International Journal of Industrial Organization 8 (1990) 17-35. North-Holland

INFORMATION AND COMPETITIVE ADVANTAGE

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Final version received February 1989

We study the channels through which private information affects the competitive position of firms in the marketplace. Firms try to gain a competitive advantage via strategic investments in cost reduction or demand improving effort in an uncertain context. It is found that, under regularity conditions, an improvement in the information precision of a firm has always a favorable impact in its competitive position and profitability. The rivals are hurt if the market is characterized by quantity competition but favored if price competition prevails. A better informed competitor is thus a 'nicer' competitor under Bertrand competition but the opposite happens under Cournot competition.

1. Introduction

It is a commonplace to think that firms with better information enjoy a competitive advantage over their rivals. In fact, it is widely believed that one of the main successes of postwar Japanese industrial policy, which may explain Japan's competitive advantage in many sectors, is the active role of government in promoting a system of information collection and dissemination. The public intervention on industrial information flows may be more important to explain Japan's rate of growth than the direct subsidies to R & D and production activities. In fact one successful form of promoting the technological development of industries which were, at the beginning, lagging behind the U.S. and Europe, has been the formation of research consortia in which R & D is conducted and information is shared. The smoothing of information channels seems to have been a cornerstone in the policy followed by the Ministry of International Trade and Industry (MITI). In the words of Komiya[1] (1975, p. 221):

> Whatever the demerits of the system of industrial policies in post-war Japan, it has been a very effective means of collecting, exchanging, and

*Support from the Fishman-Davidson Center at the University of Pennsylvania and from the CICYT projects PB0340 and PB86-0613 is gratefully acknowledged. Byoung Jun provided excellent research assistance at an early stage of the research. I thank two anonymous referees for helpful comments.

[1]Taken from Suzumura and Okuno (1987). See their paper for a more critical view on the subject.

> propagating industrial information. Government officials, industry people, and men from governmental and private banks gather together and spend much time discussing the problems of industries and exchanging information on new technologies and domestic and overseas market conditions... Probably information related to the various industries is more abundant and (more) easily obtainable in Japan than in most other countries. Viewed as a system of information collection and dissemination, Japan's system of industrial policies may have been among the most important factors in Japan's high rate of industrial growth, apart from the direct or indirect economic effects of individual policy measures.

In contrast, American and European firms have to rely mostly on private market mechanisms to get their information. The Japanese subsidies to information transmission make the Japanese firms better informed and may give them a competitive advantage. How does better information translate into a tangible competitive advantage?

According to Michael Porter (1985) the two main ways for a firm to obtain a competitive advantage are low costs and product differentiation. The *competitive position* of a firm would be determined thus by its capacity to produce cheaply and or to differentiate its product offer from competitors. We would like to understand the channels through which an improvement in the accuracy of the information available to a firm fosters its competitive position. We would like to know also what is the effect on the profitability of a firm of better information for the *rivals* in the industry.

These issues, although they have been raised many times, have not yet received a lot of attention in formal economic models. We propose to examine them in the context of a two-stage game. A firm has the opportunity to make an investment which will yield a demand or cost advantage at the market stage. Firms make investments at the first stage anticipating the market outcome and trying to gain a competitive advantage. Between the two stages they receive private information about an uncertain payoff-relevant parameter, some firms being better informed than others. A hypothesis we want to explore is whether better informed firms will have an incentive to invest more at the first stage and therefore enjoy a competitive advantage in the market.

Fudenberg and Tirole (1984) provided a taxonomy of the incentive for a firm to invest strategically to obtain a more favorable position to face competition in the marketplace. The crucial elements identified by these authors are whether investment makes the firm tough or soft (aggressive or mild) and whether competition in ther market is characterized by upward sloping or downward sloping reaction curves. Our work can be seen as an extension of theirs in the presence of private information. In our uncertain context a firm's investment will affect not only its *aggressiveness* at the market stage, measured, say, in terms of expected output or price, but also its *responsiveness* to information (to the private signals received). Aggressiveness and responsiveness will be the crucial determinants of profitability.

More formally, we will investigate the perfect Bayesian equilibria of the two-stage game with a linear-quadratic duopoly specification. Our model admits two interpretations. In the first, with linear demand for homogeneous product and quadratic production costs, firms will invest at the first stage to lower production costs. In the second, with linear demand for differentiated products, firms will invest at the first stage to expand their own market. In both cases there is a demand or cost uncertain parameter and firms receive noisy signals. The uncertain parameter and the signals will be related by an information structure which parameterizes the precision of information and allows us to compute explicitly the second stage Bayesian equilibrium payoffs as a function of first stage investments. The market stage can be characterized by price (Bertrand) or quantity (Cournot) competition when interpreting first stage investment as demand improving effort. Cost reduction investment is only compatible in our model with second stage Cournot competition.[2]

Our basic result is that an improvement in the accuracy of information of a firm always fosters its competitive position and profitability and enhances or diminishes the rival's competitive position and profitability depending on whether competition is in prices or quantities. In our context we do not encounter the 'perverse' results, which can be traced back to Hirschleifer (1971), that information has no value or that more information may hurt an agent,[3] but we do find that under Bertrand competition a better informed competitor is a 'preferred' competitor while under Cournot competition it is disliked. Consequently the evaluation of competitors can not be identified only by their intrinsic characteristics independently of the type of competition prevailing in the market. The key idea to understand the result is to realize that an increase in the precision of information of a firm j will make the firm more responsive to the signal received, both directly (at the market stage and given its competitive position) and through the added incentive to invest more. From the point of view of the rival $(i \neq j)$ this will be good news if they compete via prices since firm i will be induced to respond more to information also: a firm would like to follow the price movements of other firms since best replies are upward sloping. Neverthless if they compete via quantities the increased responsiveness of firm j is bad news for firm i since the latter is induced to 'absorb' the larger output fluctuation of the former

[2]See Vives (1989) for a fuller analysis of technological competition with Cournot behavior and private information.

