LaunchiNG Successful E-Markets: A Broker-Level Diffusion Analysis of Two Options Exchanges

Abstract

New financial markets try in a number of ways to achieve successful diffusion and attract a critical mass of participation and usage. Two innovative, all-electronic options exchanges, the International Securities Exchange (ISE) and the Boston Options Exchange (BOX), opened for trading in 2000 and 2004, and offered immediate order execution, direct user access to the market, and reduced costs. ISE and BOX gained trading volumes in competition with four incumbent markets in the U.S. including the largest, the Chicago Board Options Exchange (CBOE). To explain the markets’ diffusion patterns, we first develop a simplified model of broker order routing decisions among competing markets. The model generates hypotheses about new market growth, which we test using a panel of six years of quarterly disclosures from 24 major brokerage firms. We extend prior research and find that firm heterogeneity, including factors such as membership affiliations and firm characteristics, are at least as influential as network effects in explaining the diffusions of the new markets at the broker level. Policy considerations and implications for new trading platforms are described.

Keywords: diffusion of IT innovations, electronic markets, trading technology, adoption, market competition
Launching Successful E-Markets: A Broker-Level Diffusion Analysis of Two Options Exchanges

INTRODUCTION

Interdependent adoption decisions and network effects can delay the diffusion of new information technologies and prevent firms from realizing IT’s value. When technological progress does diffuse into the operational processes of acquiring firms, researchers have sought to identify the economic and sociological drivers of adoption (Abrahamson and Rosenkopf, 1997; Brynjolfsson and Kemerer, 1996; Griliches, 1957; Weber, 2006). IS research has traditionally focused on electronic market pricing, transaction costs, and online auction mechanisms (Bakos, 1997; Ghose and Yao, 2010; Overby and Jap, 2009; Tang et al., 2010). A survey of e-markets papers appearing in top journals from 1997 to 2008 found that 90, or nearly half of the 196 papers covered, were on auctions alone (Standing et al., 2010). There is an apparent gap in the literature dealing with issues of successfully opening and operating e-markets. Our goal is to begin filling this gap by examining the factors influencing options exchange usage among U.S. brokerage firms that led to differing growth patterns for two new financial markets. The results highlight the role of early adopters in creating value, and have implications for operators of new markets and participants in the financial trading industry.

Financial markets provide a particularly interesting setting for IT diffusions. Exchange markets depend on the participation of multiple, heterogeneous firms and users, and the liquidity and value of a market grow with its user base. The first all-electronic exchange for trading equity options, the International Securities Exchange (ISE) opened for trading in 2000, and the Boston Options Exchange (BOX), opened for trading in 2004. Compared to the incumbent floor markets, ISE and BOX offer immediate trading, direct user access to the market, and reduced costs. The new exchanges gained trading volumes in competition with four incumbent markets in the
U.S. including the largest, the 37-year old Chicago Board Options Exchange (CBOE). While ISE reached 30% market share after three years, BOX only achieved 6% in the three years from its launch, for reasons that we will examine.

We first present a model of broker choice from which we develop hypotheses regarding exchange market share. Using a panel of six years of quarterly disclosures from 24 major brokerage firms, we model the markets’ diffusion patterns at the firm level. Estimating seemingly unrelated regression models of the new markets’ growth we find both ‘sociological’ (firm characteristics, affiliation) and economic factors (network effects) are influential in the diffusion of the new markets across trading firms.

Our results are important for three reasons. First, we present a reduced form model of broker choice. The optimal order routing explains why brokers do not submit all of their orders to one exchange only.

Second, we advance academic literature by empirically studying competition between multiple electronic exchanges as opposed to electronic versus physical markets. This is a relatively understudied but emerging area of the Information Systems (IS) literature (Koh et al., 2010).

