Better Observability Favors More Flexibility in Strategic Environments

by

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1. Introduction

We reconsider in the context of two-stage games the assumption that first stage choices are observable by all players before stage-two competition in product markets occurs. More specifically, we consider the outcome of a technological flexibility adoption game in a two-stage duopoly framework, in which firms first choose their degree of technological flexibility and then compete for market shares in two product markets.[1] Firms can choose between a flexible technology and dedicated technologies; the flexible technology gives the firm the possibility to operate on both product markets while each of the two dedicated technologies allows it to operate on one market only.[2] The standard assumption in such a context is that between the two stages, each firm can observe the technologies adopted by its competitors. Hence, technological choices are typically perfectly observable and are considered long term choices (to which firms are committed) whereas products and quantities are short term choices. We consider here the opposite polar case, in which the technological (flexibility) choices are unobservable, and we compare it with the perfect observability case. We show that the observability assumption is crucial to the determination of the technological configuration and to competition levels in product markets.

Bagwell (1995) has shown that even a little amount of uncertainty can destroy the commitment power of some actions in a Stackelberg game. Our context clearly differs from Bagwell's. But it is informative to consider his results. He starts by noting that "[m]odels of commitment make two assumptions: there is a first mover, and his action is perfectly observed by the subsequent mover. The purpose of the paper is to disentangle these two assumptions, in order to see if a strategic benefit from commitment remains when the first mover's choice is imperfectly observed. The basic finding is that the first-mover advantage is eliminated when there is even a *slight* amount of noise associated with the observation of the first mover's selection." Our context is different but related as we do not consider a Stackelberg game but a two-stage game where firms are committed to their first stage decisions when the second stage competition starts. Indeed, in many cases these flexibility choices are difficult to observe. The degree of flexibility depends on the technology used but also on the internal organization of the

[1] See Boyer and Moreaux (1997) and Jacques (2003) for a discussion of literature.
[2] There exist many kinds of technological flexibility. See Gerwin (1993) for a meticulous classification of the different concepts of flexibility and Boyer and Moreaux (1989) for a review of formal definitions.

firm and on the design of its contracts with suppliers, workers and retailers. These contracts are difficult to observe and are often kept as secret as possible. Even the degree of machine tool flexibility may be difficult to observe for an outsider. So competitors may discover the degree of flexibility of their rivals only after a long delay.

More generally, it is important to understand how technological configurations of industries depend on the standard assumptions on timing and observability of technological choices. Such an analysis is missing. There exist also intermediate situations. According to Van Biesebroeck (2003, page 171) "Eiji Toyoda who oversaw the development of the Toyota Production System, visited the Ford Rouge assembly plant in Detroit in 1950. Ford engineers made the reverse journey in 1981, visiting Mazda's main production complex in Hiroshima, which was modelled after Toyota city."[3] In this regard, we also consider the case of asymmetric observability, in which one firm observes the technology of its rival but not vice-versa and see what this implies on the technological configuration and product market competition in the industry.

We develop a model with two firms competing on two substitute product markets. Each firm may either adopt a technology finely tuned for producing one good, that is a dedicated technology (D), or a flexible technology (F) capable of producing both goods. We compare the equilibrium technological configurations under the two polar cases of perfect observability and complete unobservability. We show that better observability favors the adoption of flexible technologies, thereby increasing competitive pressures on product markets.

More precisely, our main results are as follows. First, the (D,D) equilibria are more likely under unobservability that under observability while (F,F) equilibria are equally probable under both observability conditions. Second, the existence of better substitutes promotes dedicated configurations (D,D). Third, mixed configurations (F,D) never emerge under observability provided that the goods are not too strong substitutes. Fourth, both (D,D) and (F,F) equilibria exist for some parameter values whatever the observability conditions. Fifth, the firms would always earn higher profits in (D,D) situations than in (F,F) situations; thus, if (F,F) is an equilibrium, a fortiori if it is the only equilibrium, as it is the case for some values of the parameters, this equilibrium is a flexibility trap.

[3] Note however that Hino (now out of the car market) started car production by building the popular French Renault 4cv and Nissan (marketed as Datsun in these earlier times) by building the English Morns Oxord. Thus, it is difficult to believe that Renault and Morrins engineers were not aware of what happened in some Japanese plants, although at that time (in the fifties) the Japanese production model was probably not fully developed.

This paper is organized as follows. In section 2, we present the model. We analyze in section 3 the polar case of independent markets and the case of substitute goods in section 4. Some problems raised by the endogeneization of the observability conditions are examined in section 5. We conclude in section 6.

2. The model

We use the modelization of demands and costs introduced by Röller and Tomback (1990). Letting q^A and q^B be the quantities of two substitute goods, the inverse demand functions are:

$$p^x(q^x, q^y) = \max\{1 - q^x - \lambda q^y,\ 0\}, \quad x, y \in \{A, B\} \text{ and } x \neq y, \quad 0 < \lambda < 1.$$

Two firms, indexed by $i = 1$, 2, make simultaneous technological choices in a first stage before competing *à la Cournot* in a second stage. Each firm may either choose a dedicated (D) technology of the flexible (F) technology. Each technology is characterized by a fixed or investment cost and a variable cost. The fixed costs of the D technologies are assumed to be the same whatever the good and equal to I_D. The fixed cost of the F technology is higher than the fixed cost of a D technology but lower than the fixed costs of twice the D technologies: 0 < I_D < I_F < $2I_D$. We assume that the marginal cost is the same for all technologies and constant at c, with c < 1. Also, I_D and I_F are low enough that both firms will be operating. Although outlays and revenues do not occur at the same time, we neglect discounting for the sake of simplicity. We denote by $m = 1 - c$ an index of the market size, by f the incremental cost $I_F - I_D$ so that f/m^2 is the incremental fixed cost normalized by the market size.

<u>Observability</u> (o). For firm i observing the technological decision of firm j before the Cournot stage of the game, a pure strategy is a pair $s_i = (T_i, \sigma_i)$, where $T_i \in \Gamma = \{D^A, D^B, F\}$ is the technological choice made at the first stage of the game and σ_i is the second stage decision function: $\sigma_i : \Gamma^2 \to \Re^2_+$. Let $T :=(T_1, T_2) \in \Gamma^2$ and Σ_i be the set of second stage decision functions, then

$$\sigma_i \in \Sigma_i \Rightarrow \forall\ T \in \Gamma^2 : \sigma_i(T) = \left(\sigma_i^A(T),\ \sigma_i^B(T)\right) \in \Re^2_+$$

with

$$\{ T_i = D^x \} \Rightarrow \sigma_i^y(T) = 0\,, \quad x, y \in \{A, B\} \text{ and } x \neq y$$