[3]This does not mean, obviously, that in an oligopoly context we can not obtain such results. For example, in Gal-Or (1987) a Stackelberg leader prefers to observe less precise information when the follower can infer its information from the leader's action.

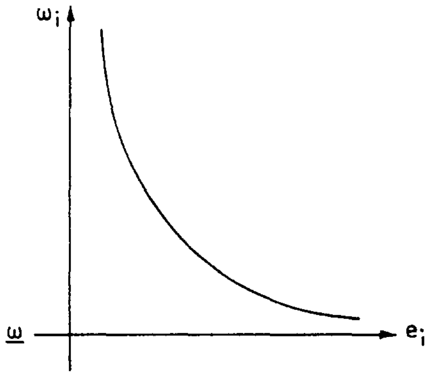

Fig. 1

(best replies are decreasing). In consequence, firm i responds less to information and reduces its profitability.

The plan of the paper is as follows. A deterministic version of the model is considered in section 2 where the basic cost and demand assumptions are laid down. Section 3 introduces uncertainty and the information structure. Competition in the market stage is dealt with in section 4 while section 5 expounds the full game and main results. Concluding remarks follow.

2. The certainty model

There are two firms in the market. Competition proceeds in two stages. Firms may invest first to try to gain a competitive cost or demand advantage for the subsequent market stage. Investment may be in cost reduction or product differentiation effort.

The *competitive position* of firm i will be associated to the parameter ω_i. A lower ω will mean a better competitive demand or cost position. Firm i by expanding e_i will get a position $\omega_i = H_i(e_i)$. It will be more convenient to work with the inverse of H_i, assumed well defined and denoted by G_i. By choosing a position ω_i the firm will expend $G_i(\omega_i)$. $G_i(\cdot)$ will be termed the *innovation possibility curve* of firm i. We assume: $G_i\colon(\underline{\omega}, \infty) \to R_{++}$ is twice-continuously differentiable, strictly decreasing ($G_i' < 0$) and strictly convex ($G_i'' > 0$). Furthermore

$$\lim_{\omega \to \underline{\omega}} G_i(\omega) = \infty \quad \text{and} \quad \lim_{\omega \to \infty} G_i(\omega) = 0.$$

This assumption means that there are decreasing returns to expenditure in order to gain a better position in the market. Fig. 1 depicts $G_i(\cdot)$.

Once the respective competitive positions (ω_i, ω_2) of the firms are established the short run payoff to firm i is given by

$$\pi_i = (\theta - (\beta + \omega_i) y_i - \beta y_j)\, y_i, \qquad j \neq i,\ i = 1, 2,$$

where y_i is the market action of firm i (price or quantity, for example), θ is a positive parameter and β a real number. This parametrization allows for three interpretations of short run competition:

(a) Cournot competition in a homogeneous product market with increasing marginal costs.
(b) Cournot competition with differentiated products and constant marginal costs.
(c) Bertrand competition with differentiated products and constant marginal costs.

With (a) $\beta > 0$ and $\underline{\omega} \geqq 0$. We can rewrite the payoff as

$$\pi_i = (\theta - \beta(q_i + q_j))\, q_i - \omega_i q_i^2.$$

Interpreting the actions as outputs (q) this corresponds to Cournot competition with quadratic costs. Investment lowers then total and marginal costs, MC (see fig. 2).

With (b) $\beta > 0$ and $\underline{\omega} \geqq 0$. The inverse demand for the product of firm i is given by

$$p_i = \theta - (\beta + \omega_i) q_i - \beta q_j.$$

The parameter θ represents the intercept net of the constant marginal production costs. The products are substitutes and demand is downward sloping since $\beta + \omega_i$ and β are both positive and therefore the price firm i can get is decreasing in both outputs. Notice that the own effect dominates the cross effect: $\beta + \omega_i \geqq \beta$. A firm by investing can expand its demand by lowering the own-effect parameter $\beta + \omega$ (see fig. 3).

With (c) $\beta < 0$ and $\underline{\omega} = 2|\beta|$. The demand for the product of firm i is given by

$$q_i = \theta - (\beta + \omega_i) p_i - \beta p_j.$$

Here prices may be taken to be net of the constant marginal cost. The products are gross substitutes and demand is downward sloping since $\beta + \omega_i > 0$ and $\beta < 0$. Again the own effect dominates the cross effect: $\beta + \omega_i > |\beta|$. A firm by investing may expand its demand by lowering the parameter $\beta + \omega$ (see fig. 4).

