Discussion of Aradillas-Lopez and Tamer

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1 A simple Aradillas-Lopez and Tamer estimator

To illustrate the power and ease of Aradillas-Lopez and Tamer's approach, I will estimate a simple entry model in the spirit of Bresnahan and Reiss (1991) using only the restrictions that players use rationalizable strategies, on data from the ready-mix concrete industry. While this empirical exercise is fairly stripped down, it can be adapted for greater realism, such as allowing for different types of entrants, or correlation in the unobserved component of firm profits. In the second section, I discuss the realism of Nash Equilibrium in applied work.

1.1 Data

I use data on entry patterns of ready-mix concrete manufacturers in isolated towns across the United States. In previous work such as Collard-Wexler

(2006) I have studied entry patterns in the ready-mix concrete market. Concrete is a material that cannot be transported for much more than an hour, and thus it makes sense to study entry in local markets. I construct "isolated markets" by selecting all cities in the United States which are at least 20 miles away from any other city of at least 2000 inhabitants. I then count the number of ready-mix concrete establishments in the U.S. Census Bureau's Zip Business Patterns for zip codes at most 5 miles away from the town. [1] [2]

I call the number of ready-mix concrete firms in a market N_j and the number of potential entrants in a market N^e. I set the number of potential entrants to 6, the maximum number of firms in any market in the data. I estimate the probability of entry using nonparametric regression:

$$\hat{P}(x_i) = \frac{1}{N^e} \sum_{x_j \neq x_i} N_j K(\frac{x_j - x_i}{h}) \tag{1}$$

I use a normal density as a kernel $K()$, and I choose a smoothing parameter $h = 0.43$ in order to minimize the sum of squared errors from the regression. Figure 1 presents the number of ready-mix concrete establishments in a town plotted against town population, along with a non-parametric regression of this relationship where $\hat{N}(x_i) = N^e \hat{P}(x_i)$.

1.2 Estimator

I use a entry model similar to the one discussed in Aradillas-Lopez and Tamer. Firms are ex-ante identical, but receive different private information shocks

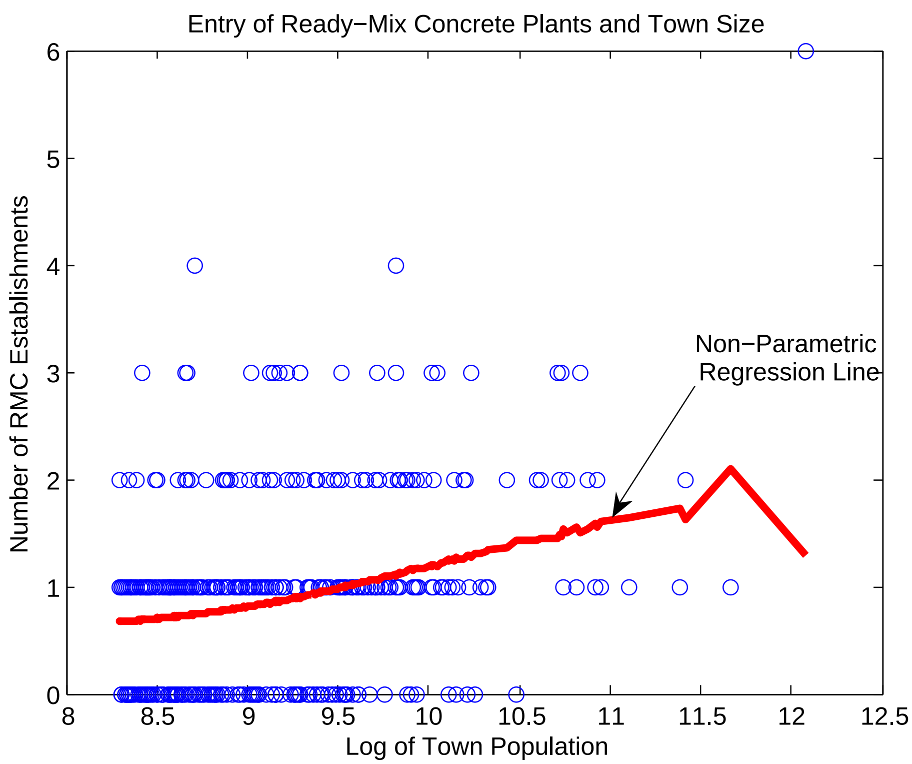

Figure 1: Entry Patterns of Ready-Mix Concrete Plants in Isolated Markets.

