Information Acquisition and Entry

Sjaak Hurkens*
Department of Economics
Universitat Pompeu Fabra
Ramon Trias Fargas 25-27
08005 Barcelona, Spain

Nir Vulkan*
Department of Economics
University of Bristol
8 Woodland Road, BS8 1TN
Bristol, UK

May 2000

Abstract

This paper provides a framework for explicitly modelling the information gathering activities of potential entrants and analyzes how entry behavior is affected by these activities. We assume that information is acquired *secretly* and that firms face uncertainty about *more than one variable*. When costs of information gathering are small, entry decisions are *as if* firms had perfect information so that lack of information cannot cause too much nor too little entry. This *as if* behavior is even exhibited in specialization equilibria in which different firms obtain information about few but distinct variables. Such equilibria are both socially desirable and robust.

Keywords: Secret Information Acquisition; Entry.

Journal of Economic Literature Classification Numbers: C70, D80, M31.

*We thank Ken Binmore, Tilman Börgers, Gary Charness, Roland Strausz, an anonymous referee, the associate editor and the co-editor for helpful comments. Hurkens gratefully acknowledges financial support from EC grant ERBCHGCT 93-0462, Generalitat de Catalunya (1999SGR 00157) and from the DGES (PB96-0302).

1 Introduction

Understanding entry is an important goal of the modern theory of industrial organization, since the structure of any market is determined to a large extent by the entry decisions of potential entrants. The key to these decisions lies in the enormous risk faced by entrants, especially in the case of a new market: Firms may be uncertain about both demand and cost of production.

However, firms can and do try to reduce uncertainty concerning post-entry profitability by gathering information about the variable factors that determine this profitability. For example, a firm may hire the services of a consulting agency or set up its own market research department. How (much) uncertainty about future profits is resolved is likely to affect the decision of a firm concerning whether to enter. Incorporating the information gathering and entry decisions of the firm into one model is therefore of great relevance to economic theory and to industrial organization and market structure in particular. The purpose of this paper is to provide a general framework for explicitly modelling the information gathering activities by potential entrants, and to examine the role of such activities in determining entry behavior and, consequently, the market structure which eventually will emerge.

Information acquisition has not been addressed in the literature on entry, but it has received some attention in the industrial organization literature on price and quantity competition. Ponssard (1979) and Ockenfels (1989) consider an oligopolistic market where demand is stochastic. Each firm may choose to perfectly learn (at some cost) the demand prior to its quantity decision.[1] Here firms can guarantee nonnegative profits by not producing so that the issue of entry does not arise.[2] However, if firms have to sink investments to enter a market with uncertain profitability, they better acquire information *before* even entering the market. This is the subject of our paper.

Our modelling of uncertainty and information acquisition differs in two ways from

[1]Some more recent papers (Chang and Lee (1992), Hwang (1993, 1995), Li *et. al.* (1987) and Vives (1988)) have generalized Ponssard's model by allowing firms to choose the precision of their signal about demand from a continuum (as opposed to Ponssard's binary choice between no learning and perfect learning).

[2]Ockenfels' model is rather special in that it assumes that firms either produce one unit or do not produce at all. Producing firms incur a fixed cost. The number of firms that can produce and have positive profits is determined by the state of demand. This model can be interpreted as an entry model where the profit of entrants (*i.e.,* producing firms) is simply determined by the number of entrants and the state of demand. As we will see shortly, this model is closely related to our model of entry.

the above-mentioned papers. First, our model is more general as we allow for multidimensional uncertainty: There may be several stochastic variables (for example, demand and cost) that affect profitability. Secondly, we consider *secret* information acquisition, so that a firm cannot observe whether its rival entrants have acquired information.

We obtain two types of positive results for the case of small but positive information costs. First, entry decisions are *as if* firms had perfect information about the state of the world (Propositions 1 and 2 in section 2). This does not necessarily mean that all firms gather all information; it does imply, however, that lack of information cannot cause too much or too little entry. Second, there may be multiple equilibria that exhibit the *as if*-behavior. In some of these equilibria firms specialize: Firms become informed about only few variables, with different firms becoming informed about different variables. In other equilibria many firms learn about all variables. The latter equilibria are socially undesirable because many firms do the same research and substantial time and money are wasted. The socially desirable specialization equilibrium is shown to be robust to several variations and perturbations of the model, whereas the undesirable equilibria are not: The specialization equilibrium is feasible for a wider range of information cost parameters, complexity constraints cannot destroy it, and firms have no incentives to free ride on other firms' research efforts.

