Excess Absorptive Capacity and the Persistence of Monopoly

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Abstract

We consider a monopolist's precommitment to imitate a potential entrant's innovation as a means of entry deterrence. This precommitment, i.e. excess absorptive capacity, always decreases the entrant's efforts to innovate whereas it increases (decreases) the monopolist's efforts if potential duopoly profits are low (high). If potential competition is à la Bertrand, a certain degree of excess absorptive capacity indeed suffices to render the monopolist more innovative than the entrant, such that even if the innovation is drastic, monopoly will tend to persist. More excess absorptive capacity increases the monopolist's equilibrium payoff whereas it decreases the entrant's.

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Keywords: Absorptive Capacity; Persistence of Monopoly; Entry deterrence; Innovation; Imitation

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1 Introduction

In high-tech industries the persistence of dominant, monopolistic firms can be explained by superior innovative performance of the monopolist relative to a potential entrant. Superior performance, in turn, follows greater incentives to invest in new products or processes. Accordingly, market structure in high-tech industries is tied to the question whether it is the incumbent or the entrant who has greater incentives to innovate. Arrow (1962), Gilbert and Newberry (1982) and Reinganum (1983) provide seminal answers based on asymmetries in the monopolist's and the potential entrant's returns from a successful innovation (see below). Numerous refinements[1] of these early works argue that an incumbent's initial technological lead or some kind of precommitment to innovate (Etro 2004) reduces an entrant's incentives to innovate and induces the persistence of monopoly respectively.

As an alternative explanation we consider how an incumbent's precommitment to *imitate* preserves its dominant position. The idea is based on the fact that innovations, in general, are subject to knowledge spillovers[2] for which the recipient needs to have absorptive capacity, i.e. the "ability to identify, assimilate, and exploit knowledge from the environment and to apply it to commercial ends" (Cohen and Leventhal 1989 and 1990). Our central assumption is that an incumbent rather than an entrant has built up and maintains such a capacity, either simply as a by-product of previous R&D or, somewhat more purposely, by means of basic research (Rosenberg 1990) and "large numbers of small and apparently unproductive [research] programs" (Henderson and Cockburn 1996). In either case some costs of imitation are sunk. This precommitment to imitate constitutes a credible (counter-)threat to the entrant's innovative threat.

Apparently a monopolist only needs absorptive capacity to affect potential competition. Analogous to the Spence (1977) and Dixit (1980) models with *physical* capacity precommitment, we highlight the strategic dimension

[1] See Tirole (1988), chapter 10, for an overview.

[2] See Griliches (1992) for an overview.

with the notion of *absorptive* capacity in *excess* to the amount needed if there were no potential competition (i.e. zero absorptive capacity[3]).

To illustrate the idea of excess absorptive capacity, consider Microsoft's reaction to Netscape's competitive threat. Case evidence provided by Klein (2001) suggests that Microsoft's browser, Internet Explorer, was clearly inferior to Netscape's Navigator during 1995-96[4]. But "during 1995-97, Microsoft devoted more than $ 100 million per year to browser software development", and in September 1997 Microsoft achieved superiority in internet browser technology with the release of Internet Explorer 4.0. Apparently Microsoft not only possessed the absorptive capacity to catch up with the progress in browser technology but also had stronger investment incentives to develop the superior and hence eventually successful browser[5].

In light of the initially cited theories on incentives to innovate, Microsoft's massive investments are by no means self-evident. According to Gilbert and Katz (2001) the battle between Microsoft and Netscape was essentially about establishing a programming platform; in particular Navigator was a distribution vehicle for Java and server based applications whereas Internet Explorer was linked to Windows. Due to network effects the dominant programming platform would in turn promote the persistence of Microsoft's monopoly or the creation of new monopoly, respectively. Hence, in the terminology of Reinganum (1983), the innovation at stake was drastic (no efficiency effect) such that the entrant, Netscape, should have invested more than the in-

[3] Needless to say, this picture is highly stylized in the sense that a monopolist which is not threatened by entry may still benefit from an absorptive capacity due to knowledge spillovers from research institutes or universities. We abstract from such linkages for the sake of simplicity.

[4] The quality evaluation of Internet Explorer and Navigator was based on the share of "wins" in three independent computer magazines.

[5] Microsoft's success in the battle with Netscape has been primarily related to its aggressive (zero) pricing of Internet Explorer and its tying of Internet Explorer to Windows. Klein (2001), however, reports that it was not before Microsoft had a comparable product available until Internet Explorer's usage began to increase.

cumbent[6]. At the same time Arrow's (1962) replacement effect might have arguably been strong due to Microsoft's comfortable returns from Windows whereas Netscape possessed the initial technological advantage, which, again, supports less investments by the incumbent Microsoft.

How does excess absorptive capacity help to explain this investment behavior? And to which degree does it benefit (hurt) the incumbent (entrant)? These are the questions we seek to answer in this paper. In particular we set up a model in which the incumbent maintains excess absorptive capacity. It is measured by the probability of an immediate imitation of an entrant's innovation. Knowing this probability firms choose their investments to innovate under uncertainty.

With respect to the first question, we show that excess absorptive capacity reduces the entrant's innovation investments and has two effects on the incumbent's investments. On the one hand it induces an *aggressive innovation effect*: deterring the entrant's innovation efforts increases the profitability of the incumbent's investments. On the other hand excess absorptive capacity creates a *copycat effect*, countervailing the former: an incumbent reduces its own innovation efforts to free ride on a successful innovation by the entrant. The copycat effect vanishes if profits in post-innovation competition approach zero (i.e. Bertrand competition). Then the aggressive innovation effect might indeed be sufficiently strong to guarantee more innovation efforts by the incumbent; even, as illustrated above, if the innovation is drastic (as defined by Reinganum 1983) and the incumbent replaces, for the most part, itself (Arrow 1962). These findings are consistent with the (scarce) empirical evidence on innovation behavior by incumbents and entrants[7].

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[6] Even if one argued that the development of the internet browser technology was deterministic rather than uncertain the Gilbert and Newberry (1982) model would predict at least innovation efforts of equal size. Yet, we do not intend to explain the case by excess absorptive capacity alone. For instance, Netscape's relatively weak proprietary position regarding Java as compared to Microsoft's strong position with respect to Windows might too have reduced Netscape's investment incentives.

[7] Blundell and Griffith (1999) find a positive relationship between innovation and market

The second question, i.e. to what extent excess absorptive capacity benefits (hurts) the incumbent (entrant), is closely related to Cohen and Levinthal's (1994) analysis of a monopolist's incentives to invest in absorptive capacity. Their model, however, regards absorptive capacity as a public good to be shared with potential entrants, namely the identification of promising new technologies. As criticized by Joglekar et al. (1997), their model omits "one critical element of absorptive capacity, namely a firm's ability to defend itself against the threat of external technology". Whereas Joglekar et al. (1997) "never indicate how their alternative specifications change [Cohen and Levinthal's] results"[8], our model addresses this question. Excess absorptive capacity clearly mimics such a defense capability, and we find it increases (decreases) the incumbent's (entrant's) equilibrium payoff.

The paper is organized as follows. Section two presents a description of the model. In section three we analyze how (a given) excess absorptive capacity affects the incumbent's and the entrant's incentives to innovate. In particular we start with the simple case of post-innovation Bertrand competition and then extend our findings to the general case in which a post-innovation duopoly is profitable. Building on the results of three, section four analyzes an incumbent's incentives to accumulate excess absorptive capacity. We first investigate the change of the firms' equilibrium payoffs due to excess absorptive capacity and then establish its absolute (maximum) value. Section five concludes.

