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Better Observability Promotes the Adoption of More Flexible Technologies*

Marcel Boyer†, *Armel Jacques*‡, *Michel Moreaux*§

Résumé / Abstract

On étudie dans cet article comment les choix technologiques et les configurations techniques d'équilibre dépendent premièrement des caractéristiques de l'industrie (fonctions de demande et paramètres de coûts spécifiques de la technique multiproduit flexible et de la technique de production, non flexible, de chaque bien), ainsi que des conditions d'observation des choix des concurrents. On montre qu'une meilleure observabilité des choix favorise l'émergence de technologies plus flexibles.

We study in this paper how the technological flexibility choices and equilibrium configurations depend first on the industry characteristics (demand function and cost parameters specific to the multiproduct flexible technology and to the product dedicated technologies) and, second, on the observability conditions prevailing in the industry. We show that better observability tends to promote the adoption of more flexible technologies.

Mots Clés : Technologie flexible, engagement, équilibre stratégique

Keywords : Flexible manufacturing technology, commitment, strategic equilibrium

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* Corresponding Author: Marcel Boyer, CIRANO, 2020 University Street, 25th floor, Montréal, Qc, Canada H3A 2A5 Tel: (514) 985-4002 Fax: (514) 985-4035 e-mail: boyerm@cirano.umontreal.ca

† École Polytechnique de Montréal, Université de Montréal and CIRANO

‡ GREMAQ-CNRS, Université des sciences sociales de Toulouse

§ Institut Universitaire de France, GREMAQ-CNRS and IDEI, Université des sciences sociales de Toulouse

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1 INTRODUCTION

Most studies of the adoption of flexible technologies assume a two stage framework in which firms choose first their type of equipment before competing for market shares.[1] Between the two stages, each firm can observe the type of plant adopted by its competitors.[2]

That firms can observe the true technology chosen by their competitors is a rather extreme assumption. In many cases these choices are not fully observed and are, as far as possible, kept secret.[3] In this paper we first study the other polar case in which the technological choices are unobservable. But there exist also intermediate situations. For example if neither Ford, General Motor or Chrysler seemed to have observed the kind of factories built up by Nissan and Toyota in the late sixties and early seventies, the converse was not true. Nissan and Toyota were well aware of the manufacturing systems of both Ford and GM. Hence we examine also the case where some firm observes the manufacturing system of its competitor but not vice versa. Note also that the attractiveness of non simultaneous moves by the firms, at the technological stage of the game, is clearly dependent upon the prevailing observability conditions.

There exist many kinds of flexibility.[4] In this paper we are interested by product flexibility rather than by volume flexibility. We consider two firms competing for two markets of substitute goods. Each firm may either adopt a technology finely tuned for producing one good, that is a dedicated technology (D thereafter), or a flexible technology (F in what follows) for producing the both goods, as in Röller and Tombak (1990). We compare the equilibrium technological configurations under alternative observability conditions and alternative move sequences in the adoption of technologies by the firms. We show that, broadly speaking, better observability tends to promote more flexible technologies, thus increasing competitive pressures.

The paper is organized as follows. In section 2 we present the assumptions on demand and costs and we specify the kinds of game in which the duopolists could be involved. In section 3 we examine the case of full observability of the technological choices, in which the pure

[1] See Boyer and Moreaux (1997) for a list of such papers.

[2] A notable exception is the work of Vives (1989).

[3] If an essential feature of the technology is the plant location, as in Eaton and Schmitt (1994), it is difficult to argue that the choice may be kept wholly secret.

[4] See for example Gerwin (1993) for a meticulous classification of the different concepts of flexibility.

strategy equilibrium never results in a mixed technological configuration where some firm would choose the F technology whereas its competitor would adopt a D technology.[5] Section 4 is devoted to the case of unobservable technological choices. It is precisely in this case and in the case of asymmetric observability analyzed in section 5 that mixed technological structures may appear in pure strategy equilibria. We briefly conclude in section 6.

2 THE MODEL

2.1 Demand

On the demand side a representative consumer is assumed to maximize a separable quadratic utility function: $U\left(Q^A, Q^B\right) + I$ where Q^A and Q^B are the quantities of the two differentiated goods A and B respectively and I is the quantity of some composite Hicksian good whose price is normalized to 1. Function U is given by the following where: $X,\ Y \in \{A, B\}$ and $X \neq Y$.

$$U\left(Q^A, Q^B\right) = \begin{cases} \alpha\left(Q^A + Q^B\right) - \frac{1}{2}\left\{\beta\left[\left(Q^A\right)^2 + \left(Q^B\right)^2\right] + 2\lambda Q^A Q^B\right\}, & \\ \qquad \text{if } Q^X < \frac{\alpha}{\beta} - \frac{\lambda}{\beta}Q^Y, & \\ \frac{1}{2}\frac{\alpha^2}{\beta} + \frac{\alpha(\beta-\lambda)}{\beta}Q^X - \frac{1}{2}\frac{\beta^2-\lambda^2}{\beta}\left(Q^X\right)^2, & \\ \qquad \text{if } Q^Y \geq \frac{\alpha}{\beta} - \frac{\lambda}{\beta}Q^X & \\ \qquad \text{and } Q^X < \frac{\alpha(\beta-\lambda)}{\beta^2-\lambda^2}, & \\ \frac{\alpha^2}{\beta-\lambda}, \qquad \text{if } Q^X \geq \frac{\alpha}{\beta+\lambda}. & \end{cases}$$

We assume that $\alpha > 0$ and $\beta > \lambda > 0$ so that the goods are substitutes (closer substitutes as λ converges to β). Let p^A and p^B be the prices of goods A and B respectively.

Taking for granted that the income is sufficiently high, the inverse demand function or market clearing prices function, $p : \Re^2_+ \rightarrow \Re^2_+$, is

[5] Clearly, mixed technological structures could appear with positive probability in mixed strategy equilibria. See Kim, Röller and Tombak (1992).

given by:

$$p\left(Q^A, Q^B\right) = \left(p^A\left(Q^A, Q^B\right), p^B\left(Q^A, Q^B\right)\right)$$

where

$$p^X\left(Q^X, Q^Y\right) = \max\left\{\alpha - \beta Q^X - \lambda Q^Y, 0\right\}$$

Denoting by $Q : \Re^2_+ \to \Re^2_+$, the direct demand function, we get:

$$Q^X\left(p^X, p^Y\right) = \begin{cases} \dfrac{\alpha}{\beta+\lambda} - \dfrac{\beta}{\beta^2-\lambda^2}P^X + \dfrac{\lambda}{\beta^2-\lambda^2}P^Y, \\ \qquad\qquad\qquad \text{if } p^X < \dfrac{\alpha\left(\beta-\lambda\right)}{\beta} + \dfrac{\lambda}{\beta}p^Y, \\ \dfrac{\alpha}{\beta} - \dfrac{1}{\beta}p^X, \text{ if } p^X < \alpha \text{ and } p^Y \geq \dfrac{\alpha\left(\beta-\lambda\right)}{\beta} + \dfrac{\lambda}{\beta}p^X, \\ 0, \qquad\qquad\qquad \text{if } p^X \geq \alpha \text{ and } p^Y \geq \alpha. \end{cases}$$

2.2 Costs

Each firm may either choose a D technology or the F technology. With a D technology for good X, a firm may produce good X only, whereas with the F technology it may compete on both markets. In either case a technology is characterized by a fixed cost and a variable cost. The fixed costs of the D technologies are assumed to be the same, $F_D > 0$, whatever the good to be manufactured, either A or B. The fixed cost of the F technology, $F_F > 0$, is higher than the fixed cost of the D technology but lower than the fixed costs of operating two D factories: $2F_D > F_F > F_D$. As for the variable costs we assume that the marginal costs are constant, the same for both technologies and the same for both goods, and equal to c. Hence the cost functions are:

– either $F_D + cQ_i^X$, for firm i, if firm i selects the D technology for producing good X,

– or $F_F + c\left(Q_i^A + Q_i^B\right)$, if firm i chooses the F technology and produces both goods.

We emphasize the technological choice issues rather than entry preventing issues. Hence we assume that both fixed costs F_D and F_F are low enough that it is never optimal[6] for a firm to stay out of both markets.

2.3 Game structure, observability and strategies

We consider two firms, indexed by $i = 1, 2$, which make first a long run technological decision and then a short run production decision. Last market clearing prices are set. Although investment, production outlays and revenues do not occur at the same time, we neglect discounting problems for the sake of simplicity. We examine two kinds of move structure for the first technological commitment stage of competition: either simultaneous moves or sequential moves. For the second or production stage of the competition, we always assume that the moves are simultaneous and that the firms are involved in a Cournot type of competition.

2.3.1 Simultaneous technological move games

Full observability For firm 1 observing the technological decision of firm 2 before the Cournot stage of the game, a pure strategy is a pair $s_1 = (T_1, \sigma_1)$ where:
i) $T_1 \in \mathcal{T} := \left\{D^A, D^B, F\right\}$ is the long run technological choice made at the first stage of the game;
ii) σ_1 is the second stage quantity decision function selected amongst the set Σ_1 of such functions:

$$\sigma_1 \in \Sigma_1 \Rightarrow \forall \left(T_1, T_2\right) \in \mathcal{T}^2 : \sigma_1 \left(T_1, T_2\right) = \left(\sigma_1^A \left(T_1, T_2\right), \sigma_1^B \left(T_1, T_2\right)\right) \in \Re_+^2$$

with:

$$T_1 = D^X \Rightarrow \sigma_1^Y \left(T_1, T_2\right) = 0.$$

A strategy s_2 is defined in a similar way. Following a well established tradition[7] we call such strategies, markovian or closed-loop strategies. We will denote by S_i the set of closed-loop strategies of firm i observing the technological decision of its competitor j.