The rest of the paper is organized in the following way. In the next section we introduce the formal model of secret information acquisition in an entry game and we state and prove the propositions about the limiting case when costs of information tend to zero. In section 3 we characterize the structure of equilibria when information costs are small, and argue that those equilibria where firms specialize are more robust. In section 4 we describe behavior when information costs can be high, and we give a detailed example of two firms facing uncertainty about two variables. In section 5 we show, by means of an example, that our propositions do not hold when information acquisition is not secret but instead is modelled in the traditional way. Section 6 concludes.

2 The Model

Firms face uncertainty about several stochastic variables that influence the profitability of the market. For example, firms may be uncertain about the costs of labor, material, distribution and advertising and about factors as fashion, the weather, income distribution of consumers and the state of the economy that jointly determine demand. Firms can learn the outcome of each variable by investing some resources in research. Each firm must decide about which variables it wants to be informed. After having obtained this information firms then decide whether or not to enter. We assume that a firm cannot observe whether other firms have gathered information so that its entry decision cannot depend on the information gathering activity of rival firms. That is, we consider *secret* information gathering. [3]

We imagine that after entry has taken place firms compete in an oligopolistic market, but we do not explicitly model this final stage. Instead, we assume that an entrant's payoff is a function of the number of firms that enter and on the joint realization of all the stochastic variables. Our modelling choice is justified if the initial uncertainty about market profitability is resolved after entry has taken place but before competition begins. This might occur when the physical process of entry (*e.g.*, building up capacity) is slow and information about underlying variables is revealed over time. In this case the competition stage takes place under perfect information and will (under general assumptions) have a unique equilibrium (in which the payoffs depend on the joint realization of the stochastic variables and the number of firms that entered). Even if no extra information is revealed during the process of entry, entrants who only became informed about one variable may be able to infer some information about other variables by observing which other firms entered. In fact, in the equilibria of our model entrants will be able to infer perfectly all information about all variables. For example, if in equilibrium firm A becomes informed about demand and enters only if demand turns out to be *High,* all other entrants can deduce that demand is *High* from the fact that firm A entered. This is even so if none of the other firms decided to gather information about demand.

We will now formally introduce the model. There are n identical firms that have to decide whether to enter a market. The profitability of this market depends on the state of the world, $\omega \in \Omega$, which is an N-tuple $(x_1, \cdots, x_N)$. Each variable x_i is the outcome of a discrete random variable X_i and can take two values, *Good* or *Bad*. Let $K = |\Omega| = 2^N$ denote the number of states and denote by $\rho : \Omega \to (0, 1]$ the probability distribution over the states of the world induced by the variables X_i. Every state ω corresponds to an entry game $g(\omega) = (A, u^\omega)$, where $A_i = \{e, d\}\ \forall i$. A firm that chooses action d (don't enter) receives a profit of zero. The profit of a firm that chooses e (enter) depends on the state of the world ω and on the total number of firms that enter, k. We denote this profit by $\pi(\omega, k)$. Profits are decreasing in the number of firms that choose to enter. Hence, for each ω there exists a unique number $0 \leq k(\omega) \leq n$ such that if $k(\omega)$ or less

[3] The alternative would be to follow the existing literature on information acquisition and assume a two-stage process. In section 5 we do this and show that results change drastically.

firms enter they will make a strictly positive profit, and if more choose to enter they will make a loss. These assumptions imply that the pure equilibria of $g(\omega)$ are those where exactly $k(\omega)$ firms enter. Firms are identical, so that any subset of $k(\omega)$ firms can enter.

Now we are ready to introduce the information acquisition and entry game, which we will denote by Γ. We will start with a description of the available strategies. A firm can learn whether the realization is *Good* or *Bad* for any of the variables. It has to decide for which variables it wants to learn the realization and, after observing those realizations, it must decide whether or not to enter. Suppose firm j chooses to be informed about the variables in some subset $I_j \subset \{X_1, ..., X_N\}$. Clearly, if two states ω and ω' differ only with respect to variables not included in I_j, firm j will not be able to distinguish these two states and must therefore make the same entry decision in those states. Formally then, a strategy for firm j in Γ is a pair (I_j, s_j), where I_j denotes the set of variables to be informed about and where $s_j : \Omega \to \{e, d\}$ is such that $s_j(\omega) = s_j(\omega')$ whenever $\omega_{I_j} = \omega'_{I_j}$. (That is, s_j is *measurable* with respect to I_j.)