The model, and consequently the three interpretations, share the property that firm's i first stage investment has a *direct* effect only on its own market

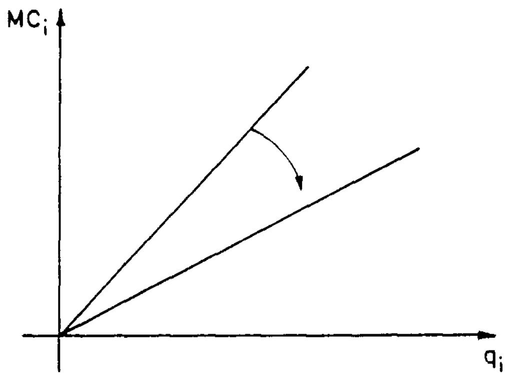

Fig. 2

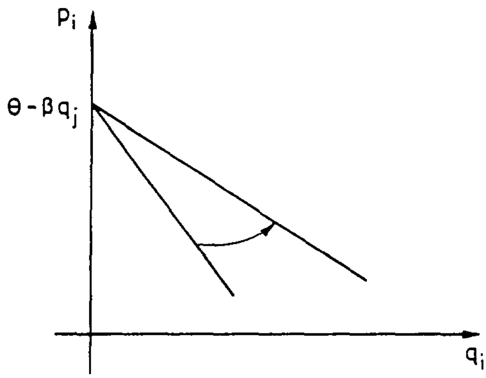

Fig. 3

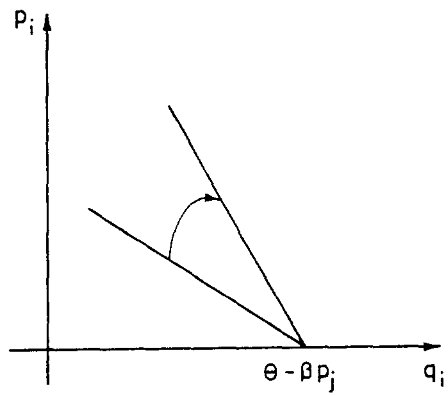

Fig. 4

profitability. That is π_i depends directly only on $\omega_i, i \neq j, i=1,2$. This means in particular that the demand enhancing investments in interpretations (b) and (c) are of different nature. In case (b) (fig. 3) the investment of firm i enlarges its market like if the firm were to get more customers. In case (c) (fig. 4) the investment of the firm results in customers willing to pay more for the good. Each effect could be obtained with a different type of advertising, for example. In any case it is worth remarking again that in both (b) and (c) the advertising effort of a firm improves its relevant demand position without hurting the rivals' position. The relevant position refers to the inverse demand when quantities are the strategic variable and to the direct demand when prices are the strategic variables.

3. The uncertainty game

Let us suppose now that the parameter θ is randomly distributed with mean μ and variance σ^2. Firms will receive private signals once the competitive positions are fixed but before market actions are taken. Firm i receives a noisy estimate s_i of $\theta, s_i=\theta+\varepsilon_i$ where

$$E\varepsilon_i=0, E\varepsilon_i^2=v_i, \quad \mathrm{Cov}(\theta,\varepsilon_i)=\mathrm{Cov}(\varepsilon_i,\varepsilon_j)=0, \quad j\neq i,\ i=1,2.$$

Error terms are independent across firms and with the parameter θ. $1/v_i$ represents the informativeness of the signal received by firm i. When $v_i=0$ information is perfect, when $v_i=\infty$ it is useless. We also assume that $E(\theta|s_i)$ is affine in s_i. It follows then from Ericson (1969) that

$$E(\theta|s_i)=(1-t_i)\cdot\mu+t_is_i, \quad \text{where} \quad t_i=\sigma^2/(\sigma^2+v_i).$$

Furthermore,

$$E(s_j|s_i)=E(\theta|s_i) \quad \text{and} \quad \mathrm{Cov}(s_i,s_j)=\mathrm{Cov}(s_i,\theta)=\sigma^2, \quad j\neq i.$$

The conditional estimate of θ is thus a convex combination of the prior mean μ and of the signal s_i. When information is perfect $(v_i=0)\, t_i=1$ and $E(\theta|s_i)=s_i)=s_i$, when it is useless $(v_i=\infty)$, $t_i=0$ and $E(\theta|s_i)=\mu$. For convenience sometimes we will use t_i as a measure of the precision of information keeping σ^2 fixed.

Information structures which satisfy the assumptions above include the pairs prior–likelihood, Normal–Normal, Beta–Binomial and Gamma–Poisson [see Ericson (1969) and DeGroot (1970) for more examples]. In these examples the sample mean is a sufficient statistic for θ and a more precise signal just means a larger sample.

The structure of the game is as follows. Firms invest first to obtain a competitive position ω, receive private signals and then compete in the marketplace. We will look at subgame perfect equilibria of this two-stage game. Firms choose their first stage investment with a view towards modifying the market game to their advantage.[4] As usual we will deal first with the second stage equilibria, Bayesian–Nash equilibria in our case.

4. Short run competition

Given the respective competitive positions firms compete in the marketplace with incomplete information. It is a computational matter to find the Bayesian–Nash equilibria of the second-stage game given our assumptions. In a Bayesian–Nash equilibrium each firm holds correct conjectures about the behavior of the rival and optimizes accordingly. Quadratic payoffs coupled with the affine information structure yield computable equilibria. Lemma 1 characterises the unique equilibrium given that firms have taken positions (ω_1, ω_2).

