department of economics
"S. Cognetti de Martiis"

Via Po, 53 – 10124 Torino (Italy)
Tel. (+39) 011 6702704 - Fax (+39) 011 6702762
URL: http//www.de.unito.it

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A monopolist supplier and learning effects in technology adoption

Elisabetta Ottoz

Dipartimento di Economia "S. Cognetti de Martiis"

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Elisabetta Ottoz

Università degli studi di Torino, Dipartimento di Economia

Via Po n. 53, 10124 Torino, Italy

Abstract.

The aim of this paper is to study the consequences of the introduction of supply side and learning effects in the process of technological adoption. Explicit consideration of supply side makes endogenous the price path, whereas the occurring of learning enables a better understanding of the coordination process.

The model describes an open-loop two stage dynamic game of imperfect information: the players are a monopolist offering a cost reducing process innovation and two identical firms who, observing the innovation prices, are to simultaneously decide when to adopt it, in presence of learning by using and spillover.

Open-loop equilibrium in symmetric adoption is the solution for incremental innovations, whereas for drastic innovations the resulting equilibrium might be one of diffusion or simultaneous adoption, both early and late, according to g , the probability that adopters will choose to adopt early. Independently of the particular equilibrium which will take place, drastic innovations's first period prices are always higher than incremental ones.

Keywords: technological adoption, process innovation, monopolist, two period game, learning by using.

JEL classification: D42, 033.

Introduction.

The main purpose of an inquiry on technological diffusion is to understand why a superior innovation is not taken up immediately by all potential adopters, in other words why diffusion process is time intensive.

The explanatory approaches initially proposed in the literature have been in the sixties the logistic and the probit ones. Although widely used for empirical testing, both models resulted theoretically inadequate giving rise to many contributions referring to four main aspects: the role of strategic behavior, the uncertainty inborn in the innovation itself, the role played by the supply side and the possibility of increasing returns.

The paper attempts to share the above intuitions through a dynamic game of imperfect information with three players. In the first stage a monopolist offers a cost reducing process innovation, in the second stage two identical firms are concerned with the timing of innovation adoption.

The inclusion in a game theoretic model of technology adoption of both supply side and increasing returns in adoption represents a theoretical improvement: the innovations' price path is made endogenous, the equilibrium selection is shown to play a role in the monopolist choice, whereas the implications of learning effects are seen in the two extreme cases of absent or complete learning spillover effects in adoption.

The results show the conditions under which diffusion equilibrium is no longer the only possibility, but simultaneous earlier adoption appears as one of the equilibria when the monopolist is a player of the game.

The paper is organized as follows.

The first part provides a conceptual framework; the second introduces the model in terms of a dynamic game of imperfect information; the third stresses the decision rule adopted by the monopolist supplier, whereas the last offers some concluding remarks.

1. A conceptual framework.

Game theory has been widely applied to technological diffusion. This attempt is particularly appropriate as the firm's decision to adopt a new technology heavily depends not only from considerations related to risk and profitability, but also from rival firms' behavior.

A thorough understanding of the theoretical evolution in this field leads us to examine the models initially proposed in the literature.

In her seminal contributions, Reinganum (1981a, 1981b) shows that n! asymmetrical Nash equilibria define the optimal adoption dates of ex ante identical firms in a precommitment model. . The eventuality of immediate symmetric adoption is just mentioned as "*a degenerate case…in which adjustment costs do not decline sufficiently rapidly as to warrant waiting,….immediate adoption is a dominant strategy for each firm.*" Fudenberg and Tirole (1985) study the effects of preemption, when firms can observe and respond to their rivals' actions, obtaining the result that in a feed-back equilibrium the rents of the leader and the follower are equalized, both in asymmetric and symmetricadoption dates.

More recently Stenbacka and Tombak (1994) focus on the uncertainty in the time lag between the adoption of the new technology and its succesful implementation, which is an increasing function of the time since adoption, finding that an open-loop equilibrium with simultaneous adoption can appear as a solution of the game. Gotz (1997) questions the fact that the rents of non identical firms are equalized.

These models, though following different approaches are all based uniquely on the demand side; necessary conditions are that adoption costs, represented by the innovation price, decrease over time and that expected benefits from adoption decrease with the number of adopters.

As it is evident they share:

1) the exogeneity of the supply side;

2) the lack of a proper investigation of the equilibrium selection problem;

3) the inverse correlation between diffusion and expected revenues of the adopters.

All three assumptions are problematic.

