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INNOVATIVE ACTIVITY
AND
BARRIERS TO ENTRY⁺

by

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+ The author benefited from a discussion with Morton Kamien on the topic of this paper.

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1. Introduction.

Economists continue to search for the market structure which most spurs innovative activities. Resolution of this issue is needed to evaluate public industrial policies affecting market structures for their impact on technological advance. Earlier discussions emphasized the virtues for innovative activity of the (large firm) monopoly, with superior abilities to finance innovative efforts and appropriate the resulting rewards, or of vigorous non-price competition with strong incentives for technological change. Empirical research on both sides of the Atlantic fails however to clearly support simple generalizations [for reviews see Markham (1974), Kamien and Schwartz (1975a), De Bondt (1977a)] , so that renewed research on the link between market structure and innovation appears in order.

Already progress has been made in this regard, most recently by Kamien and Schwartz (1976), on the effects of technological rivalry for being the innovator. We intend to focus on the consequences of the post-innovation appearance of rivals for the private innovative efforts of a technological leader. Previous formal economic analysis suggests that such innovative activities are stimulated by increased protection from the threat of post-innovation rivalry

[see, however, Kamien and Schwartz (1975b)]. Nordhaus (1969) found innovative investment expenditures to increase with the patent life in an otherwise perfect competitive industry, while Kamien and Schwartz predict that the pace of innovation will be tempered by shortening the patent life (1974) or by the intensification of exogenous potential post-innovation rivalry (1976). In this paper we present a modified set of predictions for an innovator recognizing that the expected length of its temporary monopoly position is directly related to the magnitude of its innovative efforts, the height of (exogenous) barriers to entry, and possibly an entry lag. Our setting differs from the pioneering frameworks in the following way.

First, we recognize that in reality entry (possibly imitation) is not free, as is implicit in a perfect competitive setting. The innovator may be able to appropriate sufficient rewards to undertake its efforts due to the presence of traditional barriers to entry which may discourage rapid entry decisions and/or because new rivals need in any case an entry lag to become effective rivals. Such a lag may, but need not, be created by effective patent protection [Nutter (1956), Scherer (1970)]. Second, the threat of new rivalry is not treated as exogenous to the innovator. We envisage a technological leader realizing that by increasing the magnitude of its innovative efforts it may discourage new competition, it may mold the barriers to entry to its advantage [Jacquemin (1972a), Jacquemin and Thisse (1972b)]. The more important a process innovation, the lower the corresponding short-run profit maximizing or rule-of-thumb price may be and the less profitable entry may appear.

The range and sophistication of product characteristics resulting from intense innovative efforts may make it too costly for prospective rivals to come up rapidly with technical and market feasible substitutes in the presence of other barriers, and their appearance may consequently be retarded. In summary, we explore exogenous and endogenous elements determining the appropriation possibilities of the innovator which were not considered and/or integrated in earlier formal work.

Our central results are that innovative investment expenditures will either (i) be discouraged by a reduction in the barriers to entry (and imitation) when innovation is costly and yielding small short-run rewards or, (ii) increase with an increase in the threat of entry up to some point, peak, and decline with a further intensification of this threat, given low costs and important profit opportunities. These inferences are in accordance with the Kamien and Schwartz predictions (1976) for technological pre-innovation rivalry and help to explain reported empirical findings [Williamson (1965), Comanor (1967), Philips (1970), among others]. In addition we find that lengthening of the entry lag stimulates innovation in case (i), but in situation (ii) only when the other barriers to entry are low. When in these circumstances already high barriers are present, innovative activity will be tempered by an increased entry lag (say patent life).

The presentation is organized as follows. In a following section we detail the formal framework, next we discuss our results, and finally present the conclusions. For the reader's convenience, mathematical arguments

have been deferred to an appendix.

2. The Model.

We posit a firm contemplating a choice between a range of potential innovations which differ as to the magnitude they require of innovative (R & D) investment expenditure I . It facilitates the argumentation somewhat if we think of the potential innovations as being different with regard to the physical characteristics determining the "quality" of a new product. A larger effort I , then, is one permitting a better quality. Occasionally we will point to wider interpretations.