Regarding the payoff structure, consider the strategy profile $(I, s) = ((I_1, s_1), ..., (I_n, s_n))$. Let $E[(I, s), \omega]$ denote the number of firms that will enter in state ω according to this profile. That is,

$$E[(I,s),\omega] = \#\left\{i : s_i(\omega) = e\right\}.$$

The payoff for firm j is the expected payoff in $g(\omega)$ over all $\omega \in \Omega$ minus the cost of acquiring information, $c(I_j)$. That is,

$$\Pi_j(I,s) = \left(\sum_{\omega \text{ s.t. } s_j(\omega)=e} \rho(\omega) \cdot \pi\left(\omega, E[(I,s),\omega]\right) \right) - c(I_j).$$

We assume that $c(\emptyset) = 0$ and that $I \subset I'$ implies that $c(I') > c(I)$. That is, learning about additional variables is costly.

We are now ready to state, prove and discuss our main results. Clearly, the equilibria of Γ will generally depend on the costs of information gathering. In particular, if costs are prohibitively large, no player will gather any information. Hence, there will be some fixed number of firms that enter, independent of the state of the world that actually occurs. In some states ω this number will be greater than $k(\omega)$, whereas in other states ω' this number will be smaller than $k(\omega')$. Too little or too much entry could also occur for more moderate values of information costs. The next proposition, however, shows that this cannot happen if information costs are very small.

Proposition 1 Fix Ω and $g(\omega)$. Suppose that learning about all variables costs $c > 0$. For small enough c, any equilibrium of the information acquisition and entry game induces an equilibrium in each entry game $g(\omega)$.

Proof. Suppose the statement is false. We will derive a contradiction.

Let (I, s) be an equilibrium of Γ that does not induce an equilibrium in $g(\omega)$ for some state ω. Hence, there exists a player j whose entry decision $s_j(\omega)$ is not optimal in $g(\omega)$, given the decisions of the other firms when state ω occurs. Without loss of generality, assume that $s_j(\omega) = e$ while it would be better to stay out. Let $\varepsilon = -\pi(\omega, E[(I, s), \omega]) > 0$ denote the gain for player j in $g(\omega)$ when he switches to d. Then, for small enough information cost, the strategy (I_j, s_j) cannot be optimal in Γ for player j. Namely, he could deviate by choosing to learn about all variables and then choose $\widetilde{s}_j(\omega) = d$ and $\widetilde{s}_j(\omega') = s_j(\omega')$ for all $\omega' \neq \omega$. This will increase his expected payoff by at least $\rho(\omega)\varepsilon - c$. For small c this deviation is profitable, so that (I, s) cannot be an equilibrium of Γ. $\square$

Note that the proposition only holds if information about *all* variables is cheap. One might think that if information about one variable is cheap, there will be at least one firm that will choose to learn about it. This intuition, however, turns out to be wrong as we show by means of an example in section 4.

Proposition 1 shows that an equilibrium of the information acquisition and entry game implies equilibrium in all entry games, if information costs are small. The opposite also holds, *i.e.* any combination of pure equilibria of the entry games constitutes an equilibrium of the game with endogenous information acquisition.

Proposition 2 For all $\omega \in \Omega$ let s^ω denote a pure Nash equilibrium of $g(\omega)$. Let learning about all variables cost $c > 0$. For small enough c the information acquisition and entry game Γ has an equilibrium (I, s) which induces the play of s^ω in entry game $g(\omega)$.

Proof. For all j let $I_j = \{X_1, ..., X_N\}$ and define $s_j(\omega) = s_j^\omega$ for all ω. That is, each firm learns about all variables and plays in state ω the action s_j^ω. Clearly, s_j is then measurable with respect to I_j so that (I_j, s_j) is a well-defined strategy. Moreover, since s^ω is an equilibrium of $g(\omega)$, no player will want to change his entry decision. However, the strategy profile (I, s) need not be an equilibrium of Γ. It might be that some player can make the same entry decisions with less than full information about the state of the world. In particular, player j need not learn about variable X_i if $s_j(Good, \omega_{-i}) = s_j(Bad, \omega_{-i})$ for all ω_{-i}. Delete all such variables from I_j and call the remaining set $\widetilde{I}_j$. The strategies $(\widetilde{I}_j, s_j)$ do obviously constitute an equilibrium of Γ, and induce the play of s^ω in entry game $g(\omega)$. $\square$

Proposition 1 says that if information costs are very small, in each of the states of the world the players will act *as if* the state of the world was known to all. This does not imply that all firms actually must know the state of the world. In fact, the proof of proposition 2 already shows that firms may be able to make the correct entry decisions with less than perfect information. In the following section we will show that this *as if* behavior can be sustained even when firms gather very small amounts of information. We will even argue that such equilibria are more plausible and robust than those where firms must gather a lot of information.