Lemma 1. *Given (ω_1, ω_2) with $\omega_i > \omega$, $i=1,2$, there is a unique Bayesian–Nash equilibrium $(y_1(\cdot), y_2(\cdot))$ where*

$$y_i(s_i) = a_i(s_i - \mu) + b_i\mu, \quad \text{with}$$

$$a_i = (2(\beta + \omega_j) - \beta t_j)t_i/D, \quad b_i = a_i\big|_{t_1 = t_2 = 1}, \quad j \neq i,\ i = 1,2,$$

and $D = 4(\beta + \omega_1)(\beta + \omega_2) - \beta^2 t_1 t_2$. Equilibrium expected profits of firm i are $E\pi_i = (\beta + \omega_i)E(y_i(s_i))^2$.

Proof: Standard. See, for example, Basar and Ho (1974) and Vives (1984).

Several *properties* of the market solution are immediate:

(i) the equilibrium actions are certainty equivalent: $Ey_i = b_i\mu$, which corresponds to the Nash equilibrium when $\theta = \mu$ a.s.;

(ii) the responsiveness of the action of firm i to the signal received increases with its precision of information; that is the slope of the strategy, a_i, increases with t_i;

(iii) the responsiveness of the action of firm i to the signal received increases (decreases) with the precision of the rival firm under Bertrand (Cournot) competition; that is, a_i is increasing (decreasing) in t_j if β is negative (positive);

(iv) an increase in the first-stage investment of firm i increases both the expected value of the market action of the firm, $Ey_i = b_i\mu$, and the responsiveness to signals, a_i, since both are decreasing in ω_i;

[4] In Vives (1989) we analyzed in an oligopoly context the effects of increased uncertainty on the strategic commitment and flexibility values of capacity investment.

Table 1

Effect on an increase in.[a]

	t_i	t_j	e_i	e_j
Expected output (Ey_i)	0	0	+	C: − B: +
Responsiveness (a_i)	+	C: − B: +	+	C: − B: +
Expected profits ($E\pi_i$)	+	C: − B: +	+	C: − B: +

[a]C: Cournot, B: Bertrand.

(v) an increase in the first-stage investment of the rival firm j increases (decreases) both the expected value and the responsiveness of the market action of firm i under Bertrand (Cournot) competition: $b_i\ \mu$ and a_i are decreasing (increasing) in ω_i if β is negative (positive).

(vi) equilibrium expected profits for firm i are increasing in the accuracy of its information and decreasing (increasing) in the accuracy of the rival under Cournot (Bertrand) competition.

(vii) equilibrium expected profits for firm i are increasing in the firm's investment and decreasing (increasing) in the rival's investment under Cournot (Bertrand) competition.

The explanation of these properties, summarized in table 1, is as follows: (*i*) is a consequence of quadratic payoffs. According to (*ii*) if the precision of information of a firm increases the firm trusts more the signal received and consequently responds more to it. The intuition for (*iii*) is a little more subtle. Take the Cournot case first. Suppose that firm 1 has perfect information ($t_1 = 1$) and that firm 2 receives a useless signal ($t_2 = 0$), then the equilibrium strategy of firm 2 is flat, $y_2(s_2) = b_2\mu$. If firm 2 has perfect information ($t_2 = 1$) then if demand is high ($s_2 = \theta > \mu$) firm 2 will produce more than $b_2\mu$ and if it is low ($s_2 = \theta < \mu$) it will produce less than $b_2\mu$. Therefore firm 1 wants to produce less when demand is high and more when demand is low than in the case where firm 2 is uniformed. This reflects the fact that best reponses are downward sloping in this context. In the Bertrand case they are upward sloping and when firm 2 is perfectly informed firm 1 wants to put a higher price when demand is high and a lower price when demand is low, reversing the effect of an increase in the precision of information of firm 2.[5]

(*iv*) is not surprising if we think about the types of investment we are

[5]$a_1 = (2(\beta+\omega_1))^{-1}$ when $t_1 = 1$, $t_2 = 0$ and $a_1 = b_1 = (\beta+2\omega_2)/(4(\beta+\omega_1)(\beta+\omega_2)-\beta^2)$ when $t_1 = t_2 = 1$.

considering, lowering the slope of marginal costs or flattening and expanding the demand (inverse in the Cournot case) perceived by the firm. By investing more the firm will produce or price at a higher level in expected terms and also will respond more to information since the net benefits of doing so have increased.
(v) follows from straightforward computation since

$$\operatorname{Sign}\left\{\frac{\partial a_i}{\partial \omega_j}\right\}=\operatorname{Sign}\{\beta t_j(2(\beta+\omega_i)-\beta t_i)\}.$$