to the profits they will receive upon entry. I parametrize a firm's profits as:

$$\pi_i = \beta \underbrace{x_i}_{\text{Log Population}} + \alpha \underbrace{N_i}_{\text{Number of Entrants}} + \underbrace{\epsilon_i}_{\text{private information shock}}$$

where β measures the effect of population on profits and α is the effect of an additional competitor on profits. Initially, the highest prior I can assign to the entry probability of my opponents is that all opponents enter, i.e. $\bar{e}(x_i)^0 = 1$. Likewise, the lowest possible prior I can have is that no other firms enter the market, i.e. $\underline{e}(x_i)^0 = 0$. Given these upper and lower bounds on beliefs, a firm choose to enter if it makes positive profits. Aradillas-Lopez and Tamer define Level-k rationality or Level-k rationalizability as behavior that can be rationalized by some beliefs that survive at least k-1 steps of iterated deletion of dominated strategies. Thus the first stage of this process of iterated deletion of dominated strategies assigns possible entry probabilities at 0 and 1. Bounds on a firm's expected profits π_i^k (where k denotes the level-k of rationality) given the assumption that effect of additional firms is to decrease profits are:

$$x_i\beta + \alpha N^e \bar{e}(x_i)^0 + \epsilon_i \leq \pi_i^0 \leq x_i\beta + \alpha N^e \underline{e}(x_i)^0 + \epsilon_i$$

The bounds on the probability that a firm will enter given $K = 0$, denoted $e_i(\theta)$ follow directly:

$$F_\epsilon(x_i\beta + \alpha N^e \bar{e}(x_i)^0) \leq e_i(\theta) \leq F_\epsilon(x_i\beta + \alpha N^e \underline{e}(x_i)^0)$$

where F_ϵ is the c.d.f. of ϵ.

From here it is straightforward to iterate on the upper and lower bounds for entry probabilities for levels of rationality higher than $K = 0$, and this process of iteration is equavalent to deleting dominated strategies. The upper bound on the entry probability for a firm is denote $\bar{e}(x_i)^k$ and the lower bound is denoted $\underline{e}(x_i)^k$, and these are given recursively by:

$$\bar{e}(x_i)^{k+1} = F_\epsilon(x_i\beta + \alpha N^e \underline{e}(x_i)^k) \tag{2}$$

$$\underline{e}(x_i)^{k+1} = F_\epsilon(x_i\beta + \alpha N^e \bar{e}(x_i)^k) \tag{3}$$

In my application I will just assume that ϵ has a standard normal distribution, i.e. $\epsilon \sim N(0, 1)$.

Aradillas-Lopez and Tamer define the identified set for level-k rationality as the set of parameter values that satisfy the level-k conditional moment inequalities for each $1 \geq k' \geq k$ with probability one. Thus, a natural estimator for this model can be derived from looking for cases when the entry probabilities in the data are outside of the upper and lower bounds. The criterion for one such estimator is presented in equation (4):

$$Q^k(\theta) = \sum_i ([\hat{P}(x_i) - \bar{e}^k(\theta, x_i)]^+)^2 + ([\underline{e}^k(\theta, x_i) - \hat{P}(x_i)]^+)^2 \tag{4}$$

The identified set is just the set of parameters θ for which there are no violations of the upper and lower bounds:

$$\hat{\Theta}^I = \{\theta \in \Theta : Q^k(\theta) = 0\} \tag{5}$$

In contrast, the standard estimator using a symmetric Nash Equilibrium, such as the model of Seim (2005), would look for an entry probability e^* which is a fixed point to the Best-Response mapping, i.e. e^* such that:

$$e^* = F_\epsilon(x_i\beta + \alpha N^e e^*)$$

This would lead to an estimator with the following criterion function, the distance between the symmetric Nash solution and the data:

$$Q^N(\theta) = \sum_i [\hat{P}(x_i) - e^*(\theta, x_i)]^2 \tag{6}$$

Note that the estimator which minimizes the Nash Criterion in equation (6) will be in general point identified. The estimated parameter for the Nash Criterion is $\hat{\theta}^N = \text{argmin}_\theta Q^N(\theta)$, the (generically) unique parameter which minimizes the deviations of the Nash prediction from the data.

Figure 2 presents the prediction of both the Rationalizable model for up to 100 levels of iterated deletion of dominated strategies and the Nash Equilibrium model; for the parameters $\alpha = -0.42$ and $\beta = 0.1$. The green lines show the upper bound on the number of firms which enter, corresponding to the smallest possible belief about the number of other firms that might enter.

