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Semi-Empirical Likelihood Estimation of Manufacturing Interaction-Based Model with Asymmetric Information

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Abstract

A semi-empirical likelihood estimator is proposed for models where agents interact under asymmetric information. The methodology focuses on situations where some variables that were privately observed when choices were made become available to the econometrician afterwards. This variables are assumed to have a finite support. The main feature of the estimator is that structural parameters, beliefs and unknown probability distribution function of these privately observed variables are estimated simultaneously under the assumption that observed outcomes are the result of a Bayesian-Nash Equilibrium. The methodology is applied to three-actions and three-types of agents. Firms decide to be aggressive, neutral or passive in their investment decision. Estimation shows a significant component of strategic interaction in the case of small and medium size (type) of firms. Interaction is more significant to small firms than the others.

Keywords: Empirical Likelihood, Asymmetric Information, Bayesian-Nash Equilibrium.

Resumen

Un estimador de máxima verosimilitud semiparamétrico se propone modelos donde interactúan agentes bajo información asimétrica. El econometrista observa realizaciones de las empresas que provienen de cierto comportamiento estratégico. Se hace el supuesto de que los resultados de las decisiones de los agentes provienen de un equilibrio de Nash-Bayesiano con información incompleta y, con base en dicho supuesto, se analizan los determinantes que hacen que las empresas se comporten, en materia de inversión, en forma agresiva, neutral o pasiva, en función de lo que esperan que hagan los otros competidores, según su tamaño: chicos, medianos o grandes.

Se estiman simultáneamente los parámetros que determinan el comportamiento de los agentes, las creencias de lo que los oponentes van a hacer (en promedio) y, finalmente, los parámetros que recogen la interacción estratégica de los agentes. La estimación muestra que la interacción estratégica entre los agentes es significativa en el caso de las empresas pequeñas y medianas, pero que la decisión de las empresas medianas y grandes de ser agresivas afecta más a las empresas pequeñas a la hora de tomar decisiones de inversión.

Palabras clave: interacción estratégica, estimación semiparamétrica, equilibrio de Nash Bayesiano.

Semi-Empirical Likelihood Estimation of Manufacturing Interaction-Based Model with Asymmetric Information

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October 24, 2011

Abstract

A semi-empirical likelihood estimator is proposed for models where agents interact under asymmetric information. The methodology focuses on situations where some variables that were privately observed when choices were made become available to the econometrician afterwards. This variables are assumed to have a finite support. The main feature of the estimator is that structural parameters, beliefs and unknown probability distribution function of these privately observed variables are estimated simultaneously under the assumption that observed outcomes are the result of a Bayesian-Nash Equilibrium. The methodology is applied to three-actions and three-types of agents. Firms decide to be aggressive, neutral or passive in their investment decision. Estimation shows a significant component of strategic interaction in the case of small and medium size (type) of firms. Interaction is more significant to small firms than the others.

Keywords: Empirical Likelihood, Asymmetric Information, Bayesian-Nash Equilibrium.

1 Interaction-Based Models

Econometric analysis of qualitative response models was developed by McFadden (1984). The dependent variable including in the analysis is intrinsically categorical. Qualitative variables could be binomial (yes/no), or multinomial, and multinomial models may be naturally ordered or unordered. In this framework, agents should make their choices in a qualitative sense. But this models do not capture the interaction[1] between the agents. Brock and Durlaf (2001), study "interaction-based models", which are mathematically equivalent to logistic models of discrete choice, Blume (1993) and Broke (1993). By interaction-based models, they refer to "a class of economics environment in which the payoff function of a given agent takes as direct arguments the choices of the other agents".
A natural extension of interaction-based models is those that includes asymmetric information, using game theoretical foundations. Indeed, Aradillas-Lopez (2003), proposed an estimator in order to find the interaction coefficients in a context of economic interaction models with asymmetric information. "The presence of asymmetric information implies that agents must construct beliefs about other' agent". If we assume that observed choices are derived from a Bayesian-Nash equilibrium, this beliefs must be rational and satisfy the conditions consistent with such an equilibrium. Let us illustrate these ideas considering following simple example: suppose we have 2 x 2 game in which players simultaneously (i.e., before observing their opponent's choice) must choose between two actions: "Enter" or "Don't Enter". We can assume the following payoff matrix: without loss of generality:

Figure 1
A simple 2 x 2 game

		PLAYER 2	
		Enter	Don't
PLAYER 1	Enter	$t_1 - \alpha_1, t_2 - \alpha_2$	$t_1, 0$
	Don't	$0, t_2$	0,0

Now suppose that α_1 and α_2 are known by both players but that t_1 and t_2 are private information, but it is common knowledge that they are

[1]Interaction means interdependences between individual decisions which are not mediated by markets, Brock and Durlaf (2001).

both independent random draws from the same -known by both players- distribution with cdf given by $\mathcal{P}(t)$.
Let

π_1=Probability that player 1 choose Enter.
π_2=Probability that player 2 choose Enter.
$E[\pi_2]$≡Player 1's belief that player 2 will choose Enter.
$E[\pi_1]$≡Player 2's belief that player 1 will choose Enter.

Now let $E_1[u_1^{Enter}]$ and $E_2[u_2^{Enter}]$ be the *expected* payoff from playing Enter for players 1 and 2 respectively. Then, due to the linearity of the payoff functions, these expected payoffs are simply given by:

$$E_1[u_1^{Enter}] = t_1 - E_1[\pi_2]\alpha_1 \text{ and } E_2[u_2^{Enter}] = t_2 - E_2[\pi_1]\alpha_2$$

Given the fact that the payoff of "don't enter" has been normalized to be zero in this case, then players 1 and 2 will choose "enter" if and only if $E_1[u_1^{Enter}] > 0$ and $E_2[u_2^{Enter}] > 0$. This imply that Bayesian-Nash equilibrium beliefs must satisfy

$$E_1[\pi_2] = 1 - \mathcal{P}(E_2[\pi_1]\alpha_1) \textit{ and } E_2[\pi_1] = 1 - \mathcal{P}(E_1[\pi_2]\alpha_2) \tag{1}$$

Now, in order to include econometric considerations for estimating beliefs, we need to consider the stochastic characteristics of our game. Payoff functions are unobservable. Suppose t_1 and t_2 can be expressed as a functions of $(\mathbf{X}_1, \varepsilon_1)$ and $(\mathbf{X}_2, \varepsilon_2)$ respectively. The following assumptions preserve the stochastic and informational assumptions of this game.

A1.-$\mathbf{X}_1 \in \mathbb{R}^k$ and $\mathbf{X}_2 \in \mathbb{R}^k$ are independent draws from the same distribution with (joint) cdf given by $F(\boldsymbol{x})$, and corresponding pdf given by $dF(\boldsymbol{x})$

A2.-$\varepsilon_1 \in \mathbb{R}$ and $\varepsilon_2 \in \mathbb{R}$ are independent draws from the same distribution with cdf given by $G(\epsilon)$.

A3.-ε_p is independent from $\mathbf{X}_p$ for $p \in \{1, 2\}$

A4.- *At the time the game is played*, the realizations of $(\mathbf{X}_1, \varepsilon_1)$ and $(\mathbf{X}_2, \varepsilon_2)$ are privately known by players 1 and 2 respectively. This is consistent with the following situations:

A4.1.- Both players deliberately and effectively conceal the true values of $(\mathbf{X}_p, \varepsilon_p)$, $p \in \{1, 2\}$.

A4.2.- It could be possible for a player $p \in \{1, 2\}$ to learn the realization of is opponent's $(\mathbf{X}_{-p}, \varepsilon_{-p})$ but it is not profitable to do so.

A5.- Distributions $(F(\boldsymbol{x}), G(\epsilon))$ are known by both players.

Suppose that, without loose of generality, we can parameterize private information, t_1 and t_2, in the next way:

$$t_1 = \boldsymbol{\beta}'\mathbf{X}_1 - \varepsilon_1, \qquad t_2 = \boldsymbol{\beta}'\mathbf{X}_2 - \varepsilon_2$$

where the parameter vector $\boldsymbol{\beta}$ is known by both players, and is assume to be the same. Then, Bayesian-Nash equilibrium conditions become:

$$\begin{aligned} E_2[\pi_1] &= \int_{\boldsymbol{x}} G(\boldsymbol{\beta}'\mathbf{X}_1 - E_1[\pi_2]\alpha_1) dF(\boldsymbol{x}) \\ E_1[\pi_2] &= \int_{\boldsymbol{x}} G(\boldsymbol{\beta}'\mathbf{X}_2 - E_2[\pi_1]\alpha_1) dF(\boldsymbol{x}) \end{aligned} \tag{2}$$

Now, suppose some time after the game was played by a random sample of M pairs of players, the econometrician has access to the M outcomes and the following is true:

B1.-Assumptions (A1-A5) were satisfied when the game was played by each of the N pairs of players.

