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Strategic R&D Delays Generate Market Power

Maggie Xiaoyang Chen
Department of Economics, University of Colorado at Boulder
Boulder, Colorado

Murat Iyigun
Department of Economics, University of Colorado at Boulder
Boulder, Colorado

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Center for Economic Analysis
Department of Economics

University of Colorado at Boulder
Boulder, Colorado 80309

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Maggie Xiaoyang Chen
xiaoyang.chen@colorado.edu

Murat Iyigun
murat.iyigun@colorado.edu

University of Colorado

Abstract

We develop a theoretical model in which both the R&D resources to develop new product applications and the market structure of consumption goods manufacturing are determined endogenously. There exists uncertainty with respect to the development date of an inaugural product, although higher R&D spending shortens the expected product development stage. Once an inaugural product application is introduced, the costs of imitation decline. According to the model, the time between a patent application and the development of an inaugural product is influenced by two factors: returns to scale in R&D and "strategic delays." Strategic delays in new product development are most

determined endogenously. There exists uncertainty with respect to the development date of an inaugural product, although higher R&D spending shortens the expected product development stage. Once an inaugural product application is introduced, the costs of imitation decline.

Using this framework, we are able to reach several novel conclusions. For instance, we find that the time between a patent application and the development of an inaugural product is influenced by two factors. First, if the marginal return to new product development is decreasing in the state of the existing technologies, then the length of time between a patent application and the development of new products would obviously and inevitably widen as technologies mature. In that case, reductions in the length of effective patent protection would be caused by "natural" delays due to diminishing returns to R&D. Second and more interestingly, in deciding how much to spend on new product development, patent holders would take into account the costs of imitation–and the inherent market structure commensurate with those costs–in deciding how much to spend on R&D. As a consequence, patent holders would adjust their product development efforts in an attempt to maximize their market power over the length of a patent. If indeed patentees reduce the investment in new product development based on such concerns, then the expected development date of an inaugural product would again be delayed. Thus, lower R&D intensity in product development based on such concerns would generate "strategic" delays. Naturally, strategic delays in new product development are most likely to occur when earlier dates of new product development enable a larger number of imitators to penetrate an industry. When that is the case, product developers would reduce their R&D intensity with the recognition that the sooner is the date of the inaugural product launch, the longer is the amount of time they face competition over the length of the patent. Taking into account both natural and strategic R&D delays, we show that the effective length of patents–the interval of time between the introduction of inaugural products and the expiration of patents–would be shorter when there exists decreasing returns to scale in R&D and imitation costs are relatively low.

Our model produces some strong normative repercussions as well. In particular,

recognizing that there may be strategic delays in new product development drastically

spending, expected number of imitators and patent lengths.[5]

2. Related Literature

Our work is most related to Aghion et al. (2004) who first document that R&D in innovation reacts positively (negatively) to firm entry in technologically advanced (laggard) industries, and then proceed to develop a Schumpeterian growth model to backup this empirical finding. Their theoretical results are driven by the fact that, in technologically sophisticated industries, R&D firms can step up their innovative efforts to escape entry whereas, in technologically more mature industries, R&D firms cut back on R&D based on the recognition that they are at a competitive disadvantage vis-a-vis new entrants. The theory we develop below complements the work of Aghion et al. in three different dimensions. First, because we focus on product development based on existing and

of imitation on patenting decisions. The most relevant example in this strand is Gallini

firms in this industry use a homogenous consumption good as their only input. When the discovery of a new idea is made, R&D firms apply for a patent that lasts $T \geq 0$, periods from the date of application.[6] Each new idea can serve as the basis of one new product

of differentiated products that hold value to consumers. In equations (2) and (3), $_t$ denotes the household's total expenditure on goods, represents its wealth at time zero, is its inelastic labor supply, and $_t$ is the wage income of the household at time . By assumption, , 1

Following Grossman and Helpman (1991a, 1991b), the consumer's problem can be broken down into three stages: the allocation of life-time wealth across time; the allocation of spending across products at each instant; and the determination of expenditure on the available product quality levels at each instant. We now discuss each of these

Any firm producing a consumption good faces an inverse demand curve that takes the form 1 $_{i,t}$ = $_{i,t}$. The firm sets its price so that ($_{i,t}$ $_t$) $_{i,t}$ = 1 [($_{i,t}$ $_{i,t}$) ($_{i,t}$ $_{i,t}$)]. This is the standard monopoly pricing rule where the markup to price ratio is equal to inverse demand elasticity. Optimal pricing yields a manufacturing profit of per consumer and total profits of , .