We will denote by S_i^0 the set of such strategies s_i^0, by S^0 the product $S_1^0 \text{ x } S_2^0$ and by B_i^0 the profit (benefits) of firm i as a function of its own strategy and the strategy of its competitor:

$$\forall \ s^0 \in S^0: \ B_i^0(s^0) = \sum_{x \in \{A,B\}} \left\{ \left[p^x(\sum_{j=1,2} \sigma_j(T)) - c \right] \sigma_i(T) \right\} - I_{T_i}$$

where $I_{T_i} = I_D$ if $T_i \in \{D^A, D^B\}$ and $I_{T_i} = I_F$ if $T_i = F$. A pair of strategies is an equilibrium if each one is a best response to the other. An equilibrium s^{0*} is a (subgame) perfect equilibrium if, for any given $T \in \Gamma^2$, the pair of decisions $(\sigma_1^*(T), \sigma_2^*(T))$ is an equilibrium of the subgame whose payoff functions are:

$$B_i^0((T_i, \sigma_i), (T_j, \sigma_j)), \quad i, j = 1, 2\,, \ i \neq j \text{ and } \sigma_k \in \sum\nolimits_k \ , \ k = 1, 2.$$

Unobservability (u). For a firm i not aware of the technological decision of its competitor, a pure strategy s_i^u 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 supplied, here independent of $T_j, j \neq i$. Let S_i^u be the set of firm i's strategies and S^u the product $S_1^u \text{ x } S_2^u$. The profit function of firm i, denoted by B_i^u, is:

$$\forall \ s^u \in S^u : B_i^u(s^u) = \sum_{x \in \{A,B\}} \left[p^x(\sum_{j=1,2} q_j^x) - c \right] q_i^x - I_{T_i}$$

An equilibrium is a pair of strategies, each one being a best reply to the other. Since the technological choice of a firm cannot be observed by its competitor, there is no subgame.

3. **The polar case of independent markets** ($\lambda = 0$)

That observability of the technological choices matters and favours the emergence of flexible configurations can be more easily understood in the extreme case of independent markets. Let π_i^x be the profits over operating cost of firm i in market X. Easy calculations lead to:

$\pi_i^x = m^2/4$ in case of a firm i monopoly in market X

$\pi_i^x = m^2/9$ in case of a duopoly in market X

$\pi_i^x = m^2/16$ in case of a firm i responding optimally to a firm j producing the monopoly output $m/2$ in market X.

3.1 The observability case

Let us consider the observability case. Given the technological choice of firm j, if firm i is changing its technological choice, then firm j will change the quantities it is supplying since for any pair of technological choices, the subgame perfection condition implies that in each market the quantities must be the Cournot equilibrium quantities. Let us determine the conditions (the parameter values) under which (F,F), (D,D) and (D,F) may be the first stage choices at equilibrium, that is the conditions under which no deviation is profitable.

In a hypothetical (F,F) equilibrium with independent goods, each firm is earning twice the duopoly operating profits minus the fixed cost of the flexible technology I_F, that is $(2m^2/9) - I_F$. If instead firm i chooses the dedicated technology for good X, then it would loose the duopoly operating profits in market Y, $m^2/9$, but would benefit from the lower investment cost I_D, thus saving f. Hence, depending on whether f/m^2 is lower or higher than $1/9$, firm i is better off with technology F or with technology D given that the competitor is staying with technology F.

Consider now a technological configuration (D,D) in which each firm is specialized in some market, say for example i in market X and j in market Y, $Y \neq X$. Each firm would earn the monopoly operating profits minus the fixed cost of a dedicated technology, that is, $(m^2/4) - I_D$. If instead firm i chooses the flexible technology, it would retain its monopoly profits in the market it was initially supplying and obtain the additional duopoly operating profits in the other market, $(m^2/9)$, at the incremental cost f. Thus it is better to stay with technology D than switch to F provided that $f/m^2 > 1/9$, better to switch to F provided that $f/m^2 < 1/9$, and it is a matter of indifference if $f = m^2/9$.

What the above cost-benefit analysis of the deviations shows is that, whatever the technological choice of its competitor, either D or F, the best response of any firm is to adopt F

if $f/m^2 < 1/9$, D if $f/m^2 > 1/9$, and is indifferent in the case $f/m^2 = 1/9$. We may conclude that the only equilibria are (F,F) if $f/m^2 < 1/9$, (D,D) if $f/m^2 > 1/9$, and either (F,F), (D,D) or (D,F) if $f/m^2 = 1/9$, all these equilibria being dominant strategy equilibria (more on this point in the following paragraph). Generically, the firms choose the same strategies in equilibrium, in the case of observability.

In this case of observability, the Cournot equilibrium is played at the second stage conditional to the first stage technological choices. For this reason, this game admits a reduced form, the strategies of which are the first stage technological choices. The payoffs of this reduced game appear in table 1, as a two player two strategy game.

Table 1

Payoffs of the reduced form game in the case of observability and independent markets

Firm j

		D_j^y	F_j
Firm i	D_i^x	$\left(\frac{m^2}{4} - I_D,\ \frac{m^2}{4} - I_D\right)$	$\left(\frac{m^2}{9} - I_D,\ \frac{13m^2}{36} - I_F\right)$
	F_i	$\left(\frac{13m^2}{36} - I_F,\ \frac{m^2}{9} - I_D\right)$	$\left(\frac{2m^2}{9} - I_F,\ \frac{2m^2}{9} - I_F\right)$

In the above game, whatever the strategy of firm j, either D_j^y or F_j, the operating profits accruing to player i are higher when it plays F_i than when it plays D_i^x, the difference being equal to $m^2/9$ in each case. Thus, for $f/m^2 < 1/9$, D_i^x is a dominant strategy for player i and D_j^y a dominant strategy for player j, resulting in an equilibrium $\left(D_i^x, D_j^y\right)$ at which the vector of payoffs is $\left(\frac{m^2}{4} - I_D,\ \frac{m^2}{4} - I_D\right)$. The rankings of the different payoffs are:

$$\frac{m^2}{4} - I_D > \frac{13m^2}{36} - I_F > \frac{m^2}{9} - I_D > \frac{2m^2}{9} - I_F, \quad for\ 1/4 > f/m^2 > 1/9$$

$$\frac{m^2}{4} - I_D > \frac{m^2}{9} - I_D > \frac{13m^2}{36} - I_F > \frac{2m^2}{9} - I_F, \qquad \textit{for } f/m^2 > 1/4.$$

In both cases, the equilibrium payoff vector is the Pareto dominant payoff vector of the reduced form game as illustrated in Figures 1 and 2 below. On these figures, the equilibrium payoff vector is (1). In Figure 1, (1) corresponds to (D^x, D^y) and should firm i [j] alone deviate to F, the corresponding payoff vector would be (3) [(4)] inducing a fall of its own payoff, hence it does not deviate. Starting from (4) corresponding to (D^x, F), should firm i deviate, the payoff would be (1), thus firm i deviates. We have the same story starting form (3) corresponding to (F, D^y) and a deviation by firm j to F. Finally, starting from (2) corresponding to (F, F), should firm i [j] deviate, the payoff would be (3) [(4)], hence firm i deviates. In Figure 2, we have the same kind of profit driven structure.

