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A Discrete Choice Approach to Measuring Competition in Equity Option Markets

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Abstract

This paper examines competition between exchanges that trade equity options. I allow exchanges to make strategic entry decisions by employing a discrete choice model using exchange entry patterns as a signal of the underlying profitability in each option market. I estimate latent profit equations for exchanges as a function of the underlying company's characteristics and the pattern of entry. This work extends the emerging literature on competition between option exchanges through its use of a novel econometric approach. I also extend the existing discrete choice literature on firm entry by estimating the effect of entry by specific exchanges on their competitors' profits. I find that the presence of smaller exchanges has a large effect on the entry probability of major exchanges, while major exchanges only exert a moderate influence on the entry probability of other major exchanges. The analysis also reveals that asset size, volatility, and trading volume of the underlying stock are significantly and positively related to exchange entry decisions.

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I Introduction

A basic tenet of economics is that entry into a market lowers profits earned by firms and prices paid by consumers. With no artificial impediments, firms enter any market in which they can earn profits. Typical game theoretic models of firm entry show that the equilibrium number of firms is inversely related to profit earned. The equity option market is a particularly interesting setting in which to examine the effects of entry on profits given that exchanges compete in many distinct markets. Analysis of the profitability of exchanges, here taking the role of firms, will shed light on the theorized link between entry and market results.

The analysis of exchange profitability is complicated by the simultaneity of the number of exchanges in a market and profits. That is, profit is determined by the number of exchanges competing in a market and at the same time the number of exchanges drawn into a market is determined by the profit available. This problem is not unique to equity options and affects the study of all markets with free entry. Most past studies of the effect of competition in equity option markets have employed instrumental variables techniques in cross-sectional models of the bid-ask spread, a measure of per-unit exchange revenue. However, successful implementation of this technique requires finding variables that affect the number of exchanges offering an option but not bid and ask prices or profits. The difficulty with this approach is that the applicable theory does not provide guidance as to what variables should be used and thus the choice of instrument tends to be arbitrary. Another difficulty with this approach is that the bid-ask spread is a measure of revenue, not profit. No good, observable measure of profits exists.

My paper uses a discrete strategic choice model to formalize the relationship between the number of exchanges and profits and thus avoids the problem of finding appropriate instrumental variables. In equilibrium with a small number of potential entrants such as in the markets for equity options, an exchange enters if it will make profits given the entry decisions of the other exchanges. The discrete choice model uses the fact that the observed pattern of entry in a market provides information about the underlying profitability of exchanges. By using the entry patterns and observed characteristics of the underlying securities, I can determine which characteristics the exchanges likely perceive to be associated with profitability. I employ data from The Options Clearing Corporation, Compustat data base and the Center for Research in Security Prices (CRSP) data base to estimate these effects.

This paper contributes to the existing literature on competition in option exchanges by employing a novel econometric approach to account for the endogeneity problem. In addition, the econometric model estimated in this paper extends the existing discrete choice literature by making use of the identity of the exchange. Previous models have relied upon the equilibrium number of firms, not the unique identity of each firm.

The remainder of this paper is organized as follows. Section II describes the market for equity options. Section III discusses the theoretical and empirical models. Section IV describes the data used and the estimation results. In Section V, I use the estimation results to simulate entry patterns for the exchanges during a period of alleged restrictive listing agreements. Section VI concludes.

II The Market for Equity Options

A History of Regulations on Listings

Equity options were first traded on the Chicago Board of Exchange (CBOE) on April 26, 1973. A call is a financial instrument which gives the purchaser the right, but not the obligation, to buy a particular underlying instrument (in this case, a stock) for a certain price (the strike price) within a certain time frame (before the expiration date). In 1975, the American Stock Exchange (AMEX) and the Philadelphia Stock Exchange (PHLX) began equity option trading, and the Midwest Stock Exchange followed the next year. In February 1976, the CBOE began trading options that were already being trading on the PHLX. This was the first instance of multiple listing, or the trading of an option on more than one exchange. This was followed by further instances of multiple listing, as well as rapid growth in the trading of equity derivatives. The Pacific Stock Exchange and the Midwest Stock Exchange began trading in 1976.

The Securities and Exchange Commission (SEC), the regulatory body charged with monitoring equity option markets, became involved with the listing of options in mid-1977 when it asked the exchanges to voluntarily suspend the listing of any new options until option markets could be studied in more detail. This moratorium ended in 1980 when the SEC decided not to allow further multiple listing of options because of concerns about market fragmentation. They were especially concerned about the potential for trade-throughs, or transactions taking place on one exchange while there was a more favorable price available on another exchange. Instead, the individual exchanges devised an "Allocation Plan." This plan, approved by the SEC in 1980, allowed individual exchanges to have a monopoly over the trading of new options. Options that were already multiple listed prior to the moratorium were allowed to continue to be traded on more than one exchange. In addition, options on OTC stocks were allowed to be multiple listed.

During this regulated period, the process by which an exchange decided to list an option has been likened to the NFL draft and was sanctioned by the SEC. Internal staff at the exchange, either exchange officials doing their own research or at the urging of market makers or perhaps at the request of a broker dealer, decide on what companies they would like to list. There are minimum listing requirements relating to the underlying company such as share price and capitalization. After deciding upon a list of possible companies, the exchanges participate in a draft. One exchange says "I'll take Company A," the next takes Company B, etc.

The SEC again reviewed the issue of multiple listing in 1986. Robert Neal, under the auspices of the Office of the Chief Economist, was the author of one of two studies put forth by the SEC which attempted to quantify the effect that multiple listing was having on bid-ask spreads in equity options. The bid-ask spread is the difference between the price at which the market-maker is willing to buy an option (the bid) and the price at which the market-maker is willing to sell an option (the ask) and is the market-maker's revenue on a roundturn trade. Neal's study, later published in *The Journal of Finance*, concluded that spreads for options listed on multiple exchanges were significantly lower than spreads for options listed on only one exchange. This was true in spite of the fact that trading in multiple listed options generally becomes dominated by one exchange, the "primary market." Thus, while actual competition was seemingly not a factor in these markets, potential competition was conjectured to have a significant effect in this market. Because secondary exchanges stand ready to enter the market in the presence of supracompetitive profits, the primary exchanges charge competitive spreads. Consequently, the contestable market hypothesis was found to hold in the case of market-making in equity options. Based on its review of Neal's study and other evidence, the SEC voted to allow the multiple listing of all options in May 1989.

Multiple listing of new options was allowed beginning on January 20, 1990. Allowing multiple listing of existing options was gradually phased in beginning in late 1992 and was complete by late 1994. The actual effect of the most recent rule change on option listing has been surprising. Until summer 1999, no options that were previously single listed have been listed on a secondary exchange. At the same time, a significant proportion of options being listed for the first time after the rule change are listed on one or more exchanges.[1] Additionally, the International Securities Exchange began trading in May 2000.

Options being multiple listed for the first time in the 1990s were almost always listed by exchanges at the same time. This is a result of the "Joint-Exchange Options Plan" devised by the exchanges. This plan required that an exchange announce its decision to list options 24 hours prior to trading. Other exchanges that want to trade this option must begin doing so at the same time as the first exchange or wait at least eight additional business days to list the option. In practice, listing after the initial 24-hour window was rarely done.

An antitrust investigation by the United States Department of Justice began in 1999. The DOJ alleged that the exchanges had limited competition through their practice of not listing options that are already listed on another exchange and through their use of the "Joint-Exchange Options Plan." Without admitting any guilt, the exchanges agreed to a consent decree prohibiting them from participating in any formal or informal listing agreements in 2000. Listing of all options on multiple exchanges began in earnest in 1999.

B Previous Work

Neal (1987) is one of the first to examine the issue of competition between exchanges. He examines bid-ask spreads of two groups of options trading on AMEX

[1] As of January 3, 1995, 25% of options listed for the first time after 1/20/90 were being listed on more than one exchange (236 out of 936). For example, Alliance Semiconductor Corp. (QAS) was listed on AMEX, CBOE, NYSE, and PSE on March 3, 1995. American Medical Response, Inc. (EMT) was listed on AMEX and CBOE on June 19, 1995. Amphenol Corp. (APH) was listed on only PHLX on June 2,

during 1985: single and multiple listed options. The latter group were either listed before the moratorium on multiple listing in 1977 or were options on over-the-counter stocks that could be multiple listed. Using near-term at-the-money options to generate a robust sample, Neal models the bid-ask spread as a function of volume, price, implied volatility, and a dummy variable indicating multiple listing. The multiple listing effect is captured through the dummy variable and through an interaction term with volume. He predicts that at low volume levels, spreads will be higher for single listed option and that this effect will dissipate as volume increases. The regression results confirm this hypothesis. Danis (1997) replicates Neal's study using data on options traded on CBOE and finds similar results. Wang (1999) conducts a similar study using more updated data and uses an instrumental variables technique to control for endogeneity.

