Diffusion of the innovations and uncertainty :

How can the adoption of a new profitable technology be delayed ?

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Abstract :

The diffusion of an innovation is essentially a learning process and then depends on the way the information about it spreads between these firms. Some useful information concerns the existence of an innovation, but also its profitability. However, the profitability of installing an innovation is generally viewed at first with considerable uncertainty. When a new technology is available and its profitability is uncertain, the first firm that adopts it obtains some useful information for the followers. The economic literature generally considers that the observation of the actions of the first adopter can then supply some information, which enables to evaluate better the profitability of the innovation. This work seeks to show that, if the firms are initially uncertain of the future profitability of a new technology, its diffusion can be slowed down by the first adopters. Once a firm has adopted the new technology, only this firm can observe its profitability. It can then try to profit from its private information. Indeed, if the innovation is very profitable, it may be in the interest of a first adopter to keep secret the profitability of the innovation.

Key Words : Industrial Organisation, Innovation, Diffusion, Adoption, Information manipulation.

Classification JEL : C73, D82, L15, O33.

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1. Introduction

The generation of new technologies is a well-analysed process in Economics of Innovation. However, it is only as new technologies are introduced into the economy that their benefits will be realised. Taken the Schumpeterian distinction between invention (the generation of new ideas), innovation (the development of those ideas through to the first marketing or use of a technology) and diffusion (the spread of new technology across its potential market), we know that it is the last of these which has the most decisive impact on economic welfare. Besides, recently, a gradual reorientation of policy direction toward diffusion seems to be taking place (Stoneman & Dierden, 1994).[1]

The diffusion of an innovation is essentially a learning process. However, rather than being confined to a research laboratory, the learning takes place among a considerable number of users and producers. The diffusion process then depends on the way information concerning the innovation spreads between the firms (Mansfield, 1968). Indeed, at a microeconomic level, the decision to adopt an innovation depends on some information which is available to a firm. Some useful information concerns the existence or the availability of an innovation, but also its characteristics, and in particular its profitability. Indeed, the most empirical studies of innovation diffusion have centred on identification of the major determinants of the speed of diffusion, and conclude that the diffusion is faster for innovations with higher profitability (Griliches, 1957 ; Stoneman, 1995). However, the profitability of installing an innovation is generally viewed at first with considerable uncertainty, what influences its speed of diffusion into the economy.[2] The empirical studies generally conclude that the diffusion of an innovation is faster as more information and experience accumulate, because it becomes less risky to begin using it. The way of which the profitability of a new technology is perceived by a firm is thus very important in its decision to adopt it. It is thus rather surprising that few theoretical models have centred on the uncertainty about the real profitability of a new technology.

In many theoretical models, the economists have sought to explain rather why all firms do not adopt at

[1] The US and UK governments, for example, have proposed major technology policy initiatives that both stress the importance of creating an infrastructure conducive to a rapid spread of awareness and knowledge of innovations.

[2] The examples given by Mansfield (1961) illustrate the uncertainty related to a first use of an innovation. So, there was great uncertainty about maintenance costs for diesel locomotives, “down-time” for continuous mining machines, the safety of centralised traffic control, and the useful life of by-product coke ovens.

the same time even if they are similar (Reinganum, 1981 ; Fudenberg & Tirole, 1985). However, this analysis has been conducted in the context of an innovation of known profitability. Only few models have analysed the impact of the uncertainty linked to a first industrial use on the adoption decision of a firm (Jensen 1982; McCardle, 1985; Bhattacharya and al., 1986). These models suppose that the firm reduces then the uncertainty regarding the potential benefits of using the new technology by sequentially gathering information, and adopts as soon as the probability that the technology is profitable is high enough. If these works stress the importance of gathering information in the adoption process, they do not specify its origin and do not take into account any strategic consideration, whereas these two aspects can be linked. The strategic dimension of information is indeed a well-analysed theme in Industrial Organisation literature. When a firm profits from an informational advantage, it can seek to manipulate the information transmission to its competitors. It is the case when a firm has a limit pricing behaviour (Milgrom & Roberts, 1982) or when a monopoly seeks to prevent some potential competitors from entering into the market (Kreps & Wilson, 1982a).

Since the diffusion process is a learning process, information plays an essential role. During the diffusion process, the first firms that adopt a new technology obtain some information about it which is very precious for themselves but for the firms that have not yet adopted too. It exists then an information asymmetry between the first adopters and their competitors. If, in the first stages of the adoption process, useful information concerns more particularly the existence and the availability of a new technology, a second phase consists in gathering information about the characteristics of the new technology, and in particular about its profitability.[3] This type of information can not always be obtained inside the firm, and often requires information sources outside the firm. A first information source corresponds to the suppliers of the new technology, but this source is often considered as not credible enough, and the firms are generally distrustful concerning information about the benefits to expect of a new technology, when it comes from their suppliers (Rogers, 1979 ; Von Hippel, 1988). The competitors can also constitute an important information source.[4][5] Knowing that one of its principal competitors has just been adopted a new technology can constitute a positive signal and the observation of the actions of the first adopter can influence the other firms to advance, or to delay, their date of adoption. Indeed, if, after the use of a new technology, a firm becomes more competitive and succeeds in increasing its market share,

[3] These stages are called by Rogers (1979) *the interest and evaluation stages* of the adoption process.
[4] A recent work (Monjon & Waelbroeck, 1999) precisely analyses the role of information sources on the innovation process and stresses in particular the role of the competitors as external information source.
[5] *"Information regarding the existence, characteristics and availability of the innovation is disseminated by the producers through advertisement and salesmen ; information regarding the reaction of users to the innovation tends to be disseminated*

its competitors will certainly be incited to adopt more quickly the innovation. In fact, by increasing its market share, the first adopter has revealed to its competitors that the innovation is profitable. As result, the diffusion of the innovation will then speeded up. More generally, where the profitability of using an innovation is very difficult to estimate, the mere fact that a large proportion of its competitors have introduced it may prompt a firm to consider it more favourably. On the contrary, if the firm that has just adopted seems to have some difficulties, its competitors will prefer to delay their adoption in order to know if the difficulties of the first adopter precisely come from the new technology.