As far as point 1 is concerned, the price trajectory, although the central role ascribed to it, is totally exogenous because of the exclusion of the supply side, so that the assumption of declining prices is not theoretically founded. [1]

Point 2 arises because of the multiplicity of asymmetric equilibria present in both the Reinganum, Fudenberg and Tirole and Stenbacka and Tombak models; as in Reinganum precommitment equilibria firms' profits monotonically decrease with the adoption order, it is not trivial for a firm the position it holds in the diffusion process. The problem is solved by Fudenberg and Tirole (1985) whose model shows that all the equilibria entail rent equalization for the adopters either in case of diffusion or in case of simultaneous equilibria.

Even if rent equalization solves part of the problem, as now adopters do not fight to be in first position, it is not obvious how the adopters can coordinate without making mistakes, which might give rise to adoption dates not representing an equilibrium.

[1] The explicit treatment of the supply in the form of a monopolist might appear to raise theoretical questions related to the ability of a durable goods monopolist to extract surplus, due to a dynamic inconsistency problem. In fact, here, the value of the good sold varies indeed over time according to the rival firm behaviour as profits are interdependent and not because firms have different reservation prices, so that a strategy of price decrease in this case may not necessarily be considered as an intertemporal price discrimination.

The eventuality of mistakes is ruled out by Fudenberg and Tirole: "*because of the ability of firms to istantaneously react there is no possibility of mistakes*", but I think the problem is still present.

As with point 3 the exclusion of any possibility of learning effects constitutes an important omission, because in some cases the adoption of an innovation confers positive externalities upon all users. To be more precise, Reinganum and Fudenberg and Tirole don't analyze them, but Stenbacka and Tombak do, as the expected payoff of their model exhibit experience effects, in terms of learning, though without spillover.

Various are the channels through which they are at work, with relevant consequences. (Cabral, 1992; Cowan, 1997; Katz M., Shapiro C., 1985, 1986a, 1986b, 1992,1994; Matutes C., Regibeau P., 1988).

In case of process innovations adopters' interaction has a double-sided effect on profit expectations. Traditionally mainly the adverse effect has been stressed according to which payoff interdependence negatively affects firms' expected revenues as adoption proceeds, the above explanation is not, however, exhaustive as the adopters constitute the vehicle of learning diffusion, with positive effects on the level of expected revenues and potential applications of the innovation.

Various are the effects of learning: on the demand side there is a learning by using effect which at least partially becomes common property of the entire industry and the opening up of new application possibilities giving rise to new markets and interindustrial diffusion. In the first case there is a reduction in the production costs of the final good given its final demand is invariant, in the second an increase in the final good demand.

2. The model: the adopting firms.

The analysis is focused on the role played by both the supply side and the positive externalities stemming from the interplay of the two adopters. The above considerations are expressed by a simple two-period game with three agents: a monopolist offering a cost- reducing process innovation and two identical[2] adopting firms who are to decide the adoption time.

In dynamic game theory two types of equilibria can be defined: open-loop and closed-loop or feed-back equilibria. In an open-loop game players commit to irreversible strategies determined ex ante at the beginning of the time horizon, whereas in the closed-loop equilibrium strategies are time-consistent.The following is an open-loop model in which the monopolist acts as leader, while the two firms act as followers committing to irreversible adoption times at the beginning of the planning horizon.

The dynamic game with imperfect information is then two stage: in the first stage the monopolist announces a vector of innovation prices to be practiced in the two periods; in the second stage the two firms play a simultaneous duopolistic Cournot game whose aim is to define each firm’s adoption date. Their decision is jointly based upon the sequence of prices representing the adoption cost, the behavior of the rival firm and the presence of learning by using and spillover.

At time $t = 0$ a cost reducing innovation is introduced in the market by the monopolist; the two firms, denominated A and B, may adopt either at time 1 or 2. p_1 and p_2 are the discounted prices of the innovation at time 1 and 2; adjustment costs are for simplicity set at zero.Each firm's unit cost is initially c_0, whereas after the adoption it decreases to c_1: $c_0 - c_1 = a$.

Adoption causes then an immediate reduction of costs from c_0 to c_1, which doesn't though exhaust its impact: in the period following the adoption, in fact, costs further decrease because of learning by using effects becoming: $c_1 - l - m$. λ represents personal learning by using, whereas

[2] This formulation depends on the decision to attempt to derive results from a symmetric situation so as to concentrate on the process deriving uniquely from the strategic behavior of the firms and from the postinnovation pattern of improvement of the innovation itself.

μ is spillover, which might be due to workers moving across firmser effect: [3] $m \leq l$; $0 \leq l \leq 1$; $0 \leq m \leq 1$.

q_i^j, $i = A, B$; $j = 1,2$; is the output of firm i at time j; r is the discount factor. Each firm, A and B, has two pure strategies: to adopt in the first period (10) or in the second one (01). The first payoff as usually refers to firm A, whereas the second to firm B; the first part of each payoff refers to period 1 and the second to period 2.