The rewards resulting from selling the new product accrue to the innovator from a given time zero on (the time of successful introduction). (Licensing, or a combination of licensing and selling, need not be excluded from this setting). These rewards depend on the innovative effort I but also on whether or not the firm holds a monopoly position or new entrants (possibly imitators) have introduced a substitute product. Let $B_1(I)$ denote the current pre-entry return (quasi-rent attributable to the innovator) collected by the innovating firm as long as it is a monopolist, and let $B_2(I)$ be the current post-entry rewards which are the maximum current returns the firm thinks it can earn once it lost its monopoly position. We assume (prime denotes differentiation) :

$$\begin{aligned} B_1(0) &= 0, \quad B_1'(I) > 0, \quad B_1''(I) < 0, \quad B_1(I) < \infty. \\ B_2(0) &= 0, \quad B_2(I) < B_1(I) \text{ for } I > 0, \quad B_2'(I) \geq 0, \quad B_2''(I) \leq 0. \end{aligned} \tag{1}$$

The loss of the temporary monopoly position through rival appearance diminishes the rewards, possibly to zero. We allow for a situation in which the firm continues to benefit from its earlier innovative efforts once rivals have entered, but post-entry gains may also be independent of I . This modelling does not exclude that upon entry the firm alters its product (and/or price). The concave shape of the reward functions reflects that diminishing returns associate increases in quality and/or that it is progressively more difficult to achieve a better quality from increased innovative expenditures. The latter phenomenon is a special case of a more general tendency reported by Machlup (1962) .

The innovator realizes that it takes new rivals a time span τ , $0 \leq \tau < \infty$, before they become established industry members. This entry lag which new rivals need upon an irrevocable entrance decision to become entrants, may be viewed as a recognition and/or construction period, required to learn about the new technology and to plan and construct production and distribution facilities. [Nutter (1956), Scherer (1970), De Bondt (1976)] . In the present setting we can also consider this lag as coinciding with, or being larger than, the time of effective patent protection.

The incumbent firm is uncertain when competitors will appear because it is uncertain when a first rival will have reached, at some instant after time zero, an irrevocable decision to enter. We suppose, inspired by related modelling [Kamien and Schwartz (1971), De Bondt (1976)] , that the innovator is able to assess the probability of a first rival appearance by a time t , $F(t)$,

in the following way :

$$\begin{aligned} F(t) &= 0 & 0 \leq t \leq \tau \\ F'(t)/(1-F(t)) &= \gamma G(I) & t \geq \tau \end{aligned} \quad (2)$$

with $0 \leq \gamma \leq \infty$, $I \geq 0$, $0 \leq G < \infty$, $G' \leq 0$, $G'' \geq 0$, $\lim_{I \rightarrow \infty} G(I) = 0$. The innovator expects a rival to appear at a time $\tau + 1/\gamma G(I)$. The threat of entry is indicated by the function $\gamma G(I)$, equalling the conditional probability of entry at a time t , given that no entry has yet occurred. An increase in the parameter γ reflects a reduction in the familiar barriers to entry possibly created by economies of scale (potential entrants may need a significant market share in order to achieve a unit cost equal to the unit cost of the established seller), by product differentiation advantages of the innovator (affecting the sales production and distribution costs of new entrants), by absolute cost-or, more general, know-how advantages in both production and R&D of the incumbent firm, or by other factors [see Mueller and Tilton (1969), Scherer (1970), Jacquemin (1975)] . With $\gamma = 0$, those barriers blockade entry and the firm expects to hold an indefinite monopoly position. As γ increases entry decisions are taken more readily due to a reduction of the barriers and entrants are expected sooner. For $\gamma \rightarrow \infty$, all barriers are removed and the monopoly position will cease at time τ . The function $G(I)$ reflects the believe of the innovator that by increasing its innovative investment expenditure I it may discourage entry. The firm believes that by choosing a larger magnitude of I it may secure a longer temporary monopoly position than it would otherwise. This is in accordance with the reported observations that

R&D and innovative behavior tends to define, along with other elements (captured by the parameters γ and τ), limits to entry by new firms [Phillips (1966), Scherer (1970)] or that by these investment expenditures the firm is able to mold market structural elements to its advantage [Jacquemin (1972a), Jacqueming and Thisse (1972b)]. It may be that in some industries either by reasons of anti-trust supervision or by unsophisticated behavior the established firm is not manipulating directly its pricing policy to retard entry, as is supposed with a limit-pricing behavior, but takes in adopting new technology the possible discouraging effect on new competition into account. The firm may be increasing I , for instance, be able to obtain a lower constant unit cost, equate consequently marginal revenue to marginal cost, or use a rule of thumb, to arrive at a price which will also be lower and render hereby indirectly entry unattractive (while passing on cost-savings to the consumer). More sophisticated and well-exploited product innovations resulting from more intense efforts may ensure longer temporary monopoly positions than more trivial technological changes would. This supposition is opposite to the one analyzed by Kamien and Schwartz (1972), with an increase in the magnitude of the innovation encouraging more rapid rival reaction. Perhaps the latter situation is more appropriate in industries with well-understood technologies. We will find circumstances where either of these assumptions yield the same qualitative predictions as to the effects of post-innovation protection !