Figure 1 ($\lambda = 0$)
Payoff vectors of the reduced form game in the observability case and $1/4 > f/m^2 > 1/9$
(1) : (D^x, D^y) ; (2) : (F, F) ; (3) : (F, D^y) ; (4) : (D^x, F)
NB: The equilibrium is at (1) : (D^x, D^y)

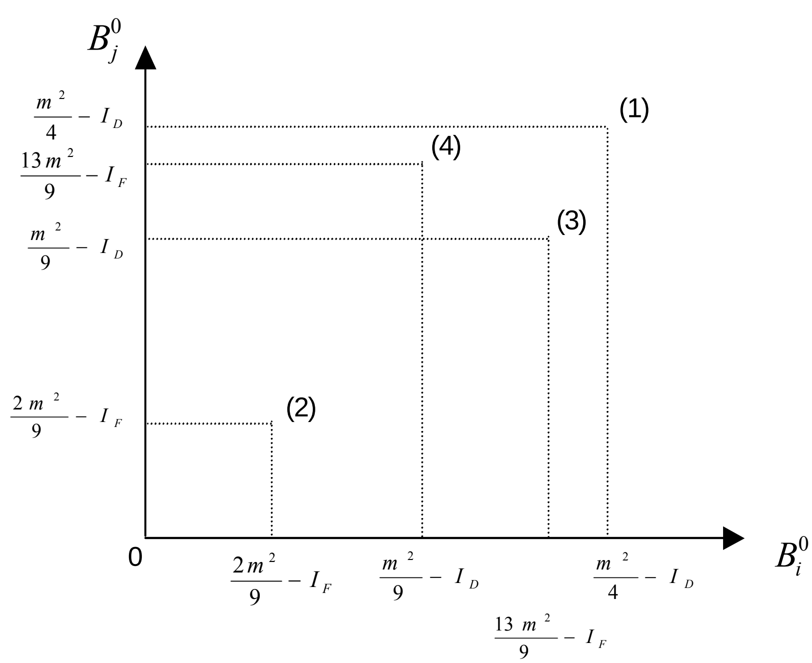
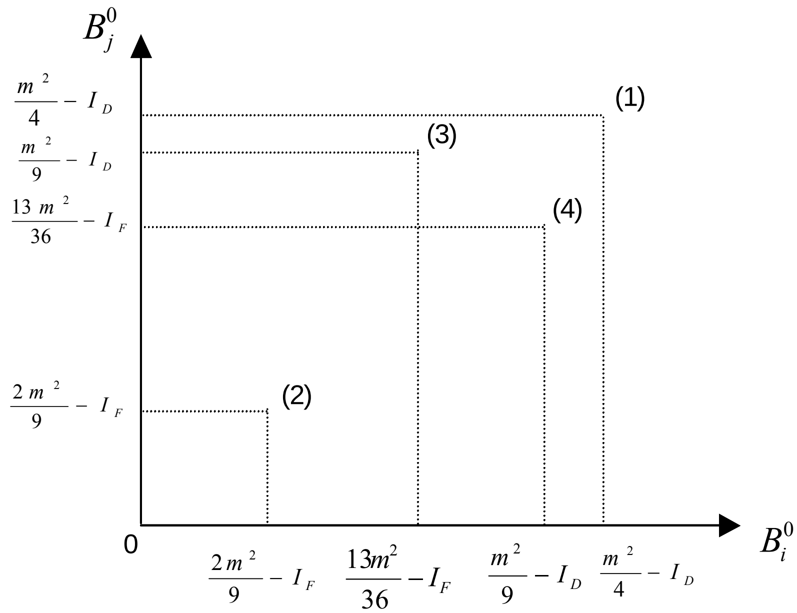


Figure 2 ($\lambda = 0$)

Payoff vectors of the reduced form game in the observability case and $f / m^2 > 1/4$

(1) : (D^x, D^y); (2) : *(F,F)* ; (3) : (F, D^y) ; (4) : (D^x, F)



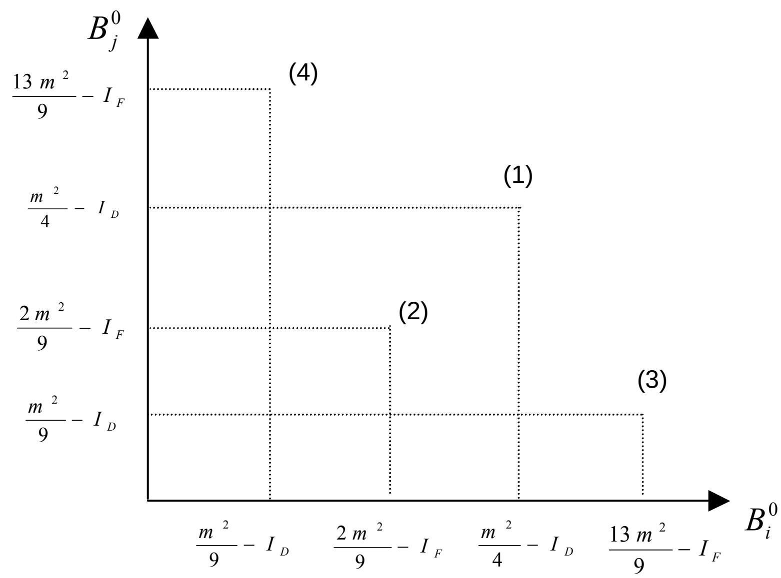
NB: The equilibrium is at (1) : (D^x, D^y)

Suppose now that $f / m^2 < 1/9$, then F is the dominant strategy. At the dominant strategy equilibrium (F, F) the payoff vector is $\left(\frac{2m^2}{9} - I_F,\ \frac{2m^2}{9} - I_F \right)$. For $f / m^2 < 1/9$, the ranking of the different payoffs is:

$$\frac{13m^2}{36} - I_F > \frac{m^2}{4} - I_D > \frac{2m^2}{9} - I_F > \frac{m^2}{9} - I_D .$$

Thus, as illustrated in Figure 3 below, we have now a prisoner's dilemma. Both firms would prefer the payoff vector (1), which they would get as dedicated monopolists, to the payoff vectors (2) they would obtain as flexible duopolists active in both markets. But starting from (1), given that j has chosen D^y, firm i would switch to F leading to the payoff vector (3) at which its profits are higher. Symmetrically, firm j too would switch to F to obtain (4). Finally, given *(F,F)*, should firm i alone switch to D the payoff vector would switch to (4), hence firm i does not deviate; should firm j alone switch to *D*, the payoff vector would switch to (3) so that j does not deviate either. Thus, the equilibrium payoff vector is the Pareto dominated vector (2).

Figure 3 ($\lambda = 0$)
Payoff vectors of the reduced form game in the observability case and $f/m^2 < 1/9$
(1) : (D^x, D^y); (2) : *(F,F)* ; (3) : (F, D^y) ; (4) : (D^x, F)
NB: The equilibrium is at (2) : *(F,F)*



3.2 The unobservability case

In the unobservability case, all the decisions concerning the technology and the quantities supplied in each market are made *simultaneously*. This does not change the decision in an *(F,F)* equilibrium, a *(D,D)* equilibrium or a *(F,D)* equilibrium. In each case, the equilibrium quantities supplied in each market are the quantities of a Cournot equilibrium. What differs now is the way the value of the deviations of a firm from a hypothetical pair of strategies is obtained. When considering a deviation, a firm must now consider that all the decisions of its competitor remains constant since the competitor cannot observe the firm's deviation or change in technology. As we shall see, in the case of independent markets, this is important only for a deviation from *D* to *F*.