B2.-The realizations of $\{\mathbf{X}_{1,i}, \mathbf{X}_{2,i}\}_{i=1}^{M}$ are now available to the econometrician.

B3.-The realizations of $\{\varepsilon_{1,i}, \varepsilon_{2,i}\}_{i=1}^{M}$ are *not* available to the econometrician.

B4.-The distribution $G(\epsilon)$ is assumed to be known -up to a finite number of parameters- to the econometrician.

B5.-No particular functional form is assumed for the distribution of $F(\boldsymbol{x})$. We only assume that this distribution does not depend on any of the payoff parameters, beliefs or the unknown parameters of $G(\epsilon)$.

The methodology proposed here is aimed at the econometric estimation of models that can be characterized by assumptions B1-B5, but in particular it can be applied to models in which all agents can belong to one of a *finite* number of "types", and each type is public information, which is our case. Player's types contain some information about their private payoffs. This would be the case for example if in the model presented above there exists a partition of $\mathbb{R}^k$, say $\{\mathcal{X}_1, ..., \mathcal{X}_T\}$, where $\mathcal{X}_s \cap \mathcal{X}_t = \emptyset$, for all $s \neq t$ and $\mathcal{X}_1 \cup ... \cup \mathcal{X}_T = \mathbb{R}^k$, or, which is the same, $\mathcal{X}_1 \sqcup ... \sqcup \mathcal{X}_T = \mathbb{R}^k$ ($\sqcup$, means *disjoint* union). We say that player p belongs to *type* τ_t if and only if $\boldsymbol{X}_p \in \mathcal{X}_t$.

Then, for all possible applications, the proposal is to estimate *simultaneously* the following elements of the model:

1.- The structural payoff parameters (α_1 ,α_2 and $\boldsymbol{\beta}$ in the model described above)

2.-Agents' beliefs ($E_1[\pi_2]$ and $E_2[\pi_1]$ in the above description)

3.-The unknown parameters of the distribution $G(\epsilon)$ of those variables that are privately observed when the game is played and remain unobservable to the econometrician.

4.- The unknown distribution $dF(\boldsymbol{x})$ of those variables that are privately observed when the game is played, but available afterwards to the econometrician.

Estimation will take place under the assumption that observed outcomes are the result of Bayesian-Nash equilibrium. The link between all of these beliefs is given by the corresponding equilibrium restrictions that these beliefs must satisfy (equation (2) in the example presented above). The issues of existence and uniqueness of an equilibrium are crucial and they will be addressed, along with the asymptotic properties of the proposed model in this paper.

2 Brief overview of empirical likelihood (EL)

Empirical Likelihood (EL) was formally introduced by Owen (1988, 1990, 1991). In its simplest form, EL was proposed as a device to construct non-parametric tests and confidence intervals for a mean of a random variable $Z \in \mathbb{R}$ with unknown probability distribution function (pdf). Suppose we have a random sample $\{Z_i\}_{i=1}^N$ and we wish to test if $E[Z] = \mu$. The optimal weights would be the solution of the problem

$$\max_{\{p_i\}_{i=1}^N} \sum_{i=1}^N \log p_i \quad \text{subject to: } p_i > 0, \ \sum_{i=1}^N p_i = 1 \text{ and } \sum_{i=1}^N p_i Z_i = \mu$$

That is, to maximize the empirical log-likelihood $\sum_{i=1}^N p_i$ subject to the weights being a well-behaved pdf, and the data obeying E[Z]=μ with this pseudo-pdf. Without the constraint $\sum_{i=1}^N p_i Z_i = \mu$, it is easy to show that the uniform weights $p_i = (1/N)\ \forall i$ maximize the empirical log-likelihood. This would be the optimal weights if $\mu = \overline{Z}$ (the sample mean of $\{Z_i\}_{i=1}^N$). Let $(\mu) = \sum_{i=1}^N \log \hat{p}_i$ be the corresponding maximum EL and define the empirical log-likelihood *ratio* $\mathcal{R}(\mu)$ as

$$\mathcal{R}(\mu) = -2 \times \left\{ (\mu) - \sum_{i=1}^N log(1/N) \right\}$$

where $\{p_i\}_{i=1}^N$ are the optimal EL weights. Now let μ_0 the true mean of Z. Owen shoued that under fairly general conditions $\mathcal{R}(\mu_0) \xrightarrow{d} \chi_1^2$. This implies that hypothesis testing and confidence interval could be based on the statistic $\mathcal{R}(\mu_0)$. The α-level confidence interval, for example, would be constructed as the set of $\mu \in \mathbb{R}$ such that $\mathcal{R}(\mu) \leq c_\alpha = 1 - \alpha$. Note that if we wanted to estimate μ by maximizing (μ), we would get $\mu = \overline{Z}$, and the corresponding optimal weights would be the uniform weights $\hat{p}_i = 1/N$.
EL was also applied to deal with moments other than the mean, and to handle vector-valued random variables, where the weights are estimates of a joint pdf. An important extension was done by Qin and Lawless (1994), who applied EL for general estimating equations. Suppose that for a random variable $\mathbf{Z} \in \mathbb{R}^d$ there exist a parameter $\boldsymbol{\theta} \in \mathbb{R}^p$ and a vector valued function $m(\mathbf{Z}, \boldsymbol{\theta}) \in \mathbb{R}^s$ such that $E[m(\mathbf{Z}, \boldsymbol{\theta})] = 0$. For a fixed $\boldsymbol{\theta}$, the corresponding EL problem is to solve

$$\max_{\{p_i\}_{i=1}^N} \sum_{i=1}^N \log p_i \quad \text{subject to: } p_i > 0, \ \sum_{i=1}^N p_i = 1 \text{ and } \sum_{i=1}^N p_i m(\mathbf{Z}, \boldsymbol{\theta}) = 0.$$

Let $(\boldsymbol{\theta}) = \sum_{i=1}^N log \hat{p}_i$ be the corresponding maximum EL. Letting $\boldsymbol{\theta}_0$ be the true parameter value, Qin and Lawless then showed that under some regularity conditions

$$\mathcal{R}(\mu) = -2 \times \left\{ (\boldsymbol{\theta}_0) - \sum_{i=1}^{N} log(1/N) \right\} \xrightarrow{d} \chi^2_q$$

where q is the rank of $Var[m(\mathbf{Z}, \boldsymbol{\theta}_0)]$. Confidence regions can be built and hypothesis can be tested for $\boldsymbol{\theta}$ using the statistic $\mathcal{R}(\boldsymbol{\theta})$. We can also use EL to estimate $\boldsymbol{\theta}$ by maximizing $(\boldsymbol{\theta})$. If p=s, then $\hat{\boldsymbol{\theta}}$ is simply given by the solution of $\sum_{i=1}^{N} m(\mathbf{z}_i, \hat{\boldsymbol{\theta}}) = 0$ and the resulting optimal weights are the uniform ones, $\hat{p}_i = 1/N$. The interest case is when $s > p$. The latter case would be the kind problem econometrician usually analyze using GMM estimation.

EL was also extended to analyze combinations if parametric and empirical likelihoods. Suppose for example that the conditional distribution of $y \in \mathbb{R}$ given $\mathbf{Z} \in \mathbb{R}^k$ is assumed to have a known parametric functional form given by $f(y|\mathbf{Z}, \boldsymbol{\theta})$, but that the marginal pdf of $\mathbf{Z}$ is unknown and denote it by $dF(\mathbf{z})$. The joint pdf of $(Y, \mathbf{Z})$ would then be given by $f(y|\mathbf{z}, \boldsymbol{\theta})dF(\mathbf{z})$. Suppose now that we know that $E[\psi(\mathbf{Z}, \boldsymbol{\theta})] = 0$ for some function $\psi \in \mathbb{R}^p$. EL would estimate $\boldsymbol{\theta}$ and $\{p_i\}_{i=1}^N$ by solving

$$\max_{\boldsymbol{\theta}, \{p_i\}_{i=1}^N} \sum_{i=1}^{N} log\ f(y_i|\boldsymbol{z}_i, \boldsymbol{\theta}) + \sum_{i=1}^{N}\ log\ p_i$$

$$\text{subject to} \quad p_i \geq 0,\ \sum_{i=1}^{N} p_i = 1,\ \sum_{i=1}^{N} p_i \psi(\boldsymbol{z}_i, \boldsymbol{\theta}) = 0$$

Qin (1994, 2000) called the combination of parametric and nonparametric likelihoods "Semi-Empirical Likelihood". Parametric and empirical likelihoods have also been combined in other settings, as in Qin (1998) for upgraded mixture models where one sample $\mathbf{z}_1, ..., \mathbf{z}_n$ is directly observed form a distribution $F(\mathbf{z})$ while another sample $\mathbf{x}_1, ..., \mathbf{x}_n$ have density $\int p(\mathbf{x}|\mathbf{z})dF(\mathbf{z})$ where $p(\mathbf{x}|\mathbf{z})$ is parameterized as $p(\mathbf{x}|\mathbf{z}, \boldsymbol{\theta})$. Parametric and empirical likelihoods have also been combined in Bayesian models. Lazar (2000) analyzed the product of prior density on the univariate mean and an empirical likelihood fort that mean.