Third, we find a counterintuitive result where the second electronic exchange’s entry causes an increase in the incumbent electronic exchange’s order routing percentage. We call this a “ legitimation” effect whereby the second electronic exchange legitimizes the technology of the incumbent exchange. This result tells managers of electronic markets that it may be beneficial to keep initial barriers to entry low as a competing market’s entry can improve the overall position of the incumbent market.
Financial Market Operations

Financial markets perform a number of basic economic functions. First, they consolidate supply and demand for securities, currencies, and derivatives contracts, and process orders and execute trades. They also disseminate price information. By providing information and price discovery for standardized instruments — stocks, bonds, foreign currencies, and futures contracts — markets play an important role by facilitating capital raising and the transfer of risks. IT has made pricing information widely available and reduced latencies for market communications, which has enhanced liquidity and provided more choices to investors. Transactions costs have fallen and volumes have risen in most major markets in the past 10 years (Harris et al., 2008).

Second, markets provide infrastructure for transferring ownership and payments, and for enforcing rules and legal contracts. Conflicts of interest and opportunities for fraud arise in markets, so investors require assurance that financial information is reliable (e.g., has been audited), and that trading rules will be enforced. Third, markets intermediate between sources of capital (savers) and users of capital (borrowers), and provide immediacy and liquidity. This means that, for instance, a ‘saver’ that purchases bonds or call option contracts on a company’s stock does not need to hold the bonds or options until their maturity or expiration date. The buyer can reverse the investment decision by selling the bonds or the calls back to buyers in the market. The liquidity of traded financial assets makes them more valuable than other assets that can not be readily converted into cash (Amihud and Mendelson, 1988).

Finally, markets are inter-organizational systems whose success depends on their participant firms, particularly at the time of launch. In such a setting, economic forces such as adoption decisions and network effects can determine the impact of technology as much as technical advantages. After constructing a simple model of broker choice among rival exchanges, the empirical question we answer is how the dynamics of an interrelated, multi-firm environment can support
the launch of two electronic options exchanges.

Diffusion Research: Economic and Sociological Factors

A large body of research has sought to understand the sociological and economic processes underlying the diffusion of new technologies. Empirical data has been used to understand the diffusion process of technological innovations. Seminal work found the diffusion pattern of new, hybrid corn seeds varied by region within the central United States in the period 1932-1956 (Griliches, 1957). The adoption of hybrid corn, a new technology, was shown to be a series of interdependent developments involving seed producers and farmers that occurred at different rates in different areas that had different characteristics.

Empirical work looking at IT innovations generally confirms the presence of network effects that influence the expected benefits from a new technology, and thus drive adoption decisions by users. The role of network effects was identified in a study of ATM adoption by banks in the period 1971-1979. At the time, technology was proprietary and ATMs were not yet linked into multi-bank networks (Saloner and Shepard, 1995). Controlling for a bank’s deposit base, it turned out the size of the bank’s branch network explained a bank’s speed in rolling out ATM machines. More branches led to less rapid ATM adoption. The results suggest predictability in diffusions across firms, and confirmed that anticipated network value leads firms to be earlier adopters of a new technology. Another study identified features of spreadsheet software that commanded premium prices, but also identified “positive network externality effects from installed base and from compatibility [that are] as important as any of the intrinsic product features” of the 93 competing software packages in the sample (Brynjolfsson and Kemerer, 1996). A study of the ISE in the period 2001-2004 showed brokers’ use was positively related to whether the firm is an online broker, its ISE membership status, and the prior period’s overall ISE market share (Weber, 2006).

One challenge for research studying the take up of new IT is that analyses based on sales of an IT
product often overstate the true diffusion process (Fichman and Kemerer, 1999). An “assimilation gap” has been identified between the acquisition of software and its deployment. This leads to the conclusion that IT innovations may enjoy robust sales, yet are “not genuinely diffusing in the sense of having a significant impact on the operational processes of acquiring firms”. Examining the assimilation of software process innovations in 608 corporate IT departments, Fichman and Kemerer develop a fitted model with five variables including department size, education, and internal training activity. The model explained 49 percent of the variance in firms’ use of software process innovations (Fichman, 2001). Devaraj and Kohli (2003) studied a sample of DSS usage in eight hospitals. Evidence of benefits were shown to be more strongly linked to the actual usage of technology than to its mere availability. Pac et al. (2010) extended the Bass diffusion model to a competitive environment in which the rival “platforms” have differing network externalities. The optimal adoption times for users are solved for as Nash equilibria, and the paper showed that under competition, the dominance of an incumbent platform translates into lagged response by users to an entrant’s innovation.