Let us consider an equilibrium candidate *(F,F)*, sustained by strategies $s_i^u = (F,\ q_i^x = \frac{m}{3},\ \ q_i^y = \frac{m}{3})$ and $s_j^u = (F,\ q_j^x = \frac{m}{3},\ \ q_j^y = \frac{m}{3})$, resulting in a payoff vector

$\left(\frac{2m^2}{9}-I_F,\ \frac{2m^2}{9}-I_F\right)$. If firm i deviates say to D^x, it will be present only in market *X* and given that $q_j^x=\frac{m}{3}$ the best it can do is to supply $q_j^x=\frac{m}{3}$ too. This is precisely what happened in the case of observability because, following the switch of i to D^x, firm *j* observing this switch was not changing its supply in market *X* (but was adapting its supply in market *Y* that its competitor was abandoning). Thus the range of values of f/m^2 for which *(F,F)* is an equilibrium is the same in both cases of unobservability and observability.

What is new is what happen for the *(D,D)* and *(F,D)* technological configuration. Let us consider a potential equilibrium *(D,D)* sustained by the pair of strategies $s_i^u=(D^x,\ q_i^x=\frac{m}{2},\ q_i^y=0)$ and $s_j^u=(D^y,\ q_j^x=0,\ q_j^y=\frac{m}{2})$. If firm i switches to *F*, its monopoly position in market *X* would be unaltered. But the value of its entry in market *Y* is lower than in case of observability. Its competitor, which was initially a monopolist in the market is supplying $m/2$ and keeps supplying that quantity since the deviation is not observed, and therefore the best the deviant can do is to supply $m/4$. In the observability case, the competitor, observing the deviation, reduced its supply from $m/2$ down to $m/3$ and the deviant supplied $m/3$ rather than $m/4$.

In case of observability, the profit margin in the *Y* market is $p^y-c=m^2/3$, the quantity sold by the deviant is $m/3$ and its operating profits are $m^2/9$. In case of unobservability, the profit margin falls to $m/4$, the quantity sold to $m/4$ and the operation profits to $m^2/16$. Hence for $f/m^2\geq 1/16$, *(D,D)* is an equilibrium technological configuration: it is therefore an equilibrium configuration for a larger range of values than the range $f/m^2\geq 1/9$ prevailing in the case of observability. This makes the (*D,D*) equilibrium more likely under unobservability.

Consider now a tentative equilibrium *(F,D)* sustained by the pair of strategies $s_i^u=(F,\ q_i^x=\frac{m}{2},\ q_i^y=\frac{m}{3})$ and $s_j^u=(D^y,\ q_j^x=0,\ q_j^y=\frac{m}{3})$ generating profits $\frac{13m^2}{36}-I_F$ for i and $\frac{m^2}{9}-I_D$ for j. If firm i switches to D^x, it would remain a monopolist on market *X*, would loose its duopoly profits $m^2/9$ in *Y* market and would save *f* in investment costs. Thus, provided that $f/m^2 \leq 1/9$, it will not deviate. Next if firm j switches to *F*, it would increase its operating profits by entering market *X* in which firm i supplies $m/2$. Thus as shown above, the increase in operating profits is $m^2/16$ and provided that $f/m^2 \geq 1/16$, the firm will not deviate.

We have now three relevant ranges of values of f/m^2. For $f/m^2 < 1/16$, *(F,F)* is the only equilibrium technological configuration; for $1/16 \leq f/m^2 \leq 1/9$, either *(F,F)* or *(F,D)* or *(D,D)* may appear in equilibrium; and for $f/m^2 > 1/9$, the only equilibrium configuration is *(D,D)*. The range of values of f/m^2 for which at least one firm would choose *D* in equilibrium is *larger* in case of unobservability. This is the precise meaning of the statement: *observability favours flexibility*.

In the case of unobservability, the game does not admit any reduced form and there are no more dominant strategies even for the values of f/m^2 for which only one type of equilibrium exists. For example the strategies $s_i^u = (D^x,\ q_i^x = m/2,\ q_i^y = 0)$ and $s_j^u = (D^y,\ q_j^x = 0,\ q_j^y = m/2)$ which support *(D,D)* as an equilibrium are not dominant strategies even if $f/m^2 > 1/9$ and *(D,D)* is the only equilibrium. If j plays $(F,\ q_j^x = 1/3,\ q_j^y = m/2)$, it would be better for i to respond by playing $(D^x,\ q_i^x = 1/3,\ q_i^y = 0)$.

There remains the fact that the best situation for the firms is that each one be a specialized monopolist, whatever f/m^2. Hence when *(F,F)* is the only equilibrium, we have a prisoner's dilemma problem. What unobservability is promoting is that now, over some part of the range of f/m^2 values for which *(F,F)* is an equilibrium, then *(D,D)* and *(D,F)* may also be equilibria so that, for $1/16 \leq f/m^2 \leq 1/9$ the problem is more a problem of coordination failure than a prisoner's dilemma trap.

4. **The effect of substitutability** ($\lambda > 0$)

Let us consider now the case of substitute goods. A switch from say a dedicated technology to the flexible one has effects not only on the new market in which the firm can compete but also in the market in which it was initially active. More supply in the new market now depresses the price in the initial market. The intuition here is that, as far as only operating profits are concerned, the gains induced by a switch from a dedicated to the flexible technology are lower the more substitutable the goods are. Thus for quasi-perfect substitute goods, using the least costly technology, that is the dedicated one, is a dominant strategy, although in the limit, for strictly perfect substitutes, no technology is "dedicated."

We show that while the range of values of f/m^2 for which *(D,D)* is the only equilibrium configuration is increasing as the goods are better substitutes and correspondingly the range of values for which *(F,F)* is the only equilibrium is decreasing, observability is still favouring flexibility. We show also that, for sufficiently strong substitutes ($\lambda > 1/2$), the mixed equilibrium configurations disappear.

As noted above, for perfect substitutes there must exist one and only one type of equipment, f = 0. Thus for stronger substitutes, the incremental cost f is most probably decreasing, being nil for perfect substitutes. Hence, depending on the value of the highest level of the incremental cost for the case of independent goods examined in the preceding section and the way it is decreasing down to zero (perfect substitutes), we may obtain different sequences of equilibrium technological configurations for goods that are increasingly better substitutes.