Let $\pi_i^{c\ell} : S \rightarrow \Re, S = S_1 \times S_2$, denote the profit function of firm i

[6] It is never an equilibrium strategy.
[7] At least in dynamic optimization. Clearly the technologies chosen by the firms are the natural state variables in this model.

when both firms play closed-loop strategies:

$$\forall s \in S : \pi_i^{c\ell}(s) = \sum_{X \in \{A,B\}} \left\{ \left[p^X \left(\sum_{j=1,2} \sigma_j(T) \right) - c \right] \sigma_i^X(T) \right\} - F(T_i)$$

where $F(T_i)$ takes the value F_D if T_i is equal to either D^A or D^B, and the value F_F if $T_i{=}F$. An equilibrium is a pair of strategies s^*, each one being a best response to the other. An equilibrium s^* is subgame perfect if, for any $T \in \mathcal{T}$, $(\sigma_1^*(T), \sigma_2^*(T))$ is an equilibrium of the subgame whose payoff functions are

$$\pi_i^{c\ell}((T_i, \sigma_i), (T_j, \sigma_j)), i, j = 1, 2 \; and \; \sigma_k \in \Sigma_k, k = 1, 2.$$

Complete unobservability For firm i not aware of the technological decision of its competitor, a pure strategy v_i is a pair (T_i, q_i) where T_i is as in the above case and $q_i = (q_i^A, q_i^B) \in \Re_+^2$, with $q_i^Y = 0$ if $T_i = D^X$, is the vector of quantities produced, here independant of T_j, $j \neq i$. This kind of strategy is called an open-loop strategy. We will denote by V_i the set of open-loop strategies of firm i. Let $\pi_i^{o\ell} : V \to \Re, V = V_1 \times V_2$, be the profit function of firm i when both firms play open-loop strategies:

$$\forall v \in V : \pi_i^{o\ell}(v) = \sum_{X \in \{A,B\}} \left\{ \left[p^X \left(\sum_{j=1,2} q_j \right) - c \right] q_i^X \right\} - F(T_i)$$

An equilibrium is a pair of strategies v^*, each one being a best reply to the other. Since the technological choices are unobservable there is no subgame.

Asymmetric observability Suppose last that some firm, say firm 2, can observe the technological choice of its competitor while the other firm, firm 1, cannot. In this case firm 1, plays open-loop whereas firm 2 plays closed-loop. Let $\pi_i^m : V_1 \times S_2 \to \Re$ be the profit function of firm i:

$$\forall (v_1, s_2) \in V_1 \times S_2 :$$

$$\pi_1^m(v_1, s_2) = \sum_{X \in \{A,B\}} \left\{ \left[p^X (q_1 + \sigma_2(T)) - c \right] q_1^X \right\} - F(T_1)$$

$$\pi_2^m(v_1, s_2) = \sum_{X \in \{A,B\}} \left\{ \left[p^X (q_1 + \sigma_2(T)) - c \right] \sigma_2^X(T) - F(T_2) \right\}$$

An equilibrium (v_1^*, s_2^*) is defined in the usual way. We show in the appendix that in this game there is no subgame.

2.3.2 Sequential technological move games

In this setting, some firm, say firm 1, is moving first at the technological choice stage and its choice is observed by firm 2. The technological choice of firm 2 may in turn either be observed by firm 1 or not, before the Cournot stage of the game.

Full disclosure of technological choices In case of full disclosure of the technological commitments, a firm 1's strategy is a pair $s_1 = (T_1, \sigma_1)$ as in the simultaneous technological moves case with full observability, while a firm 2's strategy is a pair $w_2 = (\tau_2, \sigma_2)$ where $\tau_2 : \mathcal{T} \to \mathcal{T}$ is its technological choice function, depending upon T_1, and $\sigma_2 \in \Sigma_2$ is its second stage quantity decision function. We will denote by W_2 the set of firm 2's strategies. In this case too, the strategies are closed-loop strategies. Let $\pi_i^{s1} : S_1 \times W_2 \to \Re$ be the payoff function of firm #i in this first Stackelberg game:

$$
\begin{aligned}
\forall (s_1, w_2) &\in S_1 \times W_2 : \\
\pi_1^{s1}(s_1, w_2) &= \sum_{X \in \{A,B\}} \left\{ \left[p^X \left(\sum_{j=1,2} \sigma_j (T_1, \tau_2(T_1)) \right) - c \right] \right. \\
&\qquad \left. \times\, \sigma_1^X (T_1, \tau_2(T_1)) \right\} - F(T_1) \\
\pi_2^{s1}(s_1, w_2) &= \sum_{X \in \{A,B\}} \left\{ \left[p^X \left(\sum_{j=1,2} \sigma_j (T_1, \tau_2(T_1)) \right) - c \right] \right. \\
&\qquad \left. \times\, \sigma_2^X (T_1, \tau_2(T_1)) \right\} - F(\tau_2(T_1))
\end{aligned}
$$

A Nash equilibrium is a pair (s_1^*, w_2^*) of best responses to each other. This equilibrium is subgame perfect if:

– first, for any (T_1, T_2), the pair of quantity vectors $(\sigma_1^*(T), \sigma_2^*(T))$ is a Cournot equilibrium given the constraints implied by the technological choices;

– second, whatever T_1, $(\tau_2^*, \sigma_1^*, \sigma_2^*)$ is an equilibrium of the subgame starting after the technological choice of firm 1.

Unobservability of the technological move of firm 2 Suppose now that firm 1 cannot observe the type of plant built by firm 2. Contrary to the case of simultaneous technological moves with asymmetric observability, here there exist three subgames, each one starting after the three different technological moves open to firm 1 (See appendix). In order to apply the subgame perfection criterion we must define a strategy of firm 1 by specifying not only its actual technological choice and its actual quantity choice, but also the quantities it would have chosen had it taken an other decisions at the first stage; that is we must proceed as stipulated by game theory and specify the decisions firm 1 would take at all its information sets, even those not attained as a result of its own choice at the first stage of the game. Hence we define a strategy z_1 of firm 1 as a pair (T_1, ω_1) where ω_1 :T→ $\Re_+^2$, is a quantity decision function selected amongst the set Ω_1 of such functions:

$$\omega_1 \in \Omega_1 \Rightarrow \forall T_1^{'} \in \mathcal{T} \;:\; \omega_1\left(T_1^{'}\right) = \left(\omega_1^A\left(T_1^{'}\right), \omega_1^B\left(T_1^{'}\right)\right)$$

with

$$T_1^{'} = D^X \Rightarrow \omega_1^Y\left(T_1^{'}\right) = 0,$$

The play of the game by firm 1 is first to choose T_1 at the first stage and next $\omega_1(T_1)$ at the second stage whatever the technological choice of firm 2. We will denote by Z_1 the set of firm 1 strategies. A strategy of firm 2 is a pair $w_2 = (\tau_2, \sigma_2)$ as in the first Stackelberg game. Let $\pi_i^{s2} : Z_1 \times W_2 \to \Re$, be the payoff function of firm #i in this second Stackelberg game. Then:

$$\begin{aligned} \forall (z_1, w_2) &\in Z_1 \times W_2 : \\ \pi_1^{s2}(z_1, w_2) &= \sum_{X \in \{A,B\}} \left\{ \left[p^X\left(\omega_1(T_1) + \sigma_1(T_1, \tau_2(T_1)),\right) - c \right] \right. \\ & \qquad \left. \times\, \sigma_1^X\left(T_1, \tau_2(T_1)\right) \right\} - F(T_1) \end{aligned}$$

$$\pi_2^{s2}(z_1,w_2) = \sum_{X\in\{A,B\}} \left\{\left[p^X\left(\omega_1(T_1)+\sigma_1(T_1,\tau_2(T_1)),\right)-c\right]\right\} \times \sigma_2^X(T_1,\tau_2(T_1)) - F(\tau_2(T_1))$$

An equilibrium (z_1^*, w_2^*) is a pair of mutual best replies. This equilibrium is subgame perfect if for any $T_1 \in \mathcal{T}$, the triple $(\omega_1^*(T_1), \tau_2^*(T_1), \sigma_2^*(T_1, \tau_2^*(T_1)))$ is an equilibrium of the game starting after T_1, a game without subgame as shown in Appendix A.3 (see Figure A.3).

3 THE FULL OBSERVABILITY CASE

Whatever the order of the technological choices at the first stage of the competition, the quantity decisions must be a Cournot equilibrium of the second stage subgame. So let us first characterize the second stage equilibria as functions of the first stage technological choices, before determining the equilibrium technological configuration of the industry in the simultaneous technological choices game and in the Stackelberg game.

3.1 Second stage equilibria and best response technological choices

Assuming that, if both firms choose dedicated technologies, the technologies are not dedicated to the same product,[8]we obtain:
– for $T = (D, D)$, assuming that firm 1 dedicated its technology to producing good A, then:

$$q_1^A = \frac{\alpha - c}{2\beta+\lambda},\ q_1^B = 0,\ q_2^A = 0,\ q_2^B = \frac{\alpha - c}{2\beta+\lambda}$$
$$\Rightarrow\ p^A = p^B = \alpha - \frac{(\alpha - c)(\beta+\lambda)}{2\beta+\lambda}$$

[8]Clearly choosing technologies dedicated to the same product cannot be an equilibrium of the whole game, at least as far as only pure strategies are considered, as in the present paper.

