Department of Economics UNIVERSITY OF TORONTO

Victor Aguirregabiria
Professor of Economics
150 St. George Street. Toronto Ontario Canada M5S 3G7

Phone: 416-978-4358
Fax: 416-978-6713
E-mail: victor.aguirregabiria@utoronto.ca

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Letter of Recommendation on Behalf of Zhe Yuan

It is my pleasure to write this reference letter on behalf of Zhe Yuan, who is applying for a position in your institution. Zhe is a PhD candidate from the Department of Economics at the University of Toronto working under my supervision. The other members of his dissertation committee are Andrew Ching, Mara Lederman, and Yao Luo.

I first met Zhe four years ago when he was a student enrolled in my graduate courses in Microeconometrics and in Empirical IO. Zhe's performance in these courses was outstanding. After taking these courses, we started to talk about his research interests and ideas for a Second Year Paper, and I became his PhD advisor. During the last three years, Zhe has been my TA in two graduate courses, my RA in a research project on bank network competition, and coauthor in a paper. I know Zhe Yuan's academic skills very well.

Zhe works in Empirical Industrial Organization. He has also a solid technical background in Microeconometrics. He is a brilliant, original, and ambitious researcher, and extremely careful in his work. Zhe has completed an original and interesting job market paper on network competition in the airline industry. This paper has the potential to be published in a top field journal in Industrial Organization. He has completed three other research papers. He will be a great addition to any economics department, business school, or research institution hiring in Empirical IO. I strongly recommend Zhe Yuan to you.

In his job market paper, titled *"Network Competition in the Airline Industry: A Framework for Empirical Policy Analysis,"* Zhe proposes and estimates an empirical game of competition in the airline industry that accounts for network effects between airlines' entry and capacity decisions at different city-pairs (segments). The estimation of empirical games of market entry in the airline industry is a topic that has received substantial attention in empirical IO, with important contributions by Berry (*Econometrica*, 1992) and Ciliberto and Tamer (*Econometrica*, 2009), among others. These models emphasize airlines' entry decisions in city-pairs as key strategic variables in this industry. An empirical question that has received substantial attention in this literature is whether an airline's scale of operation at the endpoint airports of a city-pair provides significant advantages over other competing airlines. These papers are also interested in the identification of the sources of this advantage, i.e., costs, demand, strategic entry deterrence (e.g., Berry, *AER* 1990). This literature acknowledges that the ideal structural model to study these empirical questions would be one that incorporates explicitly network competition between airlines at multiple city-pairs (see the discussion in the first paragraph in section 2.2 of Berry, 1992). However, for simplicity in the estimation and in the solution of the model, previous empirical papers have considered a "partial equilibrium" approach where an airline takes its overall network structure as given when it decides whether to enter or not in a city-pair market. In this type of partial equilibrium model, it is possible to study the causal effect of airport presence in the profitability of an airline, and the fundamental sources of this advantage. However, this type of model has important limitations to address other empirical questions related to network structure in the airline industry such as, among others, the estimation of the competition and cannibalization effects between different city-pairs, understanding the forces behind airlines' 'hubbing' or 'de-hubbing' decisions, or the reconfiguration of airline networks after a merger. The main goal of Zhe's job market paper is to propose a structural model of network competition in the airline industry that can be estimated in a relatively simple way, and can be used for counterfactual policy analysis to answer this type of empirical questions related to airline networks.

Zhe proposes an ambitious structural model of oligopoly competition where each airline decides its network structure (i.e., the set of city-pairs where the airline operates nonstop flights), capacities (i.e., flight frequency and number of seats) for every city-pair where they are active, and prices for nonstop and one-stop routes. The equilibrium model is defined and estimated for a network of 87 US cities that imply a total of 3741 city-pairs. Computing an equilibrium of this game is impractical. Instead, Zhe proposes an original, intelligent, and relatively simple approach to estimate the structural parameters of the model and to implement counterfactual experiments using the estimated model. Let me describe his approach in some detail.