4.1 The observability case

The different operating profits of firm i (mutatis mutandis for firm j) to take into account are now:[4]

- $\pi_i^x = m^2/(2+\lambda)^2$ if firm i is a monopolist in market *X* and firm *j* is a monopolist in market *Y;*
- $\pi_i^x = m^2/9(1+\lambda)$ if both markets are duopolies;

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[4] The equilibrium profit margins and quantities are respectively:

- in the case of a monopoly in each market by a different firm, say i in *X* and j in *Y*:

  $p^x - c = p^y - c = m/(2+\lambda)$, $q_i^x = q_j^y = m/(2+\lambda)$, $q_i^y = q_j^x = 0$
- in case of a duopoly in each market:

  $p^x - c = p^y - c = m/3$ and $q_i^x = q_i^y = q_j^x = q_j^y = m/3(1+\lambda)$
- in case of i monopoly in market *X* and a duopoly in market *Y*:

  $p^x - c = (3+2\lambda-\lambda^2)m/6(1+\lambda)$, $p^y - c = m/3$

  $q_i^x = m/2(1+\lambda)$, $q_i^y = (2-\lambda)m/6(1+\lambda)$, $q_j^x = 0$, $q_j^y = m/3$

- $\pi_i^x = (2-\lambda)m^2/18(1+\lambda)$ if firm i is a monopolist in market *Y* while market *X* is a duopoly;
- $\pi_i^x = m^2/9$ if firm *j* is a monopolist in market *Y* and market *X* is a duopoly;
- $\pi_i^x = (3+2\lambda-\lambda^2)m^2/12(1+\lambda)^2$ if firm i is a monopolist in market *X* and market *Y* is a duopoly.

In a *(F,F)* equilibrium, the operating profits of each firm is twice the duopoly profits $m^2/9(1+\lambda)$. If a firm considers a switch to a dedicated technology, say to good *X*, it would loose the duopoly profits $m^2/9(1+\lambda)$ in market *Y* but obtain the new duopoly profits in market *X*, facing now a competitor that remains present in market *X* but is a monopolist in market *Y*, that is, it obtains $m^2/9$ instead of $m^2/9(1+\lambda)$. The increase in profits in market *X* is therefore not high enough to compensate for the loss in market *Y*, leading to a net loss ℓ^u_{FF}:[5]

$$\ell^u_{FF} = (1-\lambda)m^2/9(1+\lambda)$$

In a *(D,D)* equilibrium with firm i in market *X* and firm j in market *Y*, each firm's operating profits are the monopoly profits $m^2/(2+\lambda)^2$. Should firm i choose to switch to the flexible technology, its monopoly profits in market *X* would decrease to $(3+2\lambda-\lambda^2)m^2/12(1+\lambda)^2$,[6] but the firm would obtain in market *Y* the duopoly profits $(2-\lambda)m^2/18(1+\lambda)$. The net increase in operating profits would be:

$$g^o_{DD} = \frac{(16+12\lambda-11\lambda^2-12\lambda^3-5\lambda^4)m^2}{36(1+\lambda)^2(2+\lambda)^2} > 0, \text{ for } \lambda \in (0,1).$$

But since

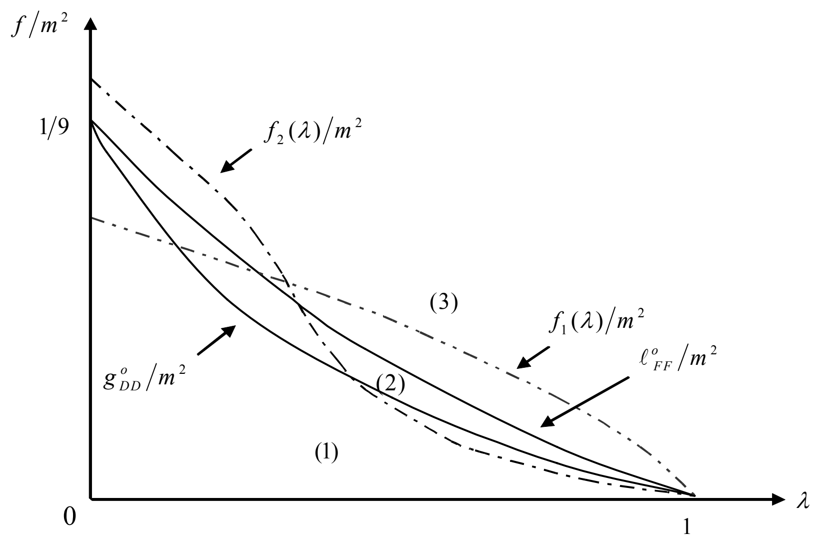
$$\frac{g^o_{DD}}{\ell^o_{FF}} = \frac{16+12\lambda-11\lambda^2-12\lambda^3-5\lambda^4}{4(1-\lambda^2)(2+\lambda)^2} < 1, \text{ for } \lambda \in (0,1),$$

[5] The notation is the following. We use ℓ and g for respectively a loss and a gain. The lower indexes refer to the situation from which a deviation is considered, the first index refers to the initial technological choice of the firm concerned by the deviation, the second one to the choice of its competitor. The upper index o stands for the observability case and u for the unobservability case.

[6] $$\frac{m^2}{(2+\lambda)^2} - \frac{(3+2\lambda-\lambda^2)m^2}{4(1+\lambda)^2} = \frac{(4\lambda+5\lambda^2+2\lambda^3+\lambda^4)m^2}{12(2+\lambda)^2(1+\lambda^2)} > 0$$

we are left with three zones in the $(f/m^2, \lambda)$ space, illustrated in Figure 4. Under the curve ℓ^o_{FF}/m^2, *(F,F)* is an equilibrium technological configuration since switching to *D* would imply for the switching firm a loss ℓ^o_{FF} in operation profits that is larger than the saving in investment cost *f*. In the zone above the curve g^o_{DD}/m^2, *(D,D)* is an equilibrium since switching to *F* would imply, for the switching firm, an increase g^o_{DD} in operating profits that is smaller than the incremental investment cost *f*. Thus, in the zone under g^o_{DD}/m^2, *(F,F)* is the only equilibrium technological configuration and in the zone above the curve ℓ^o_{FF}, *(D,D)* is the only equilibrium technological configuration; in both cases, the equilibria are dominant strategy equilibria. In the zone between the two curves, either *(F,F)* or *(D,D)* may appear in equilibrium and clearly there does not exist any dominant strategy. Note that *(F,D)* cannot be an equilibrium since by switching to *D*, the flexible firm would loose[7] g^o_{DD} but save a higher incremental cost *f*.

Figure 4 ($\lambda > 0$)
Type of technological equilibria in the observability case
(1) : *(F,F)* ; (2) : *(F,F)* and *(D,D)* ; (3) : *(D,D)*



[7] In the observability case:

- Under the curve ℓ^o_{FF}/m^2, starting from *(D,F)*, the dedicated firm would gain ℓ^o_{FF} in operating profits by switching to *F*
- Above the curve g^o_{DD}/m^2, starting from *(F,D)*, the flexible firm would loss g^o_{DD} by switching to *DD*.

The range of values of f/m^2 for which *(D,D)* is an equilibrium increases as the goods become better substitutes and similarly the range of values for which *(F,F)* is an equilibrium decrease down to zero. Thus for a value of $f/m^2 < 1/9$, we have unnecessarily flexible firms both exploiting separated markets for highly differentiated products, and dedicated firms exploiting some loosely defined niche for poorly differentiated goods.

If f is a decreasing function of λ, as it may probably be, many different sequences of equilibria may be obtained depending upon the shape of the curve $f(\lambda)/m^2$. As illustrated in Figure 4, with function $f_1(\lambda)$ we have the above sequence, flexible firms for strongly differentiated goods and dedicated firms for strong substitutes. But the order is reversed with function $f_2(\lambda)/m^2$. The types of equilibria could even alternate.