Period 1.

At the time preceding the introduction of the innovation both firms realize Nash equilibrium profits equal to p_0, then, in period 1, if only one firm adopts its profit is equal to p_1, whereas the firm which has not adopted gets p_2, if they both adopt profits are equal to p_3, if none adopts in period 1 profits remain p_0.

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[3] Moreover there might be a positive effect on final good consequent to the opening up of new markets or to interindustrial diffusion demand. This effect is contained in the demand function represented by

$a - q_A^1 - q_B^2$;

before the adoption, which becomes

$a' - q_A^1 - q_B^2$; after the adoption, with $\alpha' > \alpha$;

This effect is not examined in the text. To keep the model more tractable no effect on demand is considered so that:

$\alpha' = \alpha = 1$.

Period 2.

By period 2 adoption has to take place anyway, but, because of learning by using, each firm's profit depends of what has happened in period 1: rp_{31} is the discounted profit for the firm which has gained p_1 in period 1; rp_{32} is profit for the firm which has gained p_2 in period 1; rp_{33} is profit for the firm which has gained p_3 in period 1; rp_{30} is profit for the firm which has gained p_0 in period 1;

It is assumed that:

1) $p_i > 0 \forall i \in \{0,1,2,3,30,31,32,33,\}$ so that in any event firms realize positive profits;

2) $p_1 > p_3 > p_2 ; p_1 > p_0 > p_2$.

The preferred events are in the order: to be the only adopter, to be simultaneous adopters, to be the only non-adopter.

3) $(p_1 - p_0) - (p_3 - p_2) > 0$.

The increase in revenues from being the only adopter exceeds the one deriving from being the second adopter.

4) The preferred events in the second period are: $p_{31} > p_{33} > p_{30} > p_{32}$.

Table 1 is the payoff matrix representing the profits, which have to be maximized by the two firms, A and B, in the duopolistic game. Table 2 represents maximized firms profits in the different situations of the game. Table 3 has the same information as table 5, but uses a simplified notation.

Table 1.

A, B	10	01
10	$q_A^1(1-q_A^1-q_B^1-c_1)-p_1+rq_A^2(1-q_A^2-q_B^2-c_1+l+m)$ $q_B^1(1-q_A^1-q_B^1-c_1)-p_1+rq_B^2(1-q_A^2-q_B^2-c_1+l+m)$	$q_A^1(1-q_A^1-q_B^1-c_1)-p_1+rq_A^2(1-q_A^2-q_B^2-c_1+l)$ $q_B^1(1-q_A^1-q_B^1-c_0)+rq_B^2(1-q_A^2-q_B^2-c_1+m)-rp_2$
01	$q_A^1(1-q_A^1-q_B^1-c_0)+rq_A^2(1-q_A^2-q_B^2-c_1+m)-rp_2$ $q_B^1(1-q_A^1-q_B^1-c_1)-p_1+rq_B^2(1-q_A^2-q_B^2-c_1+l)$	$q_A^1(1-q_A^1-q_B^1-c_0)+rq_A^2(1-q_A^2-q_B^2-c_1)-rp_2$ $q_B^1(1-q_A^1-q_B^1-c_0)+rq_B^2(1-q_A^2-q_B^2-c_1)-rp_2$

Table 2.

A, B	10	01
10	$\left(\frac{1-c_1}{3}\right)^2+r\left(\frac{1-c_1+m+l}{3}\right)^2-p_1$ $\left(\frac{1-c_1}{3}\right)^2+r\left(\frac{1-c_1+m+l}{3}\right)^2-p_1$	$\left(\frac{1+c_0-2c_1}{3}\right)^2+r\left(\frac{1+c_1-m-2(c_1-l)}{3}\right)^2-p_1$ $\left(\frac{1-2c_0+c_1}{3}\right)^2+r\left(\frac{1-2(c_1-m)+c_1-l}{3}\right)^2-rp_2$
01	$\left(\frac{1-2c_0+c_1}{3}\right)^2+r\left(\frac{1-2(c_1-m)+c_1-l}{3}\right)^2-rp_2$ $\left(\frac{1+c_0-2c_1}{3}\right)^2+r\left(\frac{1+c_1-m-2(c_1-l)}{3}\right)^2-p_1$	$\left(\frac{1-c_0}{3}\right)^2+r\left(\frac{1-c_1}{3}\right)^2-rp_2$ $\left(\frac{1-c_0}{3}\right)^2+r\left(\frac{1-c_1}{3}\right)^2-rp_2$

Table 3.