When a new technology is available and its profitability is uncertain, the first firm that adopts it obtains some useful information for the followers. The observation of the actions of the first adopter can then supply some information, which enables to evaluate better the profitability of the innovation. As result, the risk related to the adoption decreases.[6] Besides, it is also true in a patent course. Thus, Choi (1991) shows that, when the difficulty degree of a Research & Development project is uncertain, the fact that a firm achieves a first stage of the research incites its competitors to stay longer in the course because the success of the first triggers an optimistic revision of beliefs about the difficulty of the task. The success of a firm reveals to its competitors that the project is feasible, whereas some firms were maybe discouraged and thought that the project was not feasible. But what Choi does not take into account is that the firms are conscious to be observed by their competitors and that the information conveyed by their actions can influence their future decisions. A rational firm, realising this, can then seek to manipulate its rivals' information in order to derive benefits later on. Adopting in first can yield then a leadership advantage -an informational advantage- compared to firms that have not yet adopted.

Our work seeks to show that, if the firms are initially uncertain of the future profitability of a new technology, its diffusion can be slowed down by the first adopters. Once a firm has adopted a new technology, only this firm can observe its profitability. It can then try to profit from its private information. Indeed, if the innovation is very profitable, it may be in the interest of the first adopter to keep secret this piece of information.

In section 2 we formally develop the ideas stated above. The formal treatment of this problematic requires the use of dynamic models of imperfect information and is relatively close to the game developed by

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informally and through the trade press." (Mansfield, 1968).

[6] However, Mansfield (1968) notes that the perceived risks seldom disappears after only a few firms had introduced an innovation.

Kreps and Wilson (1982a). We model adoption of a new technology when the firms do not know with certainty whether the adoption will increase their present value. The section 3 solves for the equilibrium of the game, in first of perfect information, then of imperfect information. The section 4 concludes our analysis.

2. The model

2.1 The context

We consider an industry composed of two identical firms, using the current best-practice technology and engaged in competition in quantities. Let c_0 denote the firms' initial unit cost. We suppose that a cost-reducing innovation becomes available, but that the firms are uncertain of its profitability : firms are confronted by a process technology with an uncertain reduction in their marginal cost. For simplicity, we assume that the unit cost of production of the new technology after successfully completing the adoption process is c_F (resp.c_f) with the prior probability r (resp.$(1- r)$) and that $c_0>c_F>c_f$. Since the firms are initially similar, it is natural to assume that they share the same priors. The firms have then the option at each date of making an irreversible decision to adopt or not. When a firm adopts the new technology, uncertainty regarding the innovation disappears.

We suppose that, whichever the new marginal cost, the adoption of the new technology is always profitable if only one firm does it. But if the new technology leads to a marginal cost c_F, the adoption is not profitable for two firms because the difference between the new marginal cost c_F and the old one c_0 is not enough in order that the two firms support the fixed cost of purchasing the new process technology, noted CF.[7] Consequently, if the firms do not adopt at the same time and if the first firm that adopts succeed in convincing its competitor that the new technology leads to a marginal cost c_F, the second will never adopt.[8] If the innovation leads to a marginal cost c_f, the adoption can be profitable for the two firms but only if it is used at least N_0 periods. In other words, it takes N_0 periods to recoup the cost of the new equipment. We also suppose that the innovation becomes obsolete after N periods. We can indeed imagine that new innovations emerge after some time. The non-profitability of the new technology for a second firm if the cost is c_F assumes in fact that more

[7] These hypotheses are relatively similar to the ones used in the theoretical literature about the natural monopolies, where the fixed costs constitute barriers to entry. In a some way, the fixed costs of adoption can constitute a barrier to access of an innovation.
[8] The fact that all the firms do not adopt at the same date is considered as a stylised fact of the theoretical and empirical

than N periods are necessary to support the fixed costs of adoption. These hypotheses reflect relatively well what happens in some industries, among others in the computer industry, where there is a rapid succession of new generations of computer. When an innovation appears, the potential users must decide quickly if the innovation is profitable or not, in other words if the innovation is different enough from their present equipment to be profitable. If a firm thinks that a better equipment should be available soon, it prefers to adopt the next innovation.

The situation that interests us is the one in which one firm adopted and discovered the true profitability of the innovation before its competitor. It will be noted the firm 1. The other firm, noted the firm 2, observes that its competitor has adopted the innovation, but not its new marginal cost. However, the firm 2 can observe the production decisions of its competitor because both firms know the function demand. Indeed, the firm 1 observes its new marginal cost and adjusts its output level. Its competitor observes its new output level which can constitute a signal about the profitability of the new technology. If the firm 1 increases a lot its production, the firm 2 can conclude that the innovation is profitable enough for both. So, the firm 2 can infer information from the observation of its competitor.

When the leader adjusts its output level, it must thus take into account that if it just maximises its instantaneous profit, it may reveal the profitability of the new technology, what involves the adoption of its rival. It can then be in the interest of the leader to keep secret the value of the new technology. In other words, a firm that discovers that the innovation is very profitable can seek to show that it is not the case. It behaves then as if it were a firm with a marginal cost c_F, by producing the quantity that a true firm of type F would produce, which we note q_F^*. For convenience, we reduce the set of possible production levels of the firm 1 to two quantities : q_f^* (resp. q_F^*) which correspond to the quantity that maximises the per-period profit, $p_1(q,c_f)$ (resp. $p_1(q,c_F)$), of a firm 1 with a marginal cost c_f (resp. c_F) and whose competitor has a marginal cost c_0.