Finally we suppose that the innovator chooses the level of innovative activity I to maximize the expected value of discounted net revenues. Formally :

$$\max_{I \geq 0} W(I) = -cI + \int_0^{\infty} e^{-\rho t} [B_1(I)(1-F(t)) + B_2(I)F(t)] dt \quad (3)$$

given (1) and (2), $\rho = r - g > 0$, r a rate of time discount, g an industry trend, and c a constant per unit acquisition cost of innovative input. We assume $W'' < 0$ and, without loss of generality, $G'(I^m) > 0$ for I^m solving $-cp + B'_1(I^m) = 0$.

We abstract from a number of features of the innovative process. Some of those, such as a fixed time interval between the decision on I and the date of successful introduction or pre-innovation rivalry, could be incorporated at the cost of largely unnecessary complications. Other aspects, such as decisions on the timing of introduction, uncertainties in the inventive process or time-varying exogenous technological change, complicate matters much more. Investigation of our simplified problem is hoped to be suggestive of patterns to be found with less restrictive assumptions.

Problem (3) can be rewritten by taking the integration of F from (1) into account as :

$$\max_{I \geq 0} W(I) = -cI + \ell(I)B_1(I) + m(I)B_2(I) \quad (4)$$

with

$$\ell(I) = (1 - e^{-\rho\tau})/\rho + e^{-\rho\tau}/(\rho + \gamma G(I))$$

$$m(I) = 1/\rho - \ell(I).$$

The firm attempts to maximize a weighted sum of pre- and post-entry gains. The Nordhaus framework (1969) is reobtained for $\gamma \rightarrow \infty$, $B_2 \equiv 0$ and τ the patent life.

3. Characterization of Innovative Activity.

Our intention in this section is to obtain and characterize the optimal solution I^0 to problem (4). I^0 satisfies the following conditions :

$$W'(I^0) \leq 0 \quad W'(I^0)I^0 = 0 \quad I^0 \geq 0 \quad W''(I^0) < 0 \quad (5)$$

with

$$W'(I^0) = -c + [(1 - e^{-\rho\tau})/\rho + e^{-\rho\tau}/(\rho + \gamma G(I^0))] [B_1'(I^0) - B_2'(I^0)] + B_2'(I^0)/\rho \\ - e^{-\rho\tau} [B_1(I^0) - B_2(I^0)] \gamma G'(I^0) / (\rho + \gamma G(I^0))^2$$

A first task is to characterize the solution in polar like circumstances and to indicate when interior or boundary solutions apply. An additional restriction greatly simplifies subsequent arguments (but is nonessential for our main results); we suppose :

$$(-c\rho + (1 - e^{-\rho\tau})B_1'(0) + e^{-\rho\tau}B_2'(0)) > 0 \quad \text{for} \quad \tau > 0 \quad (6)$$

Noting the assumptions and (5) one can now verify (see Appendix) :

Proposition 1 : Let $I^m > 0$ solve $-c\phi + B'_1(I^m) = 0$; then

- (a) $I^o = I^m$ for $\gamma = 0$ or $\tau \rightarrow \infty$.
- (b) $I^o \equiv I^c < I^m$ for $\gamma \rightarrow \infty$ and $\tau < \infty$, with $I^c > 0$ for $\tau > 0$.
- (c) $I^o > I^c$ and $G(I^o) > 0$ for $0 < \gamma < \infty$ and $0 < \tau < \infty$.

The innovator adopts I^m if it expects to hold an indefinite monopoly position either because the appearance of new rivals is blockaded by barriers to entry ($\gamma=0$) or because, say, an indefinite legal monopoly is granted ($\tau \rightarrow \infty$). We subsequently refer to I^m as the indefinite monopoly solution. It is a short-run decision in the sense that it is not affected by potential competition. In case entrants are certain to appear at the end of time τ , because entry is free, the firm adopts I^c . Not surprisingly we find that $I^c < I^m$, since with free entry, less appropriation of rewards results. For a zero lag τ and no post-entry gains, no appropriation is possible with free entry, and one verifies that $I^c = 0$; a classic result.

$I^o > I^c$, when barriers to entry prevent the immediate appearance of rivals at the end of time a positive τ . In this situation it is optimal to retard but not foreclose entry ($G(I^o) > 0$).

Condition (6) ensures that $I^o > 0$ for a positive lag τ . It reflects that the long-run profitability of a marginal increment in I from zero is positive when entrants are expected at the end of the positive period τ . With this restriction it is still possible that no innovative efforts are undertaken with $\tau = 0$ and an intense threat of entry γ ; without (6) this may

also be the case for small values of τ . It can easily be seen, then, that for a given threat of new competition, positive efforts are more likely to follow, the smaller the acquisition costs and the discount rate, the higher the pre- or post-entry current reward opportunities, or the growth rate, and the larger the lag τ (see also Teubal (1976)).