Kitamura (2006) has a comprehensive summary of Empirical Likelihood techniques in which study some computational strategies in order to solve the problems studied above. The methodology proposed here is a particular case of semi-empirical likelihood estimation.

2.1 Empirical Likelihood and GMM

Every GMM problem can also be estimated using EL. Asymptotic equivalence to first order approximation between GMM and EL has been well documented in a variety of settings (Owen (2001) and Kitamura(2006)) are the best comprehensive references. It has also been established that EL improves on the small sample properties of GM . However, other closely estimators have also been developed that improve on the small sample properties of GMM. Continuous updating (CUE) -also called “Euclidian Likelihood” by Owen (2001)- and exponential titling estimators (ET). All these belong to a class of Generalized Empirical Likelihood (GEL) estimators. To firs order of approximation, they all have the same asymptotic distribution as GMM but different higer order asymptotic properties. The natural question would be why use EL among the GEL family.

A growing body of literature has been devoted to exploring the higher order asymptotic properties of EL. The majority of these efforts have been aimed at test statistics. EL has been found to have higher order optimality properties consistently better than GMM and at least as good as continuous updating estimators. Kitamura (2001) proves important large deviations optimality results for empirical likelihood vis à vis GMM. Of 32 simulations performed, EL had greatest power 22 times, while 2-step, 10-step and continuous updating did this 5, 7 and 10 times respectively. He also found that EL's power ranking was best for hypothesis farther from the null.
The most relevant results to the problem we address here is Newey and Smith (2001). They compare the properties of GEL and GMM estimators and find that EL has two advantages. First, they show that its asymptotic bias does not grow with the number of moment restrictions, while the bias of the other often grows without bound. Second, they show that the bias corrected EL is asymptotically efficient relative to the other bias corrected estimators.

3 Proposed Application: Investment estrategy model

The methodology presented above can be adapted to a number of different economic situations. Instead of observing n different outcomes of a game played by n different k-tuples of players (as in the example of the previous sections) we may observe a single outcome of a game played by n different players simultaneously. The application presented here corresponds to the latter case.

The 2×2 game describe above was used to illustrate the properties of the proposed empirical likelihood estimator. A brief description of an investment strategy model with asymmetric information is presented here. It involves many players (instead only two) and beliefs (each player has more than one opponent now). In this model firms must simultaneously make an investment decision in an environment of asymmetric information. Then we will defined the meaning of "investment decision" by defining the particular space of actions for this model.

3.1 The model

For firm i denote: $d_i \equiv$ Firm's industry, and $k_i \equiv$ Firm's technological category. Note that $d_i \in \{1, 2, \ldots, D\}$, and $k_i \in \{LT, SS, SL, HT\}$[2].

3.1.1 Timing of firm's decisions

At time t the firm must choose to increase or not investment in period *t+1*. All the firms make this decision simultaneously (i.e., before observing what other firms have optimally chosen to do) and in the context of asymmetric information which will be describe bellow. Denote firms' decisions as follows:

$$Y(i) = \begin{cases} 1 & \text{If firm is } \textit{passive.} \\ \\ 2 & \text{If firm is } \textit{neutral.} \\ \\ 3 & \text{If firm is } \textit{aggressive.} \end{cases}$$

How the firms can be affected by others decisions is explained next.

[2] LT≡low-tech segment, SS≡stable tech-short horizon segment, SL≡stable tech-long horizon segment, and HT≡hi-tech segment. Hall and Vopel (1997)

3.2 Strategic interaction among firms

Economics define investment as the act of incurring an immediate cost in the expectation of future rewards, Dixit and Pindyck (1994). Given the fact that the investment is relatively irreversible, and there is uncertainty to obtain the future expected reward, we expect that firms care about the others' actions in their own decisions because of it could increase (or reduce) the probability of failure in the expected reward of the investment, seen as a sunk cost. Firms interact in many dimensions, but because a firm's relative size in its industry has been consistently cited as a determinant of investment, as well as market structure, the present model will attempt to *analyze how small, medium and large firms interact*. The goal is to answer the following questions:

1.- Do small firms care about the investment decision made by other small firms? Do they care about the decisions made by medium and large firms?

2.-Do medium firms care about the investment decision made by other medium firms? Do they care about the decisions made by small and large firms?

3.-Do large firms care about the investment decision made by other large firms? Do they care about the decisions made by small and medium firms?

Choice rules will modeled in such a way that allows us to test separately the influence of other firms' investment on a particular firm's investment decision. In particular, without lose of generality, we will model how the ith firm could be affected if the others have been "aggressive", in the investment sense.

3.3 Decision rules

We assume that the decision made by the firms are ordered according whit some criteria. Let be the "types", $k = \{S, M, L\}$, if firm is "small", "medium", and "large" respectively:

$$u_i^k = \alpha^S \pi_A^S + \alpha^M \pi_A^M + \alpha^L \pi_A^L + \boldsymbol{\beta}' X_i + \varepsilon_i \tag{3}$$

Were π_A^k is the proportion of the population of size "k" firms that will choose to be aggressive. The remaining variables, $\boldsymbol{X}$ and ε, will be describe below.

3.3.1 Optimal decision rules

Given the ordered nature of our model we can define: let be $\zeta_1 < \zeta_2$ "threshold" parameters (not observed by the econometrician), such that:

$$Y(i) = \begin{cases} 1 \ (passive) & if \ u_i^k \leq \zeta_1 \\ \\ 2 \ (neutral) & if \ \zeta_1 < u_i^k \leq \zeta_2 \\ \\ 3 \ (aggressive) & if \ u_i^k > \zeta_2 \end{cases}$$

Due to the asymmetric information nature of the model, the proportions π_A^S, π_A^M, and π_A^L are not public information. Firms will then maximize the expected version of the payoff function (3). This shall be carefully detail below.

3.4 Strategic interaction

3.4.1 Interaction coefficients

As it was mentioned above, the goal of the model is to estimate the influence of the other firms' choices on an individual firm investment. For a firm of size $k = \{S, M, L\}$, α_A^S, α_A^M, and α_A^L indicate the influence of population of small, medium, and large firms investment decisions respectively, on the firms own investment choice.

3.4.2 Why would firms interact?

Modern models of firm survival argue that a firm's innovation capabilities, which are influenced, for example, by the investment in R&D, determine its chances of surviving in the long run. Is reasonable, then, to think that firms would interact based in long-run consequences of investment.

3.5 Determinants of investment

Tobin's Q compares the capitalized value of a marginal investment in real capital to its replacement cost. According to the net present value (NPV) theory of investment, Aradillas-Lopez (2007), the firms should adjust its investments decisions according to changes in Q_i. Then, we used $\Delta Q_i = Q_{i,t} - Q_{i,t-1}$: level change in Tobin's Q from *t-1* to *t*, as explanatory variable. In order to capture the short-term firm performance we used the percentage change of the sales $\Delta\%S_i = \frac{(S_{i,t} - S_{i,t-1})}{S_{i,t-1}}$. How the firms acted in the past, could influence the future decision, that is why was included the lag of the decision variable, $y_{i,t-1}$: to be passive, neutral or aggressive, in the past period.

3.6 Distributional assumptions

Let $\boldsymbol{X} \equiv \{y_{i,t-1}, \Delta\%S_i, \Delta Q_i\}$. Then, we will assume the following:

i.-$\boldsymbol{X}$ have a unknown joint cdf given by $G_{\boldsymbol{X}}(\boldsymbol{x})$. Whose pdf is denoted as $dG_{\boldsymbol{X}}(\boldsymbol{x})$.

ii.- Conditional of $\boldsymbol{X}$, ε have a marginal cdf given by $F(\epsilon)$. We will assume a particular functional form for this distribution with parameters independent of $\boldsymbol{X}$.

3.7 Informational assumptions

We will make the following assumptions regarding the information structure of the model:

i.- When the firms make their optimal choices, the variables $\boldsymbol{X}$ and ε, are privately known.

ii.- The variables $\boldsymbol{X}$ and ε become available (for the econometrician) some time after the optimal choices have been made. The variable ε, remain unknown to the econometrician.