2.2 The timing of the game

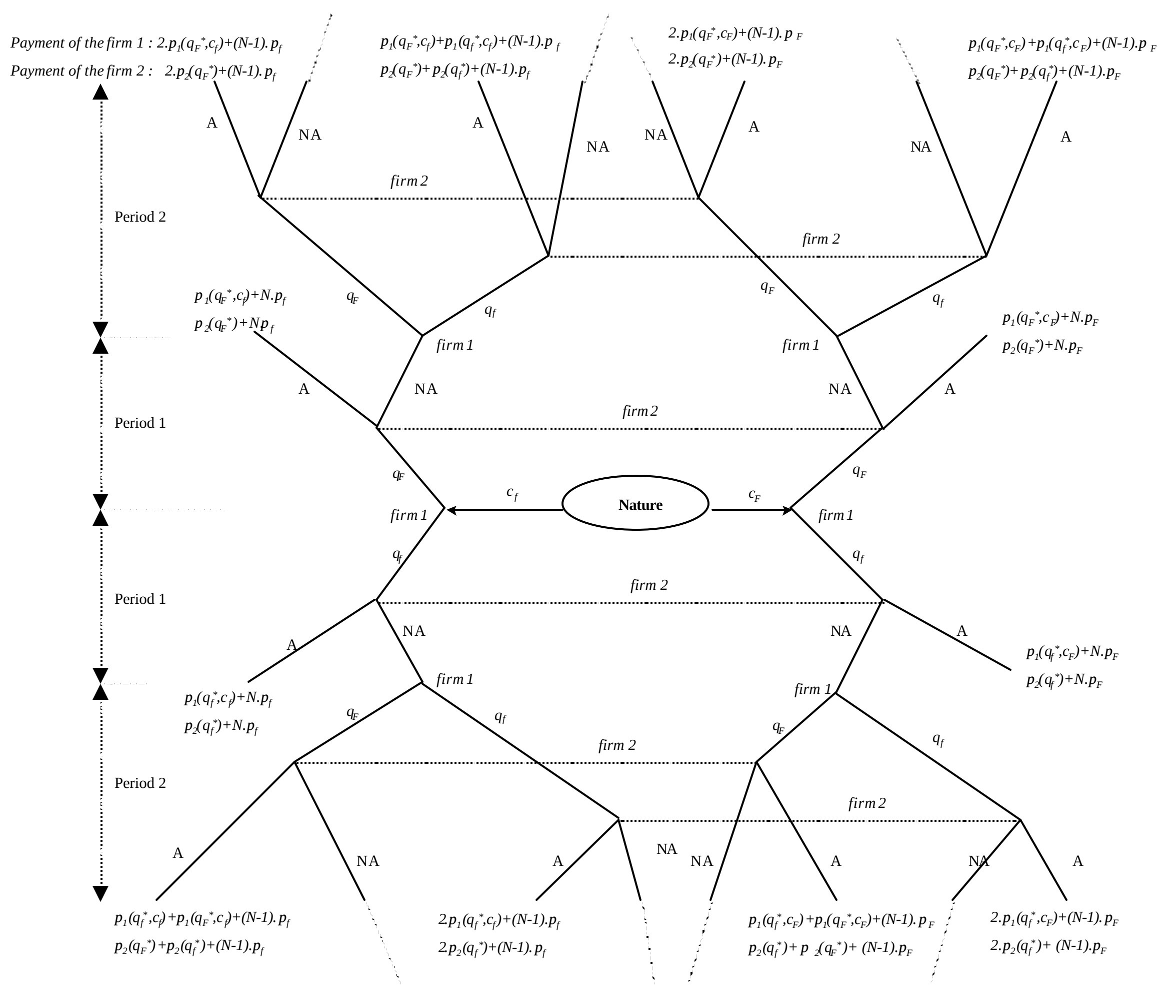
The timing of the game is as follows. At time $t=0$, a cost-reducing innovation becomes available. We consider that only one firm adopts the innovation immediately and discovers the real profitability of the innovation.[9] After

literature about the diffusion of innovations.

[9] We concentrate on this case because the game tree would be too complex to represent if we considered all the possibilities. When we will seek the equilibrium, we will consider also situations in which the firms can adopt at the same time.

this first adoption, the firms compete in quantities, the firm 1 with the new technology and the firm 2 with the old one. After having observed the quantity produced by the firm 1, the firm 2 updates its beliefs concerning the profitability of the new technology and decides whether it adopts it. If it does it, it uses it at the next period. So, the decisions of the firm 2 -level of production and adoption- are not simultaneous but are taken in the same period. For convenience, we do not take into account the production decision of the firm 2 explicitly, which simply corresponds to its best response, given the production of its competitor. This game is played a finite number of times. The game finishes when the firm 2 decides to adopt or when the new technology becomes obsolete, after *N* periods.

Two periods of the game



As we consider that the firm 2 is uncertain about the profitability of the new technology, the game is conform to Harsanyi's formulation of a game of incomplete information. Alternatively, it is a game of imperfect information and perfect recall, in which "nature" initially determines the marginal cost of the first firm to adopt, and nature's move is observed by the firm 1 but not by the firm 2.

2.3 Hypotheses about the payments of the firms

The firm 1 has two possible types, which correspond to its marginal cost : either c_F (type F), or c_f (type f). Its type constitutes private information. If only one firm adopted, we note $p_1(q_i^*,c_j)$ the per-period profit of the firm 1 with type j $(j=f, F)$, which produces a per-period quantity q_i^* $(i=f, F)$. We note $p_2(q_i^*)$ the per-period profit of the firm 2 if the firm that already adopted produces a quantity q_i^* $(i=f, F)$. If the two firms adopted, we note the per-period profit of each firm p_i $(i=f,F)$ when the new technology leads to a marginal cost c_i, what corresponds to the Cournot equilibrium profit.

Assumptions 1 :

(i) $p_1(q_f^*,c_f)>p_1(q_F^*,c_f)>p_2(q_F^*)$

(ii) $p_2(q_F^*)>p_2(q_f^*)$

(iii) $p_1(q_i^*,c_i)>p_i$ $(i=f,F)$

(iv) $p_f>p_2(q_F^*)$

(v) $p_f>p_F$

These hypotheses hold for an usual linear demand function, and are relatively similar to the ones generally used in the adoption models (Reinganum (1981), Fudenberg and Tirole (1985)). The assumption *(i)* supposes just that the firm 1 with type f earns a bigger profit than the firm 2, even if it produces the "wrong" quantity, but that it is costly to imitate the behaviour of a firm with the type F. This last assumption comes simply from the concavity of the profit function. With the assumption *(ii)*, we suppose that the per-period profit of the firm 2 is higher when it is confronted with a firm with type F than with type f. It is natural because the firm 1 with a cost c_f is more efficient than a firm 1 with a cost c_F. The assumption *(iii)* is also evident : one firm gains a higher profit if its competitor is less efficient, than if it is as much efficient. Without the assumption *(iv)*, the firm 2 would not be incited to adopt. Lastly, the assumption *(v)* comes from the fact that, when the firms are more efficient, their profits are higher.

