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Tobit models with social interactions: Complete vs incomplete information☆

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ABSTRACT

In many network data sets, the outcomes of interest are equal to zero for some agents and strictly positive for others. They can be analyzed by Tobit models with social interactions with different assumptions on information structures. Under complete information, all the observables and unobservables are publicly known. Under incomplete information, unobservables and some covariates collected by econometricians can be private information for agents. In practice, both scenarios can be feasible but will lead to different implications. A non-nested Cox-type test is proposed for the specification test. We use the Monte Carlo simulations to demonstrate its small sample properties. When applying our test to study property tax rates among adjacent municipalities in North Carolina, significant competing effects are found under both information structures. However, the Cox test is in favor of the complete information model, which implies a much larger income marginal effects and a much smaller population marginal effects on tax rates, compared to the model with incomplete information.

1. Introduction

Models of social interactions have the appealing ability to quantitatively characterize the peer's influence on outcomes in a network. In practice, some data sets have the feature that observations of individual outcomes are all non-negative with some equal to zero, such as the tax rates set by local governments. These censored outcomes can be explained as the result that agents face binding constraints, such as the non-negative constraint.[1] A Tobit model with social interactions can be used to account for both the censorship and peer effects. However, interactions between agents in a network can be modeled under different information structures. Two basic types are the complete information and incomplete information ones. In the former, agents know all the relevant characteristics of any agent in a network and each agent's behavior is directly affected by those of others; in the latter, some relevant features are private information and an agent's outcome may be influenced by her expectations on outcomes of others. These two types of information structures would imply different distributions of the outcomes conditional on exogenous characteristics and disparate marginal effects for a policy change. However, econometricians are usually lack of the knowledge about what kind of information agents know.[2] Although in the literature of game theory, there are extensive discussions on the comparison of equilibria under different information structures in terms of welfare or incentives, e.g., Bergemann and Morris (2016), there is scarce investigation on the formal test for model selection under different information structures.[3] In particular, for the

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[1] In a theoretical model on behaviors, zero outcomes can naturally come out (Bramoulle et al. (2014)).

[2] This problem also arise more generally in empirical game estimation, where according to Borkovsky et al. (2015), it is usually debatable on which information structure to use, when more than one structures can be reasonable.

[3] One exception is the work on games with binary choices in entry games by Grieco (2014) where two information structures, complete vs. incomplete information, are nested in a same flexible information model and the difference between the two information structures can be represented by the relative variance of the publicly known shocks and privately known shocks. One information structure will be rejected if its estimates are out of the confidence region of an identified set. Another exception is the work by Yang and Lee (2017b). In a linear interaction model of continuous choices, Yang and Lee (2017b) employ the J-type test to select between complete and incomplete information models.

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censored outcomes in a network, the specification test has two types of complexities, the interdependence between individual outcomes and the non-linearity due to censoring. In this paper, we try to complete the literature by constructing a game framework for Tobit models with social interactions under complete and incomplete information structures and setting up a Cox-type test for these two competing models.

As an effective way to model censored or truncated outcomes, the Tobit model has gained much attention for both empirical and theoretical microeconometrics since Tobin (1958) and Amemiya (1973). More recently, Kumar (2012) proposes an extension of nonparametric estimation methods for nonlinear budget-set models to censored dependent variables. Abrevaya and Shen (2014) consider estimation of censored panel-data models with individual-specific slope heterogeneity. Qu and Lee (2013) and Xu and Lee (2015) investigate modeling and estimation of censored outcomes in a spatial autoregressive (SAR) framework. Their models are based on a simultaneous move game under complete information. As it is shown by Yang and Lee (2017a), in the setting of social or network interactions, for some cases, it is reasonable to believe that an agent may only know a part of characteristics of peers in his/her network. Then we may model interactions as the equilibrium results of an incomplete information game.[4] In Yang and Lee (2017a), discussions are focused on continuous choices and binary choices. As an extension, we may analyze censored outcomes for socially related agents in such a general form of incomplete information.

Different information structures imply different distributions of the outcomes conditional on exogenous variables. From the Monte Carlo experiments, when we estimate models with both the true and wrong information structures, the estimated log likelihood of a model with a correct information structure tends to be larger than that of the model with wrong information structures, which motivates us to construct a test statistic based on estimated likelihoods. In the literature, two types of likelihood-based tests are used to select between two SAR models: Jin and Lee (2013) establish a Cox-type test; and Liu and Lee (2017) adopt a likelihood ratio test proposed by Vuong (1989). The former specifies one of the two competing models to be true and the latter allows both models to be misspecified. It is tricky to apply Vuong's selection test for information structures, as different information structures entail different equilibrium concepts in games. It can be debatable on how to specify an equilibrium for the unknown true information structure. In addition, most empirical studies of games and network interactions focus on either the complete or the incomplete information structure. Therefore, we develop the Cox-type test here.[5] A key technical issue in establishing the distribution of the Cox-type test statistics for two competing linear SAR models is that the dependent variables are spatially correlated. Moreover, the problem is further complicated as the Tobit model is nonlinear due to non-negative constraint and there is no closed-form solution for the joint distribution of the dependent variables.