– for $T=(F,F)$, then:

$$q_1^A = q_1^B = q_2^A = q_2^B = \frac{\alpha - c}{3(\beta+\lambda)} \Rightarrow p^A = p^B = \alpha - \frac{2(\alpha-c)}{3}$$

– for $T=(D,F)$, assuming that the dedicated technology chosen by firm 1 is dedicated to product A, then:

$$\begin{aligned} q_1^A &= \frac{\alpha - c}{3\beta},\ q_1^B = 0,\ q_2^A = \frac{2\beta-\lambda}{2(\beta+\lambda)}\frac{\alpha-c}{3\beta},\ q_2^B = \frac{\alpha-c}{2(\beta+\lambda)} \\ &\Rightarrow\ p^A = \alpha - \frac{2(\alpha-c)}{3},\ \ p^B = \alpha - \frac{\alpha-c}{2(\beta+\lambda)}\left(\beta + \frac{\lambda(4\beta+\lambda)}{3\beta}\right) \end{aligned}$$

Taking into account these subgame perfectness conditions, we get the following profits, as functions of the technological choices made at the first stage:
– for $T_1 = T_2 = F : \pi_1 = \pi_2 = \dfrac{2(\alpha-c)^2}{9(\beta+\lambda)} - F_F$,
– for $T_i = F, T_j = D : \pi_i = \dfrac{(\alpha-c)^2}{2(\beta+\lambda)}\left[\dfrac{\beta + \frac{2\lambda}{3} - \frac{\lambda^2}{3\beta} -}{2(\beta+\lambda)} + \dfrac{2}{9} - \dfrac{\lambda}{9\beta}\right] - F_F$,
$\pi_j = \dfrac{(\alpha-c)^2}{9\beta} - F_D$,
– for $T_1 = T_2 = D : \pi_1 = \pi_2 = \left(\dfrac{\alpha-c}{2\beta+\lambda}\right)^2 - F_D$.

Denoting by m the difference $\alpha - c$, that is the maximum mark-up over variable average cost (equal to marginal cost) which is an index of the size of the market, by f the difference $F_F - F_D$ between fixed costs, and assuming $\beta = 1$,[9], we get:
– D is a best response to D, denoted by $D = BR^{c\ell}(D)$, if:

$$\frac{f}{m^2} \geq \frac{(1-\lambda)\left(5\lambda^2 + 12\lambda + 16\right)}{36(1+\lambda)(2+\lambda)^2} := R_1^{c\ell}(\lambda) \qquad (1)$$

[9]Note that if the slope β of the own quantity coefficient in the inverse demand function are normalized to 1, this implies an adequate unit measure of the Hicksian generalized good. Under this normalization the maximum mark-up m is the true indicator of the economic size of the markets.

whereas $F = BR^{c\ell}(D)$ if inequality (1) is reversed;
– F is a best response to F, that is $F = BR^{c\ell}(F)$, if:

$$\frac{f}{m^2} \leq \frac{1-\lambda}{9(1+\lambda)} := R_2^{c\ell}(\lambda) \tag{2}$$

whereas $D = BR^{c\ell}(F)$ if inequality (2) is reversed.

The $R_1^{c\ell}(\lambda)$ and $R_2^{c\ell}(\lambda)$ functions are illustrated in figure 1.

[INSERT FIGURE 1 HERE]

3.2 Simultaneous technological choice equilibria

In order to get:
– a "quasi-symmetric" equilibrium with specialized firms operating D technologies and producing each one a different good, (1) must hold;
– a symmetric equilibrium with identical multiproduct firms both operating F technologies, (2) must hold;
– an asymmetric equilibrium with a specialized firm operating a D factory and producing only one good, and a multiproduct firm operating an F technology, both[10] ∼(1) and ∼(2) must hold.

Let us show that we can never have an asymmetric equilibrium. In order to have such an equilibrium there must exist some values of λ and $\frac{f}{m^2}$ for which both $D = BR^{c\ell}(F)$ and $F = BR^{c\ell}(D)$ hold, that is for which $R_2^{c\ell}(\lambda) < \frac{f}{m^2} < R_1^{c\ell}(\lambda)$; hence the ratio $\frac{R_1^{c\ell}(\lambda)}{R_2^{c\ell}(\lambda)}$ must be strictly higher than 1 on some sub-interval of $]0,1[$. But:

$$\frac{R_1^{c\ell}(\lambda)}{R_2^{c\ell}(\lambda)} = \frac{5\lambda^2+12\lambda+16}{4\lambda^2+16\lambda+16} := \frac{K(\lambda)}{L(\lambda)}$$

and clearly:

$$\frac{R_1^{c\ell}(0)}{R_2^{c\ell}(0)} = 1 \text{ and } \lim_{\lambda\to 1}\frac{R_1^{c\ell}(\lambda)}{R_2^{c\ell}(\lambda)} = \frac{33}{36} < 1$$

with:

$$\frac{dK}{d\lambda} = 10\lambda + 12 < 8\lambda + 16 = \frac{dL}{d\lambda} \quad for\ \lambda \in]0,1[\,.$$

[10] ∼(1) means that (1) is not satisfied.

Hence the ratio $\dfrac{R_1^{c\ell}(\lambda)}{R_2^{c\ell}(\lambda)}$ is decreasing from 1 to $\dfrac{33}{36}$ over the interval $]0,1[$, implying that $R_1^{c\ell}(\lambda) < R_2^{c\ell}(\lambda)$ except for $\lambda = 0$, so that :

$$\frac{R_1^{c\ell}(\lambda)}{R_2^{c\ell}(\lambda)} < 1, \quad \forall \lambda \in \left]0,1\right[. \tag{3}$$

From the above calculations we may conclude that (see figure 1):
– either $\lambda = 0$, that is the markets are separate markets, and either the ratio of fixed cost discrepancy to the maximum mark-up is low $\left(\frac{f}{m^2} < \frac{1}{9}\right)$ so that, as expected, both firms are fighting on both markets, operating multiproduct F technologies, or this ratio is high $\left(\frac{f}{m^2} > \frac{1}{9}\right)$ and each firm operates a dedicated technology thus avoiding direct competition with the other duopolist;
– or $\lambda \in \left]0,1\right[$, that is both markets are inter-linked, and there appears now some intermediate range of the $\frac{f}{m^2}$ ratio, $\frac{f}{m^2} \in \left(R_1^{c\ell}(\lambda), R_2^{c\ell}(\lambda)\right)$, on which both (F,F) and (D,D) may be equilibrium configurations, whereas for the extreme values of the ratio both firms adopt the same technologies, that is for $\frac{f}{m^2} > R_2^{c\ell}(\lambda)$, (D,D) is the sole equilibrium configuration and, for $\frac{f}{m^2} < R_1^{c\ell}(\lambda)$, (F,F) is the unique technological equilibrium.

In the intermediate range of values for $\frac{f}{m^2}$ (zone 2 in figure 1) there exists a flexibility trap. Let $\mu(F,F)$ be the profit per firm over variable costs under the (F,F) equilibrium technological configuration and $\mu(D,D)$ this profit under the (D,D) configuration:

$$\frac{\mu(F,F)}{\mu(D,D)} = \frac{2m^2/9\,(1+\lambda)}{m^2/\,(2+\lambda)^2} = \frac{2\lambda^2+8\lambda+8}{9+9\lambda} := M(\lambda)$$

For $\lambda = 0$, then $M(\lambda) = 8/9$ and for $\lambda = 1$, $M(\lambda) = 1$. The denominator is linearly increasing over the range $]0,1[$ whereas the numerator is increasing and convex. Hence $M(\lambda) < 1$, for all $\lambda \in \left]0,1\right[$ and profits over variable costs are higher when the firms are specialized and exploiting separate market segments than both competing over the whole range of products. Since furthermore the fixed cost of a multiproduct technology F_F is higher than the fixed cost of a dedicated technology F_D, then the (F,F) equilibrium is definitively less attractive than the (D,D) equilibrium. The problem is that once a firm adopts an F technology the other one wishes also adopt the F technology, hence the trap. A similar kind of flexibility trap was shown to exist in a volume flexibility context by Boyer and Moreaux (1997).

3.3 Stackelberg equilibria

Let us suppose that the firm moving first at the technological phase of the game, is firm 1. Then:
– either $\frac{f}{m^2} < R_1^{c\ell}(\lambda)$ and in this case $F = BR^{c\ell}(F) = BR^{c\ell}(D)$, that is F is a dominant strategy for firm 1, so that the equilibrium technological configuration is (F, F) as in the simultaneous moves case;
– or $\frac{f}{m^2} > R_2^{c\ell}(\lambda)$ and now $D = BR^{c\ell}(F) = BR^{c\ell}(D)$ meaning that D is a dominant strategy for firm 1, and the equilibrium technological configuration is (D, D), again as in the simultaneous moves case;
– or $R_1^{c\ell}(\lambda) < \frac{f}{m^2} < R_2^{c\ell}(\lambda)$ and in this case $D = BR^{c\ell}(D)$ and $F = BR^{c\ell}(F)$ and since, as shown above, profits are higher under the (D, D) technological configuration than under the (F, F) configuration, then the leader will choose the D technology promoting the (D, D) configuration and keeping the industry out of the flexibility trap.

It is important to notice that the leader and the follower always choose the same technology at equilibrium, and since the second stage of the game is a simultaneous move subgame both firms earn the same profits. We may conclude that under full observability, either the order of moves is of no consequence, or the sequential moves represent a form of coordination device working for the benefit of the whole industry and not for the sole benefit of some firm with detrimental effects on its competitor as in the traditional Stackelberg equilibria.

4 THE SECRET TECHNOLOGICAL CHOICE CASE

We show that if the first stage technological choices cannot be observed then there may appear asymmetric equilibria. Let us begin with some general remarks.