A comparative statics analysis confirms a similar tendency for positive innovative efforts, except for the effect of the lag τ . Let δ_1 denote a multiplicative shift parameter of the B_1 function (i.e. put $B_1(I) = \delta_1 b_1(I)$). An increase in δ_1 (from $\delta_1 = 1$) means higher pre-entry rewards for a given innovative effort and may reflect better technological and marketing capabilities and opportunities of the technological leader. Similarly, let δ_2 represent an additive reduction in the post-entry rewards (i.e. put $B_2(I) \equiv b_2(I) - \delta_2$). An increase in δ_2 (from $\delta_2 = 0$) indicates that the size of entry becomes larger and post-entry gains smaller; the innovator expects entry to be more detrimental to its short-run gains. One finds :

Proposition 2 : For $I^0 > 0$: $\partial I^0 / \partial c < 0$, $\partial I^0 / \partial r < 0$, $\partial I^0 / \partial \delta_1 > 0$,
 $\partial I^0 / \partial \delta_2 < 0$, $\partial I^0 / \partial g > 0$, $\partial I^0 / \partial \tau \gtrless 0$ as $I^0 \lesseqgtr I^m$.

All but the last results are in accordance with earlier predictions and need no further comment. More interesting is the finding that lengthening of τ , say due to an increased patent life, may also temper the innovative efforts. A characterization and explanation of this prediction will be presented after a discussion of our subsequent inferences.

We proceed to study the effect on I^o of the exogenous threat of entry represented by the parameter γ . To this end, define

$$\begin{aligned}\epsilon_B(I) &\equiv d \ln(B_1(I) - B_2(I)) & I > 0 \\ \epsilon_G(I) &\equiv -d \ln G(I) & G(I) > 0\end{aligned}\tag{7}$$

The elasticity of the transient return $(B_1 - B_2)$ with respect to I is ϵ_B , while a similar elasticity of the (positive) threat of entry is ϵ_G . Partial differentiation of $W'(I^o) = 0$ learns that for $I^o > 0$:

$$\text{sign } \partial I^o / \partial \gamma = - \text{sign} [\rho(\epsilon_B - \epsilon_G) + \gamma G(\epsilon_B + \epsilon_G)]\tag{8}$$

or, upon substitution from $W'(I^o) = 0$,

$$\text{sign } \partial I^o / \partial \gamma = \text{sign} [\rho^2(\rho c - B_1') + (\gamma G)^2((B_1' - B_2')(1 - e^{-\rho\tau}) + B_2' - \rho c)]\tag{9}$$

where for notational convenience we suppress the dependence on I^o . The effect of γ appears ambiguous at first sight. In an Appendix we explore these relations and show:

Proposition 3: Let the assumptions hold, $I^o > 0$ and $\tau < \infty$, then

- (a) with $\epsilon_B(I^m) \geq \epsilon_G(I^m)$: $\partial I^o / \partial \gamma < 0$ for $0 \leq \gamma < \infty$; I^o attains a maximum value I^m given the absence of a (exogenous) threat of entry $\gamma = 0$;
- (b) with $\epsilon_B(I^m) < \epsilon_G(I^m)$: $\partial I^o / \partial \gamma > 0$ for $0 \leq \gamma < \gamma^o$, $\partial I^o / \partial \gamma^o = 0$,
 $\partial I^o / \partial \gamma < 0$ for $\gamma^o < \gamma < \infty$; I^o reaches a maximum value $I^{oo} > I^m$ for an intermediate (exogenous) threat of entry γ^o , $0 < \gamma^o < \infty$.

Maximum innovative activity appears either with blockaded entry or with some positive threshold degree of potential competition where entry is neither free nor blockaded. Given $\varepsilon_B(I^m) \geq \varepsilon_G(I^m)$, an intensification of the threat of entry tempers innovative investments. I^o gradually decreases from its blockaded entry level I^m towards the free entry level I^c , as γ increases from $\gamma = 0$ to $\gamma \rightarrow \infty$. (For $\tau = 0$, $I^o = 0$ may be reached for a finite γ and maintained as γ increases). With $\varepsilon_B(I^m) < \varepsilon_G(I^m)$, the innovative investments increase with a fall in the barriers to entry from their blockading level, peak for some intermediate value of those barriers and decrease towards the corresponding free entry level as the barriers continue to be lowered. Innovative efforts are larger than with blockaded entry as long as entry is not too easy ($0 < \gamma < \bar{\gamma}$, $\bar{\gamma} > \gamma^o$), they are smaller than with an indefinite monopoly when potential rivalry becomes too intense ($\gamma > \bar{\gamma}$). Situation (b) appears to be in close accordance with Connor's finding (1967) for the level of research activity (measured by R&D employees) in twenty-one U.S. industries during 1955 and 1960, for which he concluded :

"Industrial research spending appears strongest in industries where some measure of technical entry barriers exist, so that rapid imitation is impeded, but also where entry has not been effectively foreclosed".