In contrast to the diffusion economics literature, sociological research emphasizes how know-how or experience with an innovation can be spread across users and become the mechanism that drives network effects (Rogers, 1976, 2003). Abrahamson and Rosenkopf (1997) propose a theory of how the structure of social networks affects the extent of an innovation’s diffusion among members. According to the theory, success is a result of knowledgeable advocates, experts and technology vendors promoting early adoption of an innovation. As it becomes more widespread, other forms of institutional pressure — business partners, consultants, etc. — persuade other, similar firms to adopt. They propose that as innovations gain managerial attention, becoming fads and fashionable, their diffusion accelerates, perhaps more so than would be justified on economic benefits alone.

While sociological research highlights knowledge sharing from adopters to non-adopters, the
economics literature principally considers how consumers or firms adopt when they *anticipate* benefits from other consumers or firms using the same technology. The economic benefits may be direct, such as for a fax owner or word processing user gaining when others acquire fax machines or buy software with the same document format. Or there may be indirect benefits, arising from the technology that is widely selected being more likely to survive and have more products compatible with it in the future. Once Blue-Ray went ahead in the format battle for High Definition DVD, your neighbor can lend you a Blue-Ray disk to play on your machine, generating an indirect benefit an HD-DVD player would not.

**Diffusion of Electronic Options Trading**

Options contracts can be either a put or a call. A put (call) option is the right, but not the obligation, to sell (buy) the underlying security at option expiration for a pre-determined price. Each contract is for 100 shares of the underlying security. Options contracts began to trade on the
Chicago Board Options Exchange in 1973. Three other exchanges for options opened in the next three years. From 1990 to 2000, when the ISE launched, daily average options trading volume grew at a compound annual rate of 13.3%. From 2000-2009, volumes rose at a compound annual rate of 19.5%, reaching 14.4 million contracts per day by the end of 2009 (Figure 1).

The flow of options orders from investors to exchanges is illustrated in Figure 2. The order begins with a customer-investor decision (upper-left) to trade a call or put option. The order may be electronically delivered to the broker or take place over the phone. Once the broker has the customer’s order, they are obligated to achieve best execution, which means selling at the price of the highest quote, or buying for the customer at the lowest offer to sell. Exchanges will often match prices/quotes elsewhere. Brokerage firms therefore need to be incentivized to “route” orders to ISE and BOX, or use “Smart Routing” systems that are programmed to send orders to ISE and BOX under certain conditions.
Compared with floor exchanges, electronic options markets offer technical advances such as immediate trading, direct user access to the market, and reduced costs. Similar to hybrid corn offering higher yields for farmers willing to invest in new planting and harvesting methods, ISE and later BOX provided brokerage firms the ability to route orders to a new exchange in return for what we call a ‘connection’ expense. The economic diffusion literature suggests electronic exchanges will succeed if they can raise initial expectations that economic value will emerge from growth of their networks and liquidity. Sociological research argues that know-how and enthusiasm for the new markets, communicated among brokers, will lead to greater levels of conversion. Information Systems (IS) research has predicted a shift towards electronic markets (Malone et al., 1987). However, even with seemingly large technological advantages, new exchanges often fail to reach sustainable market shares and have to shut down. In the 1980s and 1990s, Intex, Jiway, and Optimark offered new, fully electronic trading platforms but failed to reach critical mass.

ISE and BOX illustrate the critical mass challenges. In their four years of operation, the two ex-
changes slowly gained market share from the incumbent floor exchanges. ISE reached a market share of 30% after three years. While BOX achieved 6% market share within two years, it has not increased from that level (Figure 3).