The intuition relies again on the different strategic incentives under Cournot or Bertrand. Under Cournot the increase in investment of the rival makes her more aggressive and reduces the expected output of firm i. Under Bertrand the opposite happens, it makes her softer and increases the expected price of firm i. With respect to the reponsiveness a similar reasonement than in the explanation of (iii) applies.
(vi) $E\pi_1=\beta+\omega_1) Ey_1^2$ and $Ey_1^2=a_1^2 \operatorname{Var}(s_1)+b_1^2\mu^2$. Increasing t_1 increases the slope a_1 but decreases $\operatorname{Var}(s_1)=\sigma^2+v_1=\sigma^2/t_1$. Nevertheless the first effect dominates since

$$a_1/t_1=(2(\beta+\omega_2)-\beta t_2)/(4\beta+\omega_1)(\beta+\omega_2)-\beta^2 t_1 t_2)$$

is increasing in t_1. With respect to t_2,

$$\operatorname{Sign}\left\{\frac{\partial E\pi_1}{\partial t_2}\right\}=\operatorname{Sign}\left\{\frac{\partial a_1}{\partial t_2}\right\},$$

and the result follows from (iii).
(vii) Some computations yield

$$\frac{\partial E\pi_1}{\partial \omega_1}=-(\Delta a_1^2 \operatorname{Var}(s_1)+\bar{\Delta} b_1^2 \mu^2),$$

where

$$\Delta=(4(\beta+\omega_1)(\beta+\omega_2)+\beta^2 t_1 t_2)/(4(\beta+\omega_1)(\beta+\omega_2)-\beta^2 t_1 t_2)>0,$$

and $\bar{\Delta}\equiv\Delta|_{t_1=t_2=1}$.

With respect to ω_2,

$$\text{Sign}\left\{\frac{\partial E\pi_1}{\partial \omega_2}\right\}=\text{Sign}\left\{\frac{\partial a_1}{\partial \omega_2}\right\},$$

since $\text{Sign}\{\partial a_1/\partial \omega_2\}=\text{Sign}\{\partial b_1/\partial \omega_2\}$ except when $t_2=0$, in which case $\partial a_1/\partial \omega_2=0$.

It is interesting to note that our quadratic-affine model allows for the separation of the two effects of an increase in investment of a firm on its rival. One effect is the usual one of investment on the *aggressiveness/softness* of the firm which affect the expected level of the market actions (be it prices or quantities). This has been documented and classified by Fudenberg and Tirole (1983) in a certainty world.[6] Under uncertainty with private information there is still the effect on the *responsiveness* of the firms to the signals received. Suppose that firm 2 uses the strategy

$$\hat{y}_2(s_2)=\hat{a}_2(s_2-\mu)+\hat{b}_2\mu,$$

then the best response of firm 1 can be thought as the usual one under certainty, responding to the expected level of firm 2's action $E\hat{y}_2=\hat{b}_2\mu$, when $\theta=\mu$ a.s. plus a correction according to the signal received which has zero expectation:

$$\hat{y}_1(s_1)=\frac{1-\beta\hat{b}_2}{2(\beta+\omega_1)}\mu+\frac{1-\beta\hat{a}_2}{2(\beta+\omega_1)}t_1(s_1-\mu). \qquad (*)$$

First stage investment increases both the expected level and the responsiveness to information of the market action of the firm since it decreases ω_1. The increase in the former makes the firm tough under Cournot and soft under Bertrand competition. The increase in the latter makes the firm *flexible* under both types of competition. These effects are good for expected profits since $E\pi_1=(\beta+\omega_1)Ey_1^2$. *In equilibrium* an increase in investment of firm 2 will increase the reponsiveness of firm 2 and decrease (increase) the responsiveness of firm 1 under Cournot (Bertrand) competition.

It is worth remarking that the information precision of firms has no *direct* effect on the agressiveness at the market stage. (The first summand of the right hand side of (*) does not depend on the information precision of the firms.) The effect has to go through the influence of the precision of information on the first stage investment levels. This is what we analyze now.

5. Gaining a competitive advantage

Each firm will try to position itself in a good competitive position via first period expenditures anticipating the outcome of the market stage. We will

[6]See also Bulow et al. (1983).

show first that under a convexity assumption on the innovation possibility curves of the firms (G_i) this competition results in a unique equilibrium.

Let $r_i(\omega_i)=\omega_i G_i''(\omega_i)/|G_i'(\omega_i)|$, $i=1,2$. $r_i(\cdot)$ is an index of convexity of $G_i(\cdot)$.

Proposition 1. Given the precision of information of the firms $t=(t_1,t_2)$, *if* $r_i(\cdot)$ *is large enough for* $i=1,2$, *there is a unique subgame perfect equilibrium of the two-stage game,* $\omega^*=(\omega_1^*,\omega_2^*)$. *The equilibrium is the unique solution to the equations* ($i=1,2$):

$$\Phi_i(\omega;t)\equiv -\left[\left(1+\frac{2t_1t_2\beta^2}{D}\right)\frac{a_i^2}{t_i}\,\sigma^2+\left(1+\frac{2\beta^2}{D}\right)b_i^2\mu^2\right]-G_i'(\omega_i)=0.$$

Proof. From Lemma 1 given (ω_1,ω_2) the expected profits of firm 1 are $E\pi_i=(\beta+\omega_i)E(y_i(s_i))^2$. Therefore the total payoff to the firm is

$$P_i(\omega_1,\omega_2)=(\beta+\omega_i)\ E(y_i(s_i))^2-G_i(\omega_i).$$

It can be shown, provided $r_i(\cdot)$ is large enough (proof available on request):
(*i*) P_i is strongly quasiconcave[7] in ω_i and therefore
(*ii*) firm i has a well defined continuously differentiable best reponse function $BR_i(\omega_j)$ which is decreasing (increasing) in ω_j, $j\neq i$ in the Cournot (Bertrand) case.
(*iii*) We may restrict attention to a compact rectangle Ω in R^2_{++}

$$\Omega=[\underline{\omega}_1,\bar{\omega}_1]x[\underline{\omega}_2,\bar{\omega}_2]\quad\text{where}\quad \underline{\omega}_i=\inf_{\omega_j}BR_i(\underline{\omega}),$$

and $\bar{\omega}=\sup_{\omega_j}BR_i(\omega_j)$. See figs. 5 and 6 for the Cournot and Bertrand cases respectively.