Scherer (1970) and Kamien and Schwartz (1976) review related claims, while these last authors obtained earlier from formal economic arguments similar predictions for pre-innovation technological rivalry and the timing of innovations.

To fully understand the above Proposition, it is necessary to explain the conditions determining whether (a) or (b) applies. The elasticity relations allow an intuitive and formal clarification, as will be detailed next. An increase in the innovative activity to discourage entry is clearly only relevant when entry is neither free nor blockaded ($0 < \gamma < \infty$). The debloca- tion of entry results in more intense innovative activities when such efforts entail a proportionate decrease in the threat of entry larger than the propor- tionate increase of the transient return ($\epsilon_B(I^m) < \epsilon_G(I^m)$) and in lower ef- forts otherwise ($\epsilon_B(I^m) \geq \epsilon_G(I^m)$). Intuitively, an increase only follows when the firm regards that it can mold potential competition "a lot" to its ad- vantage. In this case further intensification of this rivalry further stimu- lates innovation, but only up to some point. The higher costs associated with increased innovative investment and the deteriorated appropriation possi- bilities for any given innovation will eventually offset the effect such an increase has on discouraging new rivalry. When the threat of entry becomes too large, a further intensification results in a decrease, instead of an in- crease, of innovative activity. When even a small departure from a blockaded entry position results in smaller innovative activity, any further reduction will have the same effect. This is relevant with dim prospects to discour- age entry and a fortiori when increased innovative activity encour- ages rival entry (for $G' > 0 : \epsilon_B > \epsilon_G$) (Kamien and Schwartz (1972)). Thus, as long as $\epsilon_B(I^m) \geq \epsilon_G(I^m)$, easier entry discourages innovative activity re- gardless of whether or not the firm believes that such increased efforts en- courage or discourage the appearance of new rivalry !

We can also formally characterize when (a) or (b) are likely to prevail and these inferences can intuitively be understood given our earlier comments . Noting the dependence of I^m on c , r , δ_1 , and g , and given a weak sufficient condition that $d\epsilon_G(I^m)/dI > 0$, we see that situation (b) is more likely to apply, the lower the acquisition cost c or the discount rate r and the higher the pre-entry profit opportunities or market growth rate g , since $\epsilon_B(I^m) - \epsilon_G(I^m)$ is more likely to be smaller with such parameter magnitudes.

Precise predictions as to the combined effect of τ and γ can now be formulated by combining results from the previous Propositions. We summarize :

Proposition 4 : Given the assumptions, $I^o > 0$, and

- (a) $\epsilon_B(I^m) \geq \epsilon_G(I^m)$: $\partial I^o / \partial \tau > 0$ for $\gamma > 0$; while with
- (b) $\epsilon_B(I^m) < \epsilon_G(I^m)$: $\partial I^o / \partial \tau < 0$ with $I^o > I^m$ for $0 < \gamma < \bar{\gamma}$, and $\partial I^o / \partial \tau > 0$ with $I^o < I^m$ for $\gamma > \bar{\gamma}$, where $\bar{\gamma}$ is defined by $I^o(\bar{\gamma}) = I^m$.

Only with $\epsilon_B(I^m) \geq \epsilon_G(I^m)$ will the assurance of a longer temporary monopoly position, say through a longer patent life, stimulate innovative activity whatever the other non-blockading barriers to entry. For $\epsilon_B(I^m) < \epsilon_G(I^m)$ this need not be the case. In fact, precisely the reverse effect follows when the other barriers are rather high ($0 < \gamma < \bar{\gamma}$) and the firm considers it profitable to mold the threat of entry to its advantage by investing more than it would with blockaded entry. With an enlargement of τ these efforts may become less worthwhile since in any case longer appropriation is assured and the discouraging effect is postponed to a more distant future. Only when the other

barriers to entry are low ($\gamma > \bar{\gamma}$) and result in spending less than with a indefinite monopoly position, will an increase in τ again stimulate innovative activity. It is interesting to note that in all instances the increase of τ brings I° closer to the corresponding indefinite monopoly level. Only in this respect is the role of τ reminiscent of the effect of such a lag on a entry retarding current price policy [De Bondt (1976, 1977b)].

Our final results concern a characterization of I° and γ° .

Proposition 5. With I° and γ° defined in Proposition 3 :

- (i) $\partial I^\circ / \partial c < 0$, $\partial I^\circ / \partial r < 0$, $\partial I^\circ / \partial \delta_1 > 0$, $\partial I^\circ / \partial \delta_2 < 0$, $\partial I^\circ / \partial g > 0$,
 $\partial I^\circ / \partial \tau < 0$; and
- (ii) given $dc_G/dI > 0$; $\partial \gamma^\circ / \partial c < 0$, $\partial \gamma^\circ / \partial \delta_1 > 0$ (for $B_2 \equiv 0$), $\partial \gamma^\circ / \partial \tau < 0$; and
 (ii)' $\partial \gamma^\circ / \partial \delta_2 > 0$.