3.8 Beliefs and equilibrium conditions

As we mentioned above, when making their optimal choices, firms can't observe the population proportions of π_A^S, π_A^M, and π_A^L. Firms will then maximize the expectation in their payoff function (3). Let

$$\begin{aligned} E_i[\pi_A^S] &= \text{Firm i's expectation of } \pi_A^S \\ E_i[\pi_A^M] &= \text{Firm i's expectation of } \pi_A^M \\ E_i[\pi_A^L] &= \text{Firm i's expectation of } \pi_A^L \end{aligned} \tag{4}$$

In equilibrium, due to the informational assumptions of the model, all firms must have the same beliefs. Denote these beliefs as $\bar{\pi}_A^S$, $\bar{\pi}_A^M$, and $\bar{\pi}_A^L$. Linearity of the payoff function (3) allows to simply plug in these beliefs instead of the true probabilities in order to compute expected payoffs, which are described as follows.

$$\bar{u}_i^k = \alpha^S \bar{\pi}_A^S + \alpha^M \bar{\pi}_A^M + \alpha^L \bar{\pi}_A^L + \boldsymbol{\beta'} \boldsymbol{X}_i + \varepsilon_i \tag{5}$$

Then, decisions of the firms will be driven by:

$$Y(i) = \begin{cases} 1 \; (passive) & if \;\; \bar{u}_i^k \leq \zeta_1 \\ \\ 2 \; (neutral) & if \;\; \zeta_1 < \bar{u}_i^k \leq \zeta_2 \\ \\ 3 \; (aggressive) & if \;\; \bar{u}_i^k > \zeta_2 \end{cases} \tag{6}$$

3.9 Estimation and results

3.9.1 Identification

Identification concerns are very important in interaction-based models. This section examines issues related to the proposed model. Denote:

$$\begin{aligned} \boldsymbol{\theta}_1 &= (\bar{\pi}_A^S, \bar{\pi}_A^M, \bar{\pi}_A^L) \\ \boldsymbol{\theta}_2 &= (\alpha^S, \alpha^M, \alpha^L, \zeta_1, \zeta_2, \boldsymbol{\beta})' \\ \boldsymbol{\theta} &= (\boldsymbol{\theta}_1', \boldsymbol{\theta}_2')' \end{aligned} \tag{7}$$

Now let

$$\delta(\boldsymbol{\theta}, \boldsymbol{X}) = \alpha^S \bar{\pi}_A^S + \alpha^M \bar{\pi}_A^M + \alpha^L \bar{\pi}_A^L + \boldsymbol{\beta'} \boldsymbol{X} \tag{8}$$

Conditional of $\boldsymbol{X}$ and $\overline{\boldsymbol{\pi}}_A = \{\bar{\pi}_A^S, \bar{\pi}_A^M, \bar{\pi}_A^L\}$, we have the following results:

$$
\begin{aligned}
Pr(passive|\boldsymbol{X}, \overline{\boldsymbol{\pi}}_A) &= Pr(\boldsymbol{Y} = 1|\boldsymbol{X}, \overline{\boldsymbol{\pi}}_A) = \\
&= Pr(\bar{u}^k \leq \zeta_1) = \\
&= F(\zeta_1 - \delta(\boldsymbol{\theta}, \boldsymbol{X})) \\
Pr(neutral|\boldsymbol{X}, \overline{\boldsymbol{\pi}}_A) &= Pr(\boldsymbol{Y} = 2|\boldsymbol{X}, \overline{\boldsymbol{\pi}}_A) = \\
&= Pr(\zeta_1 < \bar{u}^k \leq \zeta_2) = \\
&= F(\zeta_2 - \delta(\boldsymbol{\theta}, \boldsymbol{X})) - F(\zeta_1 - \delta(\boldsymbol{\theta}, \boldsymbol{X})) \\
Pr(aggressive|\boldsymbol{X}, \overline{\boldsymbol{\pi}}_A) &= Pr(\boldsymbol{Y} = 3|\boldsymbol{X}, \overline{\boldsymbol{\pi}}_A) = \\
&= Pr(\bar{u}^k > \zeta_2) = \\
&= 1 - F(\zeta_2 - \delta(\boldsymbol{\theta}, \boldsymbol{X}))
\end{aligned}
$$

Where $F(\bullet)$ is the cdf of ε. Using last definition, beliefs can be modeled as follows: let be $K = \{S, M, L\}$

$$
\begin{aligned}
\bar{\pi}_A^k &= Pr(aggressive|\boldsymbol{X}, k) = \\
&= Pr(Y = 3|\boldsymbol{X}, k) = \\
&= E_{k=K}[Pr(Y = 3|\boldsymbol{X}, k)|k = K] = \\
&= \frac{\sum_{i=1}^{N}[1 - F(\zeta_2 - \delta(\boldsymbol{\theta}, \boldsymbol{X}))]\mathbf{1}\{k = K\}}{\sum_{i=1}^{N}\mathbf{1}\{k = K\}}
\end{aligned} \tag{9}
$$

Define:

$$
\begin{aligned}
\psi_1(\boldsymbol{\theta}, \boldsymbol{X}) &\equiv \bar{\pi}_A^S - \frac{\sum_{i=1}^{N}[1 - F(\zeta_2 - \delta(\boldsymbol{\theta}, \boldsymbol{X}))]\mathbf{1}\{k = S\}}{\sum_{i=1}^{N}\mathbf{1}\{k = S\}} \\
\psi_2(\boldsymbol{\theta}, \boldsymbol{X}) &\equiv \bar{\pi}_A^M - \frac{\sum_{i=1}^{N}[1 - F(\zeta_2 - \delta(\boldsymbol{\theta}, \boldsymbol{X}))]\mathbf{1}\{k = M\}}{\sum_{i=1}^{N}\mathbf{1}\{k = M\}} \\
\psi_3(\boldsymbol{\theta}, \boldsymbol{X}) &\equiv \bar{\pi}_A^L - \frac{\sum_{i=1}^{N}[1 - F(\zeta_2 - \delta(\boldsymbol{\theta}, \boldsymbol{X}))]\mathbf{1}\{k = L\}}{\sum_{i=1}^{N}\mathbf{1}\{k = L\}} \\
\Psi(\boldsymbol{\theta}, \boldsymbol{X}) &\equiv \Big(\psi_1(\boldsymbol{\theta}, \boldsymbol{X}), \psi_2(\boldsymbol{\theta}, \boldsymbol{X}), \psi_3(\boldsymbol{\theta}, \boldsymbol{X})\Big)'
\end{aligned} \tag{10}
$$

Then, Bayesian-Nash Equilibrium beliefs must satisfy

$$\int_{\boldsymbol{x}} \Psi(\boldsymbol{\theta}, X) dG_{\boldsymbol{X}}(\boldsymbol{x}) = \mathbf{0} \tag{11}$$

Existence of equilibria

For a given value of $\boldsymbol{\theta}_2$, we're interested in knowing if there exists a set of believes $\boldsymbol{\theta}_1$ such that the equilibrium condition (11) is satisfied. A sufficient condition for the existence of equilibria is that the marginal distribution of ε be continuous. Existence of equilibria for an arbitrary value of $\boldsymbol{\theta}_2$ follows from Brouwer's Fixed Point Theorem. Therefore, an equilibrium must exist for $\boldsymbol{\theta}_2^0$, the true population values of $\boldsymbol{\theta}_2$. Details are given in the appendix.

Uniqueness of equilibria

The question of uniqueness is a very important one. If, for the true values of $\boldsymbol{\theta}_2$ there exists more than one set of believes $\boldsymbol{\theta}_1$ that satisfy equilibrium condition (11), then we would have to make additional assumptions about which, among the set of equilibrium believes is used by each firm. In our formulation, for example, we would have to assume that all firms use the same equilibrium believes. The question of uniqueness can be analyzed by looking at the Jacobian

$$\nabla_{\boldsymbol{\theta}_1} \int_{\boldsymbol{x}} \Psi(\boldsymbol{\theta}_1, \boldsymbol{\theta}_2^0, \boldsymbol{x}) dG_{\boldsymbol{X}}(\boldsymbol{x}) \tag{12}$$

Where as before $\boldsymbol{\theta}_2^0$ represents the true population values of $\boldsymbol{\theta}_2$. Local unique equilibrium will be guaranteed if the Jacobian

$$\nabla_{\boldsymbol{\theta}_1} \int_{\boldsymbol{x}} \Psi(\boldsymbol{\theta}_1^*, \boldsymbol{\theta}_2^0, \boldsymbol{x}) dG_{\boldsymbol{X}}(\boldsymbol{x})$$

has a rank equal to three -full rank condition-, where $\boldsymbol{\theta}_1^*$ is a solution of

$$\int_{\boldsymbol{x}} \Psi(\boldsymbol{\theta}_1, \boldsymbol{\theta}_2^0, \boldsymbol{x}) dG_{\boldsymbol{X}}(\boldsymbol{x}) = \mathbf{0}$$

A sufficient condition for global uniqueness would be to assume that the Jacobian $\nabla_{\boldsymbol{\theta}_1} \int_{\boldsymbol{x}} \Psi(\boldsymbol{\theta}_1, \boldsymbol{\theta}_2^0, \boldsymbol{x}) dG_{\boldsymbol{X}}(\boldsymbol{x})$ has either: (i) only strictly positive principal minors or (ii) only strictly negative principal minors for all $\boldsymbol{\theta}_1 \in [0,1]^3$. This is a version of Gale-Nikaido theorem that guarantees that

$\int_{\boldsymbol{x}} \Psi(\boldsymbol{\theta}_1, \boldsymbol{\theta}_2^0, \boldsymbol{x}) dG_{\boldsymbol{X}}(\boldsymbol{x})$ is a one-to-one function of $\boldsymbol{\theta}_1$ and therefore, that the equilibrium is unique. Simply put, it says that the Jacobian not only has to be non-singular, but is also has to remain either positive quasi definite or negative quasi definite for all values of $\boldsymbol{\theta}_1$.