For the estimation of the model, Zhe has constructed a dataset that combines information from two databases of the US Department of Transportation: the DB1B dataset and the Official Airline Guide (OAG) databases. Zhe estimates his model in three stages. In a first stage, he estimates equilibrium equations for prices and quantities for every airline, route, and quarter in the data, and distinguishing between nonstop and one-stop flights. These equations relate prices and quantities in the Bertrand equilibrium with market structure (i.e., number and identity of the active airlines, and their capacities in the route) and exogenous market and firm characteristics. In principle, it is possible to replace this step with a structural estimation of demand and variable costs ala BLP. However, having closed form expressions for equilibrium revenues it is very convenient for the implementation of the other two stages in the estimation of the model and for the implementation of counterfactuals because it facilitates calculating counterfactual revenues under different hypothetical changes in market structure. This simplification has the cost of not being able to do counterfactuals that involve exogenous changes in demand or marginal costs, but this type of counterfactuals is not the focus of this paper. In a second step, Zhe uses the estimated marginal revenue function together with the marginal conditions of optimality in airlines' best responses to estimate the marginal cost of capacity. In the third stage, Zhe estimates fixed costs and entry costs using moment inequalities based on equilibrium conditions for airlines choice of network, i.e., the total profit of an airline under the observed network choice should be greater than its profit under alternative hypothetical networks. The specification of the different structural functions of the model allow for rich forms of unobserved heterogeneity, including airline and city fixed effects, and serially correlated unobservables.

Zhe also proposes and implements a novel approach to implement counterfactual experiments using the estimated model. Suppose that we are interested in evaluating the effects on all the airlines' networks of an exogenous change in the entry decision of an airline in a specific city-pair, say Atlanta-New York. Zhe distinguishes three tiers of effects: on the Atlanta-New York segment; on all the segments that have either Atlanta or New York as an endpoint; and on the rest of the city-pairs. First, taking as fixed the rest of the network, Zhe computes a Nash equilibrium in the Atlanta-New York segment. To calculate this Nash equilibrium, Zhe follows a similar approach as in Berry (1992) and assumes that airlines move sequentially, where the order of moves is determined by the observed capacity of the airline in that segment. For the other two tiers of effects, Zhe orders segments according to the geographic distance to the Atlanta-New York. Then, he applies sequentially over city-pairs the same procedure as the first step for Atlanta-New York to obtain a sequence of inter-connected local Nash equilibria at every city-pair. Though this procedure may look like a bit arbitrary, it has several attractive features. First, this approach has a clear relation with the equilibrium concept in Berry (1992) that has been a popular approach for estimation and counterfactuals in previous structural models for the airline industry. Second, it allows for rich network effects between city-pairs. Third, the best response conditions that define this sequence of local Nash equilibria are consistent with the conditions that are used for the estimation of the model. Fourth, given that the unrestricted game of network competition has a large number of Nash equilibria, this procedure can be interpreted as an assumption on the equilibrium selection mechanism. This type of assumption is not necessary for the estimation of the model but it is helpful for counterfactuals. Finally, in principle the procedure can be iterated (i.e., it takes approximately 10 hours of CPU time to implement this procedure once), and upon convergence it provides "an" equilibrium of the network game. Therefore, the proposed procedure can be interpreted as an approximation to that Nash equilibrium. It is also relatively simple to make sensitivity analysis on the order of moves of the airlines and/or city-pairs. Zhe does present this type of sensitivity analysis in the paper.

Zhe finds new and interesting results in his empirical application. One-stop service accounts for a very substantial part (around one third on average) of airline profits, and it plays a key role to explain airline entry decisions and network structure. Ignoring network structure introduces a substantial bias in the estimation of airline costs. A counterfactual (exogenous) entry of JetBlue on the Atlanta-New York segment generates substantial competition responses of other airlines at other city-pairs.

In summary, I think that Zhe's job market paper contains interesting and original contributions to the empirical literatures on structural estimation of network models, and on network competition between airlines. Furthermore, this paper shows Zhe's impressive combination of skills: construction of his own original model that is substantially different to the other models in this literature; sophisticated econometrics; computational skills; careful construction of a complex dataset, and empirical analysis using this type of data.