Furthermore from the quasiconcavity of P_i with respect to ω_i it follows that the vector of marginal profits points in at the boundary of Ω:

$$\lim_{\omega_i\to\bar{\omega}_i}\frac{\partial P_i}{\partial\omega_1}<0\quad\text{and}\quad\lim_{\omega_i\to\underline{\omega}_i}\frac{\partial P_i}{\partial\omega_i}>0$$

for all $\omega_j\in\Omega_j$, $j\neq i$, $i=1,2$ and therefore the equilibrium will satisfy the first order conditions (FOC),

[7]We say that the twice-continuously differentiable function $f:\mathbb{R}\to\mathbb{R}$ is *strongly quasiconcave* if $f'=0$ implies that $f''<0$.

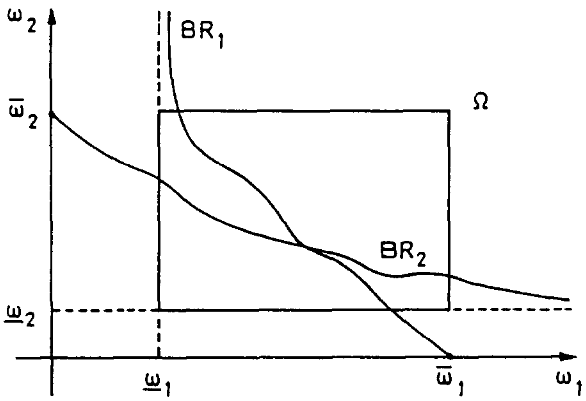

Fig. 5. Cournot case.

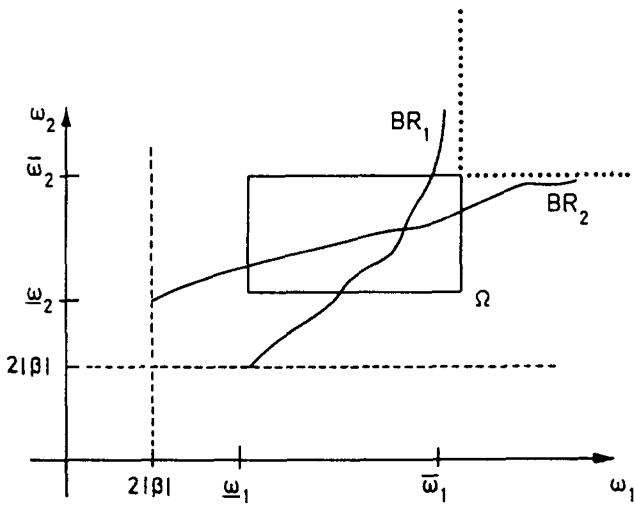

Fig. 6. Bertrand case.

$$\Phi \equiv \frac{\partial P_i}{\partial \omega_i} = 0, \quad i = 1,2.$$

It follows from the Poincaré–Hopf Index Theorem [see Gillemin and Pollack (1974, p. 134), for example] that if $\Phi: \Omega \to R^2$, where Ω is a compact rectangle of R^2_{++}, Φ points in at the boundary of Ω and the determinant of $D_\omega \Phi$ is non-zero whenever $\Phi(\omega_1, \omega_2) = 0$ then there is a unique solution to $\Phi(\omega_1, \omega_2) = 0$. Therefore, the equilibrium will be unique according to the

Index Theorem if the Jacobian determinant of $\Phi=(\Phi_1,\Phi_2)$ when evaluated along the FOC is positive.
(iv) $\Phi=0$ implies that $D_\omega\Phi$ is negative definite.
The result then follows since $\det\{D_\omega-(\Phi)\}=\det\{-D_\omega\Phi\}>0$. *Q.E.D.*

We are interested in the comparative static properties of the equilibrium expenditures $G_i(\omega_i^*)$ of the firms with respect to their precision of the information. To this end we need to know how the precision of information of the firms affects the marginal profitability of the investment.

Lemma 2. The marginal profitability of investment of firm i is always increasing in the precision of its information and decreasing (increasing) in the precision of information of the rival firm under Cournot (Bertrand) competition.