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share (to reflect incumbency) as well as between innovation and a firm's knowledge stock. In contrast, Czarnitzki and Kraft (2004) find entrants more likely to innovate which might be due to the fact that they employ a *relative* measure for innovativeness: the R&D-to-sales ratio. Our model, however, aims to explain *absolute* incentives to innovate.

[8] Cohen and Levinthal's (1997) reply to Joglekar's et al. "Comments on 'Fortune Favors the Prepared Firm'".

2 The model

We consider a two stage setting. In the first stage only the incumbent, I, exists and builds up an absorptive capacity. Subsequently, in stage two, I and the (potential) entrant, E, decide simultaneously on their efforts/investments to obtain an innovation under uncertainty. A successful innovation benefits the innovator in terms of lower production costs (process-innovation) or enhanced product quality (product-innovation); either interpretation is suitable[9]. We propose that innovations cannot be fully protected by patents which means that both firms can innovate successfully and that innovations can be imitated. Imitation, however, does not occur automatically, like 'manna from heaven', but requires absorptive capacity, the "ability to identify, assimilate, and exploit knowledge from the environment and to apply it to commercial ends" (Cohen and Levinthal 1989, 1990).

For simplicity we set the entrant's absorptive capacity to zero, whereas the incumbent's absorptive capacity is measured by the probability, β_I, of an immediate imitation of a potential entrant's innovation[10], where $0 \leqslant \beta_I \leqslant 1$. In the innovation stage the level of β_I is given and common knowledge. Furthermore we follow Rosen (1991) and Kanniainen and Stenbacka (2000) in modelling innovation efforts directly through the probability of a successful innovation by the incumbent and entrant respectively[11], α_I and α_E, where

[9] The case of homogeneous goods Bertrand competition (section 3.1) refers to process rather than product innovation. The more general case of non-Bertrand competition, which is applicable to both process and product innovation, is analyzed in section 3.2.

[10] We assume that the incumbent innovates 'automatically' with propability β_I. That is the incumbent has not to incur any extra cost of imitation once it observes an innovation by the entrant. A more sophisticated setting would include a post-innovation (third) stage of the game in which the incumbent decides on its imitation investment level. More absorptive capacity would then lower the (marginal) costs of imitation. As a consequence the commitment value of absorptive capacity is reduced to the extent that the incumbent has to incur extra costs of imitation. However this would only have a level effect on our results in the sense that c.p. more absorptive capacity is needed to deter entry. For the sake of simplicity we stick to the basic set-up.

[11] The terms innovation efforts, investments and success probability are used synony-

			gross payoffs	
			entrant	incumbent
cases	α_E	α_I	π^D	π^D
	α_E	$(1-\alpha_I)\beta_I$	π^D	π^D
	α_E	$(1-\alpha_I)(1-\beta_I)$	π^L	π^F
	$(1-\alpha_E)$	α_I	0	$\pi^M(\underline{c})$
	$(1-\alpha_E)$	$(1-\alpha_I)$	0	$\pi^M(\overline{c})$

Table 1: Firms' gross payoffs depending on innovation and imitation successes

$0 \leqslant \alpha_I, \alpha_E \leqslant 1$. The firms thus determine α_I and α_E and bear innovation costs of the form $(a/2)\alpha_I^2$ and $(a/2)\alpha_E^2$, where $a > 0$.

As displayed by Table 1, the firms' payoffs depend on which one of them gets the innovation. If both firms innovate successfully (first row), either firm earns symmetric duopoly profits π^D. The same applies if only the entrant innovates whereas the incumbent succeeds in imitating (second row). If the entrant is successful and the incumbent does neither manage to innovate nor to imitate (third row), the entrant receives (cost- or quality-) leader profits, π^L, and the incumbent gets follower profits respectively. Consider now the cases in which the entrant fails to innovate. Then, of course, the entrant earns nothing and the incumbent gets monopoly profits given by the new technology, $\pi^M(\underline{c})$, or monopoly profits for the old technology, $\pi^M(\overline{c})$, depending on whether or not the incumbent innovates successfully (fourth and fifth row).

We assume $\pi^M(\underline{c}) > \pi^M(\overline{c})$ and $\pi^L > \pi^D \geqslant \pi^F \geqslant 0$ with equality only if competition is à la Bertrand. Moreover, $\pi^M(\underline{c}) \geqslant \pi^L$ with equality only if the innovation is drastic. Finally, we make the standard assumption $\pi^M(\underline{c}) > 2\pi^D$, i.e. intensified competition reduces industry profits.

The incumbent's and the entrant's innovation stage payoff functions can

mously throughout the paper.

be written as

$$\begin{aligned} V_I &= \alpha_I(1-\alpha_E)\pi^M(\underline{c}) + \alpha_I\alpha_E\pi^D + (1-\alpha_I)(1-\alpha_E)\pi^M(\overline{c}) \\ &\quad +(1-\alpha_I)\alpha_E\beta_I\pi^D + (1-\alpha_I)\alpha_E(1-\beta_I)\pi^F - (a/2)\alpha_I^2, \end{aligned} \tag{1}$$

and, respectively,

$$V_E = \alpha_E(1-\alpha_I)(1-\beta_I)\pi^L + \alpha_E\alpha_I\pi^D + \alpha_E(1-\alpha_I)\beta_I\pi^D - (a/2)\alpha_E^2. \tag{2}$$

3 Incentives to innovate (2nd stage)

In section three we seek answers to the following questions. First, how does excess absorptive capacity change the incumbent's and the entrant's equilibrium innovation efforts? Secondly we investigate which of the firms exerts more innovation efforts in absolute terms and, as a consequence, is more likely to dominate the post-innovation market. In doing so we start with the case of potential Bertrand competition in section 3.1. In this case there exists only one effect of excess absorptive capacity, the *aggressive innovation effect*[12]. In the more general and complicated case of non-Bertrand competition (section 3.2) an additional *copycat effect* occurs.

In the second stage the incumbent maximizes (1) with respect to α_I and the entrant (2) with respect to α_E, given the incumbent's excess absorptive capacity, β_I. The first-order conditions are

$$\frac{\partial V_I}{\partial \alpha_I} = (1-\alpha_E)(\pi^M(\underline{c}) - \pi^M(\overline{c})) + \alpha_E(1-\beta_I)(\pi^D - \pi^F) - a\alpha_I = 0 \tag{3}$$

and

$$\frac{\partial V_E}{\partial \alpha_E} = (1-\alpha_I)(1-\beta_I)\pi^L + (\beta_I(1-\alpha_I)+\alpha_I)\pi^D - a\alpha_E = 0. \tag{4}$$

To assure concavity of the profit functions (1) and (2) in α_I and α_E we assume $a > \pi^M(\underline{c})$, i.e. second-order conditions are always satisfied. By

[12] We analyze homogeneous goods Bertrand competition to isolate and illustrate the aggressive innovation effect of excess absorptive capacity. The non-Betrand case is just the more general version of the model.

(3) and (4) this assumption also guarantees an interior solution to the firms' maximization problem with $\alpha_I, \alpha_E < 1$. The interpretation of this technically motivated assumption is that innovation projects are so complex that firms never find it optimal to set $\alpha_I, \alpha_E = 1$.