Propositions 1 and 2 are quite intuitive. Those propositions are almost straightforward in case information is freely available. Small positive information costs do not destroy their validity. What is perhaps more striking, though, is that neither of them hold when information acquisition is observed and entry decisions can be made dependent on the information acquisition decisions of the opponents. In this case, acquisition of information is not only valuable because of the resolution of uncertainty, it also has a strategic value because it may influence the entry behavior of other firms. In fact, *not* acquiring information may have this strategic value (entry deterrence) as well. We will come back to this issue in section 5.

3 Information Structures

If costs of information are small, propositions 1 and 2 tell us that in a pure equilibrium exactly $k(\omega)$ firms will enter in each state ω. The total number of pure equilibria of the game is therefore $\prod_{i=1}^{K} \binom{n}{k(\omega_i)}$, which could be very large. Partly this is caused by the fact that for any equilibrium of the game we can obtain another equilibrium by relabling the firms. Equilibria may, however, also differ with respect to the amount of information gathered. In this section we take a closer look at the information structures that might prevail. We will show that there are equilibria where firms specialize, and others where firms obtain the same information. We will argue that the equilibria with a high degree of shared information are not robust in three respects: increasing information costs, free riding, and complexity restrictions.

To simplify the analysis and the presentation we start under the further assumptions that the number of firms and variables are equal and that in each of the $\binom{n}{k}$ states where exactly k variables are *Good,* there is room for exactly k firms to enter. At the end of this section we will loosen these assumptions a bit.

There are many information structures that support the behavior predicted by proposition 1. In fact, proposition 2 tells us exactly how to construct such an equilibrium. Namely, let γ be a correspondence that assigns to each state ω a subset of firms F, such that the number of *Good* variables determining ω equals the cardinality of F. Now γ corresponds to an equilibrium of the game in which firm i learns the minimal amount of information that allows it to enter in state ω if and only if $i \in \gamma(\omega)$. Learning about all variables will give sufficient information, but there may be cheaper ways to implement the above strategy.

For a pure equilibrium (I, s) we define $\alpha_i(I, s) = 0$ if at most one firm learns about variable X_i, and we define $\alpha_i(I, s) = k - 1$ if k firms learn about variable X_i. Let $\alpha(I, s) = \sum_{i=1}^{n} \alpha_i(I, s)$ denote the degree of shared information in this equilibrium. Let us consider two examples with extreme degrees of shared information.

First, consider the following strategy for firm i: Learn the outcome of all variables and enter if and only if at least i variables are *Good*. It is easy to verify that these strategies form an equilibrium: Namely, when the other firms stick to this strategy and it happens that $m \geq i$ variables are *Good*, $m - 1$ of the other firms will enter. Since there is room for m firms, firm i should enter. On the other hand, if $m' < i$ variables are *Good*, m' of the other firms enter and there is no more room for firm i. It is thus optimal for firm i to stay out in this case. Moreover, the firm cannot apply this entry strategy with less than perfect information about all variables and it is thus optimal to gather information about all variables (when the cost of doing so is small enough).

We denote the equilibrium described above by $(I^{\text{full}}, s^{\text{ineff}})$. Note that the degree of shared knowledge at this equilibrium is $\alpha(I^{\text{full}}, s^{\text{ineff}}) = n(n-1)$. Profits differ from firm to firm. Each firm must incur the maximal information cost. Firm 1 enters always, except when all variables are *Bad*. Firm n, however, only enters when all n variables are *Good*. To sustain this equilibrium the cost of acquiring all this information must be less than the expected profit made by the firm that enters only if all n variables are *Good*. This means that information costs must be very low.

Next, consider the following strategy for firm i: Learn the outcome of the variable X_i and enter if and only if it is *Good*. As before, it is easily verified that these strategies form an equilibrium when the information costs are low enough. Let us denote this equilibrium by (X, s^{eff}). The degree of shared knowledge $\alpha(X, s^{\text{eff}}) = 0$ is minimal. Each firm enters in 2^{n-1} states of the world while only one variable has to be learned. On the other hand, each firm must learn about at least one variable in order to have all firms enter when all variables are *Good* and no firm entering when all variables are *Bad*. So gross profits are relatively high while information costs are at a minimum.

We see that when information costs are small, many equilibria exist which differ with respect to the total amount of money spent on research. They also differ with respect to the degree of shared information. When we now increase the information costs gradually, the equilibria where all firms learn everything will disappear. In particular, $(I^{\text{full}}, s^{\text{ineff}})$, the equilibrium with the highest degree of shared information, is the first to disappear. On the other hand, (X, s^{eff}), where the degree of shared information is minimal, will be the last to disappear. Hence, the equilibria where firms specialize in obtaining information about a particular variable are more robust to increases in information costs.