4.1 Preliminary remarks

Let us suppose now that the first stage technological choices cannot be observed and let $(v_1^* = (T_1^*, q_1^*)\,,\; v_2^* = (T_2^*, q_2^*))$ be some open-loop equilibrium. Then:

– either $T_i^* = D^A$ and we must have $\dfrac{\partial \pi_i^{c\ell}}{\partial q_i^A} = 0$,

– or $T_i^* = F$ and we must have $\dfrac{\partial \pi_i^{c\ell}}{\partial q_i^A} = \dfrac{\partial \pi_i^{c\ell}}{\partial q_i^B} = 0$;

This implies that (q_1^*, q_2^*) must be an equilibrium of the second stage quantity "game", given (T_1^*, T_2^*). Hence the only pairs of strategies which may appear as equilibrium strategies are the following three pairs:

i) quasi-symmetric equilibrium:

$$v_1^* = \left(D, q_1^{*A} = \frac{\alpha - c}{2\beta + \lambda}, q_1^{*B} = 0\right) \text{ and } v_2^* = \left(D, q_2^{*A} = 0, q_2^{*B} = \frac{\alpha - c}{2\beta + \lambda}\right)$$

ii) symmetric equilibrium:

$$v_1^* = \left(F, q_1^{*A} = q_1^{*B} = \frac{\alpha - c}{3\,(\beta + \lambda)}\right) \text{ and } v_2^* = \left(F, q_2^{*A} = q_2^{*B} = \frac{\alpha - c}{3\,(\beta + \lambda)}\right)$$

iii) asymmetric equilibrium:

$$\begin{aligned} v_1^* &= \left(D, q_1^{*A} = \frac{\alpha - c}{3\beta}, q_1^{*B} = 0\right) \text{ and} \\ v_2^* &= \left(F, q_2^{*A} = \frac{2\beta - \lambda}{2\,(\beta + \lambda)}\frac{\alpha - c}{3\beta}, q_2^{*B} = \frac{\alpha - c}{2\,(\beta + \lambda)}\right) \end{aligned}$$

It follows that, given a technological configuration of the industry that is an equilibrium of the open-loop game, the equilibrium profits accruing to the firms are those payoffs accruing to them in the closed-loop game under the same technological configuration. The difference between the two information structures lies in the best response test as we shall see.

4.2 Quasi-symmetric and symmetric open-loop equilibria

Suppose first that firm 2 is playing the strategy $v_2 = \left(D, q_2^A = 0, q_2^B = \frac{\alpha - c}{2\beta + \lambda}\right)$. Then firm 1 may play $v_1 = \left(D, q_1^A = \frac{\alpha - c}{2\beta + \lambda}, q_1^B = 0\right)$ which is its best response to v_2 conditional to having chosen D at the first stage, and generates profits $\pi_1 = \left(\frac{\alpha - c}{2\beta + \lambda}\right)^2 - F_D$. But had firm 1 chosen $T_1 = F$ rather than D at the first stage, then the quantities which would maximize its profits, given the quantities $q_2^A = 0$ and $q_2^B = \frac{\alpha - c}{2\beta + \lambda}$, chosen by firm 2, which are here fixed, that is, not dependent upon T_1, would have to be $q_1^A = \frac{\alpha - c}{2(\beta + \lambda)}$ and $q_1^B = \frac{\beta(\alpha - c)}{2(2\beta + \lambda)(\beta + \lambda)}$, generating profits $\pi_1 = \frac{\beta(5\beta + 3\lambda)(\alpha - c)^2}{4(\beta + \lambda)(2\beta + \lambda)^2} - F_F$. Thus (D, D) may be the equilibrium technological configuration of the industry provided that:

$$\frac{f}{m^2} \geq \frac{1 - \lambda}{4(1 + \lambda)(2 + \lambda)^2} := R_1^{o\ell}(\lambda). \tag{4}$$

Since:

$$\frac{R_1^{o\ell}(\lambda)}{R_1^{c\ell}(\lambda)} = \frac{9}{5\lambda^2 + 12\lambda + 16} < 1 \ , \ \forall \lambda \in]0, 1[\,, \tag{5}$$

we conclude that the set of values of the industry parameters for which (D, D) is an equilibrium is larger in case of unobservability of the technological choices than in case of full observability.

Suppose next that firm 2 selects the strategy $v_2 = \left(F, q_2^A = q_2^B = \frac{\alpha - c}{3(\beta + \lambda)}\right)$ which would be its choice under full observability, were (F, F) be the equilibrium technological configuration of the industry. The same strategy $v_1 = \left(F, q_1^A = q_1^B = \frac{\alpha - c}{3(\beta + \lambda)}\right)$ is the best response of firm 1 since the above quantities q_1^A and q_1^B are optimized conditional on the choice of $T_1 = F$. This strategy generates profits $\pi_1 = \frac{2(\alpha - c)^2}{9(\beta + \lambda)} - F_F$. The other choice of firm 1 is to choose a dedicated technology. Assuming this dedicated technology is dedicated to product A, the quantity maximizing its profits, given $q_2^A = q_2^B = \frac{\alpha - c}{3(\beta + \lambda)}$ not depending here upon T_1, is $q_1^A = \frac{\alpha - c}{3\beta}$, generating profits

$\pi_1 = \frac{(\alpha - c)^2}{9\beta} - F_D$. Thus (F, F) may be the equilibrium technological configuration of the industry provided that:

$$\frac{f}{m^2} \leq \frac{1-\lambda}{9(1+\lambda)} := R_2^{o\ell}(\lambda) = R_2^{c\ell}(\lambda) := R_2(\lambda) \tag{6}$$

This is the same condition as in the closed-loop case. Thus the (F, F) configuration may appear at equilibrium for the same range of values of the industry parameters whether the technological choices are fully disclosed or held secret.

Note that the ratio $\frac{R_1^{o\ell}(\lambda)}{R_2(\lambda)}$ is equal to:

$$\frac{R_1^{o\ell}(\lambda)}{R_2(\lambda)} = \frac{9}{4(2+\lambda)^2} < 1 \ , \ \forall \lambda \in]0, 1[\tag{7}$$

so that, as in the full observability case, for any λ there exists some range of values of the $\frac{f}{m^2}$ ratio, $\left(R_1^{o\ell}(\lambda), R_2(\lambda)\right)$, for which both types of equilibria, (D, D) and (F, F), may appear (see figure 2). For any value of the substituability index λ, $\lambda < 1$, this range of values of the $\frac{f}{m^2}$ ratio for which both configurations (D, D) and (F, F) may be equilibrium configurations, is much larger than the corresponding range under full observability. Since $R_2^{o\ell}(\lambda) = R_2^{c\ell}(\lambda)$, we could conclude that observability favors the emergence of flexible configurations.

[INSERT FIGURE 2 HERE]

4.3 Asymmetric open-loop equilibria

But it is not the end of the story in the present non-observability context. We must also check whether there exist or not, some values of the fundamental parameters of the industry for which the pair of strategies:

$$\begin{aligned} v_1 &= \left(D, q_1^A = \frac{\alpha - c}{3\beta}, q_1^B = 0\right) \\ v_2 &= \left(F, q_2^A = \frac{2\beta - \lambda}{2(\beta + \lambda)} \frac{\alpha - c}{3\beta}, q_2^B = \frac{\alpha - c}{2(\beta + \lambda)}\right), \end{aligned}$$

could be an equilibrium pair.

Suppose that firm 2 selects the above strategy v_2. Then firm 1 may either reply by v_1 above, thus obtaining profits $\pi_1 = \frac{(\alpha - c)^2}{9\beta} - F_D$, or choose instead the F technology in which case, given the q_2^A and q_2^B components of v_2 not depending here upon T_1, the quantities maximizing firm 1's profits are now $q_1^A = \frac{4\beta+\lambda}{4(\beta+\lambda)} \frac{\alpha - c}{3\beta}$ and $q_1^B = \frac{\alpha - c}{4(\beta+\lambda)}$, generating profits:

$$\pi_1 = \frac{(\alpha - c)^2}{2(\beta+\lambda)} \left\{ \frac{4\beta+\lambda}{18\beta} + \frac{1}{4(\beta+\lambda)} \left(\frac{\beta}{2} + \frac{2\lambda}{3} + \frac{\lambda^2}{6\beta} \right) \right\} - F_F.$$

Hence choosing the D technology is a best response of firm 1 to v_2, iff:

$$\frac{f}{m^2} \geq \frac{1-\lambda}{16(1+\lambda)} := R_3^{o\ell}(\lambda) \tag{8}$$

Suppose now that firm 1 plays $v_1 = \left(D, q_1^A = \frac{\alpha - c}{3\beta}, q_1^B = 0 \right)$. Then firm 2 may either play the above strategy v_2, generating profits

$$\pi_2 = \frac{(\alpha - c)^2}{2(\beta+\lambda)} \left[\frac{1}{2(\beta+\lambda)} \left(\beta + \frac{2\lambda}{3} - \frac{\lambda^2}{3\beta} \right) + \frac{2}{9} - \frac{\lambda}{9\beta} \right] - F_F,$$

or choose a D technology and produce $q_2^A = 0$ and $q_2^B = \frac{(3\beta - \lambda)(\alpha - c)}{6\beta^2}$ generating profits $\pi_2 = \frac{(3\beta-\lambda)^2(\alpha - c)^2}{36\beta} - F_D$. Hence choosing the F technology is the best response of firm 2 to v_1, iff:

$$\frac{f}{m^2} \leq \frac{(1-\lambda)(\lambda-2)^2}{36(1+\lambda)} := R_4^{o\ell}(\lambda) \tag{9}$$

Thus a necessary and sufficient condition to have an equilibrium with both a dedicated and a multiproduct firm is that for some values of λ the ratio $\frac{R_3^{o\ell}(\lambda)}{R_4^{o\ell}(\lambda)}$ be lower than 1:

$$\frac{R_3^{o\ell}(\lambda)}{R_4^{o\ell}(\lambda)} = \frac{9}{4(\lambda-2)^2}$$

with $\dfrac{R_3^{o\ell}(0)}{R_4^{o\ell}(0)} = \dfrac{9}{16} < 1$ and $\lim_{\lambda \to 1} \dfrac{R_3^{o\ell}(\lambda)}{R_4^{o\ell}(\lambda)} = \dfrac{9}{4} > 1$. Since $R_4^{o\ell}(\lambda)$ is strictly increasing over the interval $]0,1[$, then there exists some critical value $\underline{\lambda} = \frac{1}{2}$ under which this ratio is lower than 1, and above which this ratio is higher than 1.