Proof. The marginal profitability of the expenditure $G_i(\omega_i)$ is $-\partial P_i/\partial\omega_i$ ($\partial P_i/\partial\omega_i$ is the marginal profitability of lowering ω_i). Consider firm 1. $P_1=E\pi_1-G(\omega_1)$ where

$$E\pi_1=(\beta+\omega_1)\,E(y_1(s_1))^2=(\beta+\omega_1)(a_1^2\,V(s_1)+b^2\mu^2).$$

Since b does not involve v_1 or v_2 and we are interested in comparative statics results with respect to these quantities we may let $\mu=0$ without loss of generality. Fix σ^2. We want to sign $-\partial^2P_1/\partial t_j\partial\omega_1, j=1,2$.

$$-\frac{\partial^2 P_1}{\partial t_j\partial\omega_1}=-\frac{\partial}{\partial t_j}\frac{\partial E\pi_1}{\partial\omega_1}.$$

From the explanation of property (vii) in section 4 we know that $-\partial E\pi_1/\partial\omega_1=\Delta Ey_1^2$ and that Ey_1^2 is increasing in t_1 and decreasing (increasing) in t_2 under Cournot (Bertrand) competition. The marginal profitability of firm 1's investment is increasing in t_1, since Δ is easily seen increasing in t_1. Increasing t_2 in the Cournot case ($\beta>0$) lowers a_1 and therefore decreases Ey_1^2 but Δ increases with t_2. It can be shown (proof available on request) that the first effect dominates and consequently $-\partial E\pi_1/\partial\omega_1$ decreases with t_2. In the Bertrand case increasing t_2 raises both a_1 and Δ therefore the marginal profitability of firm 1 goes up. *Q.E.D.*

We are now ready to state the comparative static properties of our unique equilibrium: $(\omega_1^*(t),\omega_2^*(t))$.

Proposition 2. In equilibrium, the investment of firm i is always increasing in its precision of information and decreasing (increasing) in the rival's precision under Cournot (Bertrand) competition.

Proof. The unique equilibrium $((\omega_1^*(t), \omega_2^*(t))$ is given by the FOC:

$$\Phi_i(\omega; t) = 0, \quad i = 1, 2.$$

We compute the matrix

$$\left[\frac{\partial \omega_i^*}{\partial t_j}\right] = -(D_\omega \Phi)^{-1} D_t \Phi,$$

where $D_\omega \Phi = [\partial \Phi_i / \partial \omega_j]$ and $D_t \Phi = [\partial \Phi_i / \partial t_j]$, $i, j = 1, 2$. We know that $D_\omega \Phi$ is negative definite and therefore the diagonal is negative and $|D_\omega \Phi| > 0$. The off-diagonal terms are negative (positive) since best responses are decreasing (increasing) under Cournot (Bertrand). According to Lemma 2 the diagonal elements of $D_t \Phi$ are always negative and the off-diagonal elements are positive (negative) under Cournot (Bertrand).

In summary, under Cournot,

$$\left[\frac{\partial \omega_i^*}{\partial t_j}\right] = -\frac{1}{+}\begin{bmatrix} - & + \\ + & - \end{bmatrix}\begin{bmatrix} - & + \\ + & - \end{bmatrix} = \begin{bmatrix} - & + \\ + & - \end{bmatrix},$$

and, under Bertrand,

$$\left[\frac{\partial \omega_i^*}{\partial t_j}\right] = -\frac{1}{+}\begin{bmatrix} - & - \\ - & - \end{bmatrix}\begin{bmatrix} - & - \\ - & - \end{bmatrix} = \begin{bmatrix} - & - \\ - & - \end{bmatrix}. \qquad \text{Q.E.D.}$$

The intuition for Proposition 2 is quite simple. We will deal with the Cournot case first. Given the precision of the information of the firms, consider an initial equilibrium situation (ω_1^0, ω_2^0) as in fig. 7 and suppose that the precision of firm 1 increases. We know then that the best reponse function of firm 1 will shift inwards since, according to Lemma 2, the marginal profitability of investing has increased and given any ω_2 firm 1 will choose a lower ω_1. Similarly the best response function of firm 2 will shift outwards since its marginal profitability has declined. This means that at the new equilibrium $(\hat{\omega}_1, \hat{\omega}_2)$, $\hat{\omega}_1 < \omega_1^0$ and $\hat{\omega}_2 > \omega_2^0$ since best responses are decreasing. Note that both the effect of better information on the marginal profitability of the investment and the character of competition with downward sloping best response functions play a role.

The Bertrand case follows. Consider again an initial equilibrium position ω^0 as in fig. 8 and suppose the precision of firm 1 increases. This moves inwards both best response functions and results in an increase in the