3.3 Product Development Research

The legal patent length is . The inventor of a new idea (that could be the basis of a new product with an underlying quality level ^{m}) can invest in the development of the fi

Based on equation (4), the expected success date for the R&D firm is $1/\lambda(t)$ where $\lambda(t)$ is the hazard function in product development. By assumption, the hazard rate function $\lambda(t)$ is such that the probability density function of new product development is strictly concave in

R&D technology   . The first-order condition for this problem satisfies

$$R_t^T \quad c\,($$

Proposition 1 indicates, for a given level of imitation cost , the incentive to develop a new product first rises and then falls as the expiration date approaches. When there is a sufficiently long time to expiration, product developers have no incentive to rush since launching the product at an earlier date would entice more competition. However, as the patent expiration date nears, the threat from imitation declines but so does the

Together, they influence the extent to which product development is delayed and the length of effective patent protection changes over time. In particular, there are two potential sources of delay in product development according to this framework: one, to the extent that the marginal product of development effort is decreasing in the underlying level of technology, there is a "natural delay" over time in new product development.[9] Put differently, as technologies become more sophisticated and the expected odds of success in developing a new product decline, the equilibrium amount of development effort decreases. Two, to the extent that imitation dilutes monopoly rents, there exists some "strategic delay." That is, the ease with which imitators can enter the market is important because developers take into account how their expected timing of success influences the competition they face in the future. And as Proposition 2 indicates, in industries in which imitation is not prohibitively costly and time consuming (following the emergence of an inaugural product), the benefit of delaying product development

In contrast, when $\gamma_2 < 0$ so that the marginal success rate of developing new products also depends negatively on the state of the underlying level of technology, the equilibrium amount of effort, ℓ_t, will adjust with changes in the underlying technology level. As it becomes more and more difficult to develop new products, the expected return to product development effort will decline with improvements in the level of technology. Moreover, the delay in the introduction of inaugural products and the rate at which the effective length of patents, τ_0, decreases will depend on the ease of imitation in that industry—and the market structure of goods production commensurate with it. That is, the interaction between natural delay as a result of decreasing returns to product development and strategic delay due to market structure considerations will influence the degree to which the effective patent lengths narrow as technologies become more sophisticated.

Proposition 3 The profit-maximizing product development investment, ℓ_t, is strictly decreasing in the underlying level of technology, , when $\gamma_2 < 0$, $\gamma_{12} \leq 0$, and $\gamma_{12} < \gamma_1 \gamma_2$.

Proof: See Appendix Section A.3.

When the marginal return to product development is decreasing in the state of the existing technologies, patent extensions may be growth enhancing if and only if strategic delays are of no major significance. Put d7h]TJ/TT11Tf1.6(68.0TD0Tc0067Fj/TT21Tf0.56220TD

product developer will enjoy relative to the effective patent protection period $_0$. Of course, if the inaugural product is developed at or after date , all imitators will be deterred from entry and the original product developer will enjoy monopoly throughout the remainder of the patent protection period. The dashed line in Figure 2.a depicts the impact of lower product development spending, $_t$, on the duration of monopoly during the patent protection period. As shown, one effect of lower product development spending is to extend the duration of monopoly relative to the remaining (or effective) protection period. In Figure 2.b, we show how changes in patent length influence the expected duration of monopoly relative to the length of the effective patent period, $_0$. The solid line shows the benchmark case in which we hold constant the initial optimal product development investment. The dashed line also incorporates the adjustments in the optimal level of product development investment. As shown, strategic delays in product development kick in at longer patent lengths. That the dashed line lies above the solid line is indicative of the fact that strategic delays are at play for longer patents.

[Figures 2.a and 2.b about here.]

5. The Production Market Structure

Recall that, since the date of a new product development, $_0$, is stochastic, the actual number of imitators that would emerge in a given industry, $_t$, is also stochastic. Still, in an ex ante sense, more can be said about the degree of competition that could emerge in each industry and the factors that would influence this competition.

In expected terms, the potential number of entrants given by equation (6) can be defined as

$$_t[(_0)] = \int_t^{Z_T} (_0) (_t) \exp[(_t) _0] _0 \qquad (13)$$

18

We are able to make a number of observations with regard to the structure of

(ii) rises with more entry barriers, , if the indirect e ect of on encouraging product development investment—and therefore attracting more imitation—dominates.

Proof: See Appendix Section A.6.

