E C O N O M I C S B U L L E T I N

Industry sunk costs and entry dynamics

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Abstract

We explore an investment game where industry sunk costs provide anincentive for a firm to be a follower into the market as opposedto a leader. For some parameter values, every firm could have adominant strategy to wait, even though immediate entry is sociallyoptimal − this is a like prisoners' dilemma. In equilibrium, afirm is more likely to have a dominant strategy to wait with anincrease in the number of potential entrants. Finally, theequilibrium can display an entry cascade.

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1 Introduction

Firm entry is an important source of new products and, as a result, can significantly enhance social welfare (Geroski 1995, p. 436). When making the decision about when to enter a market a firm will consider the benefits of entering early and facing less competition, with waiting and entering the market at a later date, possibly after the technology or the market has been developed. Empirically, second-movers often do better than the firms that enter a market first (Tellis and Golder 1996). This paper examines the implications for the timing of firm entry into a market in which there is a second-mover advantage.

A second-mover advantage could arise in many different situations. In Hoppe (2000), a second-mover advantage arises in a duopoly model of technology adoption due to uncertainty and decreasing adoption costs over time. Here, on the other hand, the second-mover advantage is due to a free-rider effect. As an example, the development of a new market often involves sunk costs. Specifically, a firm may need to invest heavily in advertising in order to generate knowledge and stimulate interest in a new product. Importantly, it can be the case that a significant component of these costs are industry sunk costs, as opposed to firm-specific sunk costs. Similarly, investment in research and development can aid potential competitors when intellectual property rights are poorly protected (possibly internationally).[1] The same situation could arise if a government implements narrow (as opposed to broad) patent protection, allowing second-movers to imitate innovations easily. As a modelling tool, this paper incorporates industry sunk costs into a strategic model of investing as a leader or as a follower.

The basics of the model are as follows. Before any firm can exploit a new profitable market opportunity, a certain amount of resources needs to be expended on either advertising, to inform the public of the new product, or on non-patented research. This cost is borne by firms that initially enter the market, but this expenditure is a public good for all potential entrants in that, once the investment has been sunk, all firms can benefit of this investment if they choose to enter the market. The question then arises for each firm as to when they should enter the market: early entry allows them to benefit with fewer competitors but may mean they incur some of the industry set-up costs; delayed entry may allow a firm to avoid the set-up costs but they also forgo some benefits by not participating in the market.

Several interesting results arise out of the model. First, consider the case when there are two potential entry periods. This means a firm can enter immediately or it can sit out of the market for one period and enter in the next period. A firm cannot enter the market if it decided not to enter in both the first two periods. If sunk costs are sufficiently high, each firm has a dominant strategy to wait and not enter the market until the second potential investment period. This result is a type of prisoners' dilemma; welfare is reduced by the delay in entry but no firm has an incentive to deviate. Given the free-rider problem here, a delay in investment is more likely to occur with an increase in the number of potential entrants. This is similar to the findings of Kaplan et al (2003).[2]

[1] For example, see Stegemann (2000), Ostergard (2000) and Levy (2000) for a discussion of international protection of intellectual property and copyright. In another context, Roberts (2000) argued that patents provided limited protection to internet companies and their technologies.

[2] See Kaplan et al (2003) Corollary 1.

Second, as as future returns are discounted, if the number of potential investment periods is increased (from two periods), the benefit of waiting until the last opportunity to enter the market, evaluated at the start of the game, is reduced. When the potential investment horizon is sufficiently long, in the symmetric equilibrium the firms will adopt a mixed strategy between investing and not investing in this period - this is a coordination game. Note, this game differs from the usual coordination game somewhat; it is, instead, similar to what Binmore (1992) described as an Australian Battle of the Sexes.

Third, once one firm has entered the market, all other potential firms enter as soon as possible. This creates an entry cascade. A similar cascade occurs in Zhang (1997) when firms have differing private information regarding an investment opportunity and in Fudenberg and Tirole (1985), for certain parameter values, when the cost of adopting a new technology is decreasing over time. The model presented generates an investment cascade without private information and decreasing investment costs.