Early empirical research into electronic markets generally compared new electronic markets to traditional, manual markets (Clemons and Weber, 1990; Hess and Kemerer, 1994). This paper goes further to compare two electronic markets competing with one another, and with the traditional floor markets they challenged.

The rest of the paper is organized as follows. The next section describes a model of broker choice for allocation of orders between exchanges. Specific hypotheses on electronic market diffusions and competition are developed in section 3. Section 4 provides a description of the data used. Several models are presented in section 5. Section 6 estimates the models from data on brokerage firms’ use of the two new exchanges to understand the diffusions of the ISE and BOX and provides several tests of adoption and attrition to explain ISE’s sustained growth, and what prevented BOX from achieving the same. We also test for differences between broker types. Section 7 discusses the implications for electronic exchanges and concludes.

A MODEL OF BROKER CHOICE

Description of Model

In this section we describe a model where brokers must choose the fraction of their orders \( p_i \) to send to each of \( i = \{1, \ldots, N\} \) possible exchanges. Of these exchanges, we will consider the first \( L \) exchanges to be electronic exchanges and the remaining \( N - L \) exchanges to be traditional floor exchanges.

We assume the goal of the broker is to minimize the cost of completing the orders received from its customers. There is an overall cost of trading, \( C_T \), that is a function of the number of orders
that customers place with the broker. This cost is split between the N exchanges, with $p_i C_T$ attributable to exchange $i$.

In order to trade on the $L$ electronic exchanges, the broker must first have a necessary level of technical capability. To model this relationship we will assume that every broker has an innate technical capability $\tau \in [0, 1]$. $\tau$ represents the savings on electronic connection costs, $C_E$, brokers pay after developing interfaces to the e-exchange.\(^1\) For instance, $\tau = 0.75$ implies a 25% reduction in the cost of connecting to an electronic exchange. We further assume that online brokers (OLBs) have a higher technical capability than full service brokers (FSBs): $\tau_{OLB} > \tau_{FSB}$.

Brokers can reduce their trading costs in two other ways. First, with improved liquidity on the exchange, the broker achieves better compliance with best execution resulting in the trading cost being reduced by $\lambda_i$ percent of the cost of trading on that exchange. Second, the broker can pay a fixed amount, $C_{A,i}$, to affiliate via membership with the exchange and reduce the costs by $\alpha_i$ percent on that exchange.

During a trading day, the best transaction price can change from one exchange to another. If a broker sends all of their orders to one exchange, their customers may perceive this as favoring the exchange over their customers and take their business to a competing broker. To model this type of 'perception penalty' we add a cost equal to the sum of squared deviation from equal, $1/N$ order routing to the broker’s cost function.

Combining the costs, savings, and penalties we can formalize the total cost function that brokers

\(^1\)The Boston Options Exchange Facility Fee Schedule as of May 2010 obtained from \url{http://www.bostonoptions.com/pdf/BOX_Fee_Schedule.pdf} on June 17, 2010 shows the fees for different affiliations. Section 5 lists different technology fees such as setting up CAT-5 connections, monthly connection fees, and trade management software. These are examples of the technological capabilities required and costs that are needed to interact with electronic exchanges.
are minimizing:

\[
\min_{p_i} \left( C_E(1 - \tau) + \sum_{i=1}^{N} [C_{A,i}] + C_T \left[ \sum_{i=1}^{N} p_i (1 - \alpha_i - \lambda_i) + \sum_{i=1}^{N} \left( p_i - \frac{1}{N} \right)^2 \right] \right)
\]  

(1)

s.t.

\[
\sum_{i=1}^{N} p_i = 1
\]

\[
p_i \geq 0 \forall i
\]