We may conclude that, provided the products A and B be not too good substitutes, that is $\lambda < \underline{\lambda}$, there exist intermediate values of the ratio of the fixed cost discrepancy to the maximal mark-up, $\dfrac{f}{m^2}$, for which, in the open-loop game, a mixed technological configuration may result in equilibrium.

Let us note also that:
$R_4^{o\ell}(\lambda)/R_2(\lambda) = (\lambda - 2)^2/4$ is decreasing from 1 down to 1/4 over the interval $]0,1[$,
$R_3^{o\ell}(\lambda)/R_1^{o\ell}(\lambda) = (2+\lambda)^2/4$ is increasing from 1 up to 9/4 over the interval $]0,1[$,
$R_2(\lambda)/R_3^{o\ell}(\lambda) = 4 > 1$ for all $\lambda \in]0,1[$,
$R_4^{o\ell}(\lambda)/R_1^{o\ell}(\lambda) = (\lambda - 2)^2(2+\lambda)^2/9$ is increasing[11] from 8/9 up to 1 over the interval $]0,1[$,
from which we deduce that, for any $\lambda \in]0,1[$, this range of value of the ratio $\dfrac{f}{m^2}$ for which there exists an asymmetric technological configuration of the industry, is some sub-interval of the range of values for which both equilibria (D,D) and (F,F) may appear.

It remains to determine the best technological position. Let us denote by $\mu^F(D,F)$ and $\mu^D(D,F)$ the profits over variable costs obtained by the multiproduct firm and the dedicated firm respectively, in the asymmetric equilibrium configuration of the industry. The ratio of these two profits is given for $\beta = 1$, by:

$$\frac{\mu^F(D,F)}{\mu^D(D,F)} = \frac{13 - 5\lambda}{4(1+\lambda)}.$$

The above ratio is decreasing from $\frac{13}{4}$ for $\lambda = 0$ down to 1 for $\lambda = 1$, hence is always higher than 1 over the interval $]0,1[$. Provided that f be not too high, the multiproduct firm takes the most profitable position.

[11] We have $\frac{d}{d\lambda}(\lambda-2)^2(2+\lambda)^2 = -2(\lambda-2)(2+\lambda)^2 + 2(\lambda-2)^2(2+\lambda)^2 > 0$, for all $\lambda \in]0,1[$.

Next let us remark that:

$$\frac{\mu(F,F)}{\mu^D(D,F)} = \frac{2}{1+\lambda} > 1 \text{ and } \frac{\mu^F(D,F)}{\mu(F,F)} = \frac{13-5\lambda}{8} > 1 \ \ \forall\,\lambda \in \,]0,1[$$

Hence the ranking of profits over variable costs is the following one:

$$\mu^D(D,F) < \mu(F,F) < \mu(D,D) < \mu^F(D,F)$$

This ranking is not affected by the discrepancy of fixed costs. We have $\pi(F,F) < \pi(D,D)$ (see below), $\pi^D(D,F) < \pi(F,F)$ if and only if F is the best response to F in the closed-loop game, and $\pi(D,D) < \pi^F(D,F)$ if and only if F is the best response to D in the closed-loop game. These two conditions hold over the zone where asymmetric equilibria exist.

4.4 The implications of observability

The types of equilibrium technological configurations as functions of the industry parameters, are illustrated in figure 2. As can be seen from figures 1 and 2, for any degree of partial substituability, as well as for independent goods, that is for $\lambda \in [0,1)$, there exists a whole range of values of the $\frac{f}{m^2}$ index, namely $\frac{f}{m^2} \in \left(R_1^{o\ell}(\lambda)\,,\ R_1^{c\ell}(\lambda)\right)$, for which under full observability the sole equilibrium technological configuration is (F,F), whereas under unobservability both (D,D) and (D,F)emergence of flexibility is easier under full observability than under complete unobservability.[12].

The switch from an equilibrium configuration to another one resulting from the switch from open-loop environments to closed-loop ones is generally interpreted as a pure strategic effect.[13] If so, we could rephrase the above results as saying that the pure strategic effect is to promote the adoption of more flexible manufacturing systems.

[12]See Boyer, Jacques and Moreaux (1998) for an analysis showing that the observability has more ambigous implications in a volume flexibility context.

[13]See for example Vives (1989) for an analysis along these lines.

5 ASYMMETRIC OBSERVABILITY CONDITIONS

What happens if firm 1 cannot observe the technological choice made by firm 2 before playing the Cournot competition stage, while firm 2 is well aware of the technological choice of its competitor?

5.1 Simultaneous technological move equilibria

Let us consider first the case of simultaneous technological moves. Since firm 1 is constrained to select only open-loop strategies, firm 2 has open-loop best responses, and all the open-loop equilibria are also equilibria of this partial observability game. Furthermore since the game has no subgame, these open-loop equilibria are also subgame perfect equilibria.[14]But clearly firm 2 could take advantage of its information and it is difficult to consider the open-loop equilibria as robust equilibria, even if they are subgame perfect. This would imply for example that an equilibrium, in which firm 2 selects the flexible technology and firm 1 the technology dedicated to product A, could be supported by the very fact that firm 2 would not modify the quantities $q_2^A = \frac{2\beta - \lambda}{2(\beta + \lambda)} \frac{\alpha - c}{3\beta}$ and $q_2^B = \frac{\alpha - c}{2(\beta + \lambda)}$ after having observed that firm 1 has chosen also the flexible technology rather than the dedicated technology as expected. So let us assume that, for the second stage of the competition, firm 2 use decision functions σ_2 taking full advantage of the information at its disposal. Now, as usual such decision functions σ_2 could be implicit threats which are not credible, even if credibility is not easy to define in the present game without sub-game, except in extreme cases. An example of such an extreme case, in which the implicit threat is clearly not credible, is a σ_2 function selecting excessively large quantities of both goods when firm 1 chooses the F technology in order to enforce the choice, by firm 1, of a D technology rather than the F technology. Reasoning along these lines leads to consider as robust equilibria those equilibria supported by the strategies of firm 2 whose quantity decision component for the second stage of the game, results in playing the Cournot equilibrium quantities conditional to the technological decisions taken by the firms at the first stage of the competition. This implies, by a reflex effect, that,

[14]Open-loop equilibria are also equilibria in the full observability context, but not subgame perfect ones.

although firm 1 is playing an open-loop strategy, the true best response test of its technological choice is the closed-loop test defined by the set of conditions (1) and (2), since, given the technological choice of firm 2, would firm 1 change its own technological choice, then firm 2 would consequently change the quantities it sells at the second stage of the game. Similarly, although firm 2 is playing a closed-loop strategy, the true best response test of its technological choice is the open-loop test defined by the set of conditions (4) to (7), since, given the technological choice of firm 1, would firm 2 modify its own technological choice, then firm 1 would not change the quantities it sells at the second stage of the game. This leads to the partioning of the parameter space illustrated in figure 3 below.

[INSERT FIGURE 3 HERE]

Comparing the case of complete unobservability with the case of asymmetric observability there appear three differences. First in zones 3, 4 and 5, that is for $\frac{f}{m^2} \in \left(R_1^{o\ell}(\lambda), R_1^{c\ell}(\lambda)\right)$, $\lambda \in [0,1)$, the (D,D) configuration is eliminated from the set of equilibria. Second, in zone 3, defined by $\frac{f}{m^2} \in \left(R_4^{o\ell}(\lambda), R_1^{c\ell}(\lambda)\right)$, for $\lambda \in \left[0, \frac{1}{2}\right)$ and by $\frac{f}{m^2} \in \left(R_3^{o\ell}(\lambda), R_1^{c\ell}(\lambda)\right)$, for $\lambda \in \left[\frac{1}{2}, 1\right)$, there exists now an asymmetric equilibrium in which firm 1 adopts the flexible technology whereas firm 2 adopts the dedicated technology. Third, in zone 5, defined by $\frac{f}{m^2} \in \left(R_3^{o\ell}(\lambda), R_4^{o\ell}(\lambda)\right)$ and $\lambda \in \left[0, \frac{1}{2}\right)$, the asymmetric equilibrium in which firm 1 were choosing the dedicated technology and firm 2 the flexible one, disappears. On the whole, this asymmetric observability context is making the emergence of flexible manufacturing systems easier than under complete unobservability context, but less easy than under full observability. Furthermore, in case of asymmetric equilibrium, the firm getting the most profitable position is the firm which cannot observe the technological choice of its competitor.

5.2 Stackelberg equilibria

The difference between the simultaneous move structure and the sequential move structure is that, in the sequential choice setting, the firm moving first can determine the type of technological configuration of the industry as in the full observability case. But now there is the additional fact that the firm moving first is the firm which cannot adapt its production decision to the technological choices made at the first stage of the competition. For the range of industry parameters where the only equilibria are equilibria in which both firms choose the same technology, there is no problem. Firm 1 will determine the equilibrium generating the highest profit for itself and its competitor, that is, the (D, D) configuration rather than the (F, F) configuration, thus avoiding the flexibility trap as in the full observability case. But problems could arise in zones 3 and 5. In those zones the equilibria can be either (F, F) or (F, D). Hence on the sole observation of firm 1 choosing the F technology, firm 2 cannot infer the type of equilibrium firm 1 is playing. However, in this case, the (F, D) equilibrium is more profitable to firm 1 than the other equilibrium: (F, F). Thus firm 2 would have to infer that firm 1 is playing its most profitable equilibrium. Since (F, D) is the most profitable equilibrium for firm 1 amongst the two, then in zones 3 and 5 too, these exists a unique equilibrium in the Stackelberg case under asymmetric observability.