Likewise, the red lines correspond to the lower bound on the the number of expected entrants, if I held the greatest belief about the entry probability of opponents. The middle dashed line shows the prediction from the symmetric Nash Model. Note that while the upper and lower bounds get closer to each other as we increase the K-level of iterated deletion of strategies, they do not necessarily converge to the symmetric Nash model. Indeed, it is possible to sustain asymettric equilibria in this model of the type: 1-firms enter because they expect other firms not to enter and 2-firms stay out of the market because they expect other firms to enter. The larger the competitive interaction parameter α, the larger the split between the upper and lower bounds. In fact it is this effect of competitive interaction α on the spread between the upper and lower bound that will make it hard to reject very high competitive interactions.

Figure 3 presents the identified set described by equation (5) for the Aradillas-Lopez and Tamer model using Ready-Mix Concrete data where I let K go from 0 to 100. As k increase above 30, the blue shaded area in the top left disappears from the identified set indicating that assuming a higher level-k of rationality shrinks the identified set. In particular, the highest possible α in the identified set decreases from -0.2 to -0.5 as k goes from 0 to about 30. Above $k = 30$ the identified set stays about the same, which we should expect given that in a finite number of iterated deletion of dominated strategies gives the set of rationalizable strategies. The upper bound on the effect of competition on profits is about $\alpha = -0.50$, so we can state

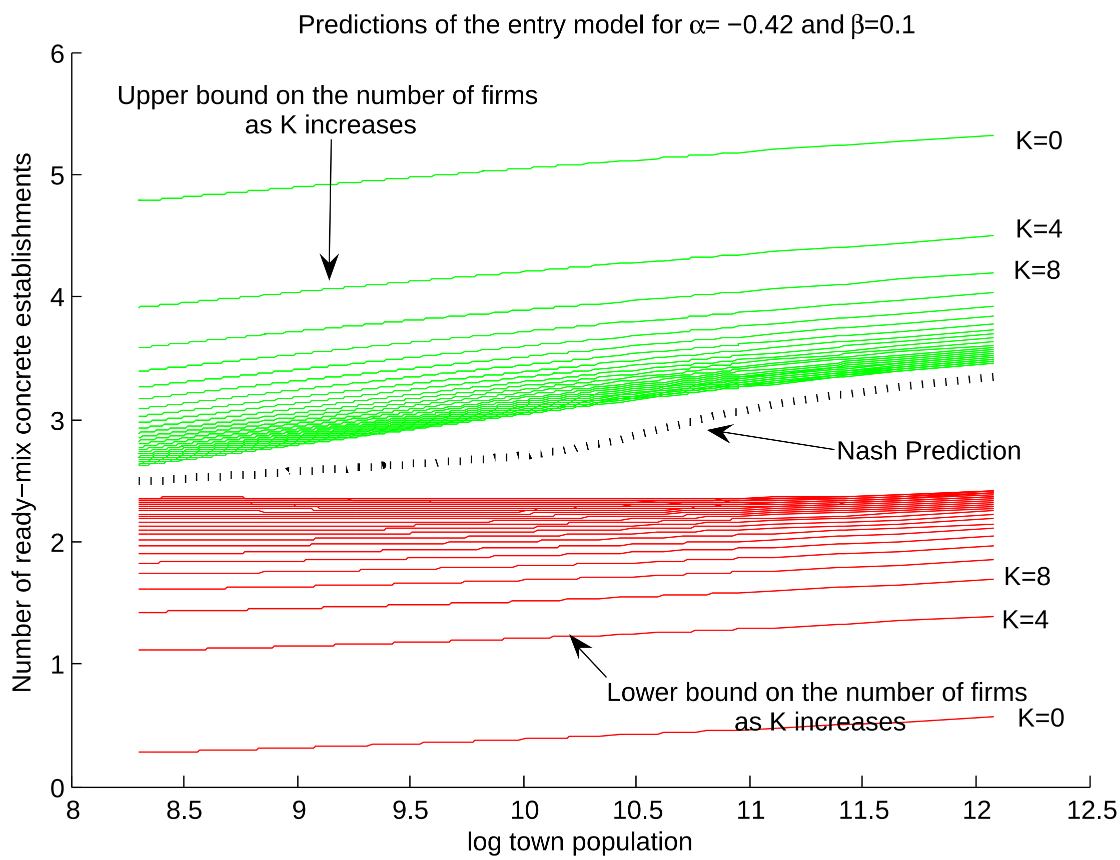

Figure 2: Model Predictions for K Levels of Iterated Deletion of Dominated Strategies and Nash Equilibrium.