A, B	10	01
10	$p_3+rp_{33}-p_1$ $p_3+rp_{33}-p_1$	$p_1+rp_{31}-p_1$ $p_2+rp_{32}-rp_2$
01	$p_2+rp_{32}-rp_2$ $p_1-rp_{31}-p_1$	$p_o+rp_{30}-rp_2$ $p_o+rp_{30}-rp_2$

The relevant equilibrium concept is subgame perfection; we are in fact dealing with a dynamic game where the two firms observe the vector of innovation prices announced by the monopolist.

Let's start from the subgame in which the two firms have to decide when to adopt the innovation.

The conditions for the different equilibria are now now:

(01,10) $p_1 - rp_2 > p_3 - p_2 + r(p_{33} - p_{32})$; (1)

(10,01) $p_1 - p_0 + r(p_{31} - p_{30}) > p_1 - rp_2$; (2)

(10,10) $p_3 - p_2 + r(p_{33} - p_{32}) > p_1 - rp_2$; (3)

(01,01) $p_1 - rp_2 > p_1 - p_0 + r(p_{31} - p_{30})$ (4)

In order to give an economic explanation we notice that for a diffusion process to be optimal conditions 1 and 2 have to be satisfied.

Condition 1 requires that the expected profit deriving from simultaneous adoption in the first period is smaller than the one deriving from adoption a period later, when the rival is likely to adopt in the first period. It is then necessary for $p_3 - p_2 + r(p_{33} - p_{32})$,[4] the preemption incentive, to be smaller than the price differential; in other words the deferred adoption loss in terms of profits, both in period 1 and in period 2, is to be smaller than the waiting advantage due to innovation price decrease. A positive λ and a zero m enhance the adoption deferment cost: a positive λ increases the cost as the firm doesn't benefit from learning by using; whereas no spillover effect means that the latecomer doesn't benefit from early rival's adoption. The adoption deferment cost is lower when complete spillover is envisaged, as in such case the latecomer will share without expenses the ultimate cost reductions.

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[4] The preemption incentive concept has been first introduced by Katz M.L., Shapiro C. (1987) in a slightly different framework. They consider in fact the rivalry between two firms which are to develop an innovation. In such a dynamic situation, after one firm has selected its strategy there is no possibility for the other one to improve its technology. The preemption incentive is then represented by $\pi_1 - \pi_2$, whereas in this model $\pi_3 - \pi_2$ is relevant.

For condition 2 to be satisfied, the opportunity cost of waiting, $p_1 - p_0 + r(p_{31} - p_{30})$, both in period 1 and in period 2, also denominated the firm stand-alone incentive to adopt, overcomes the advantages deriving from the decision postponement ($p_1 - rp_2$). $p_1 - p_0$ is increasing in a , while $r(p_{31} - p_{30})$ is always positive and increasing in the difference between l and m (cfr Table 2.). In case of no spillover effect first mover advantage is much stronger as learning by using effects don't benefit the rival firm.

Two are then the asymmetric Nash equilibria in pure strategies: (01,10) and (10,01). When the conditions for diffusion are satisfied, there is a third equilibrium in mixed strategies where both firms select the strategy 10 with probability g and the strategy 01 with probability $1-g$:

$$g = \frac{p_1 - p_0 + r(p_{31} - p_{30}) - (p_1 - rp_2)}{p_1 - p_0 + r(p_{31} - p_{30}) - (p_3 - p_2) - r(p_{33} - p_{32})} . \qquad (5)$$

For simultaneous adoption at time 1 to be optimal condition 3 must be satisfied; the preemption incentive, that is to say the waiting loss, must be greater than the waiting advantage, so that a rival adopting decision has to be immediately matched.

For simultaneous adoption at time 2 condition 4 has to be satisfied; the stand-alone incentive, that is to say the waiting loss, must be smaller than the waiting advantage.

In order to make things simpler three special cases will be considered:

In the first case, $l = 0, m = 0$; increasing returns due to learning by using are absent so that, after adoption takes place, unit cost simply decrease from c_0 to c_1; as it is evident in this case profits in period 2 don't depend any longer from what has happened in period 1, but are all the same p_3, so that conditions for the different equilibria are simplified.

The second case, $l > 0, m = 0$, represents a situation with increasing returns in adoption, in absence of spillover, so that learning by using is totally appropriated. The third case, $l > 0, m = l$, represents complete spillover, where learning by using generated within each firm is totally and freely appropriated by the other firm. Personal learning by using coupled with complete spillover makes: $p_{33} > p_{31} = p_{32} > p_{30}$.