Several recent papers have examined this issue in light of the deregulation experience. Mayhew (2001) compares spreads on CBOE-traded options between 1986 and 1997 using matched samples. Matched samples are used because the true functional form of option prices and volume in a bid-ask spread regression in unknown and is likely to be misspecified. Mayhew selects matched pairs of options by day based on option price, contract volume, aggregate option volume, and volatility of the underlying stock for the eleven years of data. He then compares the spreads of a single listed option with that of a multiple listed option. Consistent with the rest of the literature, he finds that multiple listed options have smaller spreads.

Mayhew recognizes the endogeneity issue inherent in this approach. Exchanges determine whether an option is single listed or multiple listed, and that choice is based on the same factors that determine the bid-ask spread. Mayhew employs two techniques to control for endogeneity. First, using the matched sample methodology, he finds that spreads of options delisted by an exchange, and thus those that are moved from the multiple listed category to single listed, increased. Second, using a probit model, he finds that trading volume, volatility, and option price are all positively related to the probability a CBOE option will be listed by another exchange. He uses these results to examine differences in spreads between multiple listed options and options that likely

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1994.

would have been multiple listed had it been allowed. He finds actual multiple listed options have smaller spreads. These two analyses lead to the conclusion that endogeneity is not driving his earlier results.

III Model

Economists have long sought to estimate the effect of entry on market outcomes such as profits, prices, and rates of return. Industry concentration studies model the relationship between market concentration and market outcomes using regression analysis. A problem with these studies is the endogeneity of market concentration. Using a game theoretic approach, a firm is postulated to enter a market if it makes positive profits given the entry decisions of all the other potential entrants. The Nash equilibrium behavior of each firm, and thus the number of firms in the market, can be derived. If the number of firms in the market affects the profit of each firm, then profits and market concentration are simultaneously determined and simple regression techniques cannot be used.

Bjorn and Vuong (1984) propose a modeling approach that has been used to consistently estimate the effect of entry into oligopoly markets on profits. Their approach stems from a multiple-agent qualitative-response setup in the context of a husband and wife's labor force participation decisions. What is observed is each agent's discrete choice of whether or not to work. Latent utility for each agent is a function of the observed dummy endogenous variable of the other agent's work decision.

This situation can be modeled as a system of simultaneous equations with structural shift. Amemiya (1974) and Heckman (1978) had formulated such systems previously with parameter restrictions for logical consistency. These restrictions require making either agent's utility function independent of the other agent's work decision. Structural independence of an agent's work decision is contrary to the very nature of the problem and is not appropriate.

Bjorn and Vuong rely on optimizing behavior of players in a game theoretic context to maintain the simultaneity of work decisions. They assume that "[t]he observed dichotomous variables .. are Nash Equilibrium.. outcomes of a game played between the two individuals."[2] They derive unique Nash Equilibrium outcomes for each combination of parameters and error terms and compute the associated probabilities as functions of the unknown parameters. The probabilities add to one, satisfying logical consistency, while allowing both agents' utility functions to be a function of the other's work decision. Estimation is performed by maximum likelihood techniques.

Bjorn and Voung's framework can be extended to problems of firm entry. In a Nash equilibrium, firm entry choice is made based on whether or not latent profits, observed by the firm but not by the econometrician, are positive given the entry decisions of all potential competitors. Each potential equilibrium market structure implies a set of conditions on all firms' latent profits. After imposing some additional constraints on latent profits to ensure identification (see section III.C), the probability of observing each market structure can be computed and maximum likelihood techniques employed.

Bresnahan and Reiss (1987, 1990, 1991) contribute to this strand of literature in a series of papers estimating the effect of entry in tightly defined product and geographic markets. They relate the number of firms to the size of the market, and develop ordered probit models of the number of firms in a market equilibrium. Through measuring the size of the market just necessary to support varying numbers of firms, they conclude that competition reduces profits. Asplund and Sandin (1999) uses the same methodology to test competition in Swedish driving schools and finds that per capita profits are decreasing in market size.

Berry (1992) made a methodological advance with his use of simulation estimators in modeling the effect of airlines' airport presence on profitability, allowing a richer set of estimations. Berry's paper investigates the link between an airline's airport presence and its profitability on routes flown out of that airport. He uses a method of moments simulator on the equilibrium number of firms in a market. Mazzeo (2000) looks at product differentiation in motel markets along U.S. interstates. He estimates latent profit functions by motel type and finds differing effects from various classes of competitors. Toivanen and Waterson (1999, 2000) examines the market for fast-food in the UK. They estimate reduced form profit equations in a Stackelberg theoretical

[2] Bjorn and Vuong, p. 9.

framework. These papers use a very similar methodology to study the impact of competition on firm entry.

A Game Theoretic Model of Exchange Entry

Empirical models of entry's effect on competition typically postulate that firm profits are a decreasing function of the number of firms in a market. This view relies upon the theoretical assumptions of Cournot models with firms competing in quantities. Such theoretical models are not applicable to exchange competition. Clearly, exchanges that trade equity options compete by quoting prices and not quantities. Thus, the theoretical assumptions of a Bertrand game are more appropriate. In contrast with the Cournot model, a typical static Bertrand model finds that two firms are sufficient for competitive behavior. Such a theoretical model would not be consistent with empirical models that have found profits decline with the number of firms.[3]

The usual Bertrand model in which two firms are sufficient to yield marginal cost pricing assumes perfect knowledge by market participants. Janssen and Rasmusen (2001) develop a theoretical model of Bertrand competition under uncertainty that yields the result that profits decline with the number of firms. The twist in the model of Janssen and Rasmusen is that the number of active firms is stochastic. There is a known set of N potential competitors selling a homogenous good with zero marginal cost, but each of these firms is active with probability α. There is one consumer with a valuation of the good v. The mixed strategy equilibrium consists of a function assigning a probability to each possible price charged by firm j and is given by

$$(1) \qquad F(p_j) = \begin{cases} 0 & \text{for } p_j \le (1-\alpha)^{N-1} v \\ \dfrac{1-(1-\alpha)\left(\sqrt[N-1]{\dfrac{v}{p_j}}\right)}{\alpha} & \text{for } (1-\alpha)^{N-1} v \le p_j \le v. \\ 1 & \text{for } p_j \ge v \end{cases}$$

[3] Collusive outcomes are possible in an infinitely repeated game among the competitors.

The equilibrium probability distribution function is decreasing in the number of potential competitors, *N*.

Intuitively, as a firm faces more potential competitors, it is more likely that it will face at least one firm in actual competition, and thus the equilbrium price distribution function shifts upwards and the expected price falls. As α approaches one, the standard Bertrand outcome is realized. Expected firm profit equals

$$(2) \qquad \pi_j = \alpha(1-\alpha)^{N-1} v$$

and in equilibrium is a decreasing function of the number of potential competitors.

The model of Janssen and Rasmusen assumes a fixed number of firms, *N*. In order to study entry, the number of firms must be endogenous to the model. I rely upon the basic setup of Janssen and Rasmusen to formulate exchange profit with Bertrand competition but further construct a model that allows endogenous entry decisions. Formally, define the one-shot game to be played as $\Gamma = [\{J\},\{S\},\{\pi_i\}]$. Let {*J*}, the set of players, equal the *N* potential firms in the market. The set {*S*} denotes the strategy set for each player, {enter, don't enter}. The set {π_j} denotes each player's reduced form payoff,

$$(3) \qquad \pi_j(s_j, s_{-j}) = \begin{cases} f^j(\vec{Z}, s_{-j}) & \text{if player j chooses } s_j = \text{"enter"} \\ 0 & \text{if player j chooses } s_j = \text{"don't enter"} \end{cases}$$

where $\vec{Z}$ is a vector of exogenous market-level variables that can used to characterize profit.

A Nash equilibrium strategy profile for each player *j* satisfies the inequality

$$(4) \qquad \pi_j(s_j, s_{-j}) > \pi_j(s_j', s_{-j}) \ \forall\, s_j' \in S_j \,.$$

Each firm enters if its payoff is positive, given the entry decisions of the other firms. For example, the equilibrium market structure with firm *j* acting as a monopolist implies that monopoly profits are positive for firm *j*, but duopoly profits for each firm -*j* (with firm *j* as the other competitor) are negative. This interdependence of entry decisions and profits among all the firms is at the heart of the concept of Nash equilibrium and drives the simultaneity of profits and concentration. As is typical in these games, multiple equilibria are possible.

This theoretical model setup is clearly applicable to the case of exchanges trading options. For any given time period, while the number of exchanges listing an option is known, it is unclear how many exchanges will quote bid and ask prices. There are three potential competitors: Chicago Board Options Exchange (CBOE), American Stock Exchange (AMEX), and a broadly defined category called Regional exchanges that includes the Pacific Exchange, the Philadelphia Stock Exchange, and the International Securities Exchange.[4] Market makers (or specialists) are assigned to each option class at an exchange. They are the ones setting bid and ask prices, the prices at which an option contract is bought and sold respectively, and making trades. In a model with a finite set of possible prices, market makers across exchanges set the same bid and ask prices in equilibrium.[5] Bid and ask prices represent per-unit revenue accruing to an exchange. Profits are a function of bid and ask prices but are more complex.