4.2 The unobservability case

As in the observability case, the quantities sold in equilibrium in the unobservability case are Cournot equilibrium quantities, given the technological choices. Thus, the profits are the same as those above. What is different here is the attractiveness of a deviation since, if a firm is considering a switch in technology, its competitor is staying with its initial equilibrium quantities. As we shall see, this reduces, in the $(f/m^2, \lambda)$-space, the region in which *(F,F)* is the only equilibrium configuration and enlarges the region in which both *(F,F)* and *(D,D)* are equilibria. It also happens now that, contrary to the case of observability, *(F,D)* may be an equilibrium configuration.

To determine the attractiveness of a deviation, we need the values of the operating profits, namely:

- $\pi_i^x = m^2/9$ if market *X* is a duopoly and market *Y* is a monopoly for firm j that offers in each market the quantities of a *(F,F)* equilibrium;
- $\pi_i^x = 2-\lambda(1+\lambda)m^2/2(2+\lambda)^2(1-\lambda^2)$ if firm i is a monopolist in market *X* whereas market *Y* is a duopoly, firm j producing in market *Y* the quantity of a *(D,D)* equilibrium;
- $\pi_i^x = m^2/4(2+\lambda)^2$ if market *X* is a duopoly whereas market *Y* is a monopoly for firm i, firm j producing in market *X* the quantity of a *(D,D)* equilibrium;

- $\pi_i^x = (4+\lambda)m^2 / 36(1+\lambda)$ if both markets are originally duopolies, firm j producing the quantities of a *(D,F)* equilibrium, in which it is present on both markets, whereas firm i has a technology dedicated to *X*;
- $\pi_i^x = (3+4\lambda+\lambda^2)m^2 / 48(1+\lambda)^2$ if both markets are originally duopolies, firm j producing the quantities of a *(D,F)* equilibrium, in which it is present on both markets, whereas firm i has a technology dedicated to *Y*;
- $\pi_i^x = (9-6\lambda+\lambda^2)m^2 / 36$ if both markets are originally monopolies, firm j producing in market *Y* the quantity of a *(F,D)* equilibrium, in which it is present in the market *Y* only, whereas firm i is present on both markets.

Let us consider first an hypothetical *(F,F)* equilibrium in which firm i is earning the operating profits $2m^2/9(1+\lambda)$. A deviation to D^x brings a loss of:

$$\ell_{FF}^u = (1-\lambda)m^2 / 9(1+\lambda) .$$

Thus for $f < \ell_{FF}^u$ no firm has an incentive to deviate and *(F,F)* is an equilibrium. Note that $\ell_{FF}^u = \ell_{FF}^o$ so that the set of parameter values for which *(F,F)* is an equilibrium is the same as under observability. But as we shall see the set of values for which it is the only equilibrium is reduced.

Consider now a possible *(D,D)* equilibrium in which firm i is earning $m^2/(2+\lambda)^2$. Switching to *F* would generate operating profits equal to:

$$\left[\frac{2-\lambda(1+\lambda)}{2(2+\lambda)^2(1-\lambda^2)} + \frac{1}{4(2+\lambda)^2}\right] m^2$$

So that the net gain in operating profits amounts to:

$$g_{DD}^u = \frac{(1-2\lambda+\lambda^2)m^2}{4(2+\lambda)^2(1-\lambda^2)}$$

Thus for $f > g_{DD}^u$ no firm would deviate from *(D,D)*. Note that $g_{DD}^u < g_{DD}^o$, hence the set of parameters values for which *(D,D)* is an equilibrium is larger in the case of unobservability than in case of observability.

Consider a tentative *(F,D)* equilibrium, firm i having chosen the flexible technology and firm *j* the technology dedicated to *Y*. In this equilibrium, firm i is earning:

$$\left[\frac{3+2\lambda-\lambda^2}{4(1+\lambda)^2}+\frac{2-\lambda}{18(2+\lambda)}\right]m^2$$

and would earn $(9-6\lambda+\lambda^2)m^2/36$ after a switch to D^x. Thus the net loss would be:

$$\ell^u_{FD}=\frac{4-4\lambda-3\lambda^2+4\lambda^3-\lambda^4}{36(1+\lambda)^2}m^2$$

and firm i does not switch if $f<\ell^u_{FD}$. Now firm j is earning $m^2/9$ in the hypothetical *(F,D)* equilibrium and would earn:

$$\left[\frac{3+4\lambda+\lambda^2}{48(1+\lambda)^2}+\frac{4+\lambda}{36(1+\lambda)}\right]m^2$$

after a switch to *F*. Thus the net gain amounts to:

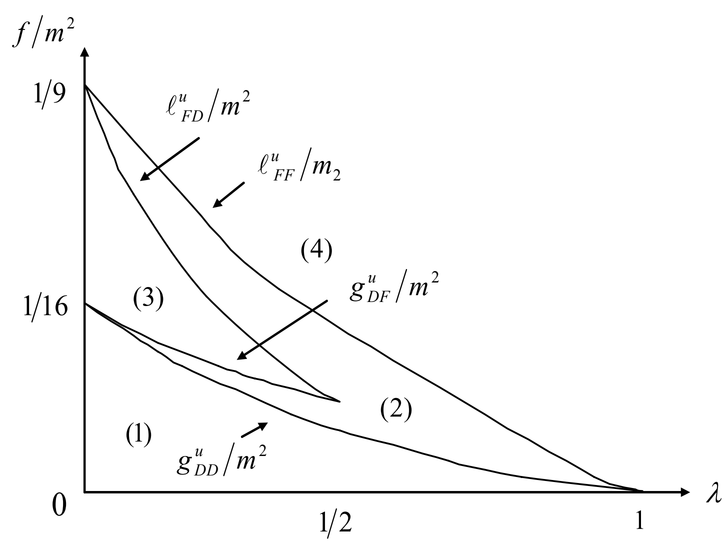
$$g^u_{DF}=\frac{(1+\lambda)m^2}{16(1+\lambda)}$$

and firm j does not switch, provided that $f\geq g^u_{DF}$. It may be easily checked that:

$$\ell^u_{FD} \; > \; = \; < \; g^u_{DF} \quad \Leftrightarrow \quad \lambda \; < \; = \; > ½\,.$$

Thus there appears now a zone in which *(F,D)* is an equilibrium, which was never the case under observability. The different zones of the $(f/m^2,\lambda)$ space are illustrated in Figure 5.

Figure 5 ($\lambda>0$)
Types of technological equilibria in the unobservability case
(1) : *(F,F)* ; (2) : *(F,F)* and *(D,D)* ; (3) : *(F,F)*, *(F,D)* and *(D,D)* ; (4) : *(D,D)*



The switch from an equilibrium configuration to another one, generated by the adoption of strategies in which the quantities are made conditional on the technology is generally interpreted as a pure strategic effect.[8] If so, we could rephrase the above results as saying that *the pure strategic effect promotes the adoption of more flexible manufacturing systems*.