An intuitive understanding of these predictions is possible. The larger the fixed innovation cost c , for instance, the smaller the intermediate exogenous threat of entry from where a further intensification fails to result in an increase in I° and instead entails a decrease in innovative activities. The more costly innovative activities, the readier it becomes less worthwhile to enlarge such efforts in an attempt to discourage potential competition. Similar arguments can be made for the other restrictions following (ii); the remaining predictions are in accordance with Proposition 2 except for the effect of τ , for which we refer to the comments given above.

4. Conclusions.

We investigated how the innovative investment expenditures may be affected by the appropriation possibilities of the resulting rewards. These possibilities were viewed as being determined by the innovative efforts itself and by market structural elements manipulable by public policy, specifically: the assurance of a temporary monopoly position during an entry-lag and barriers to entry discouraging entry decisions. Increased protection from potential competition could result from a larger entry-lag (say due to a longer patent life) or from increasing the other barriers to new competition. We found that such increased protection need only stimulate innovative efforts entailing high cost, low short-run rewards or when an intensification of such efforts encourages the appearance of new rivals. Different predictions may apply, however, when the innovative activities itself create a barrier to entry. Enlarged protection may in these circumstances temper innovation accompanying relative low costs and high profit opportunities, most likely when the barriers to entry are already high.

Our results appear to constitute, together with the Kamien-Schwartz inferences, a rich set of predictions, provided adequate empirical content can be given to the relevant parameters of the model. Some reflection also points to further avenues for theoretical work.

A first task is, of course, to explore less restrictive assumptions. In particular it would appear fruitful to combine our findings, focusing on

the magnitude of innovation for a given timing, with those of Kamien and Schwartz, relevant for the timing of an innovation of a given magnitude. A direct combination of both frameworks does not appear analytically tractable, but other approaches may be more promising.

Second, a comparison with our earlier results on limit-pricing reveals that the entry lag and the barriers to entry have possibly quite different effects on either a current (price) or an (innovative) investment policy set in an attempt to discourage entry. The short-run effects of potential competition need not be identical for such policies. This appears to have received little attention so far from scholars suggesting more general or alternative interpretations to limit-pricing. It also raises the question as to how the long-run effects compare.

Finally, subsequent research could focus on the socially optimal degree of market imperfections created by say an entry-lag and/or other exogenous barriers to entry (or by a regulatory lag (Bailey (1974), Wendel (1976))). One may proceed along the lines suggested by Nordhaus and Bailey, with a social planner realizing that these imperfections affect not only the magnitude of the private innovative efforts and, hereby, the resulting pre- and post-entry social current surplus, but also the length of the time-periods during which these come to society. While such an analysis falls outside the scope of this contribution, we can report already that within a simple setting, the social optimal entry lag may be zero given high other barriers to entry and relatively cheap but privately rewarding innovations. In those circumstances little justification appears for patent protection.

APPENDIX

In this appendix we present essential formal arguments deleted from the main text. Proposition 1 is considered first. From the equations (5), one immediately infers (a) and also learns that, given the restriction (6), $W'(0) > 0$ for $\gamma \rightarrow \infty$ and $\tau > 0$. Our claim that $I^0 \equiv I^C > 0$, follows therefore in view of the concavity assumption on W . To verify (c) we note that $W'(0)|_{\gamma=0} > 0$, $W'(0)|_{\gamma \rightarrow \infty, \tau > 0} > 0$, and $\partial W'(0)/\partial \gamma < 0$. We obtain for $\gamma \geq 0$ and $\tau > 0$: $W'(0) > 0$ and also $I^0 > 0$. In addition we find that $W'(I^C) > 0$, for $I^C > 0$, solving $[-c + ((1-e^{-\rho\tau})/\rho)(B'_1(I^C)-B'_2(I^C))+B'_2(I^C)/\rho] = 0$. Consequently $I^0 > I^C$, since $W'' < 0$ by assumption.

Finally we learn that for any $\tilde{I} < \infty$ where $G(\tilde{I}) = 0$ and hence $G'(\tilde{I}) = 0$ (in view of the assumed continuity of G') we must have $W'(\tilde{I}) = -c + B'_1(\tilde{I})/\rho < 0$. Indeed, $\tilde{I} > I^m$ because $G(I^m) > 0$ by supposition. I^0 needs to be smaller than any $\tilde{I} < \infty$ where $G = 0$ and hence $G(I^0) > 0$.