Some points are worth noticing:

Case (10,10): when both firms adopt at period 1 and there is complete spillover, $\mu = \lambda$, profits in the second period are higher as compared with $\mu = 0$.

Case (10,01): the presence of spillover effects doesn't make any difference in the first period profits of the first adopting firm. In the second period however leader profit is higher when $\mu = 0$, because cost reduction doesn't apply to the rival firm.

Case (01,10): the situation for the latecomer is better with $\mu = \lambda$ both in the first and in the second period. It is interesting to point out that in such case second period profits are equal for the leader and the follower.

Case (01,01): the situation is the same in both cases, as there is no scope for learning effect to be at work.

4. The monopolist.

The open loop equilibrium of the game may now be found; given the possible solutions of the simultaneous game played in the second stage by the two adopting firms and given He knows the necessary conditions for each of them to be implemented, the monopolist in the first stage will choose a vector of prices, such that his profit is maximized.

Let's consider the case of no learning by doing; the monopolist marginal cost will then be invariant in the two periods and profit will depend on the innovation price He can get, as He only sells one unit of the good to each firm.

To be able to decide which price vector determines the highest payoff for the monopolist several points have to be taken into account:

1. As a price sequence, constant or increasing in time, implies peculiarities in contrast to basic assumptions, prices are assumed decreasing in time, $p_1 > p_2$, so that equilibrium conditions are satisfied either in the case of diffusion or simultaneous adoption.[5]

2. The monopolist's strategies are two and refer to the different vector of prices He can select: one will induce diffusion equilibrium, while the other simultaneous early adoption,[6] consisting of concentrating the sales of the innovation in the first period, through a pricing rule which makes the demand for adoption equal to zero in the second period. We can assume that p_2, the price to be charged to the firm adopting in the second period, will be the same in both strategies, whereas p_1 is going to be different according to the monopolist's strategy.

The highest price the monopolist can set in period 1 to induce diffusion equilibrium (10,01) or (01,10) is:

$$p_1 = rp_2 + (p_3 - p_2) + r(p_{33} - p_{32}) + d = rp_2 + (p_1 - p_0) + r(p_{31} - p_{30}) - e \quad (11)$$

with:

$$e = (p_1 - p_0) + r(p_{31} - p_{30}) - (p_1 - p_2);\ 0 < e < (p_1 - p_0) - (p_3 - p_2) + r(p_{31} - p_{30}) - r(p_{33} - p_{32});$$

$$d = (p_1 - p_2) - (p_3 - p_2) - r(p_{33} - p_{32});$$

$$0 < d < (p_1 - p_0) - (p_3 - p_2) + r(p_{31} - p_{30}) - r(p_{33} - p_{32});$$

As e and d are not independent,

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[5] If $p_1 = p_2$, the optimality condition for diffusion becomes in fact:

$p_1 - p_0 + r(p_{31} - p_{30}) > 0 > p_3 - p_2 + r(p_{33} - p_{32})$;

implying $p_3 + r(p_{33} - p_{30}) < p_2$

This condition, ruled out by initial hypotheses, would require non adoption as the best choice either because of non optimality of duopoly or because of a strong spillover effect, caused for instance by easy imitation.

For simultaneous adoption at time 1 there are not problems.

For simultaneous adoption at time 2: $p_1 + r(p_{31} - p_{30}) < p_0$

It is once more an anomalous situation equally assumed away by initial conditions, which requires to be sustainable great uncertainty on the innovation evolution. It might be the case of a radical change whose real potentials are largely ignored at the first introduction.

If $p_1 < p_2$; the previous anomalous conditions are at work.

[6] A vector of prices inducing a simultaneous adoption in period 2 is excluded because it is a dominated strategy.

$e + d = (p_1 - p_0) - (p_3 - p_2) + r((p_{31} - p_{30}) - (p_{33} - p_{32}))$, from now on I will work only with d .

The highest price He can set to induce simultaneous adoption at time 1 equilibrium (1010) is lower and equal to:

$$rp_2 + (p_3 - p_2) + r(p_{33} - p_{32}) - b \ . \qquad (12)$$

$$b = (p_3 - p_2) - (p_1 - p_2) + r(p_{33} - p_{32}); \ 0 < b < p_3 - p_2 + r(p_{33} - p_{32})$$

The monopolist's aim is to set the highest possible d and the lowest possible b .