Zhe has written a second paper on the airline industry titled "*Entry and Incumbent Response in the Airline Industry*". In this paper, Zhe investigates three different hypotheses on entry deterrence in the airline industry that have been suggested in the literature. A first hypothesis (Hendricks, Piccione, and Tan, in *RAND*, 1997, and *Econometrica*, 1999) establishes that the operation of a hub-and-spoke network by the incumbent firm generates credible and effective entry deterrence. With a hub-and-spoke network, the incumbent is willing to stay in a spoke city-pair market even when its profits from this city-pair are negative because operating in this market generates profits in one-stop routes where this spoke market is a segment. The second hypothesis is the well-known product proliferation strategy for entry deterrence, from Schmalensee (*BELL*, 1978) or more recently Ellison and Ellison (*AEJ-Micro*, 2011). The third hypothesis has been suggested by multiple analysts of the airline industry and some research papers: the dominant status of an airline in an airport can give it some bureaucratic control over airport operations that can facilitate entry deterrence. Finally, incumbent advantages in demand or costs can also deter entry of potential competitors, though these factors do not correspond to strategic entry deterrence. Zhe presents a structural model of entry-exit in airline markets that incorporates these different sources of entry deterrence. Most importantly, he provides clear empirical content to each of these hypotheses and shows that their relative contribution can be separately identified from the estimation of his model. He finds that the three entry deterrence hypotheses are significant, both statistically and economically. This is a nice piece of empirical work that should be publishable in a top IO or applied journal.

Zhe is also working with Yao Luo and I in an econometrics paper on estimation of discrete choice models (including discrete choice games) using moment inequalities ("*Estimation of Discrete Choice Models based on Moment Inequalities: Using Bounds on the Expected Value of Unobserved Payoffs*"). In an influential paper, Pakes, Porter, Ho and Ishii (*Econometrica*, 2015) propose different strategies to estimate structural discrete choice models using moment inequalities. These moment inequalities are based on agents' maximization of payoffs, i.e., reveal preference implies that the payoff of the observed choice should be greater than the payoff of the other choice alternatives. This method has been applied to different structural models, including games of network competition (e.g., Ellickson, Houghton, and Timmins, *RAND*, 2013). In this approach, the structure of the error term is such that it is possible to transform the original inequalities to construct new moment inequalities where the unobservable payoff of the observed choice (that does not have mean zero because endogenous selection) is wiped out. This approach, though elegant and useful, imposes a covariance structure on the unobservables that in some applications can be quite restrictive. In this paper, we study moment inequality estimation of random utility models where we do not impose any restriction in the covariance structure and in the distribution of the unobservables. Under mild regularity conditions, the expectation of the unobserved payoff associated to the optimal choice is a positive and finite constant. We introduce an incidental parameter $K>0$ that is an upper bound to the value of this unknown constant, and we obtain moment inequalities that include the structural payoff parameters and the constant K. We provide conditions for point identification and for set identification of the structural parameters, and propose a cross-validation method for the choice of the incidental parameter. We have several Monte Carlo experiments to illustrate the trade-offs in the choice of K and the performance of our method. The paper is in an advanced stage, and we expect to have a complete version to submit to a journal by the end this year.

Zhe is also working with Yao Luo in a research project on the Chinese cigarette industry ("*Administered Prices: Implications for the Chinese Cigarette Industry*"). I will leave to Yao the detail description of this paper. Let me just say that it is nice application of IO models and methods to public policy using an interesting dataset. The paper is also in an advanced stage.

Zhe is a good presenter and I anticipate that he will be a good teacher. He has substantial teaching experience at the University of Toronto. For the last three years, he has been teaching two semester courses per year (mostly during the summer): "Markets, Competition, and Strategy" (ECO 380), and "Mathematical Methods for Economic Theory" (ECO 210). I have seen Zhe's student evaluations for these courses and they are really good. Students emphasize that he is a very dedicated and generous teacher who cares a lot about students learning. Zhe is a very friendly, generous, and modest person who gets along very well with his peers. He will be a great colleague and a generous citizen in any department.

In summary, I think that Zhe will be a great addition to any department or research institution hiring in Empirical Industrial Organization or related fields. I strongly recommend Zhe Yuan to you.

Please feel free to contact me at victor.aguirregabiria@utoronto.ca or at 416-978-4358.

Yours sincerely,

Victor Aguirregabiria
Professor in Economics