Last, the application considered here is an entry decision with industry sunk costs. The model also applies to other scenarios in which the firms must make an irreversible investment (or decision) and there is a second-mover advantage, including price-setting games (Hamilton and Slutsky 1990).

2 n-firm investment game

Consider the following set-up. There are $n \geq 2$ firms that are potential entrants to some new market. The net benefit from entering is B per period, to be shared amongst all firms that have entered.[3] Once entry has occurred there are an infinite number of production periods; all firms discount future returns by δ per period. There are some costs C that are incurred in the first period in which entry occurs, where C is shared among all the firms that enter in that initial period. Entry (by at least one firm) is efficient in that $\frac{B}{1-\delta} > C$.[4]

First, consider the situation when there are only two potential entry periods, so that a firm can enter in the first period, enter in the second period, or decide to not enter the market at all.[5] Note, in this model there is an exogenously determined deadline for entry. This could come about if the profitable opportunity dissipates after a certain point in time because, for example, of the invention of a substitute product or technology.[6] Let us show that it is always profitable for a firm to enter the market in the second period, if it has not already done so. Consider when no firm entered the market in the first period. If $m \geq 1$ firms enter in the second period, the payoff to any individual firm from entering, evaluated at the start of the game, is $\frac{\delta B}{m(1-\delta)} - \delta\frac{C}{m}$. As $\frac{B}{(1-\delta)} > C$ entry is profitable for every firm. If at least one firm entered in the first period the payoff to a firm from entering in the second period, again evaluated at the start of the two potential investment periods, is $\frac{\delta B}{m(1-\delta)}$ if a

[3] B could represent, for example, profits in the industry that the firms share with perfect collusion.

[4] Note that, given there are no firm specific sunk costs, the welfare outcome in this model is the same regardless of the number of firms producing, provided at least one firm is in the market.

[5] This two-period investment game has a similar structure to the bank run game analyzed by Gibbons (1992, pp. 73-75) and Diamond and Dybvig (1983) and Chamley's (2001) model of exchange rate speculation.

[6] Making the deadline (number of potential investment periods) endogenous is beyond the scope of the paper and is left for future research.

total of m firms entered over both periods. Clearly entry is profitable in this case. As a consequence, if a firm has not already done so it will enter the market in the final potential investment period.

Second, using the result above, now consider a firm's decision as to whether or not to enter the market in the first period. To examine this issue we consider: (a) the payoffs from entry when the firm is the only entrant; and (b) when they share entry in the first period.

If $n-1$ firms decide to wait, the benefit to the other firm from entering in the first period is

$$B - C + \frac{\delta B}{n(1-\delta)}. \tag{1}$$

If the firm does not enter in the first period, all of the firms will enter in the second period, so the payoff to this firm is just discounted by one period payoff of all firms entering

$$\frac{\delta B}{n(1-\delta)} - \frac{\delta C}{n}. \tag{2}$$

As a result, the payoff of waiting (not investing in the first period) is bigger iff

$$(1 - \frac{\delta}{n})C > B. \tag{3}$$

Conversely, the firm will enter in the first period, given all the other firms do not enter, if $B > (1 - \frac{\delta}{n})C$.

Now consider the entry decision of one firm when k of the other firms decide to enter in the first potential investment period, where $n-1 > k > 0$, and $n-k-1$ decide to wait. If the firm enters in the first period it will get the following benefit

$$\frac{B}{n(1-\delta)} + \left(\frac{1}{k+1} - \frac{1}{n}\right) B - \frac{C}{k+1}. \tag{4}$$

On the other hand, if it does not enter it will enter in the second period and receive surplus of

$$\frac{\delta B}{n(1-\delta)}. \tag{5}$$

Comparing these two equations one can infer that the benefit of waiting is bigger iff

$$C > B. \tag{6}$$

From both these cases, the firm has a dominant strategy to invest immediately if $B > C$. It is worth noting that this strategy is optimal in this case regardless of the number of firms. When $C > B > C(1 - \frac{\delta}{n})$, the firm are in a coordination game - each firm prefers to wait if k other firms enter but invest if no other firms invest, where $n > k > 0$. In this coordination game there are many asymmetric equilibria. For example, firm 1 adopts the strategy to invest immediately (and to do so in any period). All other firms will adopt the strategy to wait in every period until either another firm has already invested, or invest if it is the last period of the game. Asymmetric equilibria have the disadvantage that they do not specify why one firm enters and the other firms wait. Our focus, in response, is on symmetric equilibrium in which a firm will adopt a mixed strategy.