3.1 Bertrand competition and the aggressive innovation effect

In the case of potential Bertrand competition we have $\pi^D = \pi^F = 0$. Let α_I^r and α_E^r denote the incumbent's and the entrant's reaction-function as implied by (3) and (4), then

$$\alpha_I^r = (1 - \alpha_E)(\pi^M(\underline{c}) - \pi^M(\overline{c}))/a \tag{5}$$

and

$$\alpha_E^r = (1 - \alpha_I)(1 - \beta_I)\pi^L/a. \tag{6}$$

By (5), α_I^r is independent of β_I and thus excess absorptive capacity has no direct effect on the incumbent's optimal innovation efforts. Since competition is à la Bertrand the incumbent would actually not benefit from imitating an entrant's innovation (i.e. $\pi^D = 0$) and hence β_I does not affect its optimization procedure directly. Due to (6), however, the entrant's optimal innovation efforts are decreasing in β_I. Since (5) and (6) imply that the firms' decision variables are strategic substitutes as defined by Bulow et al. (1984), i.e. $\partial\alpha_I^r(\alpha_E)/\partial\alpha_E < 0$ and $\partial\alpha_E^r(\alpha_I)/\partial\alpha_I < 0$, the decrease of the entrant's efforts causes an increase of the incumbent's equilibrium innovation efforts (see Figure 1). Upon substitution of (6) into (5) and solving for α_I, we obtain the incumbent's equilibrium innovation efforts[13],

$$\alpha_I^* = \frac{(\pi^M(\underline{c}) - \pi^M(\overline{c}))(a - (1 - \beta_I)\pi^L)}{a^2 - (1 - \beta_I)(\pi^M(\underline{c}) - \pi^M(\overline{c}))\pi^L}, \tag{7}$$

[13] Comparative statics of α_I^* and α_E^* are discussed for the more general case in section 3.2, see Lemma 1.

and upon substitution of (5) into (6) we solve for the entrant's equilibrium efforts respectively,

$$\alpha_E^* = \frac{(1-\beta_I)(a-(\pi^M(\underline{c})-\pi^M(\overline{c}))\pi^L}{a^2-(1-\beta_I)(\pi^M(\underline{c})-\pi^M(\overline{c})\pi^L}. \tag{8}$$

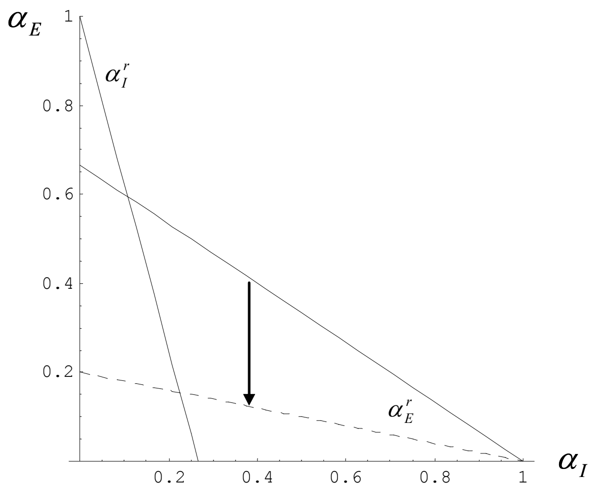

Figure 1: Bertrand competition and the aggressive innovation effect ($\partial\alpha_I^*/\partial\beta_I > 0$): the entrant's reaction curve, α_E^r, turns inward due to an increase in the incumbent's absorptive capacity. Example: $\beta_I = 0$ (solid lines), $\beta_I = 0.7$ (dashed line); $a = 15$, $\pi^M(\underline{c}) = \pi^L = 10$, $\pi^M(\overline{c}) = 6$.

The change of equilibrium innovation efforts in excess absorptive capacity. Differentiating (7) and (8) with respect to β_I yields

$$\frac{\partial\alpha_I^*}{\partial\beta_I} = \frac{a(a-(\pi^M(\underline{c})-\pi^M(\overline{c})))(\pi^M(\underline{c})-\pi^M(\overline{c}))\pi^L}{(a^2-(1-\beta_I)(\pi^M(\underline{c})-\pi^M(\overline{c}))\pi^L)^2} > 0, \tag{9}$$

and

$$\frac{\partial\alpha_E^*}{\partial\beta_I} = -\frac{a^2(a-(\pi^M(\underline{c})-\pi^M(\overline{c}))\pi^L}{(a^2-(1-\beta_I)(\pi^M(\underline{c})-\pi^M(\overline{c}))\pi^L)^2} < 0, \tag{10}$$

We can state

Proposition 1 *(a) Aggressive innovation effect: if* $\pi^D = 0$*, excess absorptive capacity increases the incumbent's efforts to innovate,* $\partial\alpha_I^*/\partial\beta_I > 0$*.*
(b) Excess absorptive capacity decreases the entrant's efforts to innovate, $\partial\alpha_E^*/\partial\beta_I < 0$*.*

Proof. Straightforward by (9) and (10).

Excess absorptive capacity acts as a *complement* to an incumbent's innovation efforts. The incumbent's absorptive capacity reduces the probability that the entrant captures, after a successful innovation, the profits of a cost- or quality-leader, π^L, which decreases the marginal profitability of the entrant's innovation efforts. The reduction of the entrant's innovation efforts in turn increases the probability of a unique innovation by the incumbent which secures monopoly profits, $\pi^M(\underline{c})$. It is worth emphasizing that here excess absorptive capacity has the purely strategic value of deterring an entrant's innovation (and entry, respectively). The incumbent itself gains nothing from its absorptive capacity, i.e. $\pi^D = 0$, once the entrant has in fact innovated[14].

Which firm will innovate with a higher probability? Note that (7) and (8) have identical denominators and hence, by the numerators, $\alpha_I^* - \alpha_E^* < 0$ if and only if

$$\pi^M(\underline{c}) - \pi^M(\overline{c}) - (1 - \beta_I)\pi^L < 0, \tag{11}$$

which implies the following

Proposition 2 *If* $\pi^D = 0$*, the entrant innovates with a higher probability than the incumbent,* $\alpha_E^* > \alpha_I^*$*, if and only if*

$$\beta_I < \frac{\pi^L - (\pi^M(\underline{c}) - \pi^M(\overline{c}))}{\pi^L}.$$

There exists a 'limit absorptive capacity' in the sense that $\alpha_E^* = 0$ *if and only if* $\beta_I = 1$*.*

[14] Again, this polar case serves for illustration purposes. Specifically, if we had $\pi^D = 0$ and strictly positive costs of imitation in a potential third stage of the game (see footnote XX), the incumbent could not credibly commit itself to imitation. In this case the set-up in section 3.2 with $\pi^D > 0$ needs to be employed.

Proof. Straightforward by (11) (first claim) and (4) (second claim).

To understand the intuition behind Proposition 2 it is useful to begin with a special case:

Corollary 1 *In the case of a drastic innovation, $\pi^L = \pi^M(\underline{c})$, the entrant innovates with a higher probability than the incumbent, $\alpha_E^* > \alpha_I^*$, if and only if*

$$\beta_I < \frac{\pi^M(\overline{c})}{\pi^M(\underline{c})}.$$

Due to Reinganum (1983) it has been well established that an entrant has greater incentives to innovate than an incumbent, provided the innovation is drastic (or if the entrant, at least, captures a sufficiently high share of the post-innovation market) and there is uncertainty in the innovation process. Corollary 1 meets these conditions and, indeed, confirms Reinganum's result in case there exist low levels of excess absorptive capacity, e.g. $\beta_I = 0$. However, since $\pi^M(\overline{c})/\pi^M(\underline{c}) < 1$, Corollary 1 also establishes that a certain degree of excess absorptive capacity, $\beta_I \leqslant 1$, suffices to make the incumbent more innovative than the entrant. How does this happen?