Existence and uniqueness have to do with identification of $\boldsymbol{\theta}_1$, the vector of believes. The functional form assumed for the expected payoff function requires two additional condition for the identification of $\boldsymbol{\theta}_2$. These condition are necessary for the asymptotic invertibility of the Hessian for the first order conditions satisfied by the EL estimator.[3]

i.- All equilibrium believes $\boldsymbol{\theta}_1^0$ must be strictly between zero and one. That is, in equilibrium the population probability of choosing the action to be aggressive must be strictly positive and this must hold for all type of firms (S,M,L). This is necessary condition for identification of $\boldsymbol{\theta}_2$.

ii.- The conditional distributions $G(\boldsymbol{X}|k = S)$, $G(\boldsymbol{X}|k = M)$ and $G(\boldsymbol{X}|k = L)$ are not identical. This is a sufficient condition for general values of $\boldsymbol{\theta}_1^0$ but it becomes a necessary one for some nontrivial possible values of $\boldsymbol{\theta}_1^0$.

Conditions (i) and (ii) together simply require that the proposed interaction be meaningful. If (i) is violated, then it would be common knowledge for example, that all small firms choose the same action: they all be neutral, for example. If (ii) is violated, it would imply that there is no strategic interaction that takes place in the type dimension (size): there is nothing essentially different between small and medium firms, etc. Violations to (i) or (ii) seem implausible to reality.

3.9.2 Estimation

Conditional likelihood

Having dealt with identification, we now present the estimator. The log-likelihood function of Y given $\boldsymbol{X}$ is given by:

[3]The role played by these identification condition is parallel to the one played by the conditions necessary to assume invertibility of the information matrix in the usual MLE problems.

$$\begin{aligned} log\ f(Y|\boldsymbol{X},\boldsymbol{\theta}) &= \mathbf{1}\{Y=1\}log[F(\zeta_1-\delta(\boldsymbol{X},\boldsymbol{\theta}))]+ \\ &+ \mathbf{1}\{Y=2\}log[F(\zeta_2-\delta(\boldsymbol{X},\boldsymbol{\theta}))-F(\zeta_1-\delta(\boldsymbol{X},\boldsymbol{\theta}))]+ \\ &+ \mathbf{1}\{Y=3\}log[1-F(\zeta_2-\delta(\boldsymbol{X},\boldsymbol{\theta}))] \qquad (13) \end{aligned}$$

Where $F(\bullet)$ is the ε's cdf.

Empirical Likelihood estimator

The proposed Empirical Likelihood estimator $\hat{\boldsymbol{\theta}}^{EL}$ is the solution to:

$$\max_{\boldsymbol{\theta},\{p_i\}_{i=1}^N} \sum_{i=1}^N log\ f(y_i|\boldsymbol{x}_i,\boldsymbol{\theta}) + \sum_{i=1}^N\ log\ p_i \qquad (14)$$

subject to

$$p_i \geq 0,\ \sum_{i=1}^N p_i = 1,\ \sum_{i=1}^N p_i\Psi(\boldsymbol{x}_i,\boldsymbol{\theta}) = 0 \qquad (15)$$

The asymptotic properties of $\hat{\boldsymbol{\theta}}^{EL}$ are detailed in the appendix. Some of its most important properties are:

1.- $\hat{\boldsymbol{\theta}}^{EL}$ has the same asymptotic distribution as the efficient GMM estimator based on the moment conditions:

$$E[\nabla_{\boldsymbol{\theta}} log\ f(\boldsymbol{Y}|\boldsymbol{X},\boldsymbol{\theta}_0)]\ and\ E[\Psi(\boldsymbol{X},\boldsymbol{\theta}_0)]$$

2.- $\hat{\boldsymbol{\theta}}^{EL}$ is more efficient than the estimator that solves

$$\max_{\boldsymbol{\theta}} \sum_{i=1}^N log\ f(\boldsymbol{y}_i|\boldsymbol{x}_i,\boldsymbol{\theta}) \text{ subject to } \frac{1}{N}\sum_{i=1}^N \Psi(\boldsymbol{x}_i,\boldsymbol{\theta}) = 0$$

i.e. the one that also uses the equilibrium conditions but imposes the uniform weights 1/N. This shows the importance of simultaneously estimating the unknown pdf $dG(\boldsymbol{X})$ and the parameters of interest.

3.- Using additional available information about the population distribution of $\boldsymbol{X}$ increases the efficiency of $\hat{\boldsymbol{\theta}}^{EL}$.

4 Empirical Application

We are trying to know how the firms interact each other given their "type" (size) and their "actions" (be aggressive, neutral or passive), considering that they belongs to a particular "industry". It was studied the United States manufacturing sector in which an "industry" is defined by the SIC classification code (Standard Industrial Classification)[4]. All information was collected from Standard and Poor's Industrial Compustat-North Amercia data set.
Using Compustat we identified 9 of the most numerous industries whose SIC number were {2834, 2836, 3674,3845, 2911, 3089, 3312, 3559, 3714}. They belong to the tech segments 1, 2 and 3, accordingly with Hall and Vopel (1997), whom proposed a classification table for 4-digit SIC industries based on Chandler's technological segments (see appendix for details).
Time period considered here was t={1991, 1993, 1995}. The difference between years is attained in attempt to mitigate the effect of time-dependance. Each industry and every year were treated as a cross-section, then, all observations were pooled together, resulting a sample size of 986[5]. Let PISHIP and PIINV denote the industry-annual price deflators for the value of shipments and total capital expenditures respectively taken from the NBER-CES Manufacturing Database.

Decision variable in our model, $y_{i_{st}}$, was constructed as follows[6]: it was used the rate capital investment, $R_{i_{st}}$, which is equal to $I_{i_{st}}/K_{i_{st-1}}$ where:

$I_{i_{st}}$: net capital investment by firm i. Capital expenditures in property plant and equipment (Compustat item: data30) deflated by PIINV.

$K_{i_{st-1}}$: net capital stock made by firm i at the end of the period t-1. It was measured as the net value of property, plant and equipment (Compustat item: data8)[7], deflated by an annual capital stock deflator which was constructed for each industry using PIINV starting in 1958 and ending

[4]SIC has been replaced by the North American Industrial Classification System (NAICS) codes, which identify companies according to economic, subsector and industry groups. There is a close link between them.

[5]Similar exercises were made for each tech-segment, but results essentially didn't change compared with the data which were pooled.

[6]the subscript i_{st} means: the firm i, which belongs to the SIC "s" at year "t"

[7]This data item is defined in Compustat as "the cost of tangible fixed property used in the production of revenue, less accumulated depreciation".

in 1997[8].

Criteria used for the main variable, $y_{i_{st}}$, was:

$$y_{i_{st}} = \begin{cases} 1 & \text{If } R_{i_{st+1}} \leq 0.75 * R_{i_{st}} \text{ (passive).} \\ 2 & \text{If } 0.75 * R_{i_{st}} < R_{i_{st+1}} \leq 1.25 * R_{i_{st}} \text{ (neutral).} \\ 3 & \text{If } R_{i_{st+1}} > 1.25 * R_{i_{st}} \text{ (aggressive).} \end{cases}$$

It means that the firm is considered *passive* if its rate capital investment in the next period $(t+1)$ is 25% less or equal than the rate at current period (t). The firm is considered *aggressive* if the rate capital investment is 25% greater than the rate of the current period. A firm will be *neutral* if its rate capital investment in t+1 is something in between.