To obtain Proposition 2 we totally differentiate $W'(I^0) = 0$ from (5), yielding for any parameter a : $\text{sign } \partial I^0/\partial a = \text{sign } \partial W'/\partial a$, because $W'' < 0$. One computes easily :

$$\partial W'/\partial c < 0, \quad \partial W'/\partial \delta_1 > 0, \quad \partial W'/\partial \delta_2 < 0 \quad (A2)$$

and, using $W'(I^0) = 0$, (suppressing the dependence on I^0) :

$$\partial W'/\partial \rho = -B'_2{}^2 \gamma G/\rho^2 (\rho + \gamma G) - (c - (B'_1 - B'_2) \gamma G' / (\rho + \gamma G)^2) / (\rho + \gamma G) < 0, \quad (A3)$$

from which $\partial W'/\partial r$ and $\partial W'/\partial g$ follow immediately. Finally :

$$\partial W'/\partial \tau = B'_1 - c\rho \quad (A4)$$

Recalling that I^m solves $B'_1(I^m) - c\rho = 0$, and noting the concavity of B_1 , we have $B'_1 - c\rho \geq 0$ as $I^\circ \leq I^m$.

To verify Proposition 3 we investigate I° as a function of the parameter γ . Given our assumptions, the equality $W'(I^\circ) = 0$ implicitly defines for $0 \leq \gamma < \infty$ and $\tau > 0$ a positive differentiable function $I^\circ(\gamma)$. For $\tau = 0$, such a function is defined for small enough γ values, while $I^\circ = 0$ for larger magnitudes of γ .

(a) Let $\epsilon_B(I^m) \geq \epsilon_G(I^m)$. It is immediate from (8) that $\partial I^\circ/\partial \gamma|_{\gamma=0} < 0$, i.e. I° decreases from I^m as γ increases from zero. In addition we claim that $\partial I^\circ/\partial \gamma > 0$ for $\gamma > 0$ and $I^\circ > 0$. This claim could only be invalidated (given the continuity of $I^\circ(\gamma) > 0$) if there exists a stationary point of $I^\circ(\gamma)$ at some $\gamma > 0$ with $0 < I^\circ < I^m$ or $I^\circ = 0$. The latter possibility is easily excluded because if I° becomes zero for some γ , it remains zero for all larger γ , since $\partial W'(0)/\partial \gamma < 0$. The former situation is likewise infeasible as any stationary point of $I^\circ(\gamma) > 0$ must necessarily be above I^m . To see this, rewrite $W' = 0$ (suppressing the dependence on I) as :

$$W'(I) = -c + B'_1/\rho - e^{-\rho\tau}\gamma^2 G G'(B_1 - B_2)/\rho(\rho + \gamma G)^2$$

$$- e^{-\rho\tau}\gamma G(B_1 - B_2) [\rho(\epsilon_B - \epsilon_G) + \gamma G(\epsilon_B + \epsilon_G)] / \rho(\rho + \gamma G)^2 = 0$$

and note that with $\partial I^\circ/\partial \gamma = 0$ the last term is zero from (8), hence also

$-c + B_1'/\rho < 0$ in view of (1) and (2).

(b) With $\varepsilon_B(I^m) < \varepsilon_G(I^m)$, we have again from (8) that $\partial I^\circ / \partial \gamma|_{\gamma=0} > 0$. Let $\tau > 0$ ($\tau = 0$ is discussed later). $I^\circ > 0$ starts increasing from I^m at $\gamma = 0$ and reaches $I^c < I^m$ as $\gamma \rightarrow \infty$ (Proposition 1), and, therefore, must peak at least once for some $0 < \gamma < \infty$, and $I^\circ > I^m$. We argue that I° will peak only once for such a γ and that this maximum is the only stationary point. From the arguments presented above we know already that $I^\circ > 0$ can have only a stationary point with $I^\circ > I^m$. Hence, once I° falls below I^m , say for $\gamma > \bar{\gamma} > 0$, it remains below I^m and decreases towards I^c as γ increases. Moreover we verify that for any positive stationary point of $I^\circ(\gamma)$, the sign $\partial^2 I^\circ / \partial \gamma^2 = \text{sign}(B_1' - \rho c) < 0$. This follows from differentiation of $\partial I^\circ / \partial \gamma$, which equals the expression between brackets in (9) divided by $\rho \gamma (\rho + \gamma G(I^\circ))^2 (-W''(I^\circ))$, and taking into account that $\partial I^\circ / \partial \gamma = 0$ at a stationary point. Consequently I° attains a unique maximum $I^{\circ\circ} = I^\circ(\gamma^\circ) > I^m$ for $0 < \gamma^\circ < \infty$ (and before it dips below I^m at $\bar{\gamma}$). This also establishes that $\partial I^\circ / \partial \gamma > 0$ for $\gamma < \gamma^\circ$ and $\partial I^\circ / \partial \gamma < 0$ for $\gamma > \gamma^\circ$.