6 CONCLUSION

We have shown in this paper how the possibility of observing the technological choices made by competitors affect firms' strategies and equilibrium technological configurations in industries characterized otherwise by six different parameters. We proposed a two stage two market framework where the choice of technologies, either dedicated or flexible, typically long term choices, are made in the first stage and production decisions, typically short term choices, are made in the second stage. We considered three different observability environments: an open-loop context where firms do not observe technological choices, a closed-loop one where they do observe those choices, and finally an asymmetric observability case where one firm observes and the other does not. In each case, we defined the strategies available to firms, we characterized best response functions and we rigourously derived and analyzed the equilibria. We can summarize our most important global result as follows: better observability tends to promote the adoption of more flexible technologies. However, in the case of asymmetric observability, we showed that the most profitable position is that of the firm not observing its competitor's technology. Also, we identified an industry parameter region in the $(\lambda, \frac{f}{m^2})$–space where a flexibility trap appears: firms may find themselves trapped in a flexible equilibrium (F, F) while they would both be better off in the alternative (D, D) equilibrium; this trap could be avoided, under the closed-loop and asymmetric observability environments, if the first stage technological choices are sequential (with the informed firm moving second in the asymmetric case) rather than simultaneous. Moreover, as figures 1, 2 and 3 clearly suggest, the paths industries would follow in adopting flexible technologies as the market size index increases (as m increases, that is, as $\frac{f}{m^2}$ decreases), as the investment cost of flexible technologies decreases (as f decreases, that is, as $\frac{f}{m^2}$ decreases), or as the coefficient of substitutability increases (as λ decreases) differ significantly between the different observability environments.

7 APPENDIX: GAME TREES AND STRATEGIES

For reasons of simplicity, we will assume in this appendix that the dedicated technology is dedicated to product A and that only two different quantities of each product X, $X \in \{A, B\}$, can be manufactured, $\overline{q}^X$ and $\widehat{q}^X$, both positive, whatever the technology used, provided that the good can be produced with this technology.

7.1 Complete unobservability

Suppose that neither firm 1 nor firm 2 may observe the technological choice of its competitor before the quantity stage of the competition. The tree of this game is illustrated in figure A.1 below. On this figure and the other figures of this appendix we denote as follows the moves at the second stage information sets of a firm following its choice of the F technology at the first stage:

For firm 1:

$$I = \left(\overline{q}_1^A, \overline{q}_1^B\right), II = \left(\overline{q}_1^A, \widehat{q}_1^B\right), III = \left(\widehat{q}_1^A, \overline{q}_1^B\right) \text{ } and \text{ } IV = \left(\widehat{q}_1^A, \widehat{q}_1^B\right)$$

For firm 2:

$$1 = \left(\overline{q}_2^A, \overline{q}_2^B\right), 2 = \left(\overline{q}_2^A, \widehat{q}_2^B\right), 3 = \left(\widehat{q}_2^A, \overline{q}_2^B\right) \text{ } and \text{ } 4 = \left(\widehat{q}_2^A, \widehat{q}_2^B\right)$$

Clearly, there is no subgame in this game.

[INSERT FIGURE A.1 HERE]

Suppose that firm 1 chooses the open-loop strategy $T_1 = D$ and $\overline{q}_1^A$ whereas firm 2 chooses the open-loop strategy $T_2 = F$ and $\left(\widehat{q}_2^A, \widehat{q}_2^B\right)$ that is 4 at the second stage according to the above notations. The implied moves at the different information sets are drawn by heavy lines on the figure. The actual play of the game is this unique path going from the origin of the tree to a terminal node. What is to be noticed here is that these so called open-loop strategies are reduced from strategies. The canonical form of a strategy in an extensive form game, as defined by Selten (1975), the main reference on this subject, is to specify the choices elected by the player at all its information sets, even at those information sets which are not attained given the choices made at preceeding information sets. Clearly here the open loop strategy of firm 2 does not specify what firm 2 would produce, had it chosen the D technology rather than the F one. Note also that open-loop strategies cannot be seen as strategies specifying implicitely that the firm would choose the same quantities at all the information sets where it must choose quantities. A firm i having chosen an open-loop strategy $T_i = F$, $\overline{q}_i^A > 0$ and $\overline{q}_i^B > 0$ cannot be reputed choosing the same quantities at its information sets (not attained) following the choice (not made) of the dedicated technology.

7.2 Simultaneous technological moves and partial observability

Suppose now that firm 1 cannot observe the technological choice of firm 2 while firm 2 is informed of the technological move of firm 1 before the Cournot stage of the competition, both firms moving simultaneous at the first technological stage. The tree of this game is illustrated in figure A.2 below. It is easy to check that this game has no subgame.

[INSERT FIGURE A.2 HERE]

7.3 Sequential technological moves and partial observability

Suppose last that firm 1 chooses its technology first, then firm 2 observing the move of firm 1 chooses its own technology and firm 1 cannot observe the technological move of firm 2 before the Cournot stage of the game. The tree of this game is similar to the tree illustrated in the above figure, excepted that the first information set of the firm 2 is split into two information sets, one for each node as illustrated in figure A.3. There appear now two sub-games each one following the different technological moves of firm 1.

[INSERT FIGURE A.3 HERE]

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Figure 1: Technological equilibrium in the closed loop equilibrium game

zone 1 : (D, D) ; zone 2 : both (D, D) and (F, F) ; zone 3 : (F, F).

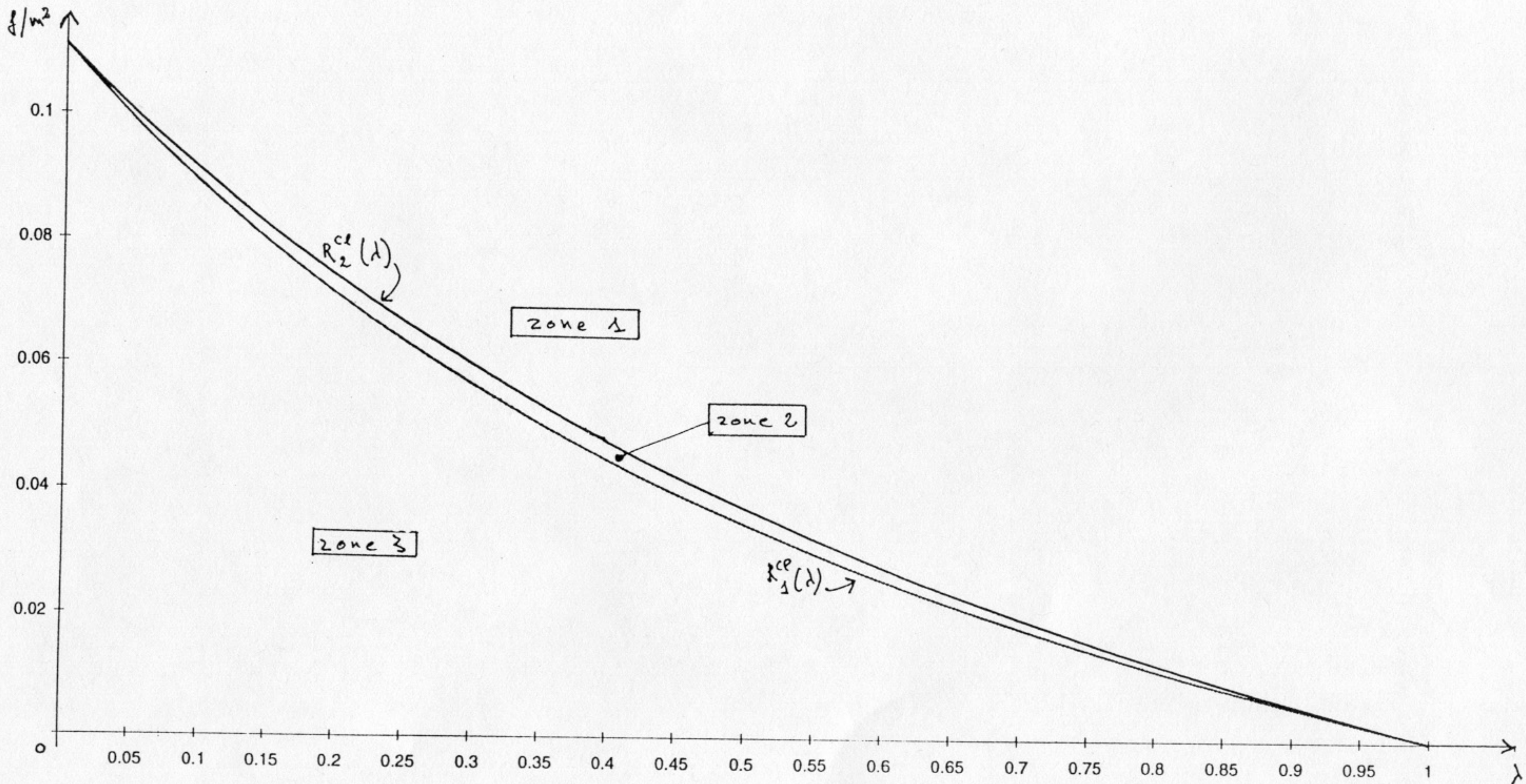


Figure 2: Technological equilibrium in the open loop game

zone 1 : (D, D) ; zone 2 : (D, D), (F, F) ; zone 3 : (D, D), (F, F) and (D, F) ; zone 4 : (F, F) .