Optimal Order Routing

Note that \( C_E(1 - \tau) + \sum_{i=1}^{N} [C_{A,i}] \) doesn’t depend on \( p_i \), \( C_T \) is scaling the minimization problem and the constraint can be restated as \( p_N = 1 - \sum_{i=1}^{N-1} p_i \). In addition, the non-negativity constraints will be non-binding for reasonable values of \( \alpha_i \) and \( \lambda_i \). This reduces the problem to:

\[
\min_{p_i} \sum_{i=1}^{N-1} p_i (1 - \alpha_i - \lambda_i) + (1 - \sum_{i=1}^{N-1} p_i)(1 - \alpha_N - \lambda_N)
\]

\[
+ \sum_{i=1}^{N-1} \left( p_i - \frac{1}{N} \right)^2 + \left( 1 - \sum_{i=1}^{N-1} p_i - \frac{1}{N} \right)^2
\]

(2)

defining the function as \( f \) we obtain F.O.C.s

\[
\frac{\partial f}{\partial p_i} = \alpha_N + \lambda_N - \alpha_i - \lambda_i + 2p_i + 2 \sum_{j=1}^{N-1} p_j - 2 = 0
\]

(3)

This can be rewritten as

\[
Xp = q
\]

(4)
where \( X \) is an \( N - 1 \times N - 1 \) matrix of the form

\[
x_{ij} = \begin{cases} 
4, & \text{if } i = j \\
2, & \text{if } i \neq j 
\end{cases}
\]  

(5)

and \( q \) is an \( N - 1 \) column vector of the form

\[
q_i = 2 + \alpha_i + \lambda_i - \alpha_N - \lambda_N
\]

(6)

Note that we can write \( X \) as

\[
X = bH + (a - b) I
\]

(7)

where \( H \) is an \( N - 1 \times N - 1 \) matrix of ones, \( I \) is the \( N - 1 \times N - 1 \) identity matrix, \( a = 4 \) and \( b = 2 \). Appendix A shows that

\[
X^{-1} = dH + (c - d) I
\]

(8)

where

\[
c = \frac{a + b(N - 3)}{(a - b)(a + b(N - 2))} \frac{4 + 2(N - 3)}{4 + 2(N - 2)} = \frac{8 + 4N - 8}{N - 1} = \frac{2N}{2N}
\]

and

\[
d = \frac{-b}{(a - b)(a + b(N - 2))} \frac{-2}{4 - 2(N - 2)} = \frac{-2}{8 + 4N - 8} = \frac{-1}{2N}
\]
Which means that

\[ p = X^{-1}q \]  \hspace{1cm} (9)

If we denote \( x'_i \) as the \( i^{th} \) row of \( X^{-1} \) so that the optimal \( p_i \) for \( i = (1, \ldots, N - 1) \) is

\[
p_i = x'_i q
\]

\[
= \frac{N-1}{2N} (2 + \alpha_i + \lambda_i - \alpha_N - \lambda_N) - \frac{1}{2N} \sum_{j \neq i, N} (2 + \alpha_j + \lambda_j - \alpha_N - \lambda_N)
\]

\[
= \frac{N-1}{N} + \frac{N-1}{2N} (\alpha_i + \lambda_i - \alpha_N - \lambda_N) - \frac{1}{2N} \sum_{k=1}^{N-2} 2 - \frac{1}{2N} \sum_{j \neq i, N} (\alpha_j + \lambda_j - \alpha_N - \lambda_N)
\]

\[
= \frac{1}{N} + \frac{N-1}{2N} (\alpha_i + \lambda_i) - \frac{1}{2N} \sum_{j \neq i, N} (\alpha_j + \lambda_j) - \frac{N-1}{2N} (\alpha_N - \lambda_N) + \sum_{k=1}^{N-2} (\alpha_N + \lambda_N)
\]

\[
= \frac{1}{N} + \frac{N-1}{2N} (\alpha_i + \lambda_i) - \frac{1}{2N} \sum_{j \neq i, N} (\alpha_j + \lambda_j) - \frac{N-1}{2N} (\alpha_N - \lambda_N) + \frac{N-2}{2N} (\alpha_N + \lambda_N)
\]