The legal patent length also infl

Proof: See Appendix Section A.7.

An implication of this proposition is that, for any given level of imitation cost and imitation lag , the expected number of imitators would first rise and then fall with extensions in patent lengths. Figure 3 depicts this result.

[Figure 3 about here.]

In Figure 4, we summarize the policy implications of our main conclusions. In industries where imitation is relatively easy and costless, there will be imitation and strategic delays in R&D investment in equilibrium. Over a broader range of , extending the length of patents in such industries would lead to lower R&D investment and even greater delays in product development. In contrast, in industries where imitation is more difficult and costly, there will be no imitation or delays in R&D investment in equilibrium as long as the length of patent licenses, , is sufficiently short. Over a broader range of , patent extensions would lead to higher R&D investment and even shorter delays in product development in such industries. For any given level of imitation cost , the growth-enhancing level of optimal patent length would be the one at the upper bound of region II in Figure 4. Thus, the higher is the cost of imitation, the longer is optimal patent protection.

[Figure 4 about here.]

6. Conclusion

The novelty of the theoretical model we developed above is that both the R&D resources to discover new product applications and the market structure of consumption goods manufacturing are determined endogenously. There exists uncertainty with respect to the development date of an inaugural product, although higher R&D spending short-

ens the expected product development stage.

7. Appendix

A.1 Proposition 1: The profit-maximizing product development investment, $_t$,

(i) is strictly decreasing in when $_1$ and it is strictly increasing in when $6 _1$;

(ii) attains an interior maximum and has an inverted U-shape with respect to .

Proof: (i) When $_t = 0$ (and hence $(_t \quad) = 0$), the first-order condition (denoted as) can be simplified as

$$\left\{ \begin{array}{c} \{ \; [\; \exp(\;) + \exp((\; + \;)) \quad \exp((\; + \;)) \; (\qquad)] \\ [1 + \; (\qquad)]\} \; _1(0 \quad) \end{array} \right\}' \qquad _2 \qquad 0$$

(a.1)

where $\exp[\; (\; + \; + \;)]$ and, due to the fact that $(\qquad) \quad 1$

According to the implicit function theorem, the sign of $_t$ depends on $_t$, where

$$
\underline{\quad} = \frac{\exp[\ (\ +\ )\ \ (\ +\ )]}{\quad}\left\{
\begin{array}{l}
\exp(\ )[\exp(\ )\ \ \exp(\ )] \\
+ \\
[\exp(\ )\ \ \ \exp((\ +\ )+\ \ ) \\
+ \\
\exp(\ +\ )\ _t\ \ \exp(\ +\ )(\ +\ _t\ ) \\
+ \\
\exp(\ )\ [(\exp(\ )\ \ 1)\ \ +\exp((\ +\ ))\ \ ]\ ]\ _1
\end{array}
\right\}
$$

(a.3)

Furthermore, we find that

$$
\frac{^2}{\quad} = \ _1\exp(\ \ )(1\ \ )\ \ 0 \tag{a.4}
$$

because at each the expected success date (1) is later than or equal to , i.e., 1
0 at and $_1$ 0. Denote $_{1k}$

be ensured for $[\prime \quad '']$ where $' \quad 0$ and $''$ So

the negative correlation with holds as well. Hence, ^{2} 0 when = . Furthermore, when = or when , = 0. Thus, 0 and

$_t$ 0 . The equilibrium product development effort, $_t$, is strictly increasing in the imitation lag, , . ¥

A.3 Proposition 3: The profit-maximizing product development investment, $_t$, is strictly decreasing in the underlying level of technology, , when $_2$ 0, $_{12}$ ⊖ 0, and $_{12}$ $_1$ $_2$

Proof: In equations (9) and (10), 12

$$\underline{\qquad} = \frac{\exp[\;(\;+\;)\qquad]}{}\{\;_1[\quad_t\exp(\quad) + \exp(\;)(\;_t + \qquad)$$

$$\exp(\;+\;(\qquad))] + [(\exp(\;)\quad\exp(\;))(\quad_{t\;1}\quad 1)]\}\qquad \text{(a.11)}$$

where

A.5 Lemma 1: The expected market structure of consumption goods production, $_t[\ (\ _0)] + 1$, is strictly increasing in the innovator's product development invest-ment, $_t$.