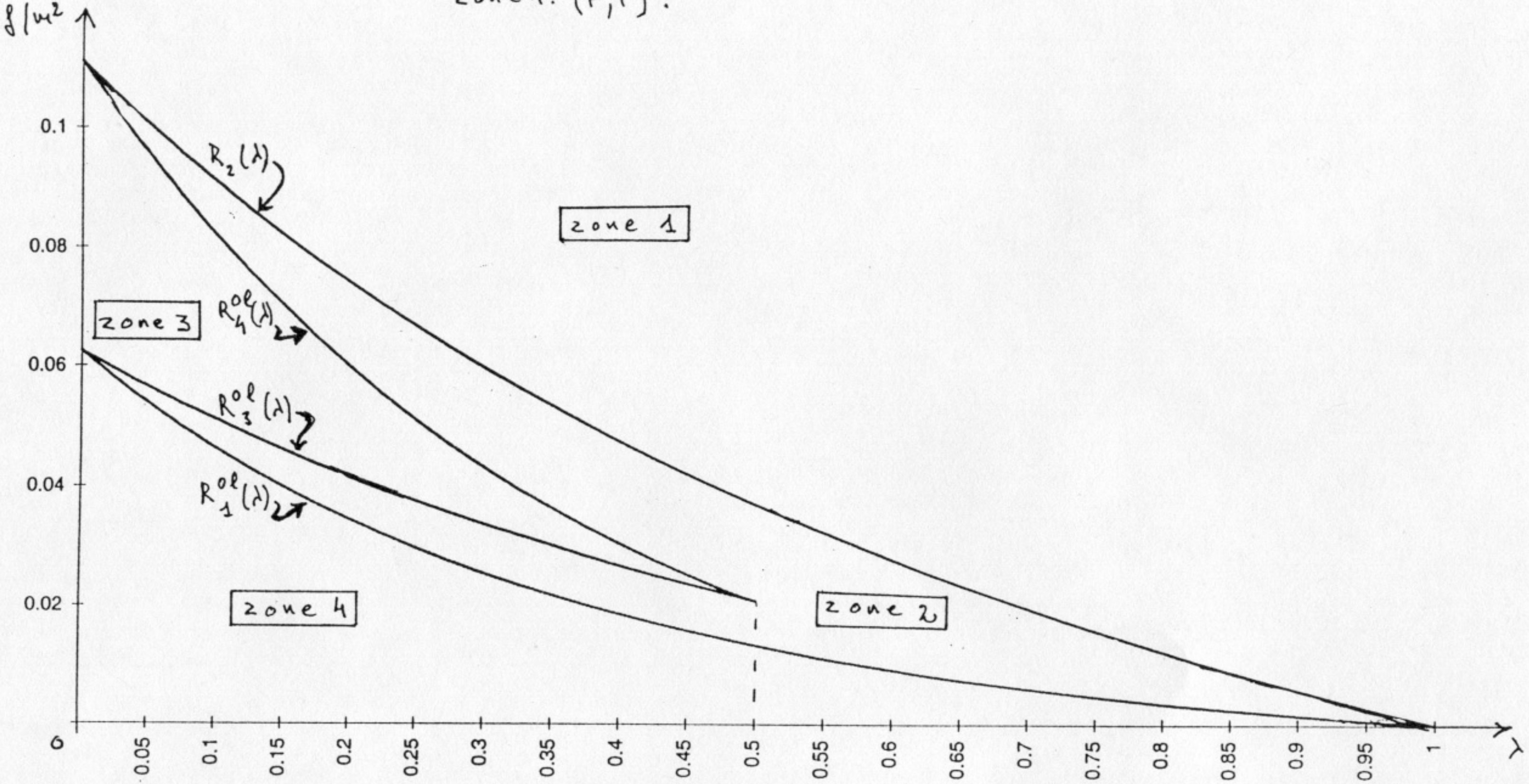
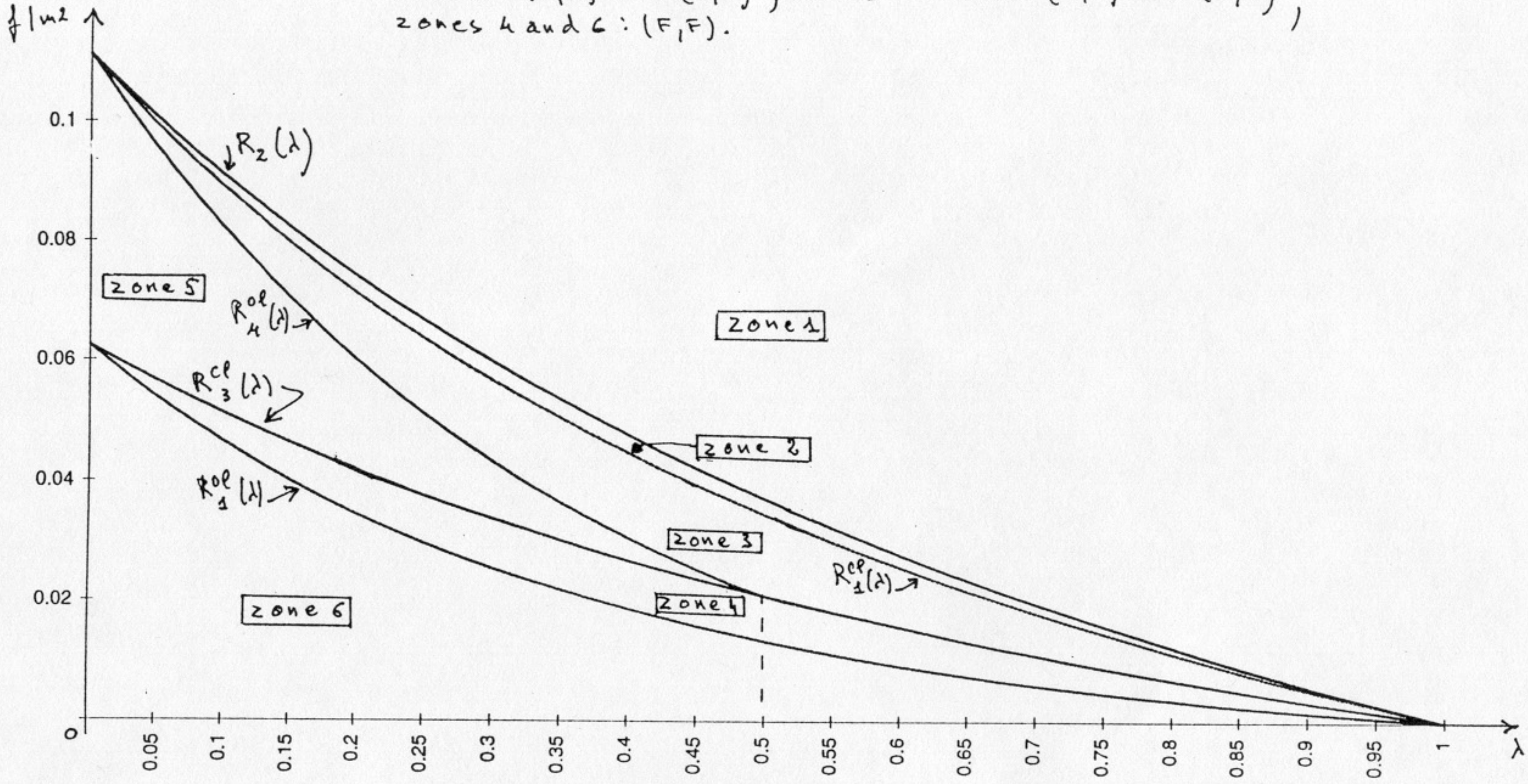


Figure 3: Technical equilibrium in the asymmetric observability game

Case of simultaneous technological moves. zone 1 : (D,D) ; zone 2 : (D,D) and (F,F) ; zones 3 and 5 : (F,F) and (F,D) ; zones 4 and 6 : (F,F).