If $B < C(1 - \frac{\delta}{n})$, the firm has a dominant strategy to wait and not invest in the first period.

Now let us consider when $B = C$ and $B = C(1 - \frac{\delta}{n})$. First, when $B = C$, if a firm enters and the other $(n-1)$ firms wait in the first period, the entering firm will receive a payoff of $B - C + \frac{\delta B}{n(1-\delta)} = \frac{\delta B}{n(1-\delta)}$. If the firm waits in this case its payoff will be $\frac{\delta B}{n(1-\delta)} - \frac{\delta C}{n}$. Given that the payoff from entering is greater than the payoff from waiting, the firm will opt to enter immediately. If, on the other hand, k firms enter in the first period, a firm will be indifferent between entering and waiting as the payoffs are the same - $\frac{\delta B}{n(1-\delta)}$. Given this indifference, many asymmetric equilibria exist in which at least one firm enters, and all the other firms can either enter, wait or mix between both. However, when $B = C$ there is only one symmetric equilibrium; in the symmetric equilibrium all firms invest immediately.

Second, consider when $B = C(1 - \frac{\delta}{n})$. If all of the other $(n-1)$ firms wait, a firm will be indifferent between entering and waiting as payoff in equation 1 equals the payoff in equation 2. If at least one other firm enters immediately, a firm will have a dominant strategy to wait as the payoff given by equation 4 is less than the payoff given by equation 5. In a similar manner to the case above, there are many asymmetric equilibria in which $(n-1)$ firms wait and the last firm can either enter, wait or mix between both. There is, however, only one symmetric subgame perfect equilibrium in which all firms will wait in the first period.

This discussion is summarized in Proposition 1.

Proposition 1. *Consider the entry game with two potential investment (entry) periods. If* $B \geq C$ *all firms invest immediately in the first period in the symmetric subgame perfect equilibrium (SPE). If* $C > B > C(1 - \frac{\delta}{n})$ *each firm will mix between entering immediately and waiting to enter in the second period in the symmetric SPE. Finally, if* $B \leq C(1 - \frac{\delta}{n})$, *in the symmetric SPE all firms will wait and only enter the market in the second period.*

If $B \leq C(1 - \frac{\delta}{n})$ the firms are in a prisoners' dilemma: the welfare of every firm would be improved if they all could commit to invest immediately but each firm has a dominant strategy to wait, reducing total surplus.

Now consider the effect of a change in n. Note that $C(1 - \frac{\delta}{n})$ is increasing in n; this increases the parameter range for which $B \leq C(1 - \frac{\delta}{n})$. Thus an increase in n makes it more likely that every firm delays entry. This result arises because increasing the number of potential entrants accentuates the free-rider problem. Corollary 1 summarizes this discussion.

Corollary 1. *An increase in the number of potential entrants (n) increases the interval for which all firms have a dominant strategy to wait.*

For arguments sake, assume that $B \leq C(1 - \frac{\delta}{n})$, so that the firms are in a prisoners' dilemma in the two-period investment game. Now consider the optimal strategies of the firms when there are three potential investment periods. In this case, the payoff from waiting for a firm if no one invests in the first period is the two-period payoff discounted by an additional δ - the extra period of delay reduces the benefit of waiting. Reducing the benefit from waiting makes immediate entry more attractive. If this reduction in the benefit from waiting is sufficient, a firm will no longer have a dominant strategy to wait. Instead they will adopt a mixed strategy between investing and waiting. Proposition 2 summarizes this discussion. This point is further illustrated in Example 1.