3. The game, facing the adopters if the monopolist chooses a vector of prices, such that:

$$p_1 - p_0 + r(p_{31} - p_{30}) > p_1 - rp_2 > p_3 - p_2 + r(p_{33} - p_{32});$$

becomes a "chicken" or hawk-dove" game entailing multiple equilibria and carrying over a problem of equilibrium selection. The announcement of a price vector, meant to induce diffusion equilibrium with: $p_1 = p_2 + (p_3 - p_2) + r(p_{33} - p_{32}) + d$, entails in fact three different equilibria: two in pure strategy, (10,01) and (01,10) and a third one in mixed strategy, where the two adopters choose 10 with probability g and 01 with probability $1 - g$.

$$g = \frac{p_1 - p_0 + r(p_{31} - p_{30}) - (p_3 - p_2) - r(p_{33} - p_{32}) - d}{p_1 - p_0 + r(p_{31} - p_{30}) - (p_3 - p_2) - r(p_{33} - p_{32})} \ . \qquad (13)$$

Once the monopolist has announced the price vector for diffusion, it is clear that g is increasing in $p_1 - p_0 - (p_3 - p_2) + r(p_{31} - p_{30}) - (p_{33} - p_{32})$ and decreasing in d , so the highest is p_1, the lower is g .

Coordination is mixed with conflict: the two firms have to coordinate so as not to adopt at the same time, but conflict relative to the fact that the payoff of the first adopter is higher than the payoff of the second one. It is a situation which can give rise to mistakes in the form of adoption dates not representing an equilibrium. Instead of adopting at different times, the two firms may either jointly adopt at time 1, paying a monopolistic price to enter a duopolistic market, or jointly adopt at time 2: obviously the first mistake benefits the monopolist, while the second harms him.

The issue can be dealt with in different ways: it is possible to assume that somehow the two adopters will be able to coordinate on one of the two equilibria in pure strategies, may be using information related to Schelling (1960) theory of "focal points", but such a solution seems unsatisfactory as it depends on the players' culture and past experience which are not explicitely taken into account in a game where the players meet for the first and last time .

The solution I follow is the one proposed by Harsanyi and Selten (1988) to tackle the problem relating on two different choice criteria: payoff dominance and risk dominance. Payoff dominance, implying the capacity to coordinate on Pareto optimal outcome, doesn't apply in this case because of the conflict existing in the payoff of the two adopters, whereas there is no risk dominance between (10,01) and (01,10), as the deviation losses at both strong equilibrium points are the same. In such case according to the authors the resulting equilibrium relies on mixed strategy and is:

$$g\left[g\left(p_3+rp_{33}-p_1\right)+\left(1-g\right)\left(p_1+rp_{31}-p_1\right)\right]+1-g\left[g\left(p_2+rp_{32}\right)+\left(1-g\right)\left(p_0+rp_{30}-rp_2\right)\right] \quad (14)$$

The announcement of a price vector with:

$rp_2+\left(p_3-p_2\right)+r\left(p_{33}-p_{32}\right)-b$, implies a unique Nash equilibrium where the adopters are able to coordinate without any conflict so as to converge on the equilibrium (10,10) implying early simultaneous adoption.

4. In deciding his choice, the monopolist must compare profit stemming from the announcement of the two possible price vectors. He has to compare a profit which is certain in the case the price choice induce (10,10) and an expected profit which depends on the probability distribution $g^*=g,1-g$ used by the adopters to select the strategies 10 or 01.[7]

The monopolist prefers then diffusion if:

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[7] Obviously for the monopolist the optimal situation would be one where the adopters have a very high g , making very likely an outcome (10,10) , even if they pay a price justified only by a temporary monopolistic position, while they in fact obtain a duopolistic position.

$$2\left(rp_2+p_3-p_2+r\left(p_{33}-p_{32}\right)-b\right)<g^2 2\left(rp_2+p_3-p_2+r\left(p_{33}-p_{32}\right)+d\right)+2g\left(1-g\right)\left(rp_2+p_3-p_2+r\left(p_{33}-p_{32}\right)d+rp_2\right)+\left(1-g\right)^2\left(2rp_2\right.$$

entailing:

$$g>\frac{\left(\left(p_3-p_2\right)+\left(p_{33}-p_{32}\right)-b\right)}{\left(p_3-p_2\right)+\left(p_{33}-p_{32}\right)+d}=\frac{\left(p_1-rp_2\right)_{(1010)}}{\left(p_1-rp_2\right)_{(1001)}}. \qquad (15)$$