Recall that the assumption of a drastic innovation eliminates Gilbert and Newberry's (1982) efficiency effect according to which the entrant lacks some incentives to innovate because, unlike the incumbent, it does not monopolize the post-innovation market if it innovates successfully. Excess absorptive capacity essentially revitalizes Gilbert and Newberry's argument because the threat of an immediate imitation reduces the expected value of the entrant's innovation. This way the entrant expects lower values from a successful innovation than the incumbent, even if the innovation itself would be sufficiently drastic to force the (non-successful) incumbent out of the market.

According to Arrow (1962) the incumbent monopolist also lacks some incentives to innovate because it only replaces its old profit stream with a new one. Therefore the smaller its incremental profits from an innovation $(\pi^M(\underline{c}) - \pi^M(\overline{c}))$, i.e. the *stronger* the replacement effect, the more excess absorptive capacity a monopolist needs to commit itself to higher innovation efforts than the entrant. Indeed if the ratio $\pi^M(\underline{c})/\pi^M(\overline{c})$ approaches 1 so must β_I. At this limit, in fact, the entrant will not try to innovate at all and neither would the incumbent, as can easily be checked by (7).

Proposition 2 relaxes the assumption of a drastic innovation and accounts for Gilbert and Newberry's argument that an entrant profits less from an innovation of a given size than an incumbent, i.e. $\pi^L < \pi^M(\underline{c})$, as long as the incumbent remains in the post-innovation market. As a consequence the lower π^L relative to $\pi^M(\underline{c})$, the less an incumbent needs an absorptive capacity to commit itself to a higher innovation level than the entrant.

3.2 Non-Bertrand competition and the copycat-effect

Consider now the more general case of $\pi^D > 0$ and $\pi^F > 0$, a setting that would reflect, for instance, Cournot competition or Bertrand competition with differentiated products. The first-order conditions (3) and (4) then imply reaction functions of the form

$$\alpha_I^r = \left[(1-\alpha_E)(\pi^M(\underline{c}) - \pi^M(\overline{c})) + \alpha_E(1-\beta_I)(\pi^D - \pi^F)\right]/a, \tag{12}$$

and

$$\alpha_E^r = \left[(1-\alpha_I)(1-\beta_I)\pi^L + (\beta_I(1-\alpha_I)+\alpha_I)\pi^D\right]/a. \tag{13}$$

By (12) and in contrast to (5), an increase in excess absorptive capacity reduces the incumbent's innovation efforts. As illustrated by Figure 2, the incumbent's reaction curve turns inward if its absorptive capacity increases. Since the post-innovation duopoly is profitable, substituting own innovation efforts with an imitation of the entrant's innovation becomes attractive and creates a *copycat-effect* of excess absorptive capacity, counteracting the aggressive innovation effect. The aggressive innovation effect is indeed still apparent since α_E^r is also decreasing in β_I, i.e. $\partial\alpha_E^r/\partial\beta_I = -(1-\alpha_I)(\pi^L - \pi^D)/a < 0$, and the firms' innovation efforts remain strategic substitutes to each other, i.e. $\partial\alpha_I^r/\partial\alpha_E < 0$ as long as $(\pi^M(\underline{c}) - \pi^M(\overline{c})) > (1-\beta_I)(\pi^D - \pi^F)$. Throughout the paper we focus on cases in which the latter inequality indeed holds by assuming that[15]

$$(\pi^M(\underline{c}) - \pi^M(\overline{c})) > (\pi^D - \pi^F). \tag{14}$$

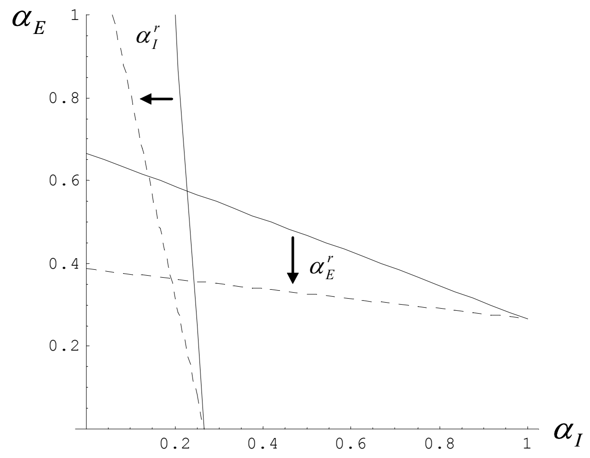

Figure 2: Non-Bertrand competition and dominance of the copycat effect ($\partial\alpha_I^*/\partial\beta_I < 0$): the entrant's and the incumbent's reaction curves, α_E^r and α_I^r, turn inward due to an increase in the incumbent's absorptive capacity. Example: $\beta_I = 0$ (solid lines), $\beta_I = 0.7$ (dashed lines); $a = 15$, $\pi^M(\underline{c}) = \pi^L = 10$, $\pi^M(\overline{c}) = 6$, $\pi^D = 4$, $\pi^F = 1$.

The occurrence of the copycat-effect raises two questions. First, under which conditions does it dominate the aggressive innovation effect, such that, as displayed by Figure 2, excess absorptive capacity decreases the incumbent's efforts to innovate instead of increasing them. Secondly, how does the copycat-effect change our predictions about whether it is the incumbent or the entrant who has greater incentives to innovate.

[15] It is true that $(\pi^M(\underline{c}) - \pi^M(\overline{c})) > (\pi^D - \pi^F)$ if potential competition is à la Cournot with linear demand (see example below). An obvious application of $\pi^M(\underline{c}) - \pi^M(\overline{c}) < \pi^D - \pi^F$, would be a strong replacement-effect and limit pricing by the entrant, $\pi^F = 0$. The assumption $(\pi^M(\underline{c}) - \pi^M(\overline{c})) > (\pi^D - \pi^F)$ could be potentially critical for the proof of the derivative of α_I^* with respect to π^D and π^L in Lemma 1 and the proof of the first claim of Proposition 5

To deal with these questions we derive the incumbent's and the entrant's equilibrium innovation efforts by solving the firms' first-order conditions (3) and (4) simultaneously for

$$\alpha_I^* = \frac{a(\pi^M(\underline{c}) - \pi^M(\overline{c})) - \Omega(\pi^L - \beta_I(\pi^L - \pi^D))}{a^2 - \Omega(1-\beta_I)(\pi^L - \pi^D)} \tag{15}$$

and

$$\alpha_E^* = \frac{a(\pi^L - \beta_I(\pi^L - \pi^D)) - (1-\beta_I)(\pi^M(\underline{c}) - \pi^M(\overline{c}))(\pi^L - \pi^D)}{a^2 - \Omega(1-\beta_I)(\pi^L - \pi^D)}, \tag{16}$$

where

$$\Omega = (\pi^M(\underline{c}) - \pi^M(\overline{c})) - (1-\beta_I)(\pi^D - \pi^F), \tag{17}$$

and $0 < \Omega < a$ by (14). The fact that $\Omega < a$ also implies that the denominators of (15) and (16) are strictly positive.

For the analysis to follow it is convenient to have the following intermediate results at hand:

Lemma 1 *(a) The incumbent's equilibrium innovation efforts, α_I^*, are increasing in $\pi^M(\underline{c})$ and decreasing in $\pi^M(\overline{c})$, π^L, π^D and π^F,*
(b) the entrant's equilibrium innovation efforts, α_E^*, are decreasing in $\pi^M(\underline{c})$ and increasing in $\pi^M(\overline{c})$, π^L, π^D and π^F.