They are also robust to complexity restrictions. We assumed above that firms can, in principle, decide to obtain as much information as possible by hiring more external market research companies. However, if a firm cannot use the services of external agencies and has to use its own research utilities, then the size of its research unit imposes an exogenous limit on the number of variables it can research, so that $(I^{\text{full}}, s^{\text{ineff}})$ may no longer be a feasible strategy combination.[4]

We now show that (X, s^{eff}) is robust against a third perturbation of the model. Suppose that firms do not always choose their strategies simultaneously. A firm can wait and observe the behavior of the other firms. Without being too formal we observe that $(I^{\text{full}}, s^{\text{ineff}})$ cannot be an equilibrium outcome of this game. This is because the firm that is only supposed to enter when all states are *Good* could free ride on the other firms. When it observes that some other firms did not enter, it can infer that not all states are *Good*. In this case it will decide to stay out without having to spend resources on research. Only when all other firms entered, will more research be needed. In fact, any equilibrium where $\alpha(I, s) > 0$ is subject to some free riding. On the other hand, (X, s^{eff}) will be an equilibrium outcome of this perturbed game. Firms have no incentive to wait in this case because the information obtained by one firm is of no use to any of the other firms.

The assumption that the number of firms is equal to the number of variables is not crucial: If there are more firms than variables $(n > N)$ then any subset of N firms can play the above strategies and the results still hold. (We here still assume that for each *Good* variable one additional firm can enter). In fact, in this case there exist equilibria which involve even more shared information. It may happen that all firms learn all information but each firm enters only in one particular state.

[4]This exogenous limit on the amount of information firms can get is similar to Fershtman and Kalai's (1993) model of bounded complexity.

If $N > n$, (X, s^{eff}) strategies need to be modified. Note that some degree of shared information is unavoidable since each firm will have to learn the outcomes of at least $N - n + 1$ variables. However, equilibria can still be ranked according to the degree of shared information. Compare the above $(I^{\text{full}}, s^{\text{ineff}})$ equilibrium, where $\alpha(I^{\text{full}}, s^{\text{ineff}}) = N(n-1)$, with the following equilibrium strategies $(\widetilde{I}_i, \widetilde{s}_i)$: Firm i learns the outcomes of variables in $\widetilde{I}_i = \{X_i, X_{i+1}, .., X_N\}$ and enters if and only if X_i is *Good*, or at least $n + 1 - i$ variables in the set $\{X_{i+1}, .., X_N\}$ are *Good*. Only 1 firm learns about the outcome of variable X_1 (namely firm 1), while 2 firms learn about variable X_2 (firms 1 and 2), etc. In addition, all firms learn about the outcomes of variables X_{N-n+1} to X_N. In total we get that $\alpha(\widetilde{I}, \widetilde{s}) = \frac{n}{2} - \frac{n^2}{2} + N(n-1) < N(n-1)$.

When the number of firms that can enter is not simply a function of the number of *Good* variables, it is possible that any equilibrium involves some positive degree of shared information and is, therefore, subject to some free riding. Still, the equilibrium with the minimal degree of shared knowledge is least subject to it.

We have argued that the more efficient 'specialization' equilibria are more robust, but the reader may object that the firms face an enormous coordination problem in order to sort out who specializes in which variable. It is true that there exists a coordination problem but this is not due to the endogenous information acquisition and the existence of this coordination problem does not provide a valid argument in favor of the inefficient equilibria. Namely, even if all firms have perfect information about the state of the world there is a huge coordination problem: firms have to sort out who will enter and who will stay out. The proof of proposition 2 shows in fact that the two coordination problems outlined above are of the same magnitude: Once one has figured out which firms enter in each possible state, one knows immediately what information each firm has to learn.

4 A Numerical Example

We have only obtained analytical results for the case of very small information costs. When information costs are very high, we know that firms will not acquire sufficient information and the entry decision will be taken under imperfect information. Entry will take place whenever a firm expects to make positive profits on average. Obviously, this may mean that some firm enters and turns out to make negative profits for some realizations of the variables. Similarly, it may happen that a firm decides to stay out and it turns out that entry would have been profitable. Without assuming a lot of structure on the payoffs and the variables we cannot obtain any analytic result for the case of high information cost. We will therefore simply consider one numerical example to highlight the possible equilibrium configurations in the case of high information costs. The same example will also illustrate the results of Propositions 1 and 2 for the case of low information costs. Moreover, we will use this same example to show that Propositions 1 and 2 do not hold when information acquisition is modelled as the traditional two-stage game.

Two firms decide whether to enter a market. The profitability of this market depends on two parameters (cost and demand) unknown to the firms at the time of the entry decision. Both parameters can only take two values. Demand (cost) is high with probability one half. For convenience, we assume that the two parameters are independent. The profits are given in Figure 1.