I abstract away from entry and exit decisions at the level of the market maker by assuming their number is fixed at each exchange. Rather, entry decisions are made more broadly at the exchange level, and a reduced form expression for exchange profit can be formulated. The Nash equilibrium composition of exchanges in a market depends on the exchanges' expected profits given the listing decisions of all exchanges.[6] An exchange decides to list an option if it expects to make positive profits contingent upon all the listing decisions.

B Estimation

The goal of the estimation is to determine the effect of the presence of competitors on exchange entry decisions. I first formulate latent profit expressions for each exchange. I then make assumptions as to which of the Nash equilibrium market outcomes results to identify the model. Incorporating the Nash equilbibrium concept and the identification conditions, I calculate the probability of observing the actual market outcome, given the parameter values. Finally, I utilize simulated maximum likelihood techniques to estimate latent profits.

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[4] Historically, the Pacific Exchange and the Philadelphia Stock Exchange were primarily regional exchanges. I group these smaller exchanges together in order to get a larger sample size.

[5] If they did not, arbitrage suggests the exchange setting the higher price would make zero profits.

[6] A market is defined in this paper as all options trading on a specific underlying equity. Calls, puts and

The latent profit equations for each exchange in market *i* are given by

$$
(5) \qquad
\begin{aligned}
\pi_{iA}^{*} &= \alpha_A + X_i\beta_{iA} + \theta_{C-A,i}C_i + \theta_{R-A,i}R_i + \varepsilon_{iA} \\
\pi_{iC}^{*} &= \alpha_C + X_i\beta_{iC} + \theta_{A-C,i}A_i + \theta_{R-C,i}R_i + \varepsilon_{iC} \\
\pi_{iR}^{*} &= \alpha_R + X_i\beta_{iR} + \theta_{A-R,i}A_i + \theta_{C-R,i}C_i + \varepsilon_{iR}
\end{aligned}
$$

where $\alpha_{ij}, j \in \{A, C, R\},$ is an exchange-specific constant capturing fixed effects, $X_i\beta_{ij}, j \in \{A, C, R\}$ represents market-level characteristics of demand, and A_i, C_i, and R_i are dummy variables indicating whether AMEX, CBOE, and Regional are in the market, respectively. To allow for correlation, the error terms are specified as

$$
(6) \qquad
\begin{aligned}
\varepsilon_{iA} &= \varepsilon_{iA}^{*} \\
\varepsilon_{iC} &= \frac{\alpha_{21}}{\sqrt{1+\alpha_{21}^2}}\varepsilon_{iA}^{*} + \frac{1}{\sqrt{1+\alpha_{21}^2}}\varepsilon_{ic}^{*} \\
\varepsilon_{iR} &= \frac{\alpha_{31}}{\sqrt{1+\alpha_{31}^2+\alpha_{32}^2}}\varepsilon_{iA}^{*} + \frac{\alpha_{32}}{\sqrt{1+\alpha_{31}^2+\alpha_{32}^2}}\varepsilon_{iC}^{*} + \frac{1}{\sqrt{1+\alpha_{31}^2+\alpha_{32}^2}}\varepsilon_{iR}^{*}
\end{aligned}
$$

where $\varepsilon_{ij}^{*} \sim N(0,1)$ for $j = A, C, R.$ The error specification leads to a variance-covariance matrix

$$
(7) \qquad
\begin{bmatrix}
1 & \frac{\alpha_{21}}{\sqrt{1+\alpha_{21}^2}} & \frac{\alpha_{31}}{\sqrt{1+\alpha_{31}^2+\alpha_{32}^2}} \\
\frac{\alpha_{21}}{\sqrt{1+\alpha_{21}^2}} & 1 & \frac{\alpha_{21}\alpha_{31}+\alpha_{32}}{\sqrt{1+\alpha_{21}^2}\sqrt{1+\alpha_{31}^2+\alpha_{32}^2}} \\
\frac{\alpha_{31}}{\sqrt{1+\alpha_{31}^2+\alpha_{32}^2}} & \frac{\alpha_{21}\alpha_{31}+\alpha_{32}}{\sqrt{1+\alpha_{21}^2}\sqrt{1+\alpha_{31}^2+\alpha_{32}^2}} & 1
\end{bmatrix}
$$

where α_{21}, α_{31}, and α_{32} are parameters to be estimated.

Profits are not observable to the econometrician. What can be seen is the entry decisions made by exchanges in each market. The observed entry decisions imply a set of conditions on latent profits based on the Nash equilbrium concept. These conditions do not, however, necessarily predict a unique outcome for any given realization of the error terms. In order to identify the model, additional assumptions must be made.

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leaps with various expirations and strike prices on a common underlying stock are all in the same market.

As a simple example of the identification problem, suppose there are two possible firms, i=1,2, in the market. Firm i's profit is given by $\Pi_i=x\beta+\theta J_{-i}+\varepsilon_i$ where J_{-i} is a dummy variable equal to one if the other firm has also entered the market. Let $x\beta$=0. The error terms, ε_i, are uncorrelated. There are four possible entry combinations in this market: both firms, firm 1 only, firm 2 only, and no firms. The game theoretic equilibrium concept employed in this model is that a firm enters if it is profitable for it to do so, given the equilibrium entry decision of the other firm. This translates into the conditions given in Table 1.

Graphing each of the areas bounded by the restrictions on the error terms in (ε_1,ε_2) space shows that one of the areas yields two possible outcomes (see Figure 1). When ε_1 and ε_2 are both between 0 and $-\theta$ both firms could profitably enter if the other firm did not. Thus, these values of ε_1 and ε_2 are consistent with both firm 1 being a monopolist and firm 2 being a monopolist. Without further assumptions, this model is not identified.

A method employed in the literature to solve the identification problem is to make assumptions on the order of entry. In a model of airline entry behavior, Berry (1992) considers two alternative approaches for achieving identification. The first approach is to assume that more profitable firms enter first. The second approach is to assume that incumbent firms move first, followed by other firms in order of profitability. I follow Berry's first approach and make the assumption that more profitable firms enter to solve the identification problem. With two firms, only one assumption is required for identification in the situation in which at least one firm has negative duopoly profits but both have positive monopoly profits. Here, I assume firm 1 enters when its monopoly profits are greater than or equal to firm 2's monopoly profits, or $\varepsilon_1 \geq \varepsilon_2$. Likewise, I assume firm 2 enters when its monopoly profits are greater than firm 1's, or $\varepsilon_1 < \varepsilon_2$. The model is now identified.

Identification in the case of three potential competitors is more complicated. The criteria to determine a unique predicted outcome must be consistent with the Nash equilibrium concept. Multiple equlbria occur in monopoly and duopoly market structures, and the criteria in these cases must incorporate the assumption that more profitable exchanges enter. The criteria for each market structure can be stated in terms of exchange profits. Let π_{ijk}^{i} be the profit accruing to firm *i* when *i*, *j*, and *k* are in the market. In order for exchange 1 to be a monopolist, the following must be true.

- Exchange 1 has positive monopoly profit: $\pi_1^1 > 0$
- A duopoly with exchanges 1 and 2 is not possible because exchange 2 has negative profit given exchange 1 entry and would thus not enter the market: $\pi_{12}^2 < 0$
- A duopoly with exchanges 1 and 3 is not possible because exchange 3 has negative profit given exchange 1 entry and would thus not enter the market: $\pi_{13}^3 < 0$
- A duopoly with exchanges 2 and 3 is not possible because (a) either exchange 2 or exchange 3 has negative profits in that market structure or (b) exchange 1 would have positive profits given entry by exchanges 2 and 3 and would thus enter the market : $\pi_{23}^2 < 0$ or $\pi_{23}^3 < 0$ or $\pi_{123}^1 > 0$
- An exchange 2 monopoly is not possible because (a) monopoly profits for exchange 1 are larger than monopoly profits for exchange 2 or (b) exchange 1 would have positive profits given entry by exchange 2 and would thus enter the market: $\pi_1^1 > \pi_2^2$ or $\pi_{12}^1 > 0$
- An exchange 3 monopoly is not possible because (a) monopoly profits for exchange 1 are larger than monopoly profits for exchange 3 or (b) exchange 1 would have positive profits given entry by exchange 3 and would thus enter the market: $\pi_1^1 > \pi_3^3$ or $\pi_{13}^1 > 0$

Similar conditions must hold true for exchanges 2 and 3 to be monopolists. In order for exchanges 1 and 2 to be duopolists, the following must be true.