conclusively that there is an effect of competition on profits in the ready-mix concrete industry. However, there is no lower bound on the effect of competition on profits, so we cannot reject the assertion that competition reduces profits by and arbitrarily large amount. To understand this result, it is worth remembering the increasing the effect of competition on profits pushes out the upper and lower bounds in Figure 2, since a big effect of competition on profits makes it possible to sustain asymettric equilibria of the type, if I expect no other firm to enter, I will enter for sure, and if I expect other firms to enter, I will choose not to enter myself. Thus, increasing the competitive parameter α will enlarge the set of permissible entry probabilities, which makes it impossible to form a lower bound on α. This seems to be a fairly generic results which casts some doubt on estimates from the entry literature on the strength of competition. Figure 3 also shows the location of the parameter that minimizes the Nash criterion function presented in equation (6). Notice that this parameter gives no incling of the size of the identified set.

2 Dynamics, Learning and Static Models

In the previous section I gave a sketch of an empirical implementation of the ideas of Aradillas-Lopez and Tamer. In this section I take a step back and discuss how closely the model that Aradillas-Lopez and Tamer propose matches common applications in empirical industrial organization.

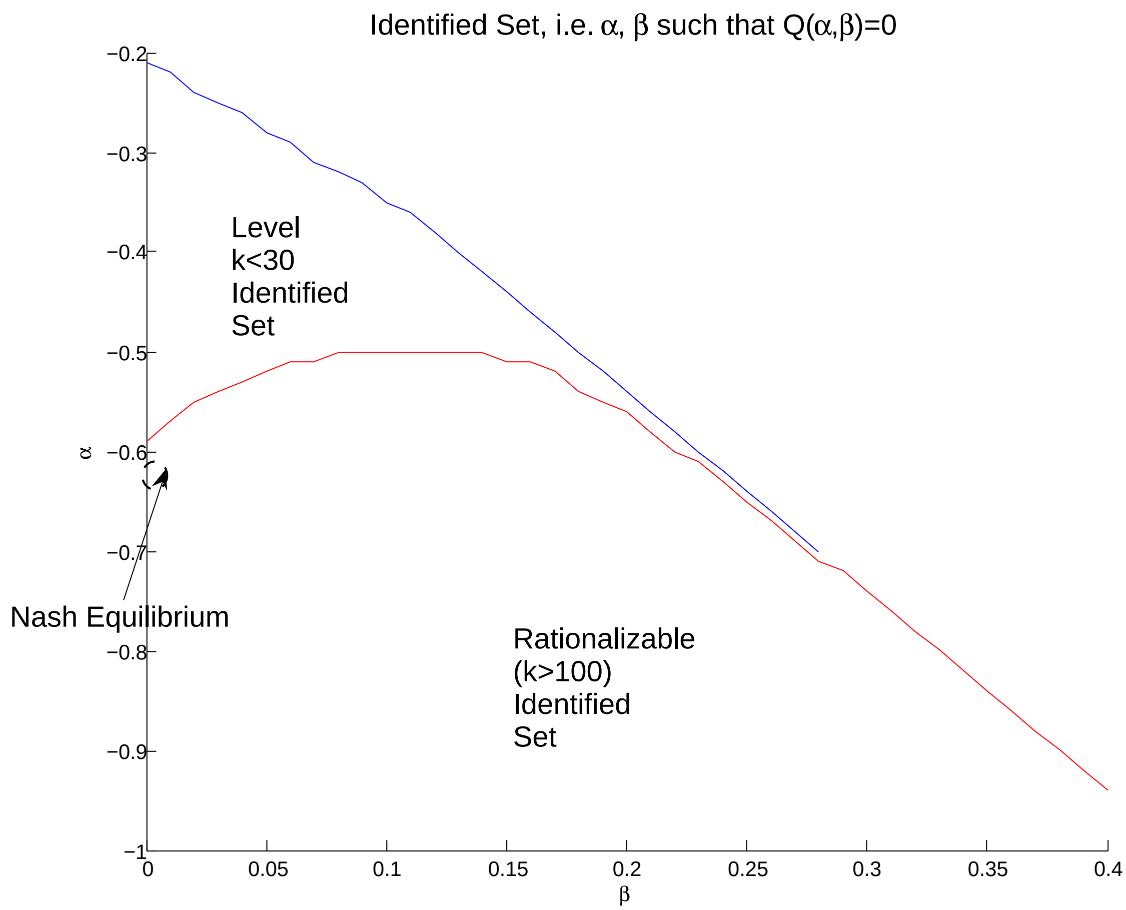

Figure 3: Identified Set for the Aradillas-Lopez and Tamer Model using Ready-Mix Concrete Data.