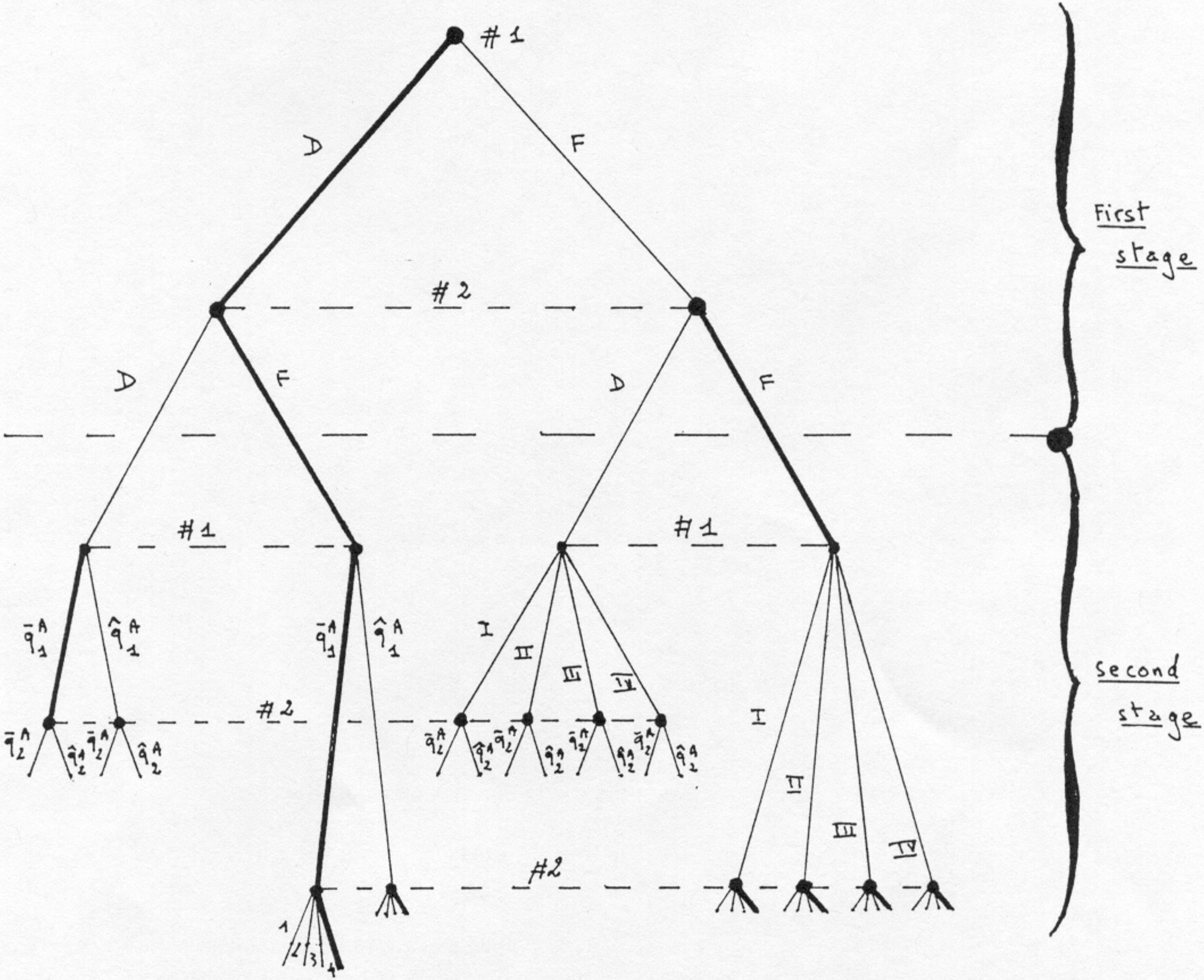


Figure A.1 Game tree in case of complete unobservability

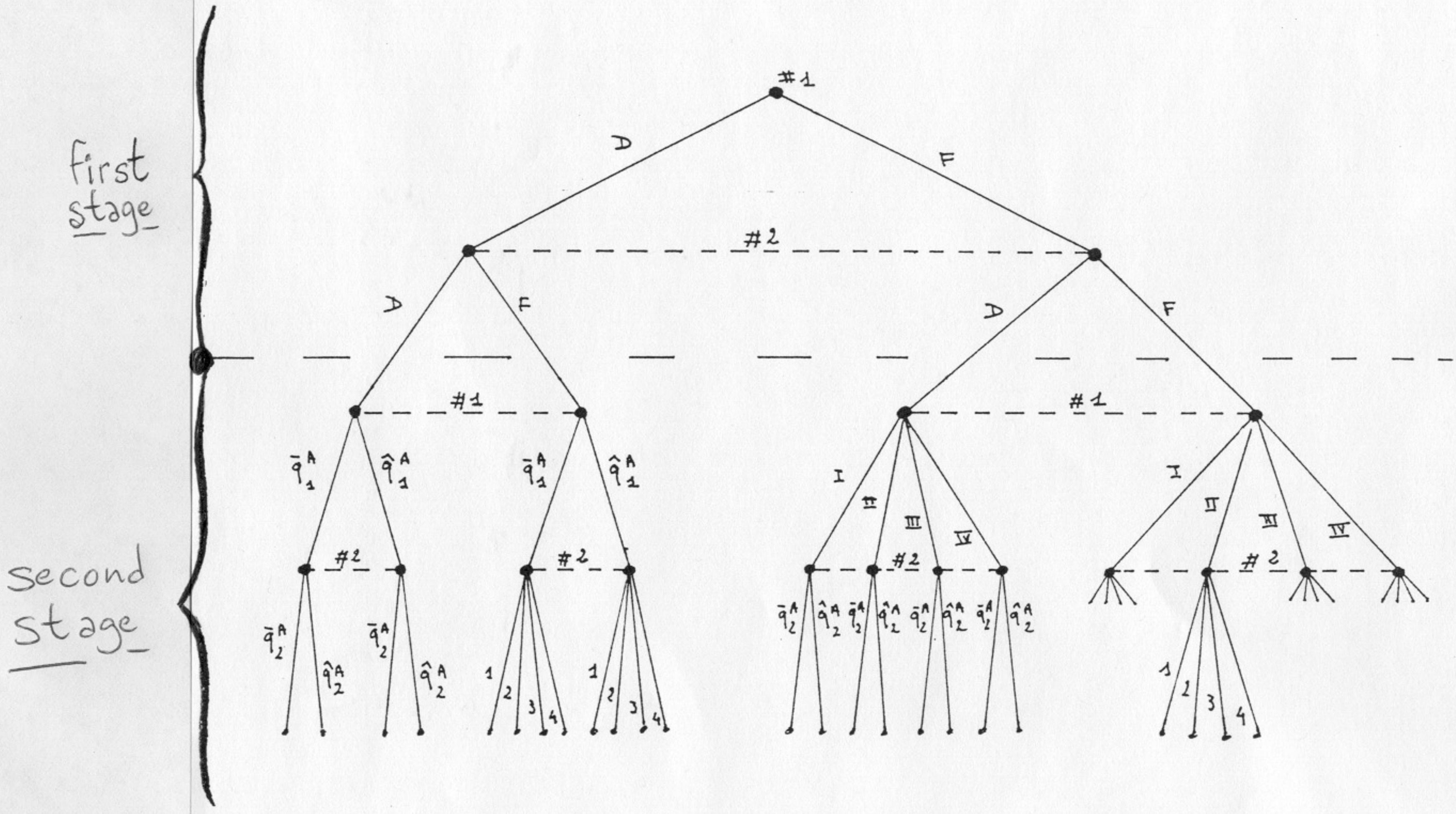


Figure A.2 Game tree in case of simultaneous moves at the first stage, the technological choice of firm #1 being observable and the choice of firm #2 unobservable

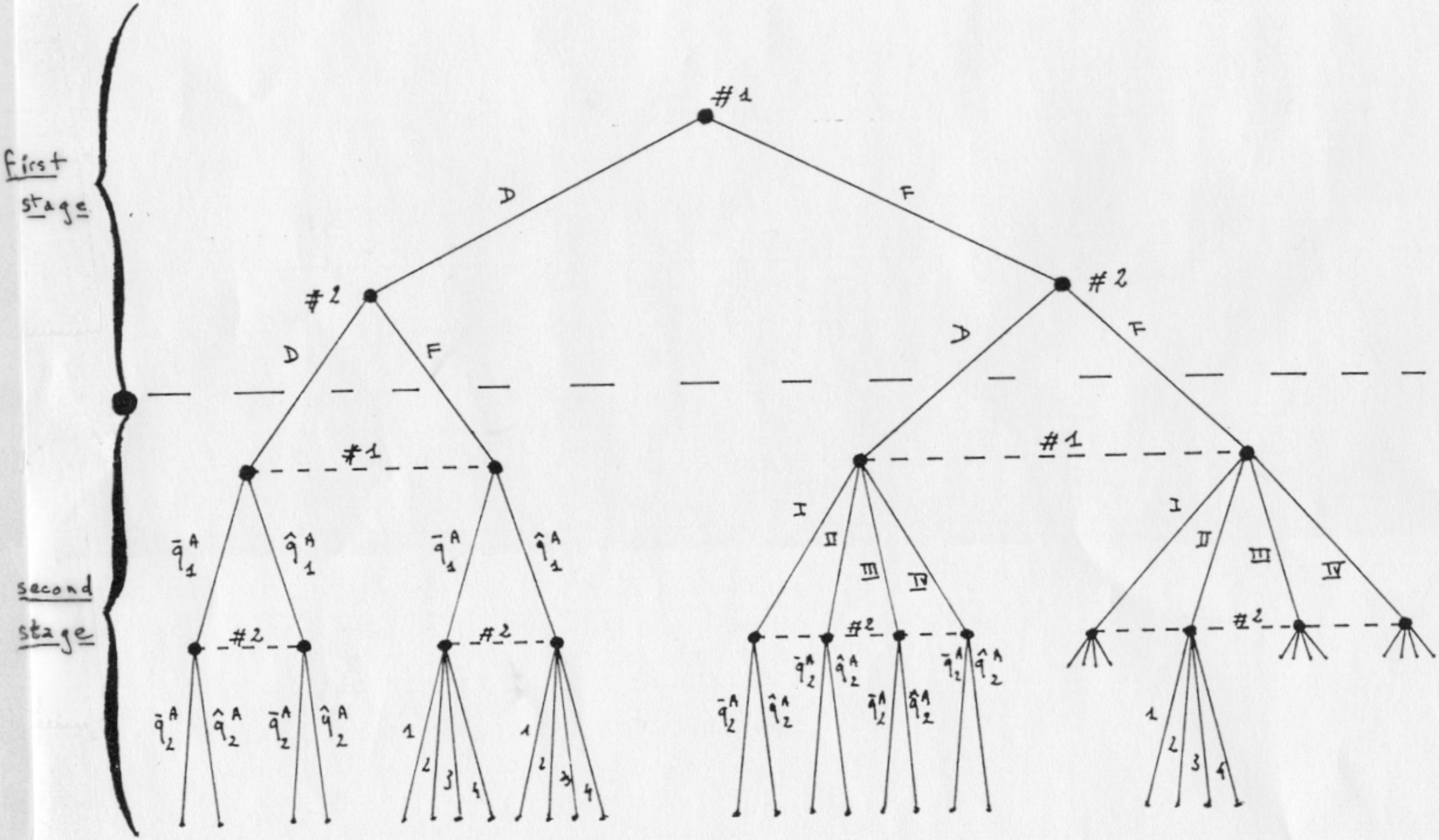


Figure A.3 Game tree in case of sequential moves at the first stage, firm #1 moving first and being observed by firm #2, while firm #2 technological choice is kept unobservable by firm #1

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