The total payoff of each player corresponds to the sum of its per-period profits in each period, from $t=0$ to N. The firm 1 knows the cost structure of the industry. The firm 2, on the other hand, initially assess probability r that the firm 1's cost is c_F. For convenience, and as Kreps and Wilson (1982a), we do not use a discount factor.

Assumption 2

$$\sum_{n=0}^{N} p_F - CF = (N+1)p_F - CF < 0$$

This assumption just expresses the fact that the innovation when its type is F is not profitable for two firms, even if they adopt it at the beginning of the game.

3. The equilibria

3.1 The game of perfect information

In perfect information, the firms know the value of the new marginal cost. If it is c_f, they adopt immediately, whereas if they learn that the cost is c_F, there are two equilibria where one firm adopts immediately and the other one never does it. The identity of the firm that adopts is not determined because the firms are identical. Then, each firm produces the quantity which maximises its per-period profit, given its marginal cost and the one of its competitor.

The fact that we do not obtain, in the game of perfect information, a diffusion process comes from the assumption of constant fixed costs. Indeed, if it is in the interest of a firm to adopt, it does it immediately. Here, it gains nothing to delay its decision. But, it is not our aim to obtain a diffusion process.[10] The goal of this paper is to determine whether a firm can have a strategic behaviour to influence the adoption decisions of its competitor, and if it is the case, under which conditions. The pertinent frame of analysis is then the game of imperfect information.

3.2 The game of imperfect information : the concept of equilibrium used

We must distinguish between two cases. In the first one, at equilibrium, the two firms adopt immediately. It will be the case if the initial beliefs, r, that the innovation leads to a marginal cost c_F are low enough. In the second case, only one firm adopts immediately. To determine the probability $\tilde{r}$ that separates the two cases, we must resolve the equilibrium when only one firm adopted and discovered the value of the innovation. There is then a period where one firm already adopted and the other has not yet. Besides, this situation is more probable than the one where the two firms adopt simultaneity.

We wish to identify the sequential equilibrium of this game (Kreps and Wilson, 1982b). This concept of equilibrium enables us to exclude equilibria that are based on expectations by one player of another's behaviour that would not be rational for the latter to carry out if called upon to do so. A sequential equilibrium results if for every period and every possible history, each firm finds that adhering to its strategy is optimal as long as other firm adheres to theirs. Since the players have perfect recall, there is no loss of generality in restricting attention to behaviour strategies. There are three basic parts to the definition of a sequential equilibrium : firstly, whenever a player must choose an action, that player has some probability assessment over the nodes in its information set, reflecting what that player believes has happened so far ; secondly, these assessments are consistent with the hypothesised equilibrium strategy ; lastly, starting from every information set, the player whose turn it is to move is using a strategy that is optimal for the remainder of the game against the hypothesised future moves of its opponent and the assessment of past moves by other players and by " nature ".

In the context of our game, when only one firm adopts immediately, an equilibrium comprises a behaviour strategy for each player and for each stage ($n=1,...,N$), a function p_n taking histories of moves up to stage n into numbers in [0, 1] such that *(i)* starting from any point in the game where it is the firm 1's move, its strategy is a best response to the firm 2's strategy (the information sets of the firm 1 are singletons), *(ii)* at each period, the firm 2's strategy (contingent on a history h_n of prior play) is a best response to the firm 1's strategy given that the firm 1 has a marginal cost c_F with probability $p_n(h_n)$, and *(iii)* each p_n is computed from p_{n-1} and the firm 1's strategy using Bayes' rule whenever possible. p_n gives thus the probability assessed by the firm 2 that the firm 1 has a cost c_F, as a function of how the game has been played up to stage n.

We note $(s_{1f})_n$ (resp. $(s_{1F})_n$) the behaviour strategy of the firm 1 of type f (resp. type F) at the stage n of the game. It corresponds to a probability distribution over $\{q_f^*, q_F^*\}$. We note $(s_2)_n$ the behaviour strategy of the firm 2 at the stage n of the game. It corresponds to a probability distribution on $\{A, NA\}$, where A refers to the adoption decision and NA to the one of not adopting. The production of the firm 2 is determined to maximise its

[10] It would be eventually a possible extension of this work.

per-period profit, given the production of the firm 1.

3.3 The equilibrium of the game when the firms do not adopt at the same time

3.3.1 The (N-N_0+1) last periods

This game must be resolved by backward induction. The strategy of the players depends on the date n and on the probability p_n. Indeed, because of the fixed costs of adoption, the decision of the firm 2 strongly depends on the number of periods remaining. If there are not at least N_0 periods remaining, the firm 2 does not adopt even if it discovers that the technology leads to a marginal cost c_f : the firm 2 can no more adopt the innovation because there are not enough periods to support the fixed costs of adoption. Thus the firm 1 can profit by the new technology without risking that its competitor adopts it : whichever its type, it plays its optimal quantity, which is q_F^* if its marginal cost is c_F, and q_f^* if it is c_f.

Result 1

For all n ³$N-N_0+1$, $(s_{1f}^*)_n=q_f^*$, $(s_{1F}^*)_n=q_F^*$ *and* $(s_2^*)_n=NA$

Concerning the probability p_n in the last periods of the game, the different types of firm 1 do not play the same strategies, which are consequently perfectly separating. The firm 2 discovers the true profitability of the innovation and revises its beliefs : if, at the period $N-N_0+1$, it observes the production level q_f^*, it concludes that the type of the innovation is f, and if it observes q_F^*, it concludes that the new technology leads to a marginal cost c_F. We suppose that its beliefs change no more after this period, even if its competitor plays a different quantity.

Result 2

For all n ³$N-N_0+1$, $$p_n=\begin{cases}1 \quad if \quad (s_{1F})_{N-N_0+1}=q_F^* \quad or \quad (s_{1f})_{N-N_0+1}=q_F^* \\ 0 \quad if \quad (s_{1F})_{N-N_0+1}=q_f^* \quad or \quad (s_{1f})_{N-N_0+1}=q_f^*\end{cases}$$

3.3.2 The incitements of the firm 1

It remains to determine the equilibrium strategies during the first $(N\text{-}N_0)$ periods. The strategies depends on function p_n. We noted r the initial probability that the innovation leads to a marginal cost c_F. At each period, the firms 1 and 2 produce and the last one revises its beliefs after having observed the production level of its competitor.