	Enter		Don't	
Enter	3	3	4	0
Don't	0	4	0	0

ω_1: High demand, low cost

	Enter		Don't	
Enter	2	2	3	0
Don't	0	3	0	0

ω_2: High demand, high cost

	Enter		Don't	
Enter	-1	-1	2	0
Don't	0	2	0	0

ω_3: Low demand, low cost

	Enter		Don't	
Enter	-3	-3	-1	0
Don't	0	-1	0	0

ω_4: Low demand, high cost

Figure 1.

If demand is high, there is room for both firms to operate profitably, independent of whether the cost is high or low. Even if the other firm decides to enter, it is optimal to enter. However, if demand is low, there is no room for both firms to enter. In fact, when costs are low this market is a natural monopoly and profits can be made only if one firm enters. In case the costs are high, the market is very bad and no profits can be made. In this case no firm wants to enter. Learning the true value of cost (resp. demand) costs c (resp. d). We assume for convenience that finding out about both costs simply $c + d$.

Since information is costly it is strictly dominated to ignore gathered information. We restrict attention to undominated strategies. Let $a_1a_2a_3a_4$ denote the strategy where the firm learns the minimal amount of information that allows it then to choose a_i in state ω_i. For example, *eedd* denotes the strategy "learn demand and enter if and only if demand is high." Note that many of the remaining 16 strategies are strictly dominated. For instance, *dded* is strictly dominated by *eeed*. After eliminating all strictly dominated strategies the game is reduced to a 4×4 game. The strategies the players have in this game are: *eeee*, *eded*, *eedd*, and *eeed*. Since firms are symmetric we write in Figure 2 only the payoffs for firm 1, the row player. The payoffs depend on the two information cost parameters c and d.

	eeee	*eded*	*eedd*	*eeed*
eeee	$\frac{1}{4}$	1	$\frac{3}{2}$	$\frac{3}{4}$
eded	$\frac{1}{2}-c$	$\frac{1}{2}-c$	$\frac{5}{4}-c$	$\frac{1}{2}-c$
eedd	$\frac{5}{4}-d$	$\frac{3}{2}-d$	$\frac{5}{4}-d$	$\frac{5}{4}-d$
eeed	$1-c-d$	$\frac{5}{4}-c-d$	$\frac{7}{4}-c-d$	$1-c-d$

Figure 2.

Figure 3 shows the types of equilibria that exist as a function of the costs of acquiring information.

[Put Figure 3 around here]

Area G corresponds to the propositions 1 and 2: Entry decisions are as if firms had perfect information. When demand is high, both firms enter. When demand and cost are low only one firm can make positive profits and only one firm does indeed enter. In the bad state with low demand and high cost not even a monopolist can make positive profits and indeed no firm enters.

In the other regions information cost are too high and too little or too much entry occurs. For instance, in area B only one firm enters when demand and costs are high, while two firms could profitably co-exist. On the other hand, when demand is low and costs are high, one firm enters and loses money. This firm is compensated for this loss by the high profits it makes as a monopolist in the case of high demand and high costs.

An interesting phenomenon occurs in the part of area F where c is close to zero. In the pure equilibria of this region no firm will choose to learn about costs. The firm that learns about demand cannot gain from learning costs, given the fact that the other firm will always enter. The other firm could gain from learning about costs, because it could prevent entry in the worst state of the world, ω_4. But then the firm also needs to know about demand, otherwise entry in the profitable state ω_2 is impossible. Learning about demand, however, is quite costly.

This example shows the importance of having the possibility to gather information about more than one variable. Suppose that it were impossible to get information about demand. If costs are low (high) firms play the "average" game $\frac{1}{2}g(\omega_1)+\frac{1}{2}g(\omega_3)$ ($\frac{1}{2}g(\omega_2)+\frac{1}{2}g(\omega_4)$, respectively). From proposition 1 it follows that if it is cheap to get information about costs (*i.e.* c close to zero), one firm will learn about it and enter only if costs are low, the other firm will enter without getting information. Now giving the firms the additional possibility to get information about demand at a high cost d (such that (c, d) is in area F) changes the result remarkably: nobody will obtain information about the cheap variable. Our example shows that results that hold in a world of one-dimensional uncertainty, might not hold in a world where uncertainty exists about more than one variable.

5 Observable Information Acquisition

Traditionally, the literature on information acquisition in oligopoly markets (mentioned in the introduction) assumes that each firm observes the information acquisition decisions of its rivals before determining its price or quantity. This observability assumption is convenient since it implies that the model is given by a two-stage game which can be solved using backward induction. Instead, we have assumed that information acquisition is secret since we believe that this scenario is more realistic and, to say the least, deserves attention. In this section we analyze to which extent our secrecy assumption is crucial for our results.