Then we have:

$$y_{i_{st}} = \begin{cases} 1 & \text{365 firms (37.71\%)} \ (passive) \\ 2 & \text{193 firms (19.94\%)} \ (neutral) \\ 3 & \text{410 firms (42.36\%)} \ (aggressive) \end{cases}$$

This try to model the decisions taken by the firms which were supposed that used (5) and (6) as action choice criteria. On the other hand, let be

$S_{i_{st}}$: firms' net sales (Compustat item: data12)[9] deflated by PISHIV. This variable will be used for constructing both: percent change in sales (explanatory variable) and "size" (type of the firms).

4.1 Size (Type of the firm)

Let define $Size_{i_{st}} \equiv \frac{S_{i_{st}}}{median(S_{i_{st}})}$, as the size (type) of the i's firm. We have three "types": *small*, *medium* and *large*. Criteria which define types followed in this paper was:

[8] It was necessary to use a linear projection with the purpose of obtain index's value for the year 1997, assuming constant depreciation rate across all industries.

[9] It was used Employees (Compustat item: data29) as a criteria for determining $Size_{i_{st}}$, but results did not change essentially.

$$Size_{i_{st}} = \begin{cases} S & \text{if i's firm } S_{i_{st}} \leq 1/3 \text{ (Small).} \\ M & \text{if i's firm } S_{i_{st}} \in (1/3, 2/3] \text{ (Medium).} \\ L & \text{if i's firm } S_{i_{st}} > 2/3 \text{ (Large).} \end{cases}$$

It was used the median, instead of mean, with the purpose of getting away extremum values in the construction of the size index.

4.2 Explanatory Variables

Tobin's Q was calculated as in Jovanovic and Rousseau (2003).

$$Q_{i_{st}} = FMV_{i_{st}}/FBV_{i_{st}}$$

Where $FMV_{i_{st}}$ is the *Firm Market Value* which is the addition of current value of common equity (Compustat items: data24×data25), book value of preferred stock (Compustat item: data130) and short and long-term debt (Compustat items: data34×data9). And $FBV_{i_{st}}$ is the *Firm Book Value*, which is the sum of book value of common equity (Compustat item: data60), book value of preferred stock(Compustat item: data130) and short and long-term debt (Compustat items: data34×data9). $\Delta\%S_{i_{st}} = \frac{(S_{i_{st}} - S_{i_{st-1}})}{S_{i_{st-1}}}$, is the percentage change of firm's net sales, were $S_{i_{st}}$ was computed as above. $y_{i_{st-1}}$ was derived using the same criteria what defined $y_{i_{st}}$, but for a period before. Then, we have:

$$\boldsymbol{X}_{i_{st}} = (y_{i_{st-1}}, \Delta\%S_{i_{st}}, \Delta Q_{i_{st}})$$

4.3 Semi-Empirical Likelihood Estimation

Given the fact that we have 3 periods, 9 SIC industry and 3 types (S,M,L), there is 81 "moment condition", i.e., the vector defined in (8) here is 1×81.

$$\Psi(\boldsymbol{\theta}, \boldsymbol{X}) \equiv \Big(\psi_1(\boldsymbol{\theta}, \boldsymbol{X}), \ldots, \psi_{81}(\boldsymbol{\theta}, \boldsymbol{X})\Big)' \tag{16}$$

and should satisfy

$$\int_{\boldsymbol{x}} \Psi(\boldsymbol{\theta}, \boldsymbol{X}) dG_{\boldsymbol{X}}(\boldsymbol{x}) = \boldsymbol{0} \tag{17}$$

4.3.1 ε-distribution

We assume that ε_i is orthogonal to $\mathbf{X}_{i_{st}}$ and believes. It is assumed too that ε_i adopt a logistic distribution.

$$\Lambda(\epsilon) \equiv \frac{e^{\epsilon}}{1+e^{\epsilon}} \tag{18}$$

4.3.2 Conditional likelihood

Under the distributional assumption of ε, and using (8), conditional likelihood function (13) can be expressed as follows:

$$\begin{aligned} log\ f(y_{i_{st}}|\boldsymbol{X}_{i_{st}}, \overline{\boldsymbol{\pi}}_{i_{st}}, \boldsymbol{\theta}) &= \mathbf{1}\{y_{i_{st}}=1\}log[\Lambda(\zeta_1-\delta(\boldsymbol{X}_{i_{st}}, \boldsymbol{\theta}))]+ \\ &+ \mathbf{1}\{y_{i_{st}}=2\}log[\Lambda(\zeta_2-\delta(\boldsymbol{X}_{i_{st}}, \boldsymbol{\theta}))-\Lambda(\zeta_1-\delta(\boldsymbol{X}_{i_{st}}, \boldsymbol{\theta}))]+ \\ &+ \mathbf{1}\{y_{i_{st}}=3\}log[1-\Lambda(\zeta_2-\delta(\boldsymbol{X}_{i_{st}}, \boldsymbol{\theta}))] \end{aligned} \tag{19}$$

Where $\overline{\boldsymbol{\pi}}_{i_{st}} \equiv \{\overline{\pi}^S_{A,i_{st}}, \overline{\pi}^M_{A,i_{st}}, \overline{\pi}^L_{A,i_{st}}\}$, vector of believes.

Then we will get the estimator by solving (for details, see the appendix):

$$\max_{\boldsymbol{\theta}, \{p_{i_{st}}\}_{i_{st}=1}^N} \sum_{i_{st}=1}^{N} log\ f(y_{i_{st}}|\boldsymbol{X}_{i_{st}}, \overline{\boldsymbol{\pi}}_{i_{st}}, \boldsymbol{\theta}) + \sum_{i_{st}=1}^{N}\ log\ p_{i_{st}} \tag{20}$$

subject to

$$p_{i_{st}} \geq 0, \ \sum_{i_{st}=1}^{N} p_{i_{st}} = 1, \ \sum_{i_{st}=1}^{N} p_{i_{st}} \Psi(\boldsymbol{X}_{i_{st}}, \theta) = 0 \tag{21}$$

Using Lagrange multipliers technique, is straightforward to show that

$$\sum_{i_{st}=1}^{N} log\ f(y_{i_{st}}|\boldsymbol{X}_{i_{st}}, \overline{\boldsymbol{\pi}}_{i_{st}}, \boldsymbol{\theta}) - \sum_{i_{st}=1}^{N} log(1+\boldsymbol{\nu}'\Psi(\boldsymbol{X}_{i_{st}}, \boldsymbol{\theta})) - NlogN \tag{22}$$

where $\boldsymbol{\nu} \in \mathbb{R}^{81}$, are Lagrange multipliers.

4.3.3 Estimation results

NPV theory of capital investment predicts a positive coefficient for $\Delta Q_{i_{st}}$, however, economic theory does not provide a clear prediction for the sign of any remaining covariates in $\boldsymbol{X}_{i_{st}}$. Extremum values of the sample were eliminated because they were source of bias.

By solving (22) we found next results summarized in Table 1 and Table 2. All Lagrange multipliers were statistically significant equal to zero:

Table 1. Estimation Results for strategic coefficients

(Standard Errors in parentheses)

α^S	0.7989*
	(0.3574)
α^M	0.6356*
	(0.3082)
α^L	0.3122
	(0.3015)

($*$) Statistically significant at a 5% level.

The estimates for α^S and α^M were significant at 5% confidence level. Both were positive, which means that small and medium firms care about actions of their own type. For example, small firms will be aggressive if they believe that other small firms would be aggressive. Parallel analysis could be made for the medium size firms. On the other hand, the coefficient α^L was not statistical significant. It means that large firms are not affected by decisions made by other large firms.
It was rejected the hypothesis test[10] $H_0 : \alpha^S + \alpha^L = 0$, which means that small firms care about the large firms decisions tending to be aggressive if they believe that large firms will be aggressive. It was rejected too the hypothesis of $H_0 : \alpha^M + \alpha^L = 0$. The analysis for medium firm is the same as in the small case. It can be notice that $|\alpha^S + \alpha^L| > |\alpha^M + \alpha^L|$, and $|\alpha^S| > |\alpha^M| > |\alpha^L|$. This means that small firms are more worry about other decisions than medium and large size firms. Small firms would be aggressive if they believe that medium or large firms would be aggressive. That can be reasonable explained using "survivor" analysis. This idea is confirmed by the fact that the coefficient α^S is statistically more significant than the others.

[10] All hypothesis test were made at 5% level of significance.

Table 2. Estimation Results
for private information variables
(Standard Errors in parentheses)

$y_{i_{st-1}}$	-0.6310*
	(0.0774)
$\Delta\%S_{i_{st}}$	-0.1767*
	(0.0684)
$\Delta Q_{i_{st}}$	0.0937*
	(0.0240)
ζ_1	-1.5137*
	(0.2765)
ζ_2	-0.6005*
	(0.2721)

(∗) Statistically significant at a 5% level.

