's investment must satisfy:

$$I_c^M \geq \max\{\bar{I}_c^{M1}, \bar{I}_c^{M0}\} = \bar{I}_c^{M1} \quad \text{if } \beta < \beta_5 \quad (A.26)$$

$$I_c^M \geq \max\{\bar{I}_c^{M1}, \bar{I}_c^{M0}\} = \bar{I}_c^{M0} \quad \text{if } \beta \geq \beta_5 \quad (A.27)$$

When the condition is satisfied, the optimal monopolistic quantity can be derived by solving the FOC of (13) w.r.t. q_S:

$$q_S^M(I_d, I_c) = \frac{a + I_d + (1-\beta)I_c}{2} \tag{A.28}$$

Substituting the optimal quantity in (13) yields S's profit function in I_d and I_c:

$$\pi_S^M(I_d, I_c) = \left(\frac{a + I_d + (1-\beta)I_c}{2}\right)^2 - \gamma_d I_d^2 - \gamma_{cS} I_c^2 \tag{A.29}$$

Solving the FOCs leads to S's optimal monopolistic investment decisions:

$$(I_d^{MI}, I_c^{MI}) = \left(\frac{a\gamma_{cS}}{H^M}, \frac{a\gamma_d(1-\beta)}{H^M}\right) \tag{A.30}$$

where $H^M = \left|\nabla^2 \pi_S^M\right| = 4\gamma_d\gamma_{cS} - \gamma_{cS} - \gamma_d(1-\beta)^2 > 0 \Rightarrow \beta > 1 - \sqrt{\frac{(4\gamma_d - 1)\gamma_{cS}}{\gamma_d}} \equiv \beta_0$ when SOC holds. On the other hand, if the IR condition for T does not hold, then entry-deterrence solutions may occur, i.e., either $I_c^M = \bar{I}_c^{M1}$ or $\bar{I}_c^{M0}$ depending on β. Substituting the corresponding $\bar{I}_c^M$ back in S's profit function (13) and solving for I_d^M results in

$$I_d^{M1} = \frac{(3\sqrt{\gamma_{cT}}+1)(3\sqrt{\gamma_{cT}} - 3 + 4\beta) + 12\gamma_{cS}}{4\gamma_d(\beta + 3\sqrt{\gamma_{cT}})^2 + 36\gamma_{cS} - (3\sqrt{\gamma_{cT}} - 3 + 4\beta)^2} \qquad \text{if } \beta < \beta_5 \tag{A.31}$$

$$I_d^{M0} = a \cdot \frac{(2-\beta)\beta + 3\gamma_{cS}}{(3-\beta)^2\gamma_d + 9\gamma_{cS} - \beta^2} \qquad \text{if } \beta \geq \beta_5 \tag{A.32}$$

The cutoff β_4 in Proposition (5), below which interior monopolistic solution (I_d^{MI}, I_c^{MI}) is the optimal investment decisions, can be obtained from $\Pi_T(\theta_c = 1 | I_d^{MI}, I_c^{MI}) = 0$; and the cutoff β_6, above which interior non-copying duopolistic solution (I_d^{0I}, I_c^{0I}) is optimal, can be obtained from $q_T^*(\theta_c = 0 | I_d^{0I}, I_c^{0I}) = \sqrt{\Pi_T(\theta_c = 0 | I_d^{0I}, I_c^{0I})} = 0$. □