It is never in the interest of a firm 1 of type F to produce the quantity q_f^* because of the concavity of its profit function. So, if the firm 2 observes that its competitor produces the quantity q_f^*, it concludes that the innovation leads to a marginal cost c_f and that it is thus interesting to adopt it. For $n<N\text{-}N_0+1$, if the history of play up to stage n includes any instance that the new technology leads to a cost c_f, set $p_n=0$. In this case, the firm 2 adopts. Moreover, we suppose, as in Kreps and Wilson (82a), that if $p_n=0$, then $p_{n+1}=0$. This assumption is useful if the firm 2 does not follow its equilibrium strategy and does not adopt : in this case, even if the firm 1 produces again a quantity q_F^*, the firm 2 stays convinced that the innovation leads to a marginal cost c_f.

Result 3

If, at a stage $n<N\text{-}N_0+1$, the quantity produced by the firm 1 is q_f^*, then $p_n(h_n)=0$ and the firm 2 adopts.

On the contrary, if the firm 2 observes that its competitor produces a quantity q_F^* with a probability 1, and if at the stage $n<N\text{-}N_0+1$, p_{n-1} ¹0,the firm 2 learns nothing and then $p_n= p_{n-1}$.

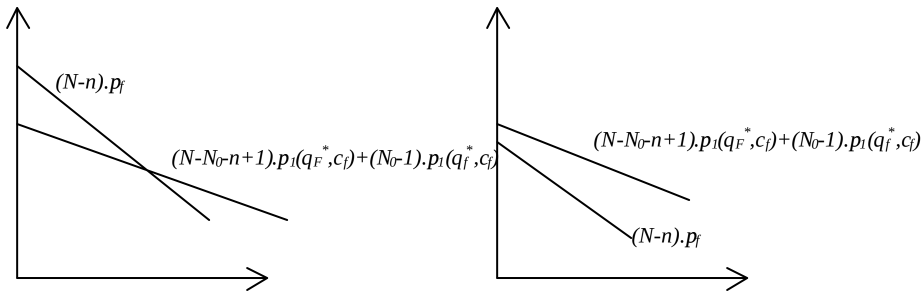
During the first $(N\text{-}N_0)$ periods, the challenge for the firm 1 with a cost c_f is eventually to prevent its competitor from adopting. In fact, it may be not in its interest to do it, because it is costly, at each period, to keep secret its type : indeed, the firm 1 must produce q_F^* instead of q_f^*. The benefits to expect will come only from the last periods, when the firm can profit from its cost advantage without risking that its competitor adopts. It is then intuitive that more N_0 is important, more the firm 1 with a type f will be incited to dissuade its competitor from adopting.

The trade-off of the firm 1 with a marginal cost c_f depends on the cost of imitating the other type $(p_f\text{-}p_1(q_F^*,c_f))$, on the benefits to be alone to have adopted $(p_1(q_f^*,c_f)\text{-}\ p_f)$, and on the duration of these different stages, respectively $(N\text{-}N_0+1)$ and N_0. A firm 1 with a marginal cost c_f is incited to imitate the other type, at a period $n<N\text{-}N_0+1$:

$$(N\text{-}N_0\text{-}n+1).p_1(q_F^*,c_f)+N_0.p_1(q_f^*,c_f)> p_1(q_f^*,c_f)+(N\text{-}n).p_f$$

$$\hat{U} \qquad (N\text{-}N_0\text{-}n+1).p_1(q_F^*,c_f)+(N_0\text{-}1).p_1(q_f^*,c_f)>(N\text{-}n).p_f \qquad (1)$$

If $p_1(q_F^*,c_f)> p_f$ so the condition *(1)* is respected whichever the value of n because, by assumption, $p_1(q_f^*,c_f)> p_f$. If $p_1(q_F^*,c_f)< p_f$ so this condition can be not respected for some n. The condition *(1)* is all the easier to respect since N_0 is big. We note that the left and right terms are both decreasing with respect to n and that the right term decreases faster than the left one. So two configurations are possible.



Case *(a)* Case *(b)*

In the case *(a)*, the condition *(1)* holds only after a certain number of periods whereas, in the case *(b)*, from the beginning, the condition *(1)* is verified. In this first case, at equilibrium, as the firm 1 with a marginal cost c_f is not incited to imitate the other type at the first period $(n=0)$, so it reveals its type and its competitor adopts immediately. This configuration holds if $(N_0\text{-}1)/N<(p_f - p_1(q_F^*,c_f))/(p_1(q_f^*,c_f)\text{-}p_1(q_F^*,c_f))$.

If we want the firm 1 of type f to be incited to imitate the other type, it must be incited to do it as soon as the game begins. In this case, it will be incited at all next periods. It is the case *(b)*. This situation emerges when there are enough periods during which the firm can profit by its cost advantage without risking its competitor adopts. In other words, the ratio $(N_0\text{-}1)/N$ must be high enough, and more precisely $(N_0\text{-}1)/N>(p_f - p_1(q_F^*,c_f))\ (p_1(q_f^*,c_f)\text{-}p_1(q_F^*,c_f))$.

In the following, we assume that the parameters verify the conditions which ensure that the firm 1 with a marginal cost c_f is incited to keep secret its type

3.3.3 The strategy of the firm 2

The strategy of the firm 2 depends on its beliefs about the type of the innovation. If, at a date $n<N\text{-}N_0+1$, $p_n=0$ then it adopts. If $p_n>0$, then at each period, the firm 2 compares its expected profits from adopting and from not adopting. At stage n, the probability that the marginal cost due to innovation is c_F is equal to p_n. So, the firm 2 prefers to adopt if :

$$p_n.\sum_{i=n+1}^{N} p_F + (1-p_n).\sum_{i=n+1}^{N} p_f - CF > p_n.\sum_{i=n+1}^{N} p_2(q_F^*) + (1-p_n).(\sum_{i=n+1}^{N-N_0} p_2(q_F^*) + \sum_{i=N-N_0+1}^{N} p_2(q_f^*))$$

Thus, at the stage n, the firm 2 adopts if the probability p_n is low enough :

$$p_n < \frac{CF - \sum_{i=n+1}^{N} p_f + \sum_{i=n+1}^{N-N_0} p_2(q_F^*) + \sum_{i=N-N_0+1}^{N} p_2(q_f^*)}{\sum_{i=n+1}^{N} p_F - \sum_{i=n+1}^{N} p_f + \sum_{i=n+1}^{N-N_0} p_2(q_F^*) + \sum_{i=N-N_0+1}^{N} p_2(q_f^*) - \sum_{i=n+1}^{N} p_2(q_F^*)}$$

which gives

$$p_n < \frac{CF - (N-n)p_f + (N-N_0-n)p_2(q_F^*) + N_0 p_2(q_f^*)}{(N-n)(p_F - p_f) + N_0(p_2(q_f^*) - p_2(q_F^*))} = \frac{A_n}{B_n}$$

The strategy of the firm 2 depends on the sign of the ratio A_n/B_n. Whichever n, B_n is always negative. But, we must distinguish between two cases concerning A_n.