Proof: The market structure of consumption goods production can be explicitly written as:

$$(\ _0) + 1 = \frac{\exp[\quad (\quad + \ _0 + \quad][\exp(\ ) \quad \exp(\ (\ _0 + \quad))]}{} \qquad (a.15)$$

which is a decreasing function of $_0$

Taking the expectation of (a.15) as in equation (13), we get

$$[\ (\ _0) + 1] = \int_t^{Z_T} [[\ (\ _0) + 1]\ (\ _t\quad)\exp[\quad (\ _t\quad)\ _0]]\quad _0 \qquad (a.16)$$

where the density function $(\ _t \quad _0)\quad (\ _t\quad)\exp[\quad (\ _t\quad)\ _0]$ is a strictly increasing function of $_t$ when $_0\quad (1\quad)$ but a decreasing function of $_t$ when $_0 > (1\quad)$. A larger $_t$ raises the value of $(\ _t\quad _0)$ for $_0\quad (1\quad)$ that has a larger $(\ _0) + 1$ while reducing the value of $(\ _t\quad _0)$ for $_0 > (1\quad)$ that has a relatively smaller $(\ _0) + 1$. Over-all, a larger $_t$ raises the expected market structure of consumption goods production, $_t[\ (\ _0)] + 1$. Hence, $(\ _t[\ (\ _0)] + 1)\quad _t\quad 0$.

Furthermore, in the derived formula for $(\ _t[\ (\ _0)] + 1)\quad _t$ we find that when rises the denominator of $(\ _t[\ (\ _0) + 1]\ \}$

Proof: Start with $(\partial_t[\rho(\rho_0)] + 1)$ $= [(\partial_t[\rho(\rho_0)] + 1)] + [(\partial_t[\rho(\rho_0)] + 1) \partial_t][\partial_t]$.
Now taking the derivative of $\partial_t[\rho(\rho_0)]$ with respect to

$[\quad_t\quad]\quad 0)$ outweighs the positive effect of the first term ($(\quad_t[\quad(\quad_0)]+1)\quad$),
$(\quad_t[\quad(\quad_0)]+1)\quad 0$. The intuition behind this result is that, in an extremely competitive industry, the innovator expects more imitators when patents are longer and has fewer incentives to develop the product.

Similar to A.4, $\quad_t[\quad(\quad_0)]+1$ attains an interior maximum, and has an inverted U-shape with respect to the legal patent length, . ¥

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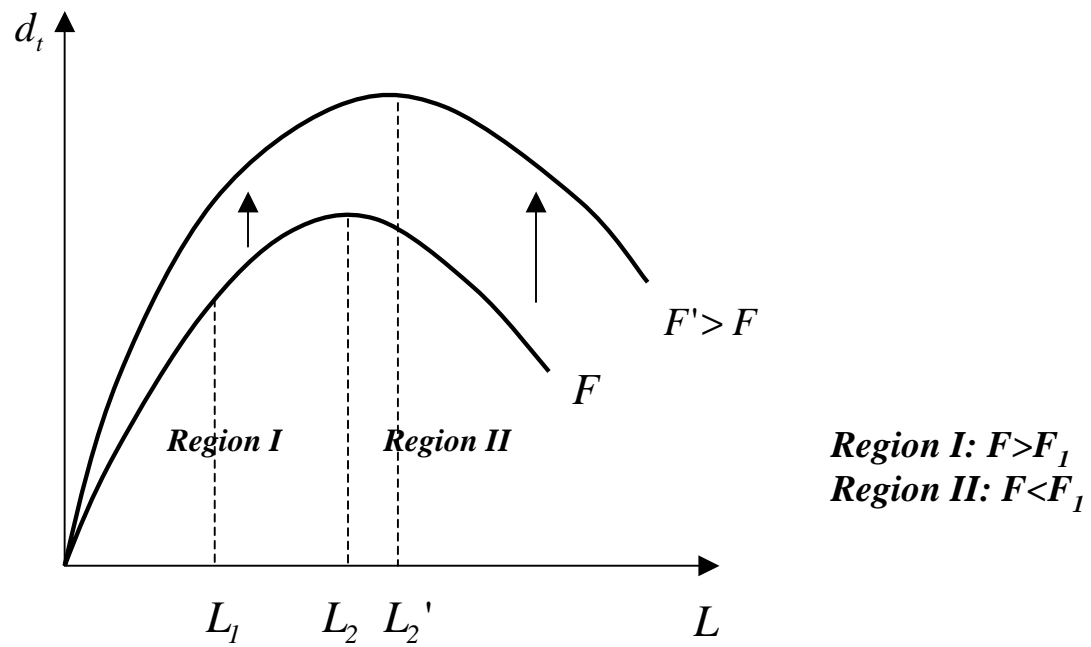
Figure 1: The relationship between
R&D and legal patent length
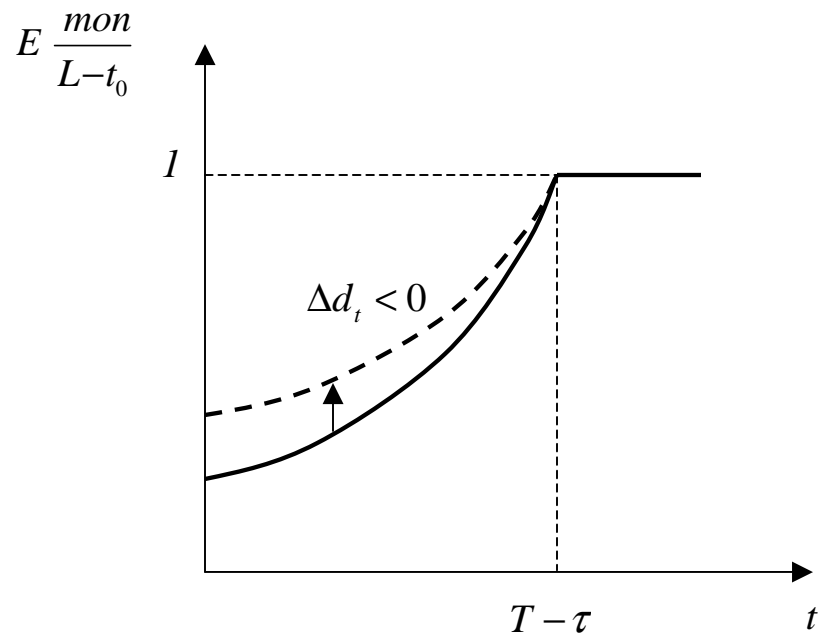
Figure 2.a: The effect of strategic delay on the effective patent protection over time