Proof. See Appendix.

The logic behind Lemma 1 can be deduced from a firm's individual incentive to innovate and the fact that innovation efforts are strategic substitutes. In particular an increase in $\pi^M(\underline{c})$ increases the profit stream the incumbent gets on top of its current monopoly profits, $\pi^M(\overline{c})$. Hence the incumbent invests more and, as a consequence of the strategic substitutability, the entrant less. This logic applies to an increase in π_L and $\pi^M(\overline{c})$ respectively. The entrant increases its innovation efforts if π^D gets larger because in the case of a profitable post-innovation duopoly it profits from its innovation even if the incumbent also innovates or imitates. The increase of α_E^* in π^D again causes α_I^* to decrease in π^D. In order to understand the change of α_I^* in π^F

note the incumbent's incentives to innovate are not only driven by the profit it gains from an innovation if the entrant does not innovate, $\pi^M(\underline{c}) - \pi^M(\overline{c})$, but also by the probability to obtain π^D rather than π^F if the entrant innovates successfully. Hence the larger the incumbent's profits as a follower the smaller its incentives to innovate with the purpose to get π^D instead of π^F. The change of the entrant's probability to innovate, α_E^*, with respect to an increase in the follower's profits is, once again, caused by the fact that α_I and α_E are strategic substitutes.

The change of equilibrium innovation efforts in excess absorptive capacity. With respect to the incumbent it is helpful to assume $\beta_I = 0$ for a second and to think of two sources that create its incentives to innovate. First the incumbent seeks to earn incremental monopoly profits $\pi^M(\underline{c}) - \pi^M(\overline{c}) > 0$ in case the entrant does not innovate successfully. Secondly, in case the entrant is successful, the incumbent's own innovation still secures incremental profits $\pi^D - \pi^F > 0$ as compared to profits from the old technology/product, π^F. Now, excess absorptive capacity, $\beta_I > 0$, works as a substitute to the incumbent's own innovation in achieving the latter benefit, $\pi^D - \pi^F$, which is attainable, just as well, through an imitation. In contrast excess absorptive capacity complements the incumbent's own innovation to accomplish $\pi^M(\underline{c}) - \pi^M(\overline{c})$ by discouraging the entrant from innovating. In essence, the incumbent adopts a copycat (aggressive innovation) strategy if the substitutional (complementary) effects dominate. We state this more precisely in

Proposition 3 *(a) Dominance of the copycat effect: if (18), then* $\partial\alpha_I^*/\partial\beta_I < 0$*, that is excess absorptive capacity decreases the incumbent's efforts to innovate,*

$$\frac{\pi^M(\underline{c}) - \pi^M(\overline{c})}{\pi^D - \pi^F} + 2\beta_I \leqslant \frac{\pi^L}{\pi^L - \pi^D} + 1. \tag{18}$$

(b) Excess absorptive capacity decreases the entrant's efforts to innovate, $\partial\alpha_E^*/\partial\beta_I < 0$.

Proof. See Appendix.

As long as the weak inequality in Proposition 3 is satisfied we are guaranteed that, in contrast to Proposition 1, excess absorptive capacity is a *substitute* to an incumbent's efforts to innovate. Even though the reverse statement to Proposition 3 does not follow immediately if the inequality does not hold we focus on this restricted case as it still captures the main economic logic.

The left- (LHS) and the right-hand-side (RHS) of the inequality in Proposition 3 balances the strengths of the complementary or substitutional effects as caused by exogenous (market and technological) conditions. In particular the LHS accounts for the conditions that directly affect the incumbent's innovation incentives as sketched above. Accordingly the larger $\pi^D - \pi^F$ relative to $\pi^M(\underline{c}) - \pi^M(\overline{c})$ the more likely the incumbent will adopt a copycat strategy and cut back on own innovation efforts as a consequence of its absorptive capacity.

The RHS takes into account the entrant's incentives to innovate and, as a consequence, the relative effectiveness of a copycat or aggressive innovation strategy by the incumbent. Note first that large leader profits π^L increase an entrant's incentives to innovate. This makes outspending the entrant on R&D rather expensive but free-riding on the entrant's (likely) success attractive: the incumbent rather adopts a copycat strategy. On the other hand $\pi^L - \pi^D$ measures the effectiveness of excess absorptive capacity in order to induce an aggressive innovation strategy: the larger the gap between π^L and π^D, the more will the incumbent's absorptive capacity discourage an entrant's innovation, which in turn increases the likelihood that the incumbent gets $\pi^M(\underline{c})$ rather than π^D after an own successful innovation. This again renders the incumbent's innovation efforts more profitable. The lower $\pi^L - \pi^D$ the more likely will the incumbent adopt a copycat strategy.

The effect of β_I in the inequality can be explained as follows. The larger the incumbent's absorptive capacity the lower are by part *(b)* of Lemma 1 the entrant's incentives to innovate. Then it is in fact unlikely that the entrant will be successful at all, hence a copycat strategy becomes less attractive.

Given the fact that a potential entrant's efforts to innovate always decrease in excess absorptive capacity whereas the incumbent's efforts may either increase or decrease the question on the net effect of these changes is apparent. We provide the answer in

Proposition 4 *Excess absorptive capacity decreases the firms' overall innovation efforts,* $\partial(\alpha_I^* + \alpha_E^*)/\partial\beta_I < 0$.

Proof. See Appendix.

Which firm will innovate with a higher probability? In the general case of $\pi^D > 0$ and $\pi^F > 0$ the corresponding result to Proposition 2 is

Proposition 5 *If (19), then* $\alpha_E^* > \alpha_I^*$*, that is the entrant innovates with a higher probability than the incumbent,*

$$\beta_I < \frac{\pi^L - (\pi^M(\underline{c}) - \pi^M(\overline{c}))}{\pi^L - \pi^D}. \tag{19}$$

The higher β_I *the more likely we have* $\alpha_I^* > \alpha_E^*$ *and* $\beta_I = 1 \Longrightarrow \alpha_E^* = (\pi^D/a)$*, i.e. there exists no 'limit absorptive capacity'.*

Proof. See Appendix.

Proposition 5 confirms the main qualitative result of Proposition 2: the higher the excess absorptive capacity of the incumbent the less likely can we guarantee that $\alpha_E^* > \alpha_I^*$. The difference to Proposition 2 is that the condition in Proposition 5 depends also on post-innovation duopoly profits, π^D. The denominator reflects, again, how effective an incumbent's absorptive capacity works as a barrier to innovation and to entry respectively. If and only if the gap between the entrant's profit as a cost-leader, π^L, and the duopoly profit, π^D, gets sufficiently large, excess absorptive capacity can threaten the entrant such that it incurs less efforts to innovate than the incumbent.