About private information variables, we can say that the sing of the coefficient $\Delta Q_{i_{st}}$ was significant at 5% confidence level and positive, as predicted by the NPV theory of investment. Coefficient of $\Delta\%S_{i_{st}}$, i.e., the variable that capture the short run behavior of the firms, has negative sing and is significant. It means that, at least in the short run, firms tend to be not aggressive, ceteris paribus. Finally, time period before firms' behavior, $y_{i_{st-1}}$, has a negative significant coefficient. It means that past behavior conduct to the firms to not be aggressive. It could be understood as an adjustment that firms make considering how they did in the past, as if they correct in a conservative way using their past experiences. Finally, both cutoffs were negative and significant at 5% confidence level. It was rejected the hypothesis that $H_0 : \zeta_1 = \zeta_2$, which means that, effectively, there are three decisions to be made: passive, neutral and aggressive[11]. Given (5), we can conclude that firms start to do their decisions at certain desutility level, in particular those that decide to be passive or neutral. This confirm that to be aggressive is the "best" state in this game.

[11]If $\zeta_1 = \zeta_2$, it means that the model should be dichotomic, in other words, decisions variable only would take two actions: be passive or aggressive.

5 Conclusions

Asymmetric information is the appropriate setting for a number of interaction based models. This asymmetric information exists because the players can't observe (at least some of) the variables that determine other players' payoffs and therefore, their choices. Econometric estimation of these models entrails the estimation of players' believes which are almost always unobservable. User proxy variables for these believes is not a satisfactory answer to the problem. However, assuming that the observed behavior is the result of a Bayesian-Nash Equilibrium imply that this believes must satisfy a set of clear-cut conditions. These conditions involve the unknown distribution of the privately observed variables. In a number of cases, portions of these privately observed variables may become available to the econometrician after the game was played.

In this case, estimation seems almost suited for empirical likelihood methods. This allows us to estimate simultaneously the payoff parameters, the believes and the unknown distribution of the privately-observed-available-afterwards-to-the-econometrician variables. Such an estimator was proposed, and its main properties were mentioned. Most importantly, the vast literature on EL shows that it has better small sample properties than GMM -which could also used for these models- it is also computationally more convenient; no first step estimators or weight matrix are needed. Identification issues are very important and uniqueness of equilibrium are important, and thankfully more tractable than they are in general, perfect information models.

An application for investment model was analyzed and estimated here. In this model we have three actions: firms decides to be passive, neutral or aggressive in the investment sense; and there are three types: small, medium and large firms. We analyzed how do they interact each other. We found evidence that the small firms care about the most, about the firms' action of their own type, and those that are form different type (medium and large). Same result can be applied to medium size firms but less strong than small size. Large firms do not care about other actions, maybe because they are "strong" and have certain "self-confidence" at the moment of make their investment decisions, or maybe the market structure could help them.

An extension of this model could be to deal with dynamic models in which be permitted the change of interaction coefficients ("$\alpha' s$") over time. In particular, this model can be extended to deal with panel data structure, but ordered response models in panel data are relatively difficult to estimate, because of the nonlinear structure of the model in which fixed effects do not disappear simply applying the first difference technique (Bo Honore (2002)).

Appendix 1

Existence of equilibria

To prove the existence of a solution of (5), note that the equilibrium conditions

$$\int_{\boldsymbol{x}} \Psi(\boldsymbol{\theta}, X) dG_{\boldsymbol{X}}(\boldsymbol{x}) = \mathbf{0}$$

can be expressed as

$$\begin{aligned}
\bar{\pi}_A^S &= \int_{\boldsymbol{x}} \frac{\sum_{i=1}^N [1 - F(\zeta_2 - \delta(\boldsymbol{\theta}, \boldsymbol{X}))] \mathbf{1}\{k = S\}}{\sum_{i=1}^N \mathbf{1}\{k = S\}} dG_{\boldsymbol{X}}(\boldsymbol{x}) \\
\bar{\pi}_A^M &= \int_{\boldsymbol{x}} \frac{\sum_{i=1}^N [1 - F(\zeta_2 - \delta(\boldsymbol{\theta}, \boldsymbol{X}))] \mathbf{1}\{k = M\}}{\sum_{i=1}^N \mathbf{1}\{k = M\}} dG_{\boldsymbol{X}}(\boldsymbol{x}) \\
\bar{\pi}_A^L &= \int_{\boldsymbol{x}} \frac{\sum_{i=1}^N [1 - F(\zeta_2 - \delta(\boldsymbol{\theta}, \boldsymbol{X}))] \mathbf{1}\{k = L\}}{\sum_{i=1}^N \mathbf{1}\{k = L\}} dG_{\boldsymbol{X}}(\boldsymbol{x})
\end{aligned}$$

Now assuming that the marginal distribution of ε is continuous, so the resulting probabilities are continuous (logistic distribution assumed here satisfy this condition). Then, for an arbitrary value of the parameter $\boldsymbol{\theta}_2$ the right hand side of the equation presented above is a continuous function of the left hand side vector, $\boldsymbol{\theta}_1$. Therefore, the right hand side is a continuous mapping form $[0,1]^3 \times [0,1]^3$ and by Brower's Fixed Point Theorem, it has a fixed point. Since this true for an arbitrary value of $\boldsymbol{\theta}_2$, it must hold for $\boldsymbol{\theta}_2^0$, the true vales of the parameters. This proves that an equilibrium exists.[12]

□

Asymptotic properties of $\hat{\boldsymbol{\theta}}^{\mathbf{EL}}$

Suppose the following conditions are satisfied.

Ap1.- All equilibrium believes are strictly between 0 and 1.

Ap2.- Identification conditions discussed above are satisfied.

[12] In our application, it holds but the mapping is $[0,1]^{81} \times [0,1]^{81}$

Ap3.- The log-likelihood log $f(Y|\boldsymbol{X}, \boldsymbol{\theta})$ satisfy the usual technical conditions for asymptotic consistency and normality of MLE.

Ap4.- The sample jacobian matrix for equilibrium conditions $\frac{1}{N}\sum_{i=1}^{N} \nabla_{\boldsymbol{\theta}}\Psi(\boldsymbol{x}_i, \boldsymbol{\theta})$, converges uniformly in probability to its expected value if $\boldsymbol{\theta}$ converges to $\boldsymbol{\theta}_0$.

A5.- Technical conditions for the asymptotic normality of $\sqrt{N}\frac{1}{N}\sum_{i=1}^{N} \nabla_{\boldsymbol{\theta}}\Psi(\boldsymbol{x}_i, \boldsymbol{\theta}_0)$ are satisfy.

Let

$\mathfrak{I}_0 = Var[f(Y|\boldsymbol{X}, \boldsymbol{\theta}_0)],\ A_0 = E[\nabla_{\boldsymbol{\theta}}\Psi(\boldsymbol{x}_i, \boldsymbol{\theta}_0)],\ B_0 = E[\Psi(\boldsymbol{x}_i, \boldsymbol{\theta}_0)\Psi(\boldsymbol{x}_i, \boldsymbol{\theta}_0)']$

Then we have that:

$$\sqrt{N}(\hat{\boldsymbol{\theta}}^{EL} - \boldsymbol{\theta}_0) \rightarrow^d N(\mathbf{0}, \boldsymbol{\Omega})$$

Where

$$\boldsymbol{\Omega} = (\mathfrak{I}_0 + A_0' B_0^{-1} A_0)^{-1}$$

Proof:
The corresponding Lagrangian for the EL estimation problem is given by

$$\begin{aligned} \mathcal{L} &= \sum_{i=1}^{N} log\ f(y_i|\boldsymbol{x}_i, \boldsymbol{\theta}) + \sum_{i=1}^{N} p_i + \\ &+ \lambda(1 - \sum_{i=1}^{N} p_i) - N\boldsymbol{\nu}' \sum_{i=1}^{N} p_i \Psi(\boldsymbol{x}_i, \boldsymbol{\theta}) \end{aligned}$$

$\lambda \in \mathbb{R}$ *and* $\boldsymbol{\nu} \in \mathbb{R}^3$ are lagrange multipliers.

F.O.C. with respect to p_i yield

$\lambda = N$ and $p_i = \frac{1}{N(1+\boldsymbol{\nu}'\Psi(\boldsymbol{x}_i|\boldsymbol{\theta}))}$, $i = \{1, 2, ..., N\}$.