- Exchanges 1 and 2 have positive duopoly profits: $\pi_{12}^1 > 0$ and $\pi_{12}^2 > 0$
- A triopoly is not possible because exchange 3 has negative profits given entry by exchanges 1 and 2 and would thus not enter the market: $\pi_{123}^3 < 0$
- A duopoly with exchanges 1 and 3 is not possible because (a) duopoly profits for either exchange 1 or exchange 3 are negative or (b) total profits in an exchanges 1 and 2 duopoly are larger than total profits in an exchanges 1 and 3 duopoly or (c) exchange 2 would have positive profits given entry by exchanges 1 and 3 and would thus enter the market: $\pi_{13}^1 < 0$ or $\pi_{13}^3 < 0$ or $\pi_{12}^1 + \pi_{12}^2 > \pi_{13}^1 + \pi_{13}^3$ or $\pi_{123}^2 > 0$
- A duopoly with exchanges 2 and 3 is not possible because (a) duopoly profits for either exchange 2 or exchange 3 are negative or (b) total profits in an exchanges 1 and 2 duopoly are larger than total profits in an exchanges 2 and 3 duopoly or (c) exchange 1 would have positive profits given entry by

exchanges 2 and 3 and would thus enter the market: $\pi_{23}^{2} < 0$ or $\pi_{23}^{3} < 0$ or $\pi_{12}^{1} + \pi_{12}^{2} > \pi_{23}^{2} + \pi_{23}^{3}$ or $\pi_{123}^{1} > 0$

Similar conditions hold for the other two duopoly cases. The remaining two cases, all exchanges enter and no exchanges enter, do not require additional identification conditions. The equilibrium condition for all exchanges to enter is

- Exchanges 1, 2, and 3 have positive tripoly profits: $\pi_{123}^{1} > 0$ and $\pi_{123}^{2} > 0$ and $\pi_{123}^{3} > 0$

and the equilibrium condition for no exchanges to enter is

- Exchanges 1, 2, and 3 have negative monopoly profits: $\pi_{1}^{1} < 0$ and $\pi_{2}^{2} < 0$ and $\pi_{3}^{3} < 0$.

Estimation of this model is by simulated maximum likelihood techniques. The likelihood function gives the joint probability distribution of the underlying data. The vector of parameters that maximizes the value of the likelihood function is found. With three potential entrants (AMEX, CBOE, Regional), there are eight possible market configurations that may result.[7] I formulate a unique expression for the probability of each market outcome occurring, incorporating both the Nash equilibrium concept and any additional constraints necessary for identification, for inclusion in the likelihood function. The probability of observing a market configuration with entry by *x*, *y*, and *z*, Φ_i^{xyz}, is the joint probability of observing epsilons in the regions bounded by the Nash equilibrium and identification conditions in market *i*.[8] The likelihood function is

(8) $$L = \prod_{i=1}^{I} \left(\Phi_i\right)^{(1-A_i)(1-C_i)(1-R_i)} \times \left(\Phi_i^{A}\right)^{A_i(1-C_i)(1-R_i)} \times \left(\Phi_i^{C}\right)^{(1-A_i)C_i(1-R_i)} \times \left(\Phi_i^{R}\right)^{(1-A_i)(1-C_i)R_i} \times \left(\Phi_i^{AC}\right)^{A_iC_i(1-R_i)} \times \left(\Phi_i^{AR}\right)^{A_i(1-C_i)R_i} \times \left(\Phi_i^{CR}\right)^{(1-A_i)C_iR_i} \times \left(\Phi_i^{ACR}\right)^{A_iC_iR_i}.$$

[7] They are: (1) no exchanges enter, (2) AMEX monopoly, (3) CBOE monopoly, (4) Regional monopoly, (5) AMEX-CBOE dupoly, (6) AMEX-Regional duopoly, (7) CBOE-Regional duopoly, and (8) all exchanges enter.

[8] For example, the probability of an AMEX monopoly, Φ_i^{A}, equals the joint probability

$$P(\alpha_A + X_i\beta_{iAi} + \varepsilon_{iA} \geq 0, \alpha_C + X_i\beta_{iC} + \theta_{A-C,i}A_i + \varepsilon_{iC} < 0, \alpha_R + X_i\beta_{iR} + \theta_{A-R,i}A_i + \varepsilon_{iR} < 0,$$
$$\alpha_C + X_i\beta_{iC} + \theta_{R-C,i}R_i + \varepsilon_{iC} < 0 \text{ or } \alpha_R + X_i\beta_{iR} + \theta_{C-R,i}C_i + \varepsilon_{iR} < 0 \text{ or } \alpha_A + X_i\beta_{iA} + \theta_{C-A,i}C_i + \theta_{R-A,i}R_i + \varepsilon_{iA} < 0,$$
$$\alpha_A + X_i\beta_{iAi} + \varepsilon_{iA} > \alpha_C + X_i\beta_{iCi} + \varepsilon_{iC} \text{ or } \alpha_A + X_i\beta_{iA} + \theta_{C-A,i}C_i + \varepsilon_{iA} > 0,$$
$$\alpha_A + X_i\beta_{iAi} + \varepsilon_{iA} > \alpha_R + X_i\beta_{iRi} + \varepsilon_{iR} \text{ or } \alpha_A + X_i\beta_{iA} + \theta_{R-A,i}R_i + \varepsilon_{iA} > 0).$$

The parameters α, β, and θ are chosen to maximize the log of the likelihood function.

Because of the complexity of the probability expressions involved in this likelihood function, it is necessary to use frequency simulation techniques to compute the probabilities. Such techniques have become the norm in this literature. Berry (1992) uses simulation techniques to calculate the entry behavior of airlines. He shows the intractability of the region of integration when putting restrictions on latent profit equations, especially as the number of potential entrants in a market increases. Reiss (1996) provides evidence that a simulated maximum-likelihood estimator works very well in a model of sequential-move entry. Mazzeo (2000) also uses simulation techniques when calculating entry behavior and product type choices of motel chains. As in Berry's work, a simulation approach is needed "because the complexity of the limits of integration make direction computation of the probability of the possible configuration infeasible."[9] Toivanen and Waterson (2000) model the entry decisions of two multi-plant firms (McDonalds and Burger King) in the U.K. fast food market and also make use of a simulation estimator.

Briefly, the technique is as follows.

a. For each market *i*, draw the error terms $\left(\varepsilon_{iA}^{*}, \varepsilon_{iC}^{*}, \varepsilon_{iR}^{*}\right)$ K times. The error terms are drawn independently from the standard normal distribution.

b. For each computation of the log likelihood function, compute the deterministic portion of the latent profit equations using the current parameter values. For each draw of the error terms, compute latent profits using the deterministic portion and the randomly selected error terms. Check if the equilibrium and identification conditions for the actual market configuration are satisfied. Count the number of times the actual market configuration conditions are satisfied for market *i*. This is essentially a series of indicator functions for whether or not each equilibrium and identification condition is satisfied. Denote the number of times the actual market conditions are satisfied as P_i. The ratio $p_i=P_i/K$ is included in the likelihood function for the Φ term corresponding to the observed pattern of entry.

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9 Mazzeo, p. 36.

c. The simulation technique described in part b performs poorly in practice. The main drawback of this frequency simulator is that its discrete nature makes it a step function. Over a large range of parameter values where latent profits remain positive or negative, the value of the simulated probability ratio does not change. Yet, for a small range of parameters values where latent profits change between negative and positive, a small change in a parameter leads to a discontinuous jump in the value of the simulated probability. (see Stern 1997.) Optimization is very difficult without a smooth underlying function. Mazzeo (2000) develops a technique to overcome this problem which I employ here.

Mazzeo's technique is to replace each indicator function described in part b with a continuous measure. When a condition such as $\pi_A > \pi_B$ is included as part of a market condition, he replaces the corresponding indicator function $I(\pi_A > \pi_B)$ with $F((\pi_A - \pi_B)/h)$, where *F* is the cumulative normal distribution function and *h* is set to an arbitrary value. In cases in which π_A is much larger than π_B, $F((\pi_A - \pi_B)/h)$ approaches 1. Conversely, in cases in which π_A is much smaller than π_B, $F((\pi_A - \pi_B)/h)$ approaches 0.

As an example of the smoothing technique, consider the case in which no exchanges enter a market. In my model of exchange entry, the Nash equilibrium profit equations are

$$\text{(9)} \qquad \begin{aligned} \pi^*_{iA} &= \alpha_A + X_i\beta_{iA} + \varepsilon_{iA} \le 0 \\ \pi^*_{iC} &= \alpha_C + X_i\beta_{iC} + \varepsilon_{iC} \le 0 \, . \\ \pi^*_{iR} &= \alpha_R + X_i\beta_{iR} + \varepsilon_{iR} \le 0 \end{aligned}$$

Without smoothing, a value of one would be added to the count P_i if each of the conditions on these three profit equations were satisfied for draw *j*. This is equivalent to the product of three indicator functions:

$$\text{(10)} \qquad I(\alpha_A + X_i\beta_{iA} + \varepsilon_{iA} \le 0)\cdot I(\alpha_C + X_i\beta_{iC} + \varepsilon_{iC} \le 0)\cdot I(\alpha_R + X_i\beta_{iR} + \varepsilon_{iR} \le 0).$$

Using Mazzeo's technique, the indicator functions are replaced with the cumulative normal distribution:

$$\text{(11)} \qquad F(-(\alpha_A + X_i\beta_{iA} + \varepsilon_{iA})/h)\cdot F(-(\alpha_C + X_i\beta_{iC} + \varepsilon_{iC})/h)\cdot F(-(\alpha_R + X_i\beta_{iR} + \varepsilon_{iR})/h).$$

This expression is a continuous variable between zero and one and is added to the count P_i. The ratio $p_i=P_i/K$ can be included in the likelihood function as before for the Φ term corresponding to the observed pattern of entry. The likelihood function is computed as in part b.