An example: Potential Cournot Competition with linear demand and constant marginal costs As yet the results stated in Propositions 4 and 5 are not linked to a particular type of product market competition. This raises the question in which relation the particular profit differences may stand to each other for a given type of competition and innovation size. As an example we consider the case of Cournot competition with linear demand, $a - bQ$, where $Q = q_I + q_E$ in the case we calculate π^L, π^D, π^F, and $Q = q_I$ if we calculate $\pi^M(\underline{c})$, $\pi^M(\overline{c})$. We suppose, moreover, constant marginal costs of production, $c - x_i$, $i = I, E$, where $x_i \leqslant a - c$ measures the size of the i'th firm's process-innovation. Note that for π^F, $\pi^M(\overline{c})$ we have $x = 0$. Straightforward algebra, which is omitted for brevity, reveals that the following relations hold depending on the size of the innovation, x:

$$\begin{aligned}
\text{minor innovation} &: \pi^L - \pi^D < \pi^D - \pi^F < \pi^M(\underline{c}) - \pi^M(\overline{c}) < \pi^L \\
\text{major innovation} &: \pi^D - \pi^F < \pi^L - \pi^D < \pi^M(\underline{c}) - \pi^M(\overline{c}) < \pi^L \\
\text{radical innovation} &: \pi^D - \pi^F < \pi^M(\underline{c}) - \pi^M(\overline{c}) < \pi^L - \pi^D < \pi^L.
\end{aligned}$$

The example suggests that it is in particular $(\pi^L - \pi^D)$ which increases in the size of the innovation. If the innovation is minor then $(\pi^L - \pi^D) < (\pi^D - \pi^F)$ and the incumbent will rather adopt the copycat strategy. However if the innovation, x, exceeds a certain degree we have $(\pi^L - \pi^D) > (\pi^D - \pi^F)$ and eventually even $(\pi^L - \pi^D) > (\pi^M(\underline{c}) - \pi^M(\overline{c}))$. By Proposition 3 drastic innovations induce an aggressive innovation strategy by the incumbent and, as confirmed by Proposition 5, monopoly tends to persist in these cases.

4 Direct and strategic effects of excess absorptive capacity (1st stage)

Thus far we have left open the question of how much absorptive capacity will be built up by an incumbent. In seeking an answer, the difficulty of determining an appropriate cost measure for absorptive capacity arises. As aforementioned a firm may build up absorptive capacity partly as a by-product of previous research and partly through specific, extra investments. In our basic model, therefore, we abstract from such specific costs and restrict our attention to the direct and strategic effects, which excess absorptive capacity has on the incumbent's and the entrant's equilibrium payoffs[16]. Needless to say, the incumbent would have to trade off its benefits from absorptive capacity against the respective costs of building it up.

Effects on the incumbent's equilibrium payoff The derivative of the incumbent's equilibrium payoff V_I with respect to β_I can be written as

$$\frac{dV_I}{d\beta_I} = \frac{\partial V_I}{\partial \beta_I} + \frac{\partial V_I}{\partial \alpha_I}\frac{d\alpha_I^*}{d\beta_I} + \frac{\partial V_I}{\partial \alpha_E}\frac{d\alpha_E^*}{d\beta_I}, \tag{20}$$

where $\partial V_I/\partial \alpha_I = 0$ by the second stage maximization problem (envelope theorem) and $d\alpha_E^*/d\beta_I = \partial \alpha_E^*/\partial \beta_I$ as given by Proposition 3. We are thus left with the direct effect $\partial V_I/\partial \beta_I$ and the strategic effect $(\partial V_I/\partial \alpha_E)(d\alpha_E^*/d\beta_I)$. Calculating the respective derivatives from (1) and substituting these into (20) yields

$$\frac{dV_I}{d\beta_I} = \underbrace{\alpha_E^*(1-\alpha_I^*)(\pi^D - \pi^F)}_{\textit{direct copycat effect, }>0} \tag{21}$$

$$\underbrace{-\left[\alpha_I^*\underbrace{(\pi^M(\underline{c}) - \pi^D)}_{\textit{success benefit}} + (1-\alpha_I^*)\underbrace{(\pi^M(\overline{c}) - \beta_I\pi^D - (1-\beta_I)\pi^F)}_{\textit{failure benefit}}\right]\underbrace{\frac{d\alpha_E^*}{d\beta_I}}_{<0}}_{\textit{strategic deterrence effect, }>0}.$$

According to (21) the incumbent benefits from more absorptive capacity for two reasons. As indicated by the first effect, the incumbent firm profits directly because it receives incremental profits $(\pi^D - \pi^F)$ if only the entrant innovates successfully. On the other hand more absorptive capacity also benefits the incumbent for strategic reasons: decreasing the entrant's incentives to innovate, $\partial\alpha_E^*/\partial\beta_I < 0$, pays off because the incumbent firm then receives $\pi^M(\underline{c}) > \pi^D$ if it innovates successfully and $\pi^M(\overline{c}) > \beta_I\pi^D + (1-\beta_I)\pi^F$ if

[16] In the terminology of Fudenberg and Tirole (1984) we are analyzing the effects of excess absorptive capacity in the case of entry accommodation and entry deterrence respectively.

it fails to innovate. This positive strategic effect indicates that an incumbent over-invests in its absorptive capacity[17]. Without costs of absorptive capacity V_I is indeed maximized at $\beta_I = 1$.

Effects on the entrant's equilibrium payoff Proceeding in a similar way as above, we obtain

$$\frac{dV_E}{d\beta_I} = \frac{\partial V_E}{\partial \beta_I} + \frac{\partial V_E}{\partial \alpha_E}\frac{d\alpha_E^*}{d\beta_I} + \frac{\partial V_E}{\partial \alpha_I}\frac{d\alpha_I^*}{d\beta_I}, \tag{22}$$

where, again, $\partial V_E/\partial \alpha_E = 0$ and $d\alpha_I^*/d\beta_I = \partial \alpha_I^*/\partial \beta_I$ as given by Proposition 3. Calculating the respective derivatives from (2) and rearranging terms slightly gives

$$\frac{dV_E}{d\beta_I} = -\alpha_E^*(\pi^L - \pi^D)\left[(1-\alpha_I^*) + (1-\beta_I)\frac{d\alpha_I^*}{d\beta_I}\right] < 0. \tag{23}$$

Of course, excess absorptive capacity only affects the entrant's equilibrium payoff in case it succeeds in innovating, that is with probability α_E^*. Then excess absorptive capacity reduces the entrant's payoff by $(\pi^L - \pi^D)$, i.e. the incremental profit of being a cost- or quality-leader instead of a symmetric duopoly competitor. By the square bracketed expression in (23) this effect is contingent on two cases. First, if the incumbent does not innovate successfully, i.e. with probability $(1-\alpha_I^*)$, an additional unit of excess absorptive reduces the potential entrant's payoff simply because it increases the probability of an immediate imitation (by one unit). However, even if the incumbent does not imitate successfully, $(1-\beta_I)$, excess absorptive capacity still affects the entrant's payoff as it changes the incumbent's innovation behavior, $d\alpha_I^*/d\beta_I$. If the aggressive innovation effect dominates, $d\alpha_I^*/d\beta_I > 0$, the former is substantiated, whereas, if the copycat effect dominates, $d\alpha_I^*/d\beta_I < 0$, it is weakened. In any case the square bracketed expression remains positive

[17] Benoit and Krishna (1991) show that preemptive capacity may facilitate entry in dynamic competition by increasing competitive intensity and, as a consequence, making a collusive outcome more sustainable. Hence if post-innovation competition is dynamic and preemptive absorptive capacity increases competitive intensity one might derive different conclusions regarding the incumbent's incentives to over-invest.

such that the overall effect of excess absorptive capacity on the entrant's equilibrium payoff is certainly negative (see appendix). Thus excess absorptive capacity constitutes a barrier to entry. We summarize these considerations in

Proposition 6 *Excess absorptive capacity increases (decreases) the incumbent's (entrant's) second stage equilibrium payoff.*

Proof. See appendix.