Note : It should be possible to show that $\bar{\gamma} > 0$, with $I^\circ(\bar{\gamma}) = I^m$. This can be achieved by rewriting $W'(I^\circ) = 0$, noting that $B_1'(I^m) - c\rho = 0$, so that $\bar{\gamma}$ is seen to solve :

$$[B_1'(I^m) - B_2'(I^m)]G(I^m)(\rho + \bar{\gamma}G(I^m)) + (B_1(I^m) - B_2(I^m))G'(I^m)\rho = 0$$

clearly $\bar{\gamma} > 0$, provided $\varepsilon_B(I^m) < \varepsilon_G(I^m)$ (Reference to $\bar{\gamma}$ may in fact guide an alternative proof and further checking on our results).

For $\tau = 0$ the arguments above largely carry over, provided the γ values where

I^o becomes zero is "large" (not smaller than $\bar{\gamma}$). If this is not the case I^o need not attain its maximum at a stationary point but possibly at a discontinuity where $I^o > I^m$ drops to zero.

Finally we come to Proposition 5. By definition I^{oo} and γ^o solve simultaneously $W' = 0$ and $\partial I / \partial \gamma = 0$, yielding from (5) and (9) two equations in I^{oo} and γ^o . After substitution of the latter equality in the first and some regrouping of terms, one finds that I^{oo} and γ^o solve :

$$X \equiv 2(\rho + \gamma G)(B_1' - \rho c) - e^{-\rho \tau} \gamma G((B_1' - B_2') + (B_1 - B_2)G'/G) = 0 \quad (A5)$$

$$Y \equiv \rho^2(B_1' - \rho c) - (\gamma G)^2(B_1' - \rho c - e^{-\rho \tau}(B_1' - B_2')) = 0 \quad (A6)$$

Total differentiation of (A5) and (A6) and application of Cramer's rule, reveals that for any parameter a , $\partial I^{oo} / \partial a = (\partial X / \partial \gamma \cdot \partial Y / \partial a - \partial Y / \partial \gamma \cdot \partial X / \partial a) / D$ and $\partial \gamma^o / \partial a = (\partial Y / \partial I \cdot \partial X / \partial a - \partial X / \partial I \cdot \partial Y / \partial a) / D$ with $D \equiv \partial X / \partial I \cdot \partial Y / \partial \gamma - \partial Y / \partial I \cdot \partial X / \partial \gamma$.

First we establish that $D < 0$. Let $U \equiv \rho X - Y$. One verifies that $D = 2\rho(\rho c - B_1')(\partial U / \partial I) / \gamma$. But we also have that $U = \rho(\rho + \gamma G)^2 W'$, hence with $W'' < 0$ it follows that $\partial U / \partial I|_{W'=0} < 0$ and consequently $D < 0$ at $I^{oo} > I^m$ where $\rho c - B_1' > 0$.

Next we establish that $\partial I^{oo} / \partial a = 2\rho(\rho c - B_1')(\partial U / \partial a) / \gamma(-D)$. From the relation between U and W' , one verifies that $\text{sign } \partial U / \partial a = \text{sign } \partial W' / \partial a$ at $W' = 0$ hence, the sign $\partial I^{oo} / \partial a = \text{sign } \partial W' / \partial a$. Part (i) of Proposition 5 now follows upon recalling (A2), (A3) and (A4).

Some tedious manipulations reveal :

$$\partial\gamma^o/\partial\tau = - (\rho c - B'_1)Z / D < 0$$

$$\partial\gamma^o/\partial c = - Z / D < 0$$

$$\partial\gamma^o/\partial\delta_1 = \rho c Z / D > 0 \quad \text{for} \quad B_2 \equiv 0$$

with

$$\begin{aligned} Z &= \rho(\rho + \gamma G)(2\partial Y/\partial I - (\rho - \gamma G)\partial X/\partial I) \\ &= \rho(\rho + \gamma G)^2 [e^{-\rho\tau} \gamma(\rho - \gamma G) A/(\rho + \gamma G) + \gamma G e^{-\rho\tau} (B''_1 - B''_2) \\ &\quad + 2\rho(\rho c - B'_1) G'/G] < 0 \end{aligned}$$

since

$$A = [(B'_1 - B'_2)G' + (B_1 - B_2)(G'' - G'^2/G)] < 0$$

ensured with $d \epsilon_G/dI > 0$ and also $(\rho - \gamma G) > 0$ for $Y = 0$ to possibly hold, see (A6). Finally :

$$\begin{aligned} \partial\gamma^o/\partial\delta_2 &= [(\rho^2 - (\gamma G)^2)B''_1 + 2\rho^2(\rho c - B'_1)G'/G \\ &\quad + e^{-\rho\tau}(\gamma G)^2(B''_1 - B''_2)] e^{-\rho\tau} \gamma G'/(-D) > 0. \end{aligned}$$

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