C Verification of Technique with Simulated Data

A comparison of the estimates produced by this method and standard probit models on simulated data yields good results for this technique. A dataset with 2,000 observations was created with three independent variables and three error terms. All variables are uncorrelated with mean zero and standard deviation one. The true latent profit functions for each exchange are

$$\begin{aligned}
&\pi_{iA} = -0.10 + 0.10 * X_{1i} + 0.15 * X_{2i} + 0.20 * X_{3i} - 0.13 * CBOE - 0.15 * reg + \varepsilon_{iA} \\
(12)\quad &\pi_{iC} = -0.15 + 0.15 * X_{1i} + 0.20 * X_{2i} + 0.10 * X_{3i} - 0.11 * AMEX - 0.16 * reg + \varepsilon_{iC} \,. \\
&\pi_{iR} = -0.20 + 0.20 * X_{1i} + 0.10 * X_{2i} + 0.15 * X_{3i} - 0.12 * AMEX - 0.14 * CBOE + \varepsilon_{iR}
\end{aligned}$$

The error term structure is equivalent to the structure outlined in equations (6). The assumed value of α_{21} is 0.5777, of α_{31} is 1.3404, and of α_{32} is -0.1912 which yields a variance-covariance matrix for ε_{iA}, ε_{iC}, and ε_{iC} of

$$(13)\quad \begin{bmatrix} 1 & 0.5 & 0.8 \\ 0.5 & 1 & 0.3 \\ 0.8 & 0.3 & 1 \end{bmatrix}.$$

The resulting profit values based on the game theoretic and identification assumptions detailed previously then determined each true market structure.

I estimate three probit models and the full model, the results of which are presented in Table 2.[10] The dependent variables for the three probit models are dummy variables for entry by each exchange. The full model is the estimation techninque described in the previous section. The full model outlined here clearly outperforms the probit models by producing estimates closer to the true values. The probit model does fairly well at estimating the coefficients on the independent variables, but the true model

[10] I also estimated a trivariate probit model using the Stata module developed by Antoine Terracol that uses the GHK simulator to approximate the appropriate integrals. The resulting parameters were similar to the single equation probit estimates, and the estimated correlations were –0.5242, -0.8153, and –0.0658. I do

performs better overall. The most significant difference between the two models concerns the dummy variables for option trading. The full model produces estimates close to the true values in all cases. The probit models, using an assumption of exogeneity of these variables, give positive coefficients for four of the six variables. The economic interpretation of this result is that the presence of a competitor in the market *increases* profits. Such a result is contrary to basic theory and illustrates the need to control for the endogeneity of entry decisions in this industry.

The predictive ability of the full model is clearly better than the probit model. Table 3 shows the average predicted probability that the conditions for each different market structure are satisfied. I compute the probabilities using simulation techniques and the game theoretic and identifying conditions outlined previously. The full model is much more accurate for several market structures. In the case of an AMEX monopoly, the probit model tends to predict that none will enter. Similarly, in the case of a Regional monopoly, the probit model tends to predict either that none will enter or that there will be an AMEX-Regional duopoly. The probit model also predicts the case of a CBOE-Regional duopoly poorly. The model tends to predict that all three exchanges will enter. The full model predicts each possible case very well.

IV Data and Results

A Data

To estimate the full model, I require data on entry patterns into option markets during the relevant time period as well as data to characterize each market. From the theoretical model described in Section III.A., latent profits and entry decisions derive from demand conditions in the market. Factors that would influence demand for a company's options include the size and industry of the underlying company, and the volatility and trading volume of the underlying stock.[11] I include assets as a measure of the size of the underlying firm. Assets are highly correlated with other measures of firm size, including sales, income, and equity. I also include volatility of the underlying stock from March 3, 2000 to June 1, 2000 as an explanatory variable. Further, I include trading

not report these results because the program did not report standard errors.

[11] See Mayhew and Mihov (2000).

volume of the underlying for the period from June 1999 to June 2000. Dummy variables for various industry segments are also included, as well as a dummy variable if the underlying stock is traded on Nasdaq.

I obtained data on the volume of contracts traded by option class for each exchange from the website of The Options Clearing Corporation. I aggregated the data by underlying stock for options on equity stocks. There were 3,897 different option contracts traded during June 2000, with a total volume of over 100 million contracts traded.[12] These option contracts were on a total of 2,462 underlying stocks.[13]

I obtained company-level information from the Compustat data base. I obtained data for all companies in the database for fiscal year 2000. There were a total of 8,631 companies with data available for this time period. I matched the option trading volume data with the underlying company-level data. This resulted in 2,036 matches of option volume data with underlying company data. There were 6,595 companies in the Compustat data base which did not have options traded on them. There were 426 companies with options traded for which I could not find any data in Compustat.[14] Option trades on these companies represent 8.7% of the total volume of contracts traded.

In order to get the universe of stocks that are eligible for option trading, I eliminate those that do not meet established minimum listing requirements. Since October 1991, companies have been required by the SEC to have a minimum of 2,000 shareholders, have a market price per share of $7.50 for the majority of the previous three calendar months, maintain a trading volume of 2.4 million shares over the previous 12 months, and have a public float of 7 million shares in order for a security to have an option listed on it. Following Mayhew (2000), I do not eliminate companies on the basis of the number of shareholders because of the difficulty in determining the true number of shareholders. I use the number of shares outstanding as a measure of public float. On this basis, 2,234 out of the 6,595 companies were ineligible for option trading.[15] An

[12] Volume figures include both the "Long" and "Short" side of transactions.
[13] I could not identify the underlying stock for 30 option contracts. Each of these contracts had a very small volume.
[14] There were 177 companies with tickers that could not be found in Compustat, and there were 249 companies who were matched to records in Compustat but the records had no data.
[15] This includes 161 companies which had missing data for the number of shares outstanding.

additional 998 companies are eliminated because their median price over the three prior months was less than $7.50, and an additional 118 companies are eliminated because their trading volume was less than 2.4 million over the period June 1999 to June 2000.

I computed the annualized volatility of the underlying stock's return using CRSP data from March 3, 2000 to June 1, 2000. I then matched this volatility data to the remaining merged Compustat/Option Trading Volume data. After the match, there was information on 2,543 companies, 1,519 of which had options and 1,024 that were eligible to have options but did not.

Table 4 contains summary statistics on the underlying companies in the sample. Companies with options listed are significantly larger by any measure. Median total assets are more than twice as large for companies with options. Median net sales are three times larger for companies with options. Similarly, total common equity, the number of shares outstanding, and trading volume are significantly larger for underlying companies on which exchanges have listed options. Table 5 breaks down the industry classifications of these companies by option listing status. Most of the companies with options are in the manufacturing sector, followed by services; finance, insurance, and real estate; and transportation, communications, electric, gas and sanitary services. Very few agricultural or construction companies are included in the sample as being eligible for option listing.

Options in the sample are predominately trading on CBOE. Market shares are given in Table 6. Approximately 40% of the total volume of options are traded on CBOE. AMEX had the second largest market share at 30%. PSE and PHLX, as historically regional exchanges, have smaller volumes at 15% and 12% respectively. The newcomer, ISE, has a mere 0.3% of the total volume.

Options can be listed on any number and combination of exchanges. Table 7 reports the distribution. Most option classes continue to be traded on only one exchange with over half of the options listed on a single exchange. Of multiple listed options, the majority were traded on two or three exchanges. Very few were listed on four or on all five exchanges.

B Results

The parameter estimates of the full model are reported in Table 8. All of the coefficients on the company-level variables describing each option market are positive and most are significant at the 99% confidence level. In order to examine the magnitude of the effects of the company-level variables on the probability of entry, I examine how changes in their values affect the probability of each market structure. Specifically, I compare the probability of entry with all the variables at their means to the probability of entry with one of the company level variables increased by one standard deviation. These probabilities are reported in Table 9. The relative probabilities at the mean values reflect the differences in the number of options traded for the three exchanges. In the baseline case, with all variables at their mean values, the probability of an option being listed on at least one exchange is 0.70. With probability 0.39, the option is listed on one exchange, with probability 0.24 two exchanges, and with probability 0.05 on all exchanges.

Changes in the underlying stock's volume have the greatest impact on exchange listing decisions. When volume increases by one standard deviation, the probability of the stock option being listed on at least one exchange is 0.96. The most likely market structure is listing by all three exchanges, followed closely by a CBOE-Regional duopoly. Each of the monopoly market structures has positive probability, and a CBOE monopoly is the most likely of the three.

The volatility of the underlying stock and the firm's assets also have a positive influence on the probability of listing, but to a lesser degree. Increasing the assets of the underlying company by one standard deviation increases the probability of listing by 0.03. The probability of either an AMEX or a Regional monopoly increases slightly, while the probability of a CBOE monopoly decreases. There is also an increase in the probability of a duopoly or a triopoly. Similarly, increases in the volatility leads to an increase of the probability of any listing by 0.11. The probability of an AMEX monopoly increases slightly, while the probability of either a CBOE or a Regional monopoly decreases. As in the case with changes in assets, the probability of a duopoly or a triopoly increases.