Adopting a flexible technology allows to supply both products. At first sight, this possibility should have more value for the firm when the switch is observed by the other firm. With observability, switching to flexibility induces the other firm to reduce its production. But provided that f is sufficiently small, it is also an incentive for the other firm to be present on both markets. Thus observability is destroying the possibility of commitment to given production levels while, by allowing such commitments, *unobservability reinforce the resistance of (D,D) to deviations*.

5. Endogenous observability

Observability may be determined by the firms themselves in different ways. First, a firm can give an easy access to its technology choices by publicizing what it is doing. Second, a firm can try to get information on what its competitor is investing in, admittedly at some cost. But at some cost too, a firm that wants to keep secret its technology choices could try to prevent, more or less efficiently, access to its decisions. We must first determine what the equilibria are in case of asymmetric observability conditions.

5.1 The asymmetric observability case

Let us assume that firm i can observe the technological choice of firm j but not the reverse. Thus the strategies of firm i are of the type s_i^o defined in section 2 whereas the strategies of firm j are of the type s_j^u. Such a game has no subgame, hence the subgame perfection argument cannot be used. An immediate consequence is that firm i could select strategies of type s_i^o which in fact would be like strategies of type s_i^u. The s_i^u strategies are nothing but particular s_i^o strategies in which the second stage production decision function σ_i take the same value whatever the pair of technologies chosen by the firms at the first stage. Under observability, these special s_i^o strategies are eliminated thanks to the subgame perfection

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

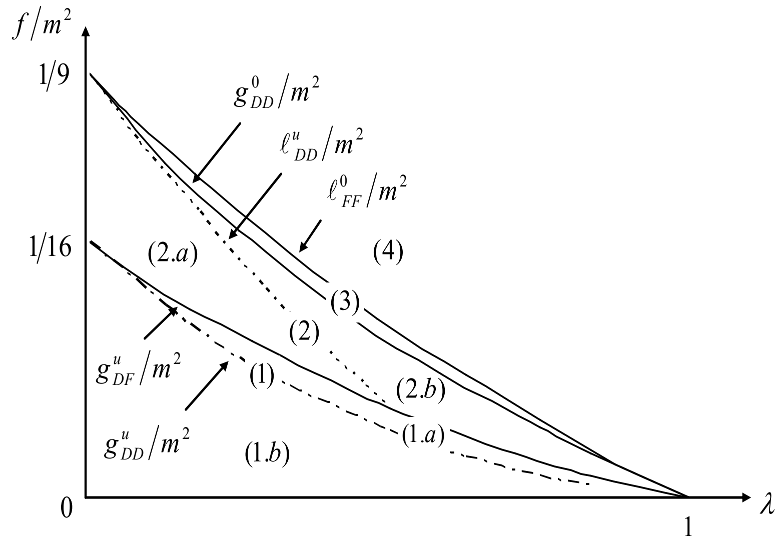
refinement. Thus an immediate consequence of the absence of refinement criterion is that the equilibria of the unobservability case are equilibria in the asymmetric observability case. Asymmetric unobservability would add nothing with respect to complete unobservability.

However, the conclusion that firm i does not take advantage of its information is rather worrying. The problem is to determine how. In order to kill the equilibria supported by non credible strategies, we assume that at the second stage of the game firm i plays Cournot quantities corresponding to the presence of firms in the different markets. For example, if firm i has observed that firm j has chosen a technology D^y and itself has chosen the D^x technology, then firm i plays the monopoly quantity in market *X*. If it had chosen the flexible technology, firm i would play the duopoly quantity in market *Y* and the monopoly quantity in market *X*. Restricting the strategies of firm i in this way generates the following effects.

Consider for example the situation in which firm j plays $\left(D_j^y,\ q_j^x = 0,\ q_j^y = m/(2+\lambda)\right)$ and firm i has chosen D_i^x so that, given the choice of j, i would play $\left(\sigma_i^x(D_i^x, D_j^y) = m/(2+\lambda),\ \sigma_i^y(D_i^x, D_j^y) = 0\right)$ at the second stage. When firm j switches to *F*, then given its choice D_i^x, firm i would play $\left(\sigma_i^x(D_i^x, F_j) = m/3,\ \sigma_i^y(D_i^x, F_j) = 0\right)$ at the second stage, so that the other component of the switch of firm j must be $q_j^x = (2-\lambda)m/6(1+\lambda)$ and $q_j^y = m/2(1+\lambda)$, to be optimized given the strategy of i. Although firm j is uninformed of the technological choice of firm i, the fact that firm i is informed of firm j's choices implies that a switch by firm j from a technology to another has the same effect as under observability. Hence, the test of the interest of such a switch is the same as under observability. Symmetrically due to the fact that firm j is uninformed, it must choose strategies where the production levels are independent of the technological choice of firm i; hence the test of the interest of a switch by informed firm i is the same as under unobservability.

Using these two tests we must now distinguish four regions in the $(f/m^2,\ \lambda)$ space, as illustrated in Figure 6. The most important fact is that, compared to the case of unobservability, all the *(D,D)* equilibria located under the curve g_{DD}^o/m^2 are eliminated because uninformed firm j would deviate. But there are more subtle changes. Let us examine these four zones in detail.

Figure 6 ($\lambda > 0$)
Types of technological equilibria in the asymmetric observability case
(1) : *(F,F)* ; (2) : *(D,F)* and *(F,F)* ; (3) : *(D,D)* and *(F,F)* ; (4) : *(D,D)*
(In zone (2), the firm that chooses the dedicated technology is the informed firm)



The zone in which *(F,F)* is the only equilibrium increases, compared to the case of unobservability, and is now the zone (1) in Figure 6 located under the curve g^u_{DF}/m^2 in case of unobservability. Under the curve g^u_{DF}/m^2, *(F,F)* is an equilibrium since $g^u_{DF}/m^2 < \ell^o_{FF}/m^2 = \ell^u_{FF}/m^2$, and it is the only one because:

- First, *(D,F)* in zone (1), with the informed firm having chosen *D* is not an equilibrium under the curve g^u_{DF}/m^2 since this firm would deviate to *F*;
- Second, *(D,F)* in zone (1), with the uninformed firm having chosen *D*, is not an equilibrium under ℓ^0_{FF}/m^2 since this firm would deviate to *F*;
- Third, *(D,D)* in zone (1) is not an equilibrium since under the curve $g^0_{DD}/m^2 > g^u_{DF}/m^2$ the uninformed firm would deviate to *F*.

In zone (2) located between the curves g^u_{DF}/m^2 and g^0_{DD}/m^2, we have two equilibrium configurations, *(F,F)* as in the case of unobservability and *(D,F)* with the uninformed firm choosing the flexible technology, for the following reasons:

- the *(F,F)* equilibrium may appear because the zone is located under $\ell^0_{FF}/m^2 = \ell^u_{FF}/m^2$;
- the *(D,F)* equilibrium with the informed firm choosing the dedicated technology may appear because above the curve g^u_{DF}/m^2 this firm does not deviate to *F*, and the uninformed firm does not deviate to *D* under the curve g^u_{DD}/m^2 ;
- the *(D,F)* equilibrium with the uninformed firm choosing the dedicated technology does not appear since this firm would deviate to *F* under the curve g^0_{DD}/m^2 , and for the same reason *(D,D)* does not appear.