(i) If $A_n > 0$, then the ratio (A_n/B_n) is negative, and the condition which incites the firm 2 to adopt never holds. This situation emerges if :

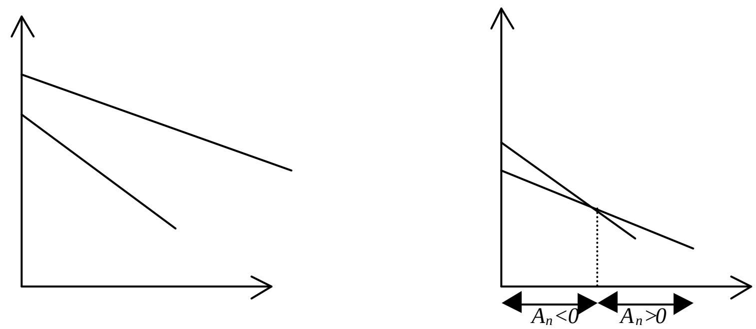
$$(N-N_0-n+1)\ p_2(q_F^*)+N_0p_2(q_f^*)>(N-n+1).p_f-CF \qquad (2)$$

It means that the fixed costs of adoption are so high that the firm 2 prefers to receive a profit $p_2(q_F^*)$, during $(N-N_0-n+1)$ periods, rather to adopt. But, despite this preference, it is not less costly for the firm 1 to prevent its competitor from adopting. Indeed, if the firm 1 produces the quantity q_f^*, the firm 2 adopts. The threat of adoption is always credible.

Under the condition *(2)*, we must distinguish between two possible configurations. The two terms are decreasing with respect to n, but the right one decreases faster.

(ia) Either the condition *(2)* always holds : it is the case if *(2)* holds for $n=0$: $CF>(N+1).p_f-(N-N_0+1).p_2(q_F^*)-N_0.p_2(q_f^*)$ (case *(a)*). This condition holds when the fixed costs are very high, or when the number of necessary periods to support the fixed costs, N_0, is low, or when the lifetime of the new technology, N, is very short.

(ib) Or, at the beginning of the game, the condition *(2)* does not hold (thus, $A_n<0$). In this case, $CF<(N+1).p_f-(N-N_0+1).p_2(q_F^*)-N_0.p_2(q_f^*)$. Eventually, the condition holds after a certain number of periods. in this case, it exists n such as $CF>(N-n+1).p_f-(N-N_0-n+1)\ p_2(q_F^*)-N_0p_2(q_f^*)$ (case *(b)*).



Case *(a)* Case *(b)*

(ii) If $A_n<0$, then the ratio (A_n/B_n) is between 0 and 1. The ratio A_n/B_n is always inferior to 1 because of our hypotheses. In this case, the strategy of the firm 2 is :

Result 4

For $n<N-N_0+1$, at the equilibrium, the firm 2 adopts at the period n, if the probability that the new technology leads to a marginal cost c_F is inferior to A_n/B_n. In the contrary case, it does not adopt. If $p_n=A_n/B_n$, then the firm plays a mixed strategy.

When $A_n<0$, the equilibrium strategy of the firm 2 is thus : $$(s_2^*)_n=\begin{cases} A \quad if \quad p_n<\dfrac{A_n}{B_n} \\ NA \quad if \quad p_n>\dfrac{A_n}{B_n} \\ \{A,NA\} \quad if \quad p_n=\dfrac{A_n}{B_n} \end{cases}$$

So, if the probability that the new technology leads to a marginal cost c_F is low enough ($p_n<A_n/B_n$), the firm 2 adopts. In the contrary case, it does not.

The cut-off probabilities (A_n/B_n) are chosen so as to achieve an optimal balance between the risk of an incorrect decision and the benefits of a good one. We note that the absolute value of each cut-off level decreases over time : the ratio A_n/B_n is decreasing with respect to the date. More n is close to $N-N_0+1$, more the firm 2 must be convinced that there is very little chance that the new technology leads to a marginal cost c_F. There are less and less periods remaining and the adoption becomes a less and less profitable action, whereas a mistake becomes more and more costly.

Result 5

For $n<N-N_0+1$, at the equilibrium, the strategy of the firm 2 is :

- *if $(N-N_0-n+1).p_2(q_F^*)+N_0p_2(q_f^*)>(N-n+1).p_f-CF$, the firm 2 does not adopt, whichever the value of p_n.*
- *if $(N-N_0-n+1).p_2(q_F^*)+N_0p_2(q_f^*)<(N-n+1).p_f-CF$, the firm 2 adopts if $p_n<A_n/B_n$, does not adopt if $p_n>A_n/B_n$ and plays a mixed strategy if $p_n=A_n/B_n$.*

3.3.4 The equilibrium strategy of the firm 1 with cost c_f during the first $(N-N_0)$ periods

If it is in the interest of the firm 1 with a marginal cost c_f to keep secret its type, its equilibrium strategy depends on the beliefs of the firm 2 concerning the type of the innovation. At the period n, before producing, the firm 1 can evaluate the beliefs of the firm 2, p_{n-1}, and can anticipate its future decision. The firm 1 knows that if it produces the quantity q_f^*, the firm 2 discovers that the innovation is profitable and it adopts. So, if the firm 1 with the type f is willing to prevent the firm 2 from adopting, it is not in its interest to produce the quantity q_f^* for $n<N-N_0+1$, since this quantity causes adoption. It can not be a sequential equilibrium for the firm 1 with cost c_f to produce q_f^* with probability one. However, if $p_{n-1}=0$, then the firm 1 with cost c_f produces q_f^* because as soon as $p_{n-1}=0$, the firm 2 stays convinced that the type of the innovation is F.