$\left(p_1-rp_2\right)_{(10,10)}$ represents the price decrease when the monopolist aims at a simultaneous early adoption equilibrium, $\left(p_1-rp_2\right)_{(10,01)}$ the price decrease possible with diffusion equilibrium. Substituting p_1 with the highest price sustainable in each equilibrium and bearing in mind the definition of g, it becomes[8]:

$$g=.\frac{p_1-p_0-\left(p_3-p_2\right)+r\left(\left(p_{31}-p_{30}\right)-\left(p_{33}-p_{32}\right)\right)-d}{p_1-p_0-\left(p_3-p_2\right)+r\left(\left(p_{31}-p_{30}\right)-\left(p_{33}-p_{32}\right)\right)}>\frac{\left(\left(p_3-p_2\right)+\left(p_{33}-p_{32}\right)-b\right)}{\left(p_3-p_2\right)+\left(p_{33}-p_{32}\right)+d}: \quad (16)$$

$$0<d<\left(p_1-p_0\right)+r\left(p_{31}-p_{30}\right)-2\left(\left(p_3-p_2\right)+r\left(p_{33}-p_{32}\right)\right); \quad (17)$$

implying that d is increasing in:

$$\left(p_1-p_0\right)+r\left(p_{31}-p_{30}\right)>2\left(\left(p_3-p_2\right)+r\left(p_{33}-p_{32}\right)\right). \qquad (18)$$

Proposition 1.

For drastic innovations the resulting open-loop equilibrium of the game might be one of diffusion or simultaneous adoption, both early and late, according to the probability distribution g^*.

The monopolist selects, in fact, the price vector $p_1=rp_2+\left(p_3-p_2\right)+r\left(p_{33}-p_{32}\right)+d$, p_2,

which will induce in the second stage of the game the mixed strategy equilibrium:

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[8] It is reasonable to assume that the monopolist will try to minimize b. The equilibrium condition is calculated for $b\to 0$.

$g[g(p_3 + rp_{33} - p_1) + (1-g)(p_1 + rp_{31} - p_1)] + 1 - g[g(p_2 + rp_{32}) + (1-g)(p_0 + rp_{30} - rp_2)]$, if

(a) the advantages, both in period 1 and period 2, for the firm adopting first are significant relative to the gains, both in period 1 and in period 2, from being the second to adopt.

(b) Such advantages in period 1 for adopting first are increasing in e, the reduction from c_0 to c_1, whereas, in period 2, they are increasing in l, personal learning by using, and decreasing in m, spillover effect.

Proposition 2.

For incremental innovations the resulting open-loop equilibrium of the game requires symmetric equilibrium in early adoption. The monopolist selects, in fact, the price vector:

$p_1 = rp_2 + (p_3 - p_2) + r(p_{33} - p_{32}) - b,\ p_2$ if:

(c) the advantages, both in period 1 and period 2, for the firm adopting first are negligible relative to the gains, both in period 1 and in period 2, from being the second to adopt.

(d) The advantages in period 1 for not adopting first increase the smaller is e, the reduction from c_0 to c_1, whereas, in period 2, they are increasing in m, spillover effect and decreasing in l, personal learning by using.

Points b and d can be illustrated as follows referring to table 2: $p_1 - p_0 - (p_3 - p_2) = \frac{4a^2}{9}$, representing the gain in period 1 from being the first to adopt, relative to the gain from being the second to adopt, is positive (assumption 3) and increasing in $c_0 - c_1 = a$.[9] $r(p_{31} - p_{30}) - r(p_{33} - p_{32}) = 4l^2 + 4m^2 - 10ml$, representing the gain in period 2 from being the first to adopt in period 1, relative to the gain from being the second to adopt, is positive if $m < \frac{l}{2}$.

Let 's look at things in more detail:

Case 1. $l = 0, m = 0$; the condition for the monopolist to choose diffusion equilibrium (10,01) or (01,10) reduces to: $(p_1 - p_0) > 2(p_3 - p_2)$. In absence of learning only the size of a makes the difference.

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[9] cfr Stembacka, 1994.

Case 2. $l > 0, m = 0;$ equilibrium (10,01) or (01,10) requires:

$r(p_{31} - p_{30}) - r(p_{33} - p_{32}) = 4l^2$ is increasing in l

Case 3. $l > 0, m = l;$ equilibrium (10,01) or (01,10) implies:

$r(p_{31} - p_{30}) - r(p_{33} - p_{32}) = 8l^2 - 10l^2 = -2l^2$. In this case the gain in period 2 from being the first to adopt in period 1, relative to the gain from being the second to adopt, is negative in l. Notice that $p_{33} > p_{31} = p_{32} > p_{30}$.

4. Concluding remarks.

The simple adoption model I analyze is focused on the role played by both the supply side and the learning effects stemming from the interplay of the two adopters. The above considerations are expressed by a two-period game with three agents: a monopolist offering a cost- reducing process innovation and two identical adopting firms who are to decide the adoption time.

The dynamic game with imperfect information is then two stage: in the first stage the monopolist announces a vector of innovation prices to be practiced in the two periods; in the second stage the two firms play a simultaneous duopolistic Cournot game whose aim is to define each firm’s adoption date. Their decision is jointly based upon the sequence of prices representing the adoption cost, the behavior of the rival firm and the presence of learning by using and spillover.