In this section we examine the two-stage version of the numerical example of section 4. In the first stage firms simultaneously choose which variables to be informed about. Before firms make their entry decision in the second stage, they are not only informed about the outcome of their research, but they also know about which variables their competitors are informed. Each firm can make its entry decision thus contingent on the other firm's information acquisition decision.

Each firm has four actions in the first stage: become informed about cost, demand, both or neither. We denote these actions by C, D, $C\&D$ and $\emptyset$, respectively. The second stage has therefore 16 starting points. We will insist that at each of these starting points a continuation equilibrium is played. Formally this means that we take sequential equilibrium as the relevant solution concept.[5] For some choices of variables in the first

[5]Since the move of Nature precedes the moves of the players, there are not many proper subgames and subgame perfection does not have much bite here.

stage there exists a unique continuation equilibrium. For example, in case neither firm learns anything entering is a dominant strategy in the second stage. For other choices of variables, however, multiple continuation equilibria exist. For example, after the choice of $(C\&D, D)$, firms can continue in three ways: (1) firm 1 enters unless demand is low and cost is high, firm 2 enters if demand is high; (2) firm 1 enters if demand is high, firm 2 enters in any case; (3) both firms mix between the strategies used in (1) and (2).[6]

The diagram in Figure 4 lists all continuation equilibria and the corresponding payoffs (excluding the information costs).

	$C\&D$		C		D		$\emptyset$	
$C\&D$	eeed,eedd	7/4,5/4			eeed,eedd	7/4,5/4		
	eedd,eeed	5/4,7/4	eedd,eeee	5/4,6/4	eedd,eeee	5/4,6/4	eedd,eeee	5/4,6/4
	mix	5/4,5/4			mix	5/4,5/4		
C			eded,eeee	2/4,4/4				
	eeee,eedd	6/4,5/4	eeee,eded	4/4,2/4	eeee,eedd	6/4,5/4	eded,eeee	2/4,4/4
			mix	2/4,2/4				
D	eedd,eeed	5/4,7/4			eeee,eedd	6/4,5/4		
	eeee,eedd	6/4,5/4	eedd,eeee	5/4,6/4	eedd,eeee	5/4,6/4	eedd,eeee	5/4,6/4
	mix	5/4,5/4			mix	5/4,5/4		
$\emptyset$	eeee,eedd	6/4,5/4	eeee,eded	4/4,2/4	eeee,eedd	6/4,5/4	eeee,eeee	1/4,1/4

Figure 4.

Now suppose that the costs of acquiring information are small but positive. Consider the strategy profile where firm 1 learns about both variables and where firm 2 learns about demand and where they then continue with playing (*eeed,eedd*). This was the equilibrium outcome of the one-stage game. But it is obvious that this is not an equilibrium outcome here: Firm 2 can deviate and choose (commit) to not obtain any information. In that case player 1 has to revise his second period strategy, because firm 2 will enter in any case. Therefore it will then choose to enter only if demand is high, and ignore its information about costs.

From this diagram it can be easily seen that, if information costs are small but positive, there is essentially a unique pure strategy equilibrium outcome: One firm learns nothing, the other firm learns about demand. To sustain this as an equilibrium outcome, firms

[6]Note that the second equilibrium is somewhat peculiar, since firms do not seem to use their information completely. For instance, learning about demand and entering in any state is a dominated strategy in the one-stage model (secret information gathering game of sections 2 and 3). But here it is a credible threat in order to deter the other firm from becoming fully informed.

must continue with the equilibrium $(eedd, eeee)$, in case the non-learning firm deviates and chooses to become completely informed. Note that the first firm will enter in case of low demand and high costs and will thus make a loss in this state of the world. Entry decisions are not as if firms had perfect information, and propositions 1 and 2 do not hold.

6 Conclusions

This paper provides a number of theoretical benchmark results in relation to entry. The paper relates the information acquisition decision of potential entrants with the final market structure. We base our model on two assumptions we feel are realistic: First, we assume that information is acquired secretly, *i.e.* firms cannot observe the information activities of each other. Second, we assume that firms face uncertainty about several (possibly correlated) variables. These assumptions lead to intuitively appealing results. If information is cheap, firms will buy all the information they need. Lack of information cannot cause inefficiencies in the sense of too much or too little entry. Other types of inefficiencies may arise, however. Some equilibria exhibit socially undesirable amounts of time and money wasted on duplicated market research. However, these inefficient equilibria are vulnerable with respect to increasing information costs, complexity constraints and free riding.