If the firm 1 produces the quantity q_F^* with probability one, the firm 2 learns nothing from observation of the first adopter, and its beliefs stay the same. So, if, at the period $(n-1)$, the firm 2 did not adopt because the probability that the innovation is not profitable was too high ($p_{n-1}>A_{n-1}/B_{n-1}$ or $A_{n-1}>0$), it will not adopt at the period n. Indeed, the ratio A_n/B_n is decreasing with respect to n and the term A_n is increasing with n. In this case, the equilibrium strategy of the firm 1 is to produce the quantity q_F^* with the probability 1. So, if $p_{n-1}>A_n/B_n$, the firm 1 plays a pure strategy at the equilibrium.

We know that $A_{n-1}/B_{n-1}>A_n/B_n>A_{n+1}/B_{n+1}$. So, if $p_{n-1}>A_{n-1}/B_{n-1}$, then $p_{n-1}>A_n/B_n$. We must then examine the beginning of the game. The initial beliefs of the firm 2 are noted r. If $r>A_0/B_0$, then $r>A_n/B_n$ whichever n. The firm 1 always produces the quantity q_F^* with probability one, the firm 2 learns nothing and never adopts. In fact, its initial doubts about the profitability of the innovation are too important, and the firm 1 profits by them.

If $r<A_0/B_0$, then if the firm 1 with a marginal cost c_f produces the quantity q_F^* with the probability one, the firm 2 will adopt. It is not an equilibrium strategy to produce q_F^* with probability one, as then the posterior

probability that the new technology leads to a marginal cost c_F would not deter adoption. Nor can it be an equilibrium strategy to produce q_f^* with probability one. Thus, at the equilibrium, the firm 1 must randomise, which requires that when the firm 1 produces q_F^*, the entrant 2 randomizes in a way that makes the firm 1 indifferent.

To make indifferent the firm 2 between adopting and not, its beliefs p_0 must be equal to A_0/B_0. The equilibrium mixed strategy of the firm 1 is then :

$$(s_{1f})_0 = \begin{cases} q_F^* \quad with \quad probability \quad \dfrac{r}{1-r}.(\dfrac{B_0}{A_0}-1) \\ q_f^* \quad with \quad probability \quad 1-\dfrac{r}{1-r}.(\dfrac{B_0}{A_0}-1) \end{cases}$$

This strategy incites the firm 2 to play a mixed strategy too since it involves $p_0=A_0/B_0$.

$$(s_2)_0 = \begin{cases} A \quad with \quad probability \quad \dfrac{N.p_f-(N_0-1)p_1(q_f^*,c_f)-(N-N_0+1)p_1(q_F^*,c_f)}{N.p_f-N_0.p_1(q_f^*,c_f)-(N-N_0).p_1(q_F^*,c_f)} \\ NA \quad with \quad probability \quad 1-\dfrac{N.p_f-(N_0-1)p_1(q_f^*,c_f)-(N-N_0+1)p_1(q_F^*,c_f)}{N.p_f-N_0.p_1(q_f^*,c_f)-(N-N_0).p_1(q_F^*,c_f)} \end{cases}$$

The obtained probability are between 0 and 1 because of our assumptions.

Result 6

For $n<N-N_0+1$, at the equilibrium, the strategy of the firm 1 is :

- *if its type is F, then it produces the quantity q_F^* with the probability one;*
- *if its type is f and if $r>A_0/B_0$, then it produces the quantity q_F^* with the probability one;*
- *if its type is f and if $r<A_0/B_0$, then, in the first period, it plays the mixed strategy given above and, in the other periods, it produces the quantity q_F^* with the probability one;*

3.3.5 The equilibrium

Two cases are possible, but only the beginning of the game is different and depends on the value of the initial beliefs r. Either, at the beginning, the initial probability that the new technology leads to a cost c_F is important, and, the firm 1, whichever its type, produces q_F^* with a probability one during the *$(N-N_0)$* first periods. The firm 2 does not adopt. After the *$(N-N_0)$* first periods, the firm 1 with a cost c_F continues producing the same quantity, whereas the firm 1 with a cost c_f produces q_f^*. During these last periods, the firm 2 does not adopt.

Or, , at the beginning of the game, the firm 2 initially believes that there is little chance that the new technology leads to a marginal cost c_F. Then the firm 1 with a cost c_F produces q_F^* with a probability 1 during the *(N-N₀)* first periods, whereas the firm 1 with a cost c_f randomises over $\{q_f^*, q_F^*\}$ which causes the randomisation of the firm 2 over *{A,NA}*. If the firm 2 adopts, the game is over; if it does not, the firm 1 with a cost c_f produces then the quantity q_F^* with probability 1 until the period $N\text{-}N_0$. After, the game is similar to the first case.

Finally, the diffusion of a new technology can be delayed, even and particularly if it is very profitable, because of some private information which receives the first firm that adopts it. We note that this result emerges when the technology is very profitable, in other words when the difference between c_f and c_F is important and when the innovation is the most desirable from a social point of view.

3.4 The equilibrium of the game when simultaneous adoptions are possible

We must now examine the case in which simultaneous adoptions are possible. At the beginning of the game, the two firms, which are identical, compare the expected profit when both adopt simultaneously, and the expected profit of a follower. At the date $t=0$, the best response to the adoption of its competitor is the adoption too if :

$$r.\sum_{i=0}^{N} p_F + (1-r).\sum_{i=0}^{N} p_f - CF > r.\sum_{i=0}^{N} p_2(q_F^*) + (1-r).(\sum_{i=0}^{N-N_0} p_2(q_F^*) + \sum_{i=N-N_0+1}^{N} p_2(q_f^*))$$

what involves a condition on r *:*

$$r < \frac{CF + N_0.(p_2(q_f^*) - p_2(q_F^*)) + (N+1).(p_2(q_F^*) - p_f)}{N_0.(p_2(q_f^*) - p_2(q_F^*)) + (N+1).(p_F - p_f)} = \frac{A}{B} \qquad (3)$$

Thus, both firms adopt at the date $t=0$, if they think that there is very little chance that the new technology leads to a marginal cost c_F. The denominator of the ratio (*A/B*) is always negative, whereas the numerator can be positive or negative.