Plug-in back p_i in our moment condition $\sum_{i=1}^{N} p_i \Psi(\boldsymbol{x}_i, \boldsymbol{\theta}) = 0$, we have:

$$\frac{1}{N}\sum_{i=1}^{N} \frac{\Psi(\boldsymbol{x}_i, \boldsymbol{\theta})}{1 + \boldsymbol{\nu}'\Psi(\boldsymbol{x}_i, \boldsymbol{\theta})} = 0$$

Solving this non linear equation, we can determine: $\hat{\boldsymbol{\nu}}(\boldsymbol{\theta})$. Equivalently, this Lagrange multipliers can be found solving the next minimization problem:

$$\min_{\boldsymbol{\nu}\in\mathbb{R}^3} - \sum_{i_{st}=1}^{N} \log(1+\boldsymbol{\nu}'\Psi(\boldsymbol{x}_i,\boldsymbol{\theta}))$$

Then, we can obtain $\hat{p}_i$, and plugging back in to the joint semi-empirical likelihood:

$$\sum_{i_{st}=1}^{N} \log f(y_i|\boldsymbol{x}_i,\boldsymbol{\theta}) - \sum_{i=1}^{N} \log(1+\boldsymbol{\nu}'\Psi(\boldsymbol{x}_i,\boldsymbol{\theta})) - N \log N$$

$\hat{\boldsymbol{\theta}}^{EL}$ and $\boldsymbol{\nu}$ should satisfy the first order conditions:

$$\begin{aligned} S_{1,N}(\hat{\boldsymbol{\theta}}^{EL},\boldsymbol{\nu}) &\equiv \sum_{i=1}^{N} \nabla_\theta \log f(y_i|\boldsymbol{x}_i,\hat{\boldsymbol{\theta}}^{EL}) - \frac{1}{N}\sum_{i=1}^{N} \frac{\nabla_\theta \Psi(\boldsymbol{x}_i,\hat{\boldsymbol{\theta}}^{EL})'\boldsymbol{\nu}}{1+\boldsymbol{\nu}'\Psi(\boldsymbol{x}_i,\hat{\boldsymbol{\theta}}^{EL})} = 0 \\ S_{2,N}(\hat{\boldsymbol{\theta}}^{EL},\boldsymbol{\nu}) &\equiv \frac{1}{N}\sum_{i=1}^{N} \frac{\Psi(\boldsymbol{x}_i,\hat{\boldsymbol{\theta}}^{EL})}{1+\boldsymbol{\nu}'\Psi(\boldsymbol{x}_i,\hat{\boldsymbol{\theta}}^{EL})} = 0 \end{aligned}$$

Which means that solving (23), we can obtain the expected estimators. Using this estimators, we can determine the asymptotic properties of them as follows.

A first order Taylor series approximation around $(\boldsymbol{\theta}_0, \mathbf{0})$ yields:

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = \begin{pmatrix} S_{1,N}^0 \\ S_{2,N}^0 \end{pmatrix} \begin{pmatrix} -I_N & -A_N' \\ A_N & -B_N \end{pmatrix} \begin{pmatrix} \hat{\boldsymbol{\theta}}^{EL} - \boldsymbol{\theta}_0 \\ \boldsymbol{\nu} \end{pmatrix} + o_p(N^{-1/2})$$

Where,

$$\begin{aligned}
S^0_{1,N} &= \frac{1}{N}\sum_{i=1}^{N} \nabla_{\boldsymbol{\theta}} \log f(y_i|\boldsymbol{x}_i, \boldsymbol{\theta}_0) \\
S^0_{2,N} &= \frac{1}{N}\sum_{i=1}^{N} \Psi(\boldsymbol{x}_i, \boldsymbol{\theta}_0) \\
I_N &= \frac{1}{N}\sum_{i=1}^{N} \nabla_{\boldsymbol{\theta},\boldsymbol{\theta}'} \log f(y_i|\boldsymbol{x}_i, \boldsymbol{\theta}_0) \\
A_N &= \frac{1}{N}\sum_{i=1}^{N} \nabla_{\theta} \Psi(\boldsymbol{x}_i, \boldsymbol{\theta}_0) \\
B_N &= \frac{1}{N}\sum_{i=1}^{N} \Psi(\boldsymbol{x}_i, \boldsymbol{\theta}_0)\Psi(\boldsymbol{x}_i, \boldsymbol{\theta}_0)'
\end{aligned}$$

Then, under regularity conditions, we have:

$$I_N \to^p \mathfrak{I}_0, \quad A_N \to^p A_0, \quad B_N \to^p B_0$$

and

$$\begin{matrix} \sqrt{N} S^0_{1,N} \\ \sqrt{N} S^0_{2,N} \end{matrix} \to^d \mathcal{N}(\mathbf{0}, \boldsymbol{\Sigma}),\ where, \quad \boldsymbol{\Sigma} = \begin{pmatrix} \mathfrak{I}_0 & 0 \\ 0 & B_0 \end{pmatrix}$$

Therefore,

$$\begin{pmatrix} \sqrt{N}(\hat{\boldsymbol{\theta}}^{EL} - \boldsymbol{\theta}_0) \\ \sqrt{N}\boldsymbol{\nu} \end{pmatrix} \to^d \mathcal{N}(\mathbf{0}, \boldsymbol{\Omega})$$

Where,

$$\boldsymbol{\Omega} = \begin{pmatrix} -\mathfrak{I}_0 & -A_0' \\ A_0 & -B_0 \end{pmatrix}^{-1} \begin{pmatrix} \mathfrak{I}_0 & 0 \\ 0 & B_0 \end{pmatrix} \begin{pmatrix} -\mathfrak{I}_0 & -A_0' \\ A_0 & -B_0 \end{pmatrix}^{-1'}$$

and so we get

$$\sqrt{N}(\hat{\boldsymbol{\theta}}^{EL} - \boldsymbol{\theta}_0) \to^d \mathcal{N}(\mathbf{0}, (\mathfrak{I}_0 + A_0' B_0^{-1} A_0)^{-1})$$

As we claimed. □

Appendix 2

Empirical Strategy

In order to reach convergency in the minimization problem exposed above, we can use the logarithm function proposed by Owen (2001):

$$log_*(z) = \begin{cases} log(z) & if\ z > \varepsilon \\ log(\varepsilon) - 1.5 + z/\varepsilon - z^2/(z\varepsilon^2) & if\ z \leq \varepsilon \end{cases}$$

for some $\varepsilon > 0$ (one recommended to use is $\varepsilon = \frac{1}{N}$)

At the same time, the initial values of $\boldsymbol{\nu}$ were values near to 0. Results are presented at the next page.

SIC Sector Description

SIC	N_s	%
2834	222	22.93
2836	86	8.88
3674	138	14.26
3845	146	15.08
2911	83	8.57
3312	80	8.26
3559	67	6.92
3089	54	5.58
3714	92	9.5
Total	968	

2834: Tech Segment 1. Pharmaceutical Preparations.

2836: Tech Segment 1. Biological Products, Except Diagnostic Substances.

3674: Tech Segment 1. Semiconductors and Related Devices.

3845: Tech Segment 1. Electromedical and Electrotherapeutic Apparatus.

2911: Tech Segment 2. Petroleum Refining.

3312: Tech Segment 2. Steel Works, Blast Furnaces (Including Coke Ovens), and Rolling Mills.

3559: Tech Segment 2. Special Industry Machinery, Not Elsewhere Classified.

3089: Tech Segment 3. Plastics Products, Not Elsewhere Classified.

3714: Tech Segment 3. Motor Vehicle Parts and Accessories.

Source of Variables (from COMPUSTAT North America)

data4: Current Assets Total.

data8: Property, Plant, and Equipment-Total (Net).

data12: Sales (Net) Total.

data24: Price-Close.

data25: Common Shares Outstanding.

data29: Employees.

data30: Property, Plant, and Equipment-Capital Expenditure (Schedule V).

data33: Intangibles.

data34: Debt in Current Liabilities.

data60: Common Equity-Total.

data130: Preferred Stock-Carrying Value.

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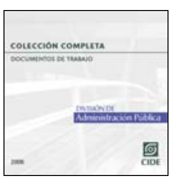

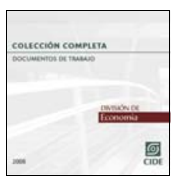

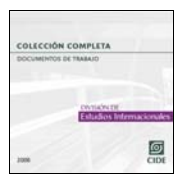

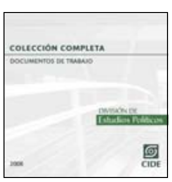

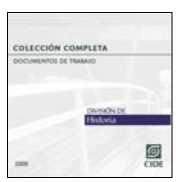

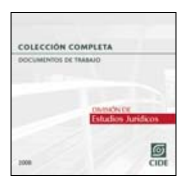

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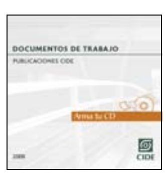

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