It is worthwhile to recall that our result would not hold in case information acquisition were to be modelled using a two-stage game, which is quite common to models of endogenous information gathering in the industrial organization literature. If information acquisition is observable, then firms may gather insufficient information. A firm that is known to be very well-informed may namely provoke aggressive behavior of the other entrants. As Geroski (1991) points out, it is difficult to observe information gathering in reality, let alone information gathering decisions. This is one reason why econometric studies of entry ignore information gathering, although it is acknowledged as being important to the entry process. If information gathering could be observed by other firms, then incentives would exist for firms to strategically manipulate it, and the predictions of our theoretical models change considerably. In addition to its informative value, acquiring information about some relevant variable could have strategic value.

We have modelled multidimensional uncertainty explicitly. We show that artificially reducing a number of variables into one variable is problematic from a theoretical viewpoint. In a world of multidimensional uncertainty firms have the opportunity to specialize in particular kinds of information. We have argued that the equilibria in which firms specialize and differentiate themselves are socially desirable and quite robust. Moreover, as we have seen in our numerical example, the value of information about a certain variable may well depend on the information that one has or can obtain about other variables. These properties are overlooked by models which only consider one-dimensional uncertainty.

References

CHANG, C.-H., AND LEE C.-W. J. (1992). "Information Acquisition as Business Strategy," *Southern Economic Journal*, **58**, 750-761.

FERSHTMAN, C. AND KALAI, E. (1993). "Complexity Considerations and Market Behavior," *RAND Journal of Economics,* **24**, 224-235.

GEROSKI, P. (1991). *Market Dynamics and Entry.* BLACKWELL: OXFORD, UK.

HWANG, H. (1993). "Optimal Information Acquisition for Heterogeneous Duopoly Firms," *Journal of Economic Theory*, **59**, 385-402.

HWANG, H. (1995). "Information Acquisition and Relative Efficiency of Competitive, Oligopoly, and Monopoly Markets," *International Economic Review*, **36**, 325-340.

LI, L., MCKELVEY, R.D., AND PAGE, T. (1987). "Optimal Research for Cournot Oligopolists," *Journal of Economic Theory*, **42**, 140-166.

OCKENFELS, P. (1989). *Informationsbeschaffung auf homogenen Oligopolmaerkten: eine Spieltheoretische Analyse.* PHYSICA-VERLAG HEIDELBERG.

PONSSARD, J.-P., (1979). "The Strategic Role of Information on the Demand Function in an Oligopolistic Market," *Management Science*, **25**, 243-250.

VIVES, X. (1988). "Aggregation of Information in Large Cournot Markets," *Econometrica*, **56**, 851-876.

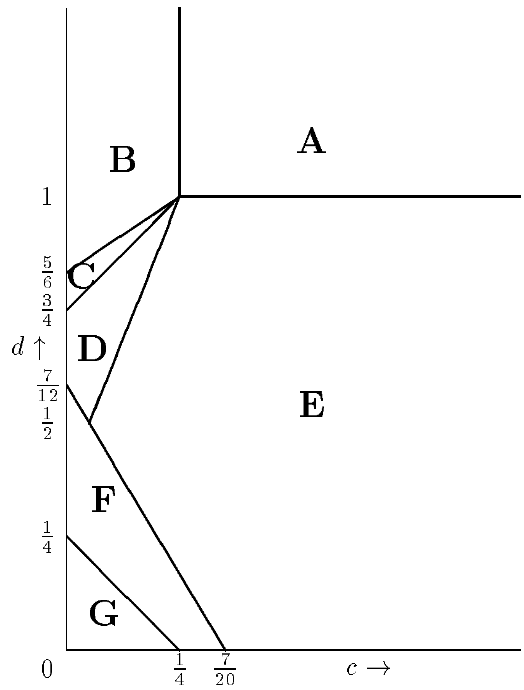

Figure 3: Equilibria of Γ

A: *(eeee, eeee)*
B: *(eeee, eded), (eded, eeee)* and mixed equilibrium with support $\{$*eeee*, *eded*$\}$
C: *(eeee, eded), (eded, eeee)* and mixed equilibrium with support $\{$*eeee*, *eded*, *eeed*$\}$
D: *(eeee, eedd), (eedd, eeee)* and mixed equilibrium with support $\{$*eeee*, *eded*, *eeed*$\}$
E: *(eeee, eedd), (eedd, eeee)* and mixed equilibrium with support $\{$*eeee*, *eedd*$\}$
F: *(eeee, eedd), (eedd, eeee)* and mixed equilibrium with support $\{$*eeee*, *eedd*, *eeed*$\}$
G: *(eeed, eedd), (eedd, eeed)* and mixed equilibrium with support $\{$*eedd*, *eeed*$\}$