2.1 Dynamic Oligopoly and Two-Period Models

The main gap between the model of Aradillas-Lopez and Tamer and the most recent work studying entry (such as Ryan (2006), Sweeting (2007) or Collard-Wexler (2006)) is the use of a two-period or static model instead of an explicitly dynamic model. In a two period model, firms first make their entry decision and then receive a continuation value given the actions of other firms. These models were first used by Bresnahan and Reiss (1991) and Berry (1992) to study entry into dental and airline markets. Two-period models can be thought of as a "reduced-form" for a fully dynamic model, since airlines or dentists enter at different times and have the option to exit and reenter in the future. [3]

Using a static model to estimate behavior which is the outcome of a dynamic entry process may lead us to misunderstand the importance of multiple rationalizable strategies. For instance, much of the uncertainty in a static model come from the fact that either I do not know what my opponents will do, or there are many possible actions that my opponents can take which are rationalizable. However, in a dynamic context this problem should be substantially mitigated since entry and exit rates in most industries tend to be fairly low. For instance, in the ready-mix concrete industry there is a 5% probability that a firm will enter or exit over the next year, and the probability of two firms entering simultaneously is less than 1%. Given how low these entry and exit rates are, it is not clear how big a difference in expected payoffs I would expect if I am using the most pessimistic or the most optimistic belief about the entry probabilities of my rivals. Moreover, given the high sunk costs in many industries, why not wait for other firms to enter before deciding to exit the market? Note that there are still multiple rationalizable strategies in dynamic games, but this is not the same problem as multiplicity in the static reduced form.

2.2 Learning and Nash

Nash Equilibrium is frequently justified as the outcome from a learning process (see Fudenberg and Levine (1998) for instance). In cases where agents have extensive experience with a market, Nash Equilibria can be justified as the outcome of a learning process. Thus rationalizeability seems to be too weak.

Alternatively Nash can be conceived as a best response to the historical distribution of strategies used by firms. Suppose I am a construction firm trying to bid in a first-price auction to build a highway. I might try to use introspection about the strategies of other players to form my beliefs about what other firms will bid. Alternatively, I can just look at similar auctions to get an idea of the distribution of the bids of my opponents. In the context of entry into the ready-mix concrete industry, I can simply estimate the entry policies of my rivals $\hat{e}(x_i)$ in similar markets. I can use these estimated probabilities to compute my expected value should I choose to enter.

Aradillas-Lopez and Tamer's model is an exact fit in a limited set of empirical applications. First, we need to look for situations where firms enter at the same time. Second, an ideal application is to an industry where there is little experience of entry which would allow firms to simply look at the distribution of the strategies of their opponents. Perhaps, the best example is Augereau, Greenstein, and Rysman (2005)'s study of the adoption of one of two types of 56K modem technology by Internet Service Providers (ISPs). Between May and June 1997 ISPs had to choose one of two incompatible 56K modem technologies. Choosing the same technology as rival ISPs lowered profits. This is clearly a one shot game since it was expensive to reverse modem choice and there was no previous experience with the technology to draw on to try to understand what opponents would do. Goldfarb and Yang (2007) extend the work Augereau, Greenstein, and Rysman (2005) by looking at weakening the Nash assumption in the 56K adoption decision. They estimate the model of Camerer, Ho, and Chong (2004), which assumes that agents are playing against a Poisson distribution of level-k types. They find evidence that managers use limited introspection into the actions of their rivals, and that the degree of introspection is positively correlated with the education level within the market.

3 Conclusion

Aradillas-Lopez and Tamer have written a provocative piece which challenges applied researchers in industrial organization to rethink the behavioral we use in empirical work. In particular, the assumption that agents are playing

Nash can be quite strong in situations where there is limited experience with a market. Moreover, in many cases Nash is more than we need to estimate parameters. As I hope that this empirical implementation demonstrates, I believe that Aradillas-Lopez and Tamer's approach will be adopted in empirical work.

Notes

[1] A description of the Zip Business Patterns dataset can be found at `http://www.census.gov/epcd/www/zbpbase` accessed September 1, 2007.

[2] More information on the construction of data on isolated towns as well as the set of towns and zip codes used to construct the dataset used in this discussion can be found at `http://pages.stern.nyu.edu/ acollard/Data%20Sets%20and%20Code.html`.

[3] There are also a limited number of situations where a simultaneous entry game corresponds exactly to the application in mind. I will discuss one particular example in the next section.

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