Whereas previous adoption models were uniquely based on demand side, here the explicit analysis of the monopolist behaviour and of learning effects makes the results somewhat more articulated.

Reinganum (1981), in her seminal work, invariably obtained diffusion equilibria for ex ante identical firms; more recently Stenbacka and Tombak (1994) introduce uncertainty with respect to the length of time required for succesful implementation of an innovation in a Reinganum’s framework. They state that in an open-loop equilibrium the extent of dispersion between adoption timings will be decreased if the advantages of being first to succeed increase relative to the gains from being the second to succeed and if the degree of uncertainty is decreased so allowing for early simultaneous equilibria.

That result of simultaneous equilibrium is maintained here, strengthened by the considerations of learning and spillover which affect second period profits and inserted in a more general game which takes into account the monopolist strategy and makes a distinction between drastic and incremental innovations.

For incremental innovations the resulting open-loop equilibrium of the game requires symmetric equilibrium in early adoption if the advantages, both in period 1 and period 2, for the firm adopting first are negligible relative to the gains, both in period 1 and in period 2, from being the second to adopt.

For drastic innovations the situation is more complicated: the resulting open-loop equilibrium of the game might be one of diffusion or simultaneous adoption, both early and late, according to the probability distribution g^*. The higher is g, the probability that adopters will choose to adopt early independently of what the rival might do, the higher is the probability that the monopolist obtains early simultaneous adoption, though selecting a high price which would be justified only by diffusion equilibrium. The first period price of drastic innovation is always higher than the price selected for incremental innovations.

Such equilibrium happens if the advantages, both in period 1 and period 2, for the firm adopting first are significant relative to the gains, both in period 1 and in period 2, from being the second to adopt. It is shown that the advantages in period 1 for adopting first are increasing in the cost reduction made possible by the adoption of the innovation, whereas, in period 2, they are increasing in personal learning by using and decreasing in the spillover effect.

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results then increasing in $e = (p_1 - p_0) - (p_1 - p_2)$, the difference between profit increase made possible by the new technology and the innovation price difference in the two periods. g is bigger the more the deferred adoption loss $(\pi_1 - \pi_0)$ overcomes the advantages deriving from the decision postponement $(p_1 - p_2)$. In other words the higher is p_1, the smaller is g . giving rise to a mixed strategy equilibrium in the adoption dates, because of the presence of 2 diffusion equilibria, none of which risk dominates the other, if:

$(p_{31} - p_{30}) - r(p_{33} - p_{32})$

$p_1 - p_0$

$p_1 - p_0 -$ epresenting the gain from being the first to adopt re to the gain from being the second to adopt, is positive (assumption 3) and increasing in $c_0 - c_1$, the cost decrease made possible by the adoption of the new technology, (cfr Stembacka 1994); whereas $(p_{31} - p_{30}) - (p_{33} - p_{32})$ is increasing in l and decreasing in m .

which determines the probability that the firm adopt in the first period anyway. The monopolist selects the price vector $p_1 = rp_2 + (p_3 - p_2) + r(p_{33} - p_{32}) + d$, p_2

Whereas previous adoption models uniquely based on the demand side invariably obtained diffusion equilibria, here the explicit introduction of the supply side makes the results more definite. In choosing his strategy, the monopolist takes into account the fact that the profit He can obtain announcing a vector of prices satisfying the diffusion equilibrium for the adopters, is a probabilistic one as the adopters play a mixed strategy equilibrium. A vector of prices, justified by a diffusion equilibrium, is then maintained for drastic innovations, where the advantages, both in period 1 and period 2, for the firm adopting first are significant relative to the gains, both in period 1 and in period 2, from being the second to adopt.

A vector of prices, entailing simultaneous early adoption is the solution for non drastic innovations where the advantages, both in period 1 and period 2, for the firm adopting first are negligible relative to the gains, both in period 1 and in period 2, from being the second to adopt. The advantages in period 1 for adopting first, included in g , are increasing in e , the reduction from c_0 to c_1 , whereas, in period 2, they are increasing in l , personal learning by using, and decreasing in m , spillover effect.

The innovation price decrease from period one to period two has to be more remarkable in the case of learning by using coupled with the absence of spillover effects; in such case in fact first mover advantage is much stronger as the successive costs reductions due to learning effects are not appropriated by the rival firm.

Price decrease is however much milder when learning advantages are completely shared by the firms, as the latecomer in such case will take advantage free of charge of the rival's ultimate cost reduction consequent to learning by using.