The coefficients on the industry variables suggest that exchanges tend to specialize in particular options. The omitted category includes all industries with small numbers of observations: agriculture, forestry, and fishing industry, mining, construction, wholesale and retail trade, and non-classifiable establishments. The coefficients for all the included industry variables were negative for Regional. Conversely, the coefficents were all positive for AMEX. The coefficients for CBOE were all positive except for manufacturing. Although the simple distribution of industry variables appears similar across exchanges, the analysis reveals that, holding all else equal, there are differences between the entry probabilities associated with each exchange based on industry classification.

The coefficient on the Nasdaq dummy variable was negative and significant for each exchange. The probability of entry into an option market whose underlying is traded on Nasdaq is smaller during this time period.

The coefficients on the θ-parameters are all negative and significant with one exception. The coefficient of the effect of CBOE entry on AMEX is negative, but insignificant. The parameters involving a Regional exchange are all much larger than the parameters involving AMEX and CBOE. The parameters involving a Regional exchange range from –0.22 for the effect of CBOE entry on Regional to -0.73 from the effect of Regional entry on CBOE. In contrast, the effect of AMEX entry on CBOE is only –0.06 and the effect of CBOE entry on AMEX is -0.01 (and insignificant). This suggests the presence of Regional exchanges exerts a large influence on the decisions of the major exchanges and vice versa, while the major exchanges only exert a moderate influence on one another.

Table 10 shows the average predicted probability that the conditions for each different market structure are satisfied using the full model. The full model performs reasonably well at predicting market structure, especially for the cases in which no exchanges or all exchanges enter. For cases in which there is a monopoly or duopoly listing the model overpredicts no listing with the full model.

For comparison, I estimate a series of three probit models.[16] The dependent variable is whether or not an exchange listed an option. Separate probits are estimated for CBOE, AMEX, and Regional exchange's listing probability. Independent variables in each specification include assets, volatility, trading volume, and a series of dummy indicator variables if other exchanges list the option. By including dummy variables for whether or not competitors are in the market, this analysis assumes that listing decisions are made independently and not in a strategic manner. Table 11 reports the coefficient estimates for each probit model.

In the non-strategic framework of these probit models, an exchange takes the actions of its competitors as given and then makes its entry decision. If profits decline in the number of exchanges, an exchange maximizing profits would be less likely to enter if it faces a competitor in the market. I would thus expect the coefficients on the dummy variables indicating whether other exchanges also list an option to be negative. Only three of the six dummy variables are significant, and two of the three are positive. CBOE's probability of entering a market is higher if AMEX is in the market and lower if Regional has entered. Similarly, AMEX's probability of entering a market is higher if CBOE has already entered. Entry of a regional exchange does, however, decrease the probability of CBOE entry and has no effect on the AMEX entry decision. A Regional exchange's decision to enter is not contingent upon whether CBOE or AMEX is in the market. These results are inconsistent with the theory and highlight the necessity of controlling for the simultaneity of entry decisions.

The full model estimation results presented in this paper are robust to the details of the estimation method and to the starting values. Changes in the number of draws result in slight decreases in the likelihood function value and slight changes in the parameter estimates. The model presented in this paper uses starting values of all zeros except for the θ terms, which are set to 0.1 and the correlation terms, which are set to 1.0. Small changes in *h*, the smoothing parameter, result in very small changes in the

[16] As in the case of the simulated data, I also estimate a trivariate probit model. The coefficients of the trivariate probit were similar to the single equation probits, and I do not report the trivariate probit results because the standard errors did not estimate. The estimated correlation between AMEX and CBOE was –0.99, between AMEX and Regional was –0.98, and between CBOE and Regional 1.00.

parameter estimates.

The estimated variance-covariance matrix is

$$(14) \qquad \begin{bmatrix} 1 & 0.38 & 0.66 \\ 0.38 & 1 & 0.65 \\ 0.66 & 0.65 & 1 \end{bmatrix}.$$

The correlation between latent profits for AMEX and Regional and for CBOE and Regional are both approximately 0.65. The correlation between AMEX and CBOE, the major exchanges, is smaller at 0.38. The positive correlation suggests, as is expected, that markets which attract entry by one exchange also attract entry by other exchanges. When estimating the model without allowing correlated error terms, the θ parameters were positive. This is against the basic economic assumption that the addition of a competitor does not increase profits to existing firms. Without correlated errors, the unobserved market-specific heterogenity appears in the θ terms. In the data, there is a tendency for exchanges to enter the same markets. If there is no allowance for this in the model, the unobserved market factors that induce entry by multiple exchanges is reflected in the θ terms. Consider a market that is particularly profitable to all exchanges because of an unobserved factor. If no allowance is made for this positive correlated error, estimated profits will increase as others offer the security, i.e., the θs are positive.

V Simulation of Entry Patterns "But for" the Alleged Collusion

By late 1994, regulations prohibiting multiple listing of all existing options were abolished. In practice, the listing of options that were already being traded on another exchange did not happen. According to a Competitive Impact Statement filed in 2000 by the Department of Justice in a lawsuit against the exchanges, this was the result of an explicit agreement among the exchanges to limit competition in this set of options. The economic ramifications of this could be quite large, as most of the actively traded American companies were listed before 1990.

It is possible to use the full model developed in this paper to estimate the impact of the alleged collusive agreement to limit entry into option markets. The estimation in Table 8 uses data from June 2000, when listing decisions were being made free of any agreements to limit competition.[17] I use the estimated parameters from the full model in conjunction with market data from 1994 to simulate the listing decisions that would have occurred in 1995 if not for the alleged collusive agreement among the exchanges.

I construct a dataset of options on 474 underlying stocks that were listed on exchanges as of January 20, 1990, just before the rule change allowing multiple listing on new options.[18] When these options were first listed, multiple listing was generally prohibited.[19] By January 1995, each of these options could be listed by another exchange but, because of the alleged agreement between exchanges, they were not. I gather data for fiscal year 1994 on assets, volatility, volume, industry, and whether or not the underlying equity is traded on Nasdaq using the same methodology as described in Section IV. I calculate volatility using the period October 3, 1994 to January 3, 1995. The median values of each continuous variable is in Table 12. The underlying companies in the 1995 sample are smaller, in general, than the companies included in the 2000 data. Also, the volatility of the underlying stocks is much smaller for the 1995 sample.

I compute latent profits using the parameters estimated during the free entry period and the data as of January 1995. I then estimate the simulated probability of each hypothetical entry pattern. Table 13 presents the results of the simulation. Of the 474 options in the dataset, 117 are listed solely on AMEX, 139 solely on CBOE, and 207 solely on a Regional exchange.[20] In addition, there are 11 multiple listed options. Of the 117 listed solely on AMEX, 5 would have been expected to have been listed by one other exchange and 5 would have been expected to have been listed by two other exchanges. Similarly, entry by one other exchange is predicted for 3 of the options trading exclusively on CBOE and entry by two other exchanges is predicted for 9 of the options. The expected entry is similar for Regional: 2 options would attract entry by one more exchange and 1 would attract entry by two more.

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[17] Filings by the DOJ indicate that the collusive agreement ended during the summer of 1999.
[18] I obtain listing information from a printout I received from CBOE entitled "Options Listing History as of Wednesday, January 24, 1996."
[19] For a short period of time at the beginning of organized option trading, multiple listing was allowed.
[20] In 1995, the regional exchanges are PHLX, PSE, and the New York Stock Exchange. NYSE transferred its options business to CBOE on April 28, 1997 when it sold its option business to CBOE.

While the number of option markets that would have had entry absent the alleged collusion is small, these markets are economically important. These options had nearly 15 billion shares of the underlying equity traded in calendar year 1994 and include underlying stocks such as AT&T and Ford Motor Company. Thus, any increase in competition in the markets for these underlying's options could be expected to have had a large impact.

VI Conclusion

This paper examines the relationship between exchange entry and competition in equity option markets. Exchanges compete in thousands of distinct markets, and the entry pattern in each market gives valuable information about profitability. By using a strategic framework, I assume that exchanges make interrelated entry decisions. In equilibrium, profits depend on the number of exchanges and in turn the number of exchanges depends on the profit available in a market. I translate this into a discrete choice model of exchange entry behavior.

Because of recent regulatory and legal actions involving exchanges trading equity options, much attention has been focused on this area. Several recent papers have analyzed the effect of exchange competition on bid-ask spreads, which is a measure of exchange revenue. This work adds to that growing body of literature by employing a novel econometric approach. I concentrate on latent profits, as evidenced by free entry decisions, instead of bid-ask spreads as is typically done. This paper also adds to the discrete choice literature by explicitly modeling the effect of specific competitors. Option exchanges are unique in that there is a well defined set of competitors in a market, and these competitors face each other in thousands of distinct markets. I take advantage of this trait of option trading to find the specific effect of certain competitors.