Figure 2.b: The effect of extending legal patent length on R&D and
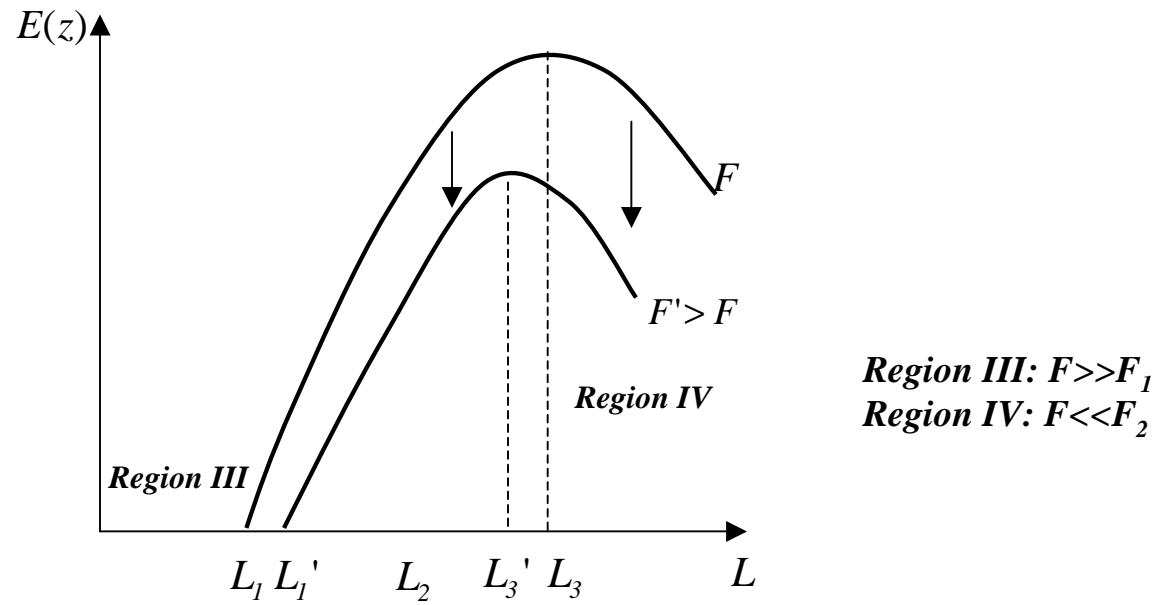
Figure 3: The relationship between
expected number of imitators and legal patent length

Region II: Imitation,

Region III: No imitation,
no strategic delay