If $(N\text{-}N_0+1)\ p_2(q_F^*)+N_0.p_2(q_f^*)>(N+1).p_f\text{-}CF$, then the ratio (*A/B*) is negative and the condition *(3)* never holds. In this case, there are never simultaneous adoptions. One of the two firms adopts at the beginning of the game and the other one never does it.

If $(N\text{-}N_0+1)\ p_2(q_F^*)+N_0.p_2(q_f^*)<(N+1).p_f\text{-}CF$, then the ratio (*A/B*) is positive and the condition *(3)* holds if the initial beliefs are low enough. In this case, there are simultaneous adoptions. In the contrary case, the initial doubts about the profitability of the innovation are too much important and only one firm adopts.

4. Conclusion

We have examined a very simple situation, where the benefits obtained when a firm prevents its competitor from adopting come just from the fact that, after some time, the competitor can no more adopt the new technology and the first adopter can then profit by its cost advantage. We have conscious that, in the reality, the competitors obtain some information from other sources, which influence its beliefs concerning the profitability of a new technology too. So, if the innovation is really very profitable, it is probable that a first adopter can, at best, delay the adoption of its competitors, and not prevent them from using the new technology. It can, at best, slow down the diffusion process but not stop it. But, sometimes, the fact to delay the adoption of its competitors can be important and strategic, and can really influence the future competition. Concerning some technologies, if a firm succeed in using it before its competitors, it can obtain a real advantage. By instance, if the technology is characterised by an important learning curve, or in the case of the networks technologies. For these last ones, the creation of a network is essential and the firm that possess the biggest network has a considerable advantage. So, it can be very strategic to delay the adoption of its competitors. But the strategic dimension of the diffusion process is often forgotten both in the theoretical works and in the technology policies.

Otherwise, our results are interesting to explain a well-known stylised fact : the price cycle during the introduction of an innovation. Indeed, generally, when an innovation is introduced for the first time, its price is very high, and decreases later. The traditional explication is that the firms sell in first to the consumers that have the highest valuations for the innovations. But, our work suggests another possible explication. Indeed, a high price (or a low production) can be a signal that the market is not enough for many firms in order to slow down the diffusion of an innovation.

Concerning a future work, it will be interesting to think about the links between market power and strategic behaviour in the adoption process. Is it more in the interest of a firm with a high market power to delay the adoption of its competitors ? It is not sure because it is more costly for this firm to keep secret a profitable innovation. The question is not evident.

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A firm implements a new technology in its production process...

the firm enjoys a monopoly in that market.

there are more than n(p0) markets remaining ...

reducing the risk that the firm adopts an unprofitable innovation.

The uncertainty concerns the cost variable which can take two values.

The economic intuition underlying ()-() is easily revealed. At any time, ...

Thus, firm face a trade-off between....

an innovation which is available at any time, but whose profitability is unknown.

To solve for the sequential equilibrium of the finite-horizon version of this game, we will first solve for the sequential equilibrium of the one-period game, then that of the two period game, and proceed by induction to solve for the game with N periods. ...Now imagine that there are two periods remaining in the game. The nature of the equilibrium depends on the prior probabilities and the parameters of the payoff function.

The firms' problem is to decide whether to adopt or to wait and gather information which can help reduce the uncertainty about the success of the innovation.

but its competitor observes the firm 1's actions at each period and tries to infer its type.

But this output decision can be strategic in the sense that the firm 1 can seek to influence the adoption decision of its competitor.

There is no uncertainty in demand and it is common knowledge.

a Cournot equilibrium in quantities.

the decision is irreversible because it requires a fixed outlay just as in Jensen (1982).

The new marginal cost due to the innovation. It is not known with certainty how low cf will be compared to c0.

Let qi be the output of the firm that has decided to adopt first. Then if he wer to adopt, the follower would choose an output...

The amount that would be produced, if it adopted

profit from not adopting

Profit due to adoption

A short-run to incentive

**

Besides, it is precisely at this moment that the Authorities could intervene. To inform the firms about the new available innovations is thus essential in a technology policy.

The logic is a bit different from the one of Kreps and Wilson (1982), because (pour eux, effet réputation est que même faible, monopole peut avoir intérêt à combattre, et donc entrant n'eentre pas car même faible il a perte. Ce qui intéresse l'entrant est plus la probabilité de combattre que réllement le type de l'autre.)

(cf intro) Prior to adoption, it is often not known whether or not the given process technology will reduce marginal costs below current levels unless one obtains cost data from a firm that already adopted the new production process. Thus risk-neutral firms could have priors about the effects of the new technology that could possibly prevent adoption. On the other hand, as more firms adopt the technology, the remaining firms keep altering their posterior beliefs about the effect of the new technology (Sadanand, 1989).

Jensen (92) examines the welfare effects of adopting an innovation when there is uncertainty about whether it will succeed or fail in a static model. But these last papers do not take into account the fact that all firms do not adopt at the same time and do not specify the origin of the information about the profitability of the new technology.

(cf intro) Imperfect information is endemic to the process of technological change. Typically, the available information on a given innovation changes over the course of the diffusion process. The literature considers three basic mechanisms by which information increases : (i) potential adopters acquire passively knowledge from the (costless) observation of the experience of actual adopters, (ii) potential adopters acquire passively information from the promotional and other information spreading activities of capital good suppliers, and (iii) potential adopters undertake active search for information. All three mechanisms are likely to give rise to market failure. For example, if late adopters learn from the experience of early adopters, then there is an externality deriving from the adoption of technology by early users. (Stoneman et dierden)

Information may be imperfect in the sense that the existence and the current characteristics of an innovation are not general knowledge.

Our next contribution concerns strategic interaction across firms. Strategic interdependancies among firms may arise for two reasons. First, the profitability of the innovation for a particular firm may depend upon how many other firms adopt the innovation, and when they adopt it. The most obvious example is the case in which the first adopter secures exclusive patent protection without possibility of imitation, relegating others' profits to zero. Reinganum (1981, 1983) examines these types of strategic relationships under the assumption that firms know the distribution of payoffs.

In our framework involving an unknown payoff distribution, there is an additional dimension to inter-firm interaction. The R&D decisions of other firms may reveal information to another firms. This information will be pooled with the experimenter's own observations in forming posterior beliefs, and is then relevant to the optimal accept/reject decision. We construct a model in which the effects of these two types of strategic interaction on firms' optimal reserach strategies can be examined.