I find, as expected, that entry probability declines in the number of exchanges. Regional exchanges, including PSE, PHLX, and ISE, exert a large influence on the probability of entry by major exchanges and major exchanges exert a large influence on Regionals. Surprisingly, major exchanges do not exert a large influence on each other. The analysis also shows that the asset size, volatility, and volume of the underlying stock being traded has a large positive effect on exchange entry.

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TABLE 1
Nash Equilibrium Profits

Market Structure	Firm 1's profit	Firm 2's profit
Both firms enter	$\theta+\varepsilon_1>0$	$\theta+\varepsilon_2>0$
Firm 1 only enters	$\varepsilon_1>0$	$\theta+\varepsilon_2<0$
Firm 2 only enters	$\theta+\varepsilon_1<0$	$\varepsilon_2>0$
No firms enter	$\varepsilon_1<0$	$\varepsilon_2<0$

FIGURE 1
Market Outcomes for Realizations of the Error Terms

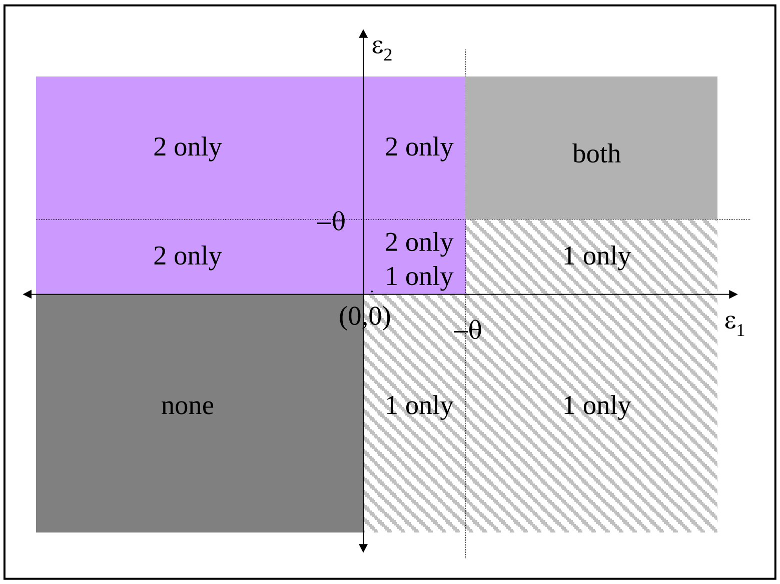

TABLE 2
Estimation Results on Listing Decisions using Simulated Data

Variable	True Value	Probit Models with Various Dependent Variables: AMEX	CBOE	Regional	Full Model
Theta coefficients:					
Effect of AMEX entry on CBOE	-0.11	--	0.5843** (0.0682)	--	-0.2185** (0.0233)
Effect of AMEX entry on Regional	-0.12	--	--	1.3003** (0.0655)	-0.2402** (0.0196)
Effect of CBOE entry on AMEX	-0.13	0.5551** (0.0646)	--	--	-0.3712** (0.0154)
Effect of CBOE entry on Regional	-0.14	--	--	-0.1380* (0.0669)	-0.0906** (0.0234)
Effect of Regional entry on AMEX	-0.15	1.2977** (0.0654)	--	--	-0.1370** (0.0138)
Effect of Regional entry on CBOE	-0.16	--	-0.1416* (0.0699)	--	-0.1136** (0.0180)
AMEX coefficients:					
X_1	0.10	0.0801** (0.0314)	--	--	0.1089** (0.0068)
X_2	0.15	0.1017** (0.0326)	--	--	0.2079** (0.0068)
X_3	0.20	0.1072** (0.0308)	--	--	0.1559** (0.0058)
CBOE coefficients:					
X_1	0.15	--	0.0436 (0.0290)	--	0.0956** (0.0074)
X_2	0.20	--	0.1260** (0.0303)	--	0.2167** (0.0078)
X_3	0.10	--	0.1541** (0.0286)	--	0.0728** (0.0060)
REG coefficients:					
X_1	0.20	--	--	0.0969** (0.0315)	0.2531** (0.0077)
X_2	0.10	--	--	0.1097** (0.0327)	0.1485** (0.0064)
X_3	0.15	--	--	0.1564** (0.0307)	0.1109** (0.0053)

TABLE 2 (continued)
Estimation Results on Listing Decisions using Simulated Data

Variable	True Value	Probit Models with Various Dependent Variables: AMEX	CBOE	Regional	Full Model
Constant coefficients:					
AMEX	-0.10	-0.9711** (0.0495)	--	--	-0.1927** (0.0077)
CBOE	-0.15	--	-0.4613** (0.0408)	--	-0.1811** (0.0119)
REG	-0.20	--	--	-0.8764** (0.0478)	-0.2621** (0.0168)
Error coefficients:					
α_{21}	0.57	--	--	--	0.7761** (0.0156)
α_{31}	1.34	--	--	--	1.1943** (0.0277)
α_{32}	-0.19	--	--	--	-0.4483** (0.0161)
Log Likelihood Function		-1,046	-1,267	-1,049	-3,621

Notes: h=0.01, 100 draws of the error terms, 2,000 observations, standard errors in parantheses.
*denotes significance at the 5% level
**denotes significance at the 1% level

TABLE 3a
Average Probability of Observing a Market Structure by Actual Market Structure using Simulated Data
(Full Model)

	Predicted Market Structure							
Actual Market Structure	None Enter	AMEX monopoly	CBOE monopoly	Regional monopoly	AMEX and CBOE duopoly	AMEX and Regional duopoly	CBOE and Regional duopoly	All Enter
None Enter	**0.95**	0.01	0.01	0.03	0.00	0.00	0.00	0.00
AMEX monopoly	0.16	**0.72**	0.04	0.02	0.02	0.02	0.00	0.00
CBOE monopoly	0.18	0.00	**0.80**	0.00	0.00	0.00	0.01	0.00
Regional monopoly	0.05	0.00	0.00	**0.89**	0.00	0.03	0.02	0.00
AMEX and CBOE duopoly	0.00	0.04	0.37	0.00	**0.56**	0.00	0.02	0.00
AMEX and Regional duopoly	0.00	0.06	0.00	0.09	0.01	**0.77**	0.02	0.05
CBOE and Regional duopoly	0.00	0.00	0.24	0.07	0.00	0.01	**0.67**	0.00
All Enter	0.00	0.00	0.01	0.00	0.16	0.03	0.11	**0.68**

TABLE 3b

Average Probability of Observing a Market Structure by Actual Market Structure using Simulated Data

(Probit Model)

Actual Market Structure	Predicted Market Structure: None Enter	AMEX monopoly	CBOE monopoly	Regional monopoly	AMEX and CBOE duopoly	AMEX and Regional duopoly	CBOE and Regional duopoly	All Enter
None Enter	**0.81**	0.00	0.10	0.08	0.00	0.08	0.01	0.06
AMEX monopoly	0.94	**0.05**	0.01	0.00	0.06	0.17	0.00	0.06
CBOE monopoly	0.11	0.00	**0.79**	0.00	0.00	0.00	0.03	0.44
Regional monopoly	0.46	0.00	0.00	**0.21**	0.00	0.59	0.01	0.17
AMEX and CBOE duopoly	0.24	0.02	0.21	0.00	**0.54**	0.01	0.00	0.27
AMEX and Regional duopoly	0.39	0.10	0.00	0.00	0.00	**0.79**	0.00	0.07
CBOE and Regional duopoly	0.06	0.00	0.16	0.01	0.00	0.01	**0.01**	0.98
All Enter	0.07	0.05	0.02	0.00	0.13	0.12	0.00	**0.69**

TABLE 4

Characteristics of Underlying Companies Eligible for Option Listing, June 2000 (medians)

	Companies with Options	Companies without Options
Total Assets ($millions)	1,107.3	420.7
Net Sales ($millions)	692.7	221.2
Total Common Equity ($millions)	421.8	151.6
Net Income ($millions)	27.5	16.3
Number of Shares Outstanding (million)	53.9	18.5
Trading Volume June 1999-June 2000 (million)	96.7	15.9

Sources: CRSP, Center for Research in Security Prices. Graduate School of Business, The University of Chicago 1999-2000. Used with permission. All rights reserved. www.crsp.uchicago.edu; Standard & Poor's COMPUSTAT (North American) data; The Option Clearing Corporation's Market Share History.

TABLE 5
Industry Classification of Underlying Companies Eligible for Option Listing, June 2000

	Companies with Options	Companies without Options
Manufacturing	596	343
Services	368	183
Finance, insurance, and real estate	137	155
Transportation, communications, electric, gas and sanitary services	118	61
Retail trade	71	36
Mining	49	23
Wholesale trade	29	18
Construction	10	9
Non classifiable establishments	5	5
Agriculture, forestry, and fishing	4	2

Sources: Standard & Poor's COMPUSTAT (North American) data; The Option Clearing Corporation's Market Share History.