5 Conclusion

As an alternative to studies that focus on how an incumbent's superior ability to innovate preserves its dominant position, this paper analyzes an incumbent's superior ability to imitate, i.e. its excess absorptive capacity, as a means of deterring an external innovation and entry respectively. The concept of excess absorptive capacity allows to relax assumptions of initial technological leads by the incumbent as well as first-mover-advantages in innovation. Yet even without these assumptions our results indicate that monopoly tends to persist. First we show that excess absorptive capacity always decreases the entrant's incentives to innovate whereas it increases (decreases) the incumbent's incentives if potential duopoly profits are low (high). In any case a larger excess absorptive capacity ensures that the incumbent tends to innovate with a higher probability than the entrant. Secondly we find excess absorptive capacity to increase (decrease) the incumbent's (entrant's) equilibrium payoffs.

Our paper suggests a number of extensions. First some of our (main) conclusions hinge on the fact that innovation efforts are strategic substitutes. If one defines innovation efforts as a flow of investments rather than an up-front expenditure, however, the firms' strategic variables are (often) complements[18] and it has to be validated in how far our results remain true

[18] See Martin (1999) for an overview of R&D games with strategic substitutes and complements.

in these cases[19]. Closely related, secondly, we applied a static set-up for something dynamic in nature. For a dynamic R&D race with knowledge accumulation Doraszelski (2003) derives simulation results that suggest firms invest more aggressively if they have a large knowledge stock. This bears resemblance to our aggressive innovation finding but seems to jar with the outcome of the copycat strategy. It appears worthwhile to integrate the advantages of both set-ups, an explicit formulation of absorptive capacity and the multistage nature of the Doraszelski (2003) model. Thirdly Kamien and Zang (2000) introduced a firm's absorptive capacity by means of a certain degree of technological proximity or connectedness to the environment. While Moltó et al. (2005) and Wiethaus (2005) find that symmetric firms endogenously minimize technology differentiation or maximize their connectedness respectively, in the case of the present paper the entrant might instead try to maximize (minimize) its technology differentiation (connectedness) to the incumbent in order to circumvent a likely imitation. Finally Hoppe et al. (2005) identify free-riding effects among several incumbents who bid for a license in order to prevent entrants from obtaining the license. Similar to their context in which each incumbent is willing to avoid entry but would rather prefer the other incumbent to pay the price of preemption, in our model several incumbents might rely on each other to bear the costs of maintaining an excess absorptive capacity.

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[19] Chen (2000) shows that an incumbent's and an entrant's innovation investments depend crucially on whether the new product is a strategic substitute or complement to the monopolists old product.

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Appendix

Proof of Lemma 1. For notational convenience let $f_I = 0$ and $f_E = 0$ denote the incumbent's and the entrant's first-order conditions as given by (3) and (4) which are satisfied in α_I^* and α_E^* as given by (15) and (16). Then we have by the implicit function rule and Cramer's rule that

$$\frac{\partial \alpha_i^*}{\partial \Pi} = \frac{\left|J_i^{\Pi}\right|}{|J|}, \quad i = I, E, \quad \Pi = \pi^M(\underline{c}), \pi^M(\overline{c}), \pi^L, \pi^D, \pi^F,$$

where $|J|$ is the Jacobian determinant of the equation system $f_I = 0$ and $f_E = 0$,

$$\begin{aligned} |J| &= \begin{vmatrix} \partial f_I/\partial \alpha_I & \partial f_I/\partial \alpha_E \\ \partial f_E/\partial \alpha_I & \partial f_E/\partial \alpha_E \end{vmatrix} \\ &= (\partial f_I/\partial \alpha_I)(\partial f_E/\partial \alpha_E) - (\partial f_I/\partial \alpha_E)(\partial f_E/\partial \alpha_I) \\ &= a^2 - \Omega(1-\beta_I)(\pi^L - \pi^D) > 0, \end{aligned} \tag{24}$$

where Ω is given by (17), $0 < \Omega < a$ by (14), and $\left|J_i^{\Pi}\right|$ is the determinant of the Jacobian with the i'th column replaced with partial derivatives, $-\partial f_i/\partial \Pi$. In particular

$$\left|J_I^{\pi^M(\underline{c})}\right| = \begin{vmatrix} -\partial f_I/\partial \pi^M(\underline{c}) & \partial f_I/\partial \alpha_E \\ -\partial f_E/\partial \pi^M(\underline{c}) & \partial f_E/\partial \alpha_E \end{vmatrix} = a(1-\alpha_E^*) > 0,$$

which implies, as $|J| > 0$ by (24), that $\partial \alpha_i^*/\partial \pi^M(\underline{c}) > 0$. Respectively we obtain

$$\begin{aligned} \left|J_I^{\pi^M(\overline{c})}\right| &= -a(1-\alpha_E^*) \Rightarrow \partial \alpha_I^*/\partial \pi^M(\overline{c}) < 0 \\ \left|J_I^{\pi^L}\right| &= -(1-\alpha_I^*)(1-\beta_I)\Omega \Rightarrow \partial \alpha_I^*/\partial \pi^L < 0 \\ \left|J_I^{\pi^D}\right| &= -a\alpha_E^*(\pi^D - \pi^F) - (\alpha_I^*(1-\beta_I) + \beta_I)\Omega \Rightarrow \partial \alpha_I^*/\partial \pi^D < 0 \\ \left|J_I^{\pi^F}\right| &= -a(1-\beta_I)\alpha_E^* \Rightarrow \partial \alpha_I^*/\partial \pi^F < 0. \end{aligned}$$

This establishes part *(a)*.

Next we calculate

$$\begin{aligned}
\left|J_E^{\pi^M(\underline{c})}\right| &= \begin{vmatrix} \partial f_I/\partial\alpha_I & -\partial f_I/\partial\pi^M(\underline{c}) \\ \partial f_E/\partial\alpha_I & -\partial f_E/\partial\pi^M(\underline{c}) \end{vmatrix} \\
&= -(1-a_E^*)(1-\beta_I)(\pi^L-\pi^D) \Rightarrow \partial\alpha_E^*/\partial\pi^M(\underline{c}) < 0.
\end{aligned}$$

Proceeding in a similar fashion yields

$$\begin{aligned}
\left|J_E^{\pi^M(\overline{c})}\right| &= (1-a_E^*)(1-\beta_I)(\pi^L-\pi^D) \Rightarrow \partial\alpha_E^*/\partial\pi^M(\overline{c}) > 0, \\
\left|J_E^{\pi^L}\right| &= a(1-\alpha_I^*)(1-\beta_I) \Rightarrow \partial\alpha_E^*/\partial\pi^L > 0, \\
\left|J_E^{\pi^D}\right| &= a(\alpha_I^*(1-\beta_I)+\beta_I) + \alpha_E^*(1-\beta_I)(\pi^D-\pi^F)(\pi^L-\pi^D) \\
&\Rightarrow \partial\alpha_E^*/\partial\pi^D > 0, \\
\left|J_E^{\pi^F}\right| &= (-1+\beta_I)^2\alpha_E^*(\pi^L-\pi^D) \Rightarrow \partial\alpha_E^*/\partial\pi^F > 0
\end{aligned}$$