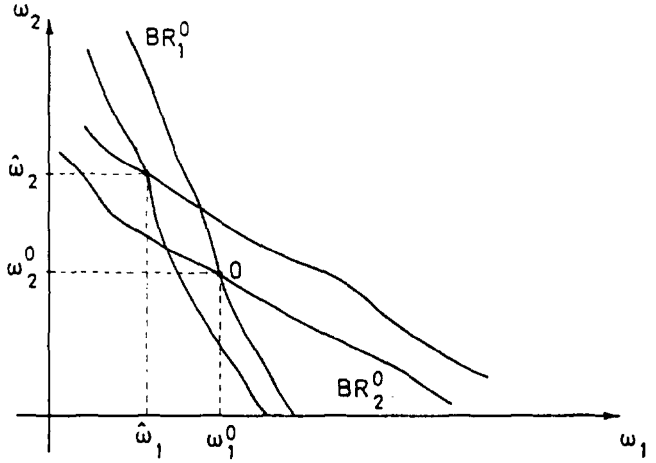

Fig. 7

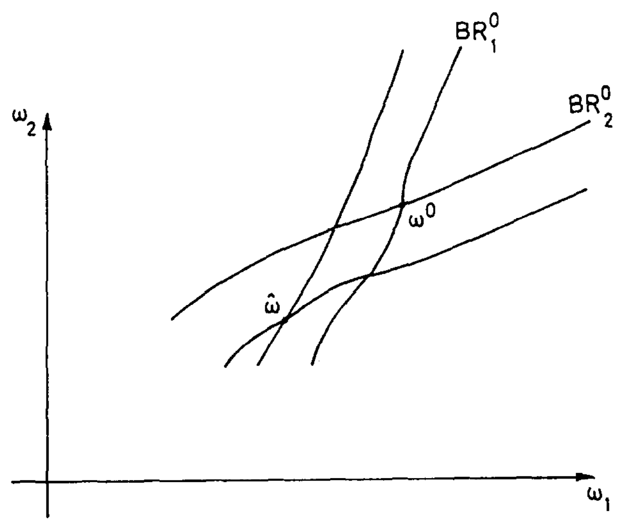

Fig. 8

equilibrium investment of *both* firms since best response curves are increasing.

We are interested in understanding how better information makes a firm more profitable. In equilibrium, an increase in the information accuracy of firm $i(t_i)$ affects its expected profits through two channels. Directly, by improving the forecasting ability of the firm at the production stage and consequently changing the short run market equilibrium. Indirectly, by changing the incentives to invest and therefore inducing new competitive positions for the firms. Total equilibrium expected profits for firm i are given by

$$P_i((\omega_1^*(t), \omega_2^*(t); t) \equiv E\pi_i((\omega_1^*(t); t) - G_i((\omega_i^*(t)).$$

Therefore, using the envelope result,

$$\frac{\mathrm{d}P_i}{\mathrm{d}t_i} = \frac{\partial E\pi_i}{\partial t_i} + \frac{\partial E\pi_i}{\partial \omega_j}\frac{\partial \omega_j^*}{\partial t_i}, \qquad j \neq i,\ i = 1,2 \text{ and}$$

$$\frac{\mathrm{d}P_i}{\mathrm{d}t_i} = \frac{\partial E\pi_j}{\partial t_i} + \frac{\partial E\pi_j}{\partial \omega_i}\frac{\partial \omega_i^*}{\partial t_i}, \qquad j \neq i,\ i = 1,2.$$

We know from properties (vi) and (vii) and Proposition 2 that in the Cournot case

$$\text{Sign}\left\{\frac{\mathrm{d}P_i}{\mathrm{d}t_i}\right\} = (+) + (+)(+) = (+),$$

$$\text{Sign}\left\{\frac{\mathrm{d}P_j}{\mathrm{d}t_i}\right\} = (-) + (+)(-) = (-),$$

and that in the Bertrand case,

$$\text{Sign}\left\{\frac{\mathrm{d}P_i}{\mathrm{d}t_j}\right\} = (+) + (-)(-) = (+), \quad i, j = 1,2.$$

In other words, better information for firm i always improves the total profitability of the firm but has a different impact on the rival firm depending on whether competition is in quantities (negative impact) or prices (positive impact). In our context the signs of the direct and indirect effect of better information are the same. Better information has always a positive *direct* impact on market profitability ($\partial E\pi_i/\partial t_i > 0$) and a positive *indirect* impact ($[\partial E\pi_i/\partial \omega_j][\partial \omega_j^*/\partial t_i] > 0$). The direct impact corresponds to the change in the short run market equilibrium induced by the improved information. The indirect impact corresponds to the change in the short run market equilibrium induced by the change in the competitive positions of the firms (ω_1, ω_2) due to the improved accuracy. Here only the change in the position of the rival matters since the firm is at an optimum. Thus better information for firm i is good because given the positions in the market, it makes the firm more responsive and further because it induces a favorable change, from the point of view of firm i, in the competitive position of the rival firm (less investment in the Cournot case and more in the Bertrand case). The impact on the profitability of the rival firm (j) can be decomposed similarly. In the Cournot case, it has negative direct and indirect effects. The indirect one follows since the competitive position of firm i is improved ($\partial \omega_i^*/\partial t_i < 0$) and this hurts firm j ($\partial E\pi_j/\partial \omega_i > 0$). In the Bertrand case both effects are positive. Improving the precision of firm i fosters the position of the firm but this is good for the rival since it means firm i will price less aggressively ($E\pi_j/\partial \omega_i < 0$). The results are summarized in Proposition 3.

Proposition 3. Better information for a firm: (a) enhances always its profitability; (b) enhances (diminishes) the rival's profitability under Bertrand (Cournot) competition.

6. Concluding remarks

Our investigation has tried to clarify the link between information and competitive advantage. Although our very simple duopoly model certainly can not encompass all the relevant aspects of industry competition between Japanese and American firms (both Japanese and American firms compete also among each other, for example) it is nevertheless supportive of the interpretation that MITI's policies, which result in an improved accuracy of information for Japanese firms, are a source of competitive advantage. Nevertheless this should not worry American and European competitors in markets characterized by price competition since they are also good for them. In contrast in markets where quantity competition prevails international competitors may be hurt and this leaves open the question of what measures of public policy would enhance information pooling in the U.S. and Europe.

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