Proposition 2. *Assume $B \leq C(1-\frac{\delta}{n})$, so that the firms are in a prisoners' dilemma in the two-period game. As the number of potential investment periods, j, is increased, for some $j > 2$ the firms will no longer have a dominant strategy to wait.*

Proof. The outcome in the two-period game is as above - all firms have a dominant strategy to wait and will receive a payoff of $\frac{\delta}{n}(\frac{B}{1-\delta} - C)$. If $j = 3$, the payoffs to the firms are the same as in the two-period game, except for the payoff if all firms opted to wait. This payoff will be the two-period payoff, discounted by δ. Provided $B + \frac{\delta B}{n(1-\delta)} - C < \frac{\delta^2}{n}(\frac{B}{1-\delta} - C)$ each firm will still have a dominant strategy to wait. There will be some $j > 2$ for which $B + \frac{\delta B}{n(1-\delta)} - C > \frac{\delta^{(j-1)}}{n}(\frac{B}{1-\delta} - C)$; with this number of periods, each firm no longer has a dominant strategy to wait. The firms are then in a coordination game. □

Example 1. *This example shows that when $B \leq C(1-\frac{\delta}{n})$ for two investment periods, as the potential investment horizon is extended the optimal strategy switches from a prisoners' dilemma game to a coordination game when there are a sufficient number of potential investment periods.*

Let $C = 5$, $B = 3$, $\delta = 0.9$. Further, assume that there are three potential firms. Figure 1 shows the normal-form game when there are two potential investment periods. In the figure, I refers to the strategy to invest immediately and W indicates that the firm does not invest in that period. The left-hand payoff matrix refers to when firm 3 invests immediately and the right-hand panel relates to when she does not invest in that immediate period (she plays W). The payoffs are calculated using equations 1, 2, 4 and 5.

Firm 3 - I

Firm 1 \ Firm 2	I	W
I	$\frac{25}{3}, \frac{25}{3}, \frac{25}{3}$	$8, 9, 8$
W	$9, 8, 8$	$9, 9, 7$

Firm 3 - W

Firm 1 \ Firm 2	I	W
I	$8, 8, 9$	$7, 9, 9$
W	$9, 7, 9$	$7.5, 7.5, 7.5$

Figure 1: A prisoners' dilemma game for three firms and two potential investment periods.

As there are two periods, the choice for each firm is to invest immediately or invest in the second and final investment period. Each firm has a dominant strategy to wait and only invest in the second period, as in a prisoners' dilemma game. This follows because $B \leq C(1-\frac{\delta}{n})$ when there are two potential investment periods.

If the potential investment horizon is extended so that there are three possible investment periods, the only payoff that is changed from the above figure is when all three firms opt to wait (W) in the first period. In this case, the game proceeds to the next period; given that there are just two potential investment periods left the game exactly resembles the two-period game. As a result, the payoff to each firm when they all decide to wait in the first period is that payoff from the two-period game (7.5) discounted by the additional period, which in this case is 6.75. The payoff for the three-period game are illustrated in Figure 2 below.

Firm 3 - I

Firm 1 \ Firm 2	I	W
I	$\frac{25}{3}, \frac{25}{3}, \frac{25}{3}$	$8, 9, 8$
W	$9, 8, 8$	$9, 9, 7$

Firm 3 - W

Firm 1 \ Firm 2	I	W
I	$8, 8, 9$	$7, 9, 9$
W	$9, 7, 9$	$6.75, 6.75, 6.75$

Figure 2: A prisoners' dilemma game for three firms in a three-period investment game.

Here, due to the additional discounting, the payoff from waiting is not as great as the payoff to investing for a firm if the other two firms do not invest immediately ($7 > 6.75$). Each firm no longer has a dominant strategy to wait, and will adopt a mixed strategy in the symmetric equilibrium. In this mixed strategy equilibrium each firm invests with a probability of approximately 0.107. □

There are several further noteworthy points that arise out of the model. Note that once (at least) one firm has entered and borne the sunk costs, all other firms will enter as soon as possible, creating an entry cascade. A similar entry dynamic occurs when firms have a dominant strategy to wait until the final period. This suggests that entry cascades can occur when there are industry sunk costs or when there is poor protection of intellectual property, as well as in the presence of asymmetric information (Zhang 1997) and decreasing investment costs (Fudenberg and Tirole 1985).

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