This establishes part *(b)*.■

Proof of Proposition 3. Unfortunately implicit differentiation as in the proof of Lemma 1 does not reveal the sign of $\partial\alpha_I^*/\partial\beta_I$ and $\partial\alpha_E^*/\partial\beta_I$ respectively. Therefore we need to consider equilibrium innovation efforts, α_I^* and α_E^*, as given by (15) and (16) explicitly. In doing so let N_I and D denote the numerator and the denominator of (15). Then

$$\frac{\partial\alpha_I^*}{\partial\beta_I} = \frac{(\partial N_I/\partial\beta_I)D - (\partial D/\partial\beta_I)N_I}{D^2}, \tag{25}$$

where

$$\frac{\partial N_I}{\partial\beta_I} = (\pi^M(\underline{c}) - \pi^M(\overline{c}))(\pi^L-\pi^D) - (\pi^D-\pi^F)\left[2\pi^L(1-\beta_I) - \pi^D(1-2\beta_I)\right],$$

and

$$\frac{\partial D}{\partial\beta_I} = \left[(\pi^M(\underline{c}) - \pi^M(\overline{c})) - 2(1-\beta_I)(\pi^D-\pi^F)\right](\pi^L-\pi^D).$$

Note that

$$\begin{aligned}
& \partial N_I/\partial\beta_I - \partial D/\partial\beta_I \\
=\; & (\pi^D-\pi^F)\left\{2(1-\beta_I)(\pi^L-\pi^D) - [2\pi_L(1-\beta_I) - \pi_D(1-2\beta_I)]\right\} \\
=\; & -(\pi^D-\pi^F)\pi^D
\end{aligned}$$

and hence $\partial N_I/\partial \beta_I < \partial D/\partial \beta_I$. Now suppose that $\partial N_I/\partial \beta_I \leqslant 0$. On the one hand, if $\partial D/\partial \beta_I > 0$ then $\partial \alpha_I^*/\partial \beta_I$ is unambiguously negative, because $D > 0 \wedge N > 0$. On the other hand, if $\partial D/\partial \beta_I < 0$ then $\partial \alpha_I^*/\partial \beta_I < 0$ because $\partial D/\partial \beta_I < 0 \Longrightarrow |\partial N_I/\partial \beta_I| > |\partial D/\partial \beta_I|$ and $D \geqslant N$. It is the case that $\partial N_I/\partial \beta_I \leqslant 0$ if and only if

$$\frac{\pi^M(\underline{c}) - \pi^M(\overline{c})}{\pi^D - \pi^F} \leqslant \frac{\left[2\pi^L(1-\beta_I) - \pi^D(1-2\beta_I)\right]}{\pi^L - \pi^D}$$

which can be re-written as

$$\begin{aligned} \frac{\pi^M(\underline{c}) - \pi^M(\overline{c})}{\pi^D - \pi^F} &\leqslant \frac{\pi^L + (\pi^L - \pi^D)(1-2\beta_I)}{\pi^L - \pi^D} \\ \Longleftrightarrow \frac{\pi^M(\underline{c}) - \pi^M(\overline{c})}{\pi^D - \pi^F} + 2\beta_I &\leqslant \frac{\pi^L}{\pi^L - \pi^D} + 1. \end{aligned}$$

This establishes the first claim.

Second claim.

$$\frac{\partial \alpha_E^*}{\partial \beta_I} = -\frac{1}{D^2}(\pi^L - \pi^D)\Phi,$$

where

$$\begin{aligned} \Phi &= a^3 - a^2(\pi^M(\underline{c}) - \pi^M(\overline{c})) \\ &+(-1+\beta_I)^2(\pi^M(\underline{c}) - \pi^M(\overline{c}))(\pi^L - \pi^D)(\pi^D - \pi^F) \\ &+a((\pi^M(\underline{c}) - \pi^M(\overline{c}))\pi^D - (1-\beta_I)(\pi^D - \pi^F)(\pi^D(1+\beta_I) + \pi^L(1-\beta_I)). \end{aligned} \tag{26}$$

Note that $\partial \alpha_E^*/\partial \beta_I$ is negative as long as Φ is positive. We have that

$$\frac{\partial \Phi}{\partial \pi^M(\underline{c})} = -a(a - \pi^D) + (-1+\beta_I)^2(\pi^L - \pi^D)(\pi^D - \pi^F) < 0$$

because $a > (\pi^D - \pi^F) \wedge (a - \pi^D) > (\pi^L - \pi^D)$ and respectively

$$\frac{\partial \Phi}{\partial \pi^M(\overline{c})} = a(a - \pi^D) - (-1+\beta_I)^2(\pi^L - \pi^D)(\pi^D - \pi^F) > 0.$$

We set $\pi^M(\underline{c}) = a$ and $\partial \pi^M(\overline{c}) = 0$ in order to evaluate Φ below its minimum level:

$$\Phi \left|_{\pi^M(\underline{c})=a,\ \pi^M(\overline{c})=0} \right. = a\pi^D(a - 2(1-\beta_I)(\pi^D - \pi^F)) > 0,$$

because $a > \pi^M(\underline{c}) > 2\pi^D$. (Second claim).■

Proof of Proposition 4. By similar arguments as in the proof of Lemma 1 we derive

$$\begin{aligned} \left|J_I^{\beta_I}\right| &= (1-\alpha_I^*)(\pi^L-\pi^D)\Omega - a\alpha_E^*(\pi^D-\pi^F) \\ \left|J_E^{\beta_I}\right| &= (\alpha_E^*(1-\beta_I)(\pi^D-\pi^F) - a(1-\alpha_I^*)(\pi^L-\pi^D), \end{aligned}$$

to establish, after some re-arrangements, that

$$\begin{aligned} \left|J_I^{\beta_I}\right| + \left|J_E^{\beta_I}\right| &= -\alpha_E^*(\pi^D-\pi^F)(a-(1-\beta_I)(\pi^L-\pi^D) \\ &\quad -(1-\alpha_I^*)(\pi^L-\pi^D)(a-\Omega) \\ &\Rightarrow \partial\alpha_I^*/\partial\beta_I + \partial\alpha_E^*/\partial\beta_I < 0. \end{aligned}$$

■

Proof of Proposition 5. First claim. Letting N_I and N_E still denote the numerators of (15) and (16) we have that $sign(\alpha_I^*-\alpha_E^*) \Longleftrightarrow sign(N_I-N_E)$. After some re-arrangements we can write

$$\begin{aligned} &N_I - N_E = a\left\{(\pi^M(\underline{c}) - \pi^M(\overline{c})) - (\pi^L - \beta_I(\pi^L-\pi^D))\right\} \\ &-\left\{(1-\beta_I)(\pi^L-\pi^D)(\pi^M(\underline{c})-\pi^M(\overline{c})) + \Omega(\pi^L-\beta_I(\pi^L-\pi^D))\right\}, \end{aligned}$$

where the first curly bracketed term is negative if and only if

$$\beta_I < \frac{\pi^L - (\pi^M(\underline{c}) - \pi^M(\overline{c}))}{\pi^L - \pi^D},$$

and the second curly bracketed term is strictly positive. This establishes the first claim.

The second claim follows by

$$\frac{\partial(N_I-N_E)}{\partial\beta_I} = -a(\pi^L-\pi^D) - (\pi^D-\pi^F)(2\pi^L(1-\beta_I) - \pi^D(1-2\beta_I)) < 0,$$

and the third claim follows straightforwardly upon setting $\beta_I = 1$ in (16).■

Proof of Proposition 6. First claim (the incumbent's equilibrium pay-off). Straightforward by (21).

Second claim (the entrant's equilibrium pay-off). By (23), $dV_E/d\beta_I < 0$ if $\Psi = (1 - \alpha_I^*) + (1 - \beta_I)(d\alpha_I^*/d\beta_I) > 0$. By (15) and (25) we can compute $\Psi = a\Phi/D^2 > 0$, where D still denotes the denominator of (15) and $\Phi > 0$ is given by (26) in the proof of Proposition 4, second claim.■

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