Compared to the unobservability case, the *(D,D)* equilibria are eliminated in zone (2). In the sub-zone (2.a) located between the curves g^u_{DF}/m^2 and ℓ^u_{FD}/m^2 , the equilibria *(D,F)* in which the informed firm choosing the flexible technology disappear. In the sub-zone (2.b) located between the curves g^u_{DF}/m^2 , ℓ^u_{FD}/m^2 and g^0_{DD}/m^2 , equilibria *(D,F)* appear in which the informed firm adopts the dedicated technology. In zone (3) both *(F,F)* and *(D,D)* equilibria can emerge and in zone (4) only *(D,D)* equilibria appear, as in both the case of observability and the case of unobservability.

On the whole, *asymmetric observability favours flexibility compared to unobservability, but less so than observability would*. Note that in case of a mixed equilibrium configuration *(D,F)* in zone (3), the uninformed firm chooses the flexible technology and gets the larger profit level.

5.2 Incentives to disclose one's choices and to spy on the other.

Consider Figure 6. In the sub-zone (1.b) under curve g^u_{DD}/m^2 and in zones (3) and (4), the equilibrium technological configurations are the same whatever the observability conditions. Thus, no firm wants either to hide its choice or get more information on its competitor. Hence we are left with three sub-zones in which the equilibria may differ depending on which firm is informed: (1.a), between curves g^u_{DD}/m^2 and g^u_{DF}/m^2 , (2.a) and (2.b). The difficulty is that, in most cases within these sub-zones, there correspond several equilibria to each observation structure, hence the interest to disclose or not and to spy or not depends upon the equilibrium selected for each information structure.

Another problem is the asymmetry between disclosing and spying, because spying equilibria can be eliminated, at least partly. Leaving aside the difficulties to model spying and protection decisions and their costs, we assume that the firms can credibly engage to disclose or not their choices *before* choosing their technology. Thus observability comes from moves by firms that force their competitor to observe or not.

Let us first show that even under such a simplifying assumption, definite conclusions are not so easy to obtain. Let us consider sub-zone (1.a). First, if under unobservability the firms played equilibrium *(F,F)*, then they would be indifferent between disclosing or not. But suppose that the firms played *(D,D)* under unobservability, hence obtaining the monopoly profits $m^2/(2+\lambda)^2 - I_D$. If firm i does not disclose, firm j would obtain these monopoly profits by not disclosing too while disclosing would precipitate both firms to be flexible duopolists on each market reducing its own profits down to $2m^2/9(1+\lambda) - I_F$. Hence *not disclose* is a best response to *not disclose* and *(not disclose, not disclose)* is an equilibrium of the reduced form game in which the strategies of each firm are *disclose* and *not disclose*.[9] Thus, *(disclose, disclose)* is also an equilibrium. However, *disclose* is a weakly dominated strategy in the reduced form game[10] and since the equilibria in which a player uses a dominated strategy may be eliminated by a trembling hand argument (Selten 1975), we may eliminate this second equilibrium.

Consider now sub-zone (2.a). Within this region:

- under unobservability, three types of equilibria may appear: *(F,F)*, *(D,F)* or *(D,D)*;
- under asymmetric observability, only *(F,F)* and *(D,F)* with the informed firm choosing *D* could emerge,
- under observability, the only equilibrium is *(F,F)*.

Clearly, there is nothing to say about the incentives to disclose or not if *(F,F)* is the equilibrium played under the three observability conditions. Hence, let us assume that under asymmetric observability, *(F,D)* would be played with the informed firm choosing *D*, and that *(D,D)* would be played under unobservability. Suppose that firm i does not disclose. By not disclosing too, firm j would bring the *(D,D)* equilibrium, earning $m^2/(2+\lambda)^2 - I_D$, while by disclosing, it

[9] Note that, should a firm disclose, then its competitor would be indifferent between disclosing or not since in both cases *(F,F)* is the only equilibrium configuration.

[10] In this reduced game *not disclose* is a best response to both *not disclose* and *disclose* while *disclose* is a best response to *disclose* only.

would bring the *(D,F)* equilibrium in which it adopts the flexible technology since under the g^{o}_{DD}/m^{2} curve it is worthwhile to switch to *F* when the other stays at *D*. Hence, *(not disclose, not disclose)* is not an equilibrium. If firm i discloses, then firm j, by not disclosing, chooses de facto the equilibrium *(D,F)* in which it adopts the dedicated technology while by disclosing, it would bring equilibrium *(F,F)*, which is better for itself under the curve ℓ^{o}_{FF}/m^{2}. Thus *(disclose, disclose)* is the only equilibrium under these assumptions.

Finally in sub-zone (2.b), the only difference with sub-zone (2.a) is that under unobservability only *(D,D)* and *(F,F)* can appear. Thus, if we assume that *(D,D)* is played under unobservability and *(D,F)* under asymmetric observability, the analysis runs as in the preceding paragraph.

6. Conclusion

The main conclusion of the paper is that, under complete unobservability of opponents' technological choices, firms can more easily end up in the most profitable *(D,D)* equilibrium as they can "commit" to a production level, which is reminiscent of the *power of the blind*. Such commitment would be impossible should the technology be observed because such commitments would not be credible, no firm being able to resist the temptation to exploit its information. Hence, *observability favors the emergence of flexibility*. Implications are that the delay necessary to observe the rival's flexibility and the degree of uncertainty of such an observation matter for the firms' technological choices and organizations. We should expect more flexibility choices and wider product lines in industries where flexibility is incorporated in heavy machine tools, which are easily observable and have long lives. We should expect less flexibility and narrower product lines in industries where flexibility rests on immaterial organizational features or on machine tools with shorter lives. Interpreted our results in a dynamic context, our results suggest that when demand grows or the cost of flexibility *f* decreases, we should expect quicker adoption of flexibility in industries where observability is easier: one would observe periods where firms have different technologies where observability is more difficult but joint adoption otherwise. Interpreted in an international context, one should expect firms located in countries where observability is easier to be more flexible with wider product line compared to firms located in countries where observability is more difficult.

The effects of relaxing some of our assumptions are easily obtained. Suppose that choosing a more flexible technology results in higher variable costs. If this is the case, it would reduce the attractiveness of the flexible technology, thus reducing the range of parameter values for which equilibria exist with at least one firm choosing a flexible technology but our general results would hold. We showed that there is a critical value of λ, over which only *(D,D)* equilibria exist. Hence, the more substitutable the goods are, the more aggressive competition is and thus, preserving monopoly power and lower operating costs, by staying entrenched in different markets, is more rewarding for firms than generalizing competition on both markets. Our results stand. As for the simultaneity of moves in the first stage of the game in the observability case, should technological choices be sequential and observable, the reduced form game would be a Stackelberg game. Consider the case of independent markets and assume that a firm moves first. We observed in sub-section 3.1 that *F* [*D*] is the dominant strategy if $f < 1/9$ [$f > 1/9$]: the choice of the second mover is independent of the choice of the first mover. But the same is also true for the first mover. Hence, the technological configuration of the industry does not depend upon the sequence of moves and our results hold.

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