TABLE 6
Market Share of Total Option Volume, June 2000

Exchange	Market Share
Chicago Board Options Exchange	42.4%
American Stock Exchange	30.4%
Pacific Stock Exchange	14.9%
Philadelphia Stock Exchange	11.8%
International Securities Exchange	0.3%

Source: The Option Clearing Corporation's Market Share History.

TABLE 7
Number of Exchanges Trading Options, June 2000

Number of Exchanges	Number
0	1,024
1	853
2	349
3	226
4	86
5	5

Source: The Option Clearing Corporation's Market Share History.

TABLE 8

Estimation Results on Listing Decisions using June 2000 Data

Variable	Full Model
Theta coefficients:	
Effect of AMEX entry on CBOE	-0.0630*
	(0.0267)
Effect of AMEX entry on Regional	-0.6340**
	(0.0157)
Effect of CBOE entry on AMEX	-0.0146
	(0.0119)
Effect of CBOE entry on Regional	-0.2212**
	(0.0204)
Effect of Regional entry on AMEX	-0.4661**
	(0.0113)
Effect of Regional entry on CBOE	-0.7259**
	(0.0158)
AMEX coefficients:	
Assets (standardized)	0.2249**
	(0.0060)
Volatility (standardized)	0.3781**
	(0.0119)
Trading Volume (standardized)	0.6119**
	(0.0067)
Manufacturing Dummy	0.1430**
	(0.0215)
Services Dummy	0.2529**
	(0.0359)
Finance, Insurance, Real Estate Dummy	0.0890**
	(0.0273)
Transportation, Communications, Electric, Gas and Sanitary Services Dummy	0.3136**
	(0.0286)
Nasdaq Dummy	-0.2466**
	(0.0158)
Constant	-0.3392**
	(0.0267)

TABLE 8 (continued)
Estimation Results on Listing Decisions using June 2000 Data

Variable	Full Model
CBOE coefficients:	
Assets (standardized)	0.0226**
	(0.0030)
Volatility (standardized)	0.3434**
	(0.0100)
Trading Volume (standardized)	1.4721**
	(0.0097)
Manufacturing Dummy	-0.0996**
	(0.0197)
Services Dummy	0.0113
	(0.0190)
Finance, Insurance, Real Estate Dummy	0.0642**
	(0.0215)
Transportation, Communications, Electric, Gas and Sanitary Services Dummy	0.2978**
	(0.0298)
Nasdaq Dummy	-0.1182**
	(0.0174)
Constant	-0.0757**
	(0.0202)

TABLE 8 (continued)
Estimation Results on Listing Decisions using June 2000 Data

Variable	Full Model
REG coefficients:	
Assets (standardized)	0.1388**
	(0.0043)
Volatility (standardized)	0.3204**
	(0.0074)
Trading Volume (standardized)	0.9381**
	(0.0100)
Manufacturing Dummy	-0.1140**
	(0.0175)
Services Dummy	-0.0116
	(0.0214)
Finance, Insurance, Real Estate Dummy	-0.0181
	(0.0261)
Transportation, Communications, Electric, Gas and Sanitary Services Dummy	-0.0020
	(0.0223)
Nasdaq Dummy	-0.1982**
	(0.0134)
Constant	0.0830**
	(0.0191)
Error coefficients:	
α_{21}	0.4124**
	(0.0133)
α_{31}	1.0713**
	(0.0162)
α_{32}	0.7045**
	(0.0188)
Log Likelihood Function	-3,887

Notes: h=0.01, 100 draws of the error terms, 2,543 observations, standard errors in parantheses. Model estimated in Fortran using GQOPT's DFP algorithm with stretching.
*denotes significance at the 5% level
**denotes significance at the 1% level
Sources: CRSP, Center for Research in Security Prices. Graduate School of Business, The University of Chicago 1999-2000. Used with permission. All rights reserved. www.crsp.uchicago.edu; Standard & Poor's COMPUSTAT (North American) data; The Option Clearing Corporation's Market Share History.

TABLE 9

Effects of Changes in Company Level Variables on the Probability of Various Market Structures, June 2000 Data

Value of Company Level Variables	None Enter	AMEX monopoly	CBOE monopoly	Regional monopoly	AMEX and CBOE duopoly	AMEX and Regional duopoly	CBOE and Regional duopoly	All Enter
Assets, Volatility, and Underlying Stock Volume at Mean Values	0.30	0.08	0.12	0.19	0.08	0.07	0.10	0.05
Assets of Underlying Stock Increased by One Standard Deviation	0.27	0.10	0.09	0.20	0.09	0.08	0.08	0.08
Volatility Increased by One Standard Deviation	0.19	0.10	0.10	0.15	0.12	0.10	0.11	0.13
Volume Increased by One Standard Deviation	0.04	0.02	0.13	0.07	0.12	0.03	0.28	0.31

TABLE 10

Average Probability of Observing a Market Structure by Actual Market Structure using June 2000 Data

Actual Market Structure	Predicted Market Structure: None Enter	AMEX monopoly	CBOE monopoly	Regional monopoly	AMEX and CBOE duopoly	AMEX and Regional duopoly	CBOE and Regional duopoly	All Enter
None Enter	0.53	0.10	0.07	0.14	0.05	0.04	0.03	0.03
AMEX monopoly	0.41	0.11	0.09	0.14	0.08	0.06	0.05	0.05
CBOE monopoly	0.39	0.10	0.10	0.14	0.09	0.05	0.06	0.06
Regional monopoly	0.45	0.10	0.09	0.15	0.07	0.05	0.05	0.04
AMEX and CBOE duopoly	0.25	0.09	0.10	0.12	0.12	0.06	0.09	0.15
AMEX and Regional duopoly	0.32	0.11	0.10	0.13	0.11	0.06	0.06	0.09
CBOE and Regional duopoly	0.23	0.08	0.11	0.12	0.12	0.06	0.11	0.16
All Enter	0.12	0.05	0.08	0.07	0.11	0.04	0.12	0.41

TABLE 11
Probit Results on Listing Decisions using June 2000 Data

	Dependent Variable		
Variable	AMEX	CBOE	Regional
Effect of AMEX entry on CBOE (θ_{A-C})		0.3956**	
		(0.0678)	
Effect of AMEX entry on Regional (θ_{A-R})			-0.0418
			(0.0669)
Effect of CBOE entry on AMEX (θ_{C-A})	0.4496**		
	(0.0676)		
Effect of CBOE entry on Regional (θ_{C-R})			-0.1093
			(0.0705)
Effect of Regional entry on AMEX (θ_{R-A})	-0.0310		
	(0.0656)		
Effect of Regional entry on CBOE (θ_{R-C})		-0.1428*	
		(0.0696)	
Assets (standardized)	0.2113**	0.0502	0.0509
	(0.0603)	(0.0431)	(0.0383)
Volatility (standardized)	0.3048**	0.1830**	0.1146**
	(0.0401)	(0.0428)	(0.0395)
Trading Volume (standardized)	0.7478**	2.1602**	1.2057**
	(0.0769)	(0.1183)	(0.0865)
Manufacturing Dummy	0.1329	0.1276	-0.0099
	(0.0816)	(0.0858)	(0.0769)
Services Dummy	0.2551**	0.1567	0.0363
	(0.0951)	(0.1005)	(0.0921)
Finance, Insurance, Real Estate Dummy	-0.0942	-0.1558	-0.1054
	(0.1221)	(0.1283)	(0.1078)
Transportation, Communications, Electric, Gas	0.3002*	0.2738*	-0.0199
and Sanitary Services Dummy	(0.1234)	(0.1314)	(0.1224)
Nasdaq Dummy	-0.2308**	-0.1992*	-0.2074**
	(0.0784)	(0.0827)	(0.0744)
Constant	-0.6414**	-0.3561**	-0.2140**
	(0.0815)	(0.0865)	(0.0756)
Log Likelihood Function	-1,248	-1,089	-1,366

*denotes significance at the 5% level
**denotes significance at the 1% level
Notes: Standard errors in parentheses, 2,543 observations.
Sources: CRSP, Center for Research in Security Prices. Graduate School of Business, The University of Chicago 1999-2000. Used with permission. All rights reserved. www.crsp.uchicago.edu; Standard & Poor's COMPUSTAT (North American) data; The Option Clearing Corporation's Market Share History.

TABLE 12
Characteristics of Companies Used in January 1995 Listing Counterfactual

Variable	Median	Standard Deviation
Assets ($ million)	3,683.9	30,466
Volatility	0.2547	0.0970
Trading Volume (annual number of shares)	6.67e+07	1.40e+08
Manufacturing Dummy	0.5274*	0.4998
Services Dummy	0.0738*	0.2618
Finance, Insurance, Real Estate Dummy	0.1203*	0.3256
Transportation, Communications, Electric, Gas and Sanitary Services Dummy	0.1245*	0.3305
Nasdaq Dummy	0.0781*	0.2685

*mean value

TABLE 13
Expected Entry in January 1995
"But For" the Alleged Collusive Agreement

Listing Status as of	Predicted Market Structure	
January 20, 1990	Duopoly	Triopoly
AMEX only (N=117)	5	5
CBOE only (N=139)	3	9
Regional only (N=207)	2	1