As an empirical application, we study the property tax rates for contiguous municipalities in North Carolina. Tax competition among local governments has been theoretically and empirically studied in the public economics literature (see Brueckner (2003) for a comprehensive review). Most researches consider the tax rate as a continuous variable. However, it is more appropriate to adopt the Tobit model as local governments' choices are subject to the non-negative constraint and some shares of sample observations across regions are zeros.[6] More recently, Porto and Revelli (2013) evaluate three empirical approaches to the analysis of spatially dependent tax policies. Their Tobit type models are based on interactions with latent variables and/or spatial time lags, which are different from ours. We model property tax rates as equilibrium outcomes from a static simultaneous-move game with either the complete information or the rational expectations under incomplete information. Then we estimate the parameters of interest and test the two information structures employing the proposed Cox test.

This paper proceeds as follows. In Section 2, we build the model with incomplete information and compare it with the complete information one. We also show that both models can be interpreted by simultaneous-move games. In Section 3. we present the Cox test statistics, establish their asymptotic distributions, and discuss the details about computation. Simulation results of the Monte Carlo experiments are presented in Section 4. Section 5 concentrates on the empirical study of the tax competition among municipalities in North Carolina. Section 6 concludes. Equilibrium expectations, parameter identification, and calculations as well as the details about the Cox tests are in the Appendices. Detailed proofs and results for additional Monte Carlo experiments can be found in the online supplementary files.

2. The Tobit models

2.1. Game theoretical foundations

Censored outcomes with social interactions can be interpreted by a simultaneous-move game where agents' best responses might be corner solutions. For example, adjacent municipal governments compete for "mobile tax bases". The total property tax revenue of a local government is determined by both the tax rates and tax bases, i.e., the individuals, firms, and institutions whose registered address is in this jurisdiction. A higher tax rate can increase the tax revenue from any unit property but might lead residents and firms to move to nearby municipalities whose tax rates are lower. Therefore, revenues from local taxes may be inter-dependent and a local government has to take into account the influence from its neighbors when making decisions on tax rates. Hence, the choice of tax rates by a local government can be viewed as its best response in a game of "tax competition".[7] In addition, as the tax rates cannot be negative, the best response may be a corner solution when the nonnegative constraint is binding. Similarly, owing to "homophily", an individual may get utilities by taking an action similar to those of his/her peers. Many actions, such as charity donations and weekly workout hours are subject to a non-negative constraint. The observed actions that individuals take are equilibrium outcomes corresponding to best responses when the non-negative constraint may be binding. To analyze these censored outcomes with social interactions, we build a game in the following generic framework.

Consider n agents, $i = 1, \ldots, n$. Each individual may be (directly) influenced by agents to who he/she is socially linked. Their social rela-

[4] Both strings of complete and incomplete information on models of social interactions have been sprung since the last decade. Lee (2007) and Boucher et al. (2014) discuss complete information models where all group and individual features are public information to all agents in a network or a social group. More traditional models of Manski (1993) and Brock and Durlauf (2001) are built on incomplete information, where an agent's actions are affected by her expectations on average behaviors of other agents and group characteristics in a social group. Manski (1993) studies linear models about socially interacted continuous choices; and Brock and Durlauf (2001) investigate binary choices for socially linked agents. Yang and Lee (2017a) extend the previous social interaction models to a more general form of incomplete information by allowing an agent to have personal or public information only on other agents' certain individual characteristics but incomplete information on other remaining individual traits which may not be publicly available but can be observed by econometricians with a specific survey in a later stage. In Yang and Lee (2017a), conditional expectations about other agents' behaviors can be functions of private information.

[5] In a setting of games under a general information structure, Bergemann and Morris (2013) propose to use "Bayes correlated equilibrium" (BCE). Recently, Syrgkanis et al. (2017) investigate auction estimation with weak assumptions on information structures using BCE. Therefore, it may be feasible to impose some weak assumptions on the true model in the context of network interactions and use BCE to derive the distribution of outcomes.

[6] In the data set of North Carolina, about 5.7% local municipalities have set zero property tax rates.

[7] See Wilson and Wildasin (2004) for more details about "tax competition".