\[
= \frac{1}{N} + \frac{N-1}{2N} (\alpha_i + \lambda_i) - \frac{1}{2N} \sum_{j \neq i} (\alpha_j + \lambda_j)
\]
Solving for $p_N$ we obtain

$$
 p_N = 1 - \sum_{i=1}^{N} p_i
$$

$$
= 1 - \sum_{i=1}^{N} \left( \frac{1}{N} + \frac{N - 1}{2N} (\alpha_i + \lambda_i) - \frac{1}{2N} \sum_{j \neq i} (\alpha_j + \lambda_j) \right)
$$

$$
= \frac{1}{N} - \frac{N - 1}{2N} \sum_{i=1}^{N-1} (\alpha_i + \lambda_i) + \frac{1}{2N} \sum_{i=1}^{N-1} \sum_{j \neq i} (\alpha_j + \lambda_j)
$$

$$
= \frac{1}{N} - \frac{N - 1}{2N} \sum_{i=1}^{N-1} (\alpha_i + \lambda_i) + \frac{1}{2N} \sum_{i=1}^{N-1} \sum_{j \neq i} (\alpha_j + \lambda_j) - \frac{N - 1}{2N} \sum_{i=1}^{N-1} \sum_{j \neq i,N} (\alpha_j + \lambda_j)
$$

$$
= \frac{1}{N} + \frac{N - 1}{2N} (\alpha_N + \lambda_N) + \frac{1}{2N} \sum_{i=1}^{N-1} \sum_{j \neq i,N} (\alpha_j + \lambda_j) - \frac{N - 1}{2N} \sum_{i=1}^{N-1} (\alpha_i + \lambda_i)
$$

$$
= \frac{1}{N} + \frac{N - 1}{2N} (\alpha_N + \lambda_N) - \frac{1}{2N} \sum_{i=1}^{N} (\alpha_i + \lambda_i)
$$

which shows that

$$
p_i = \frac{1}{N} + \frac{N - 1}{2N} (\alpha_i + \lambda_i) - \frac{1}{2N} \sum_{j \neq i} (\alpha_j + \lambda_j) \quad \forall i
$$

Equation 10 tells us that, in absence of affiliation and liquidity discounts, brokers will split their orders evenly between the exchanges. When cost advantages are sufficiently high, brokers will increase the fraction of orders sent to that exchange.

**HYPOTHESES**

Using the broker choice framework described above, we propose four hypotheses concerning how network and sociological variables influence brokers’ use of two new electronic options exchanges.
The first two hypotheses propose that broker’s affiliations, or firm-selected characteristics will be significant in predicting its market share allocated to each exchange.

For the first hypothesis, we examine broker affiliations with the exchanges. ISE and BOX have several membership categories that brokers choose (at some cost) to belong to (See Table 1).

From the model we know that \( \frac{\partial p_i}{\partial \alpha_i} = \frac{N-1}{2N} > 0 \) and \( \frac{\partial p_j}{\partial \alpha_j} = -\frac{1}{2N} < 0 \). This means that the percent of orders sent to an exchange increases when the affiliation discount increases and decreases when the affiliation discount to a different exchange increases. Since affiliating with exchange \( i \) provides a discount \( \alpha_i > 0 \) the impact is \( \Delta p_i > 0 \) and \( \Delta p_j < 0 \forall j \neq i \). This leads to four predictions:

**Hypothesis 1a (H1a):** Brokers with membership affiliation(s) with ISE will send a higher percentage of their customer orders to ISE than brokers without membership affiliation(s) with ISE.

**Hypothesis 1b (H1b):** Brokers with membership affiliation(s) with BOX will send a higher percentage of their customer orders to BOX than brokers without membership affiliation(s) with BOX.
Hypothesis 1c (H1c): Brokers with membership affiliation(s) with ISE will send a lower percentage of their customer orders to BOX than brokers without membership affiliation(s) with ISE.

Hypothesis 1d (H1d): Brokers with membership affiliation(s) with BOX will send a lower percentage of their customer orders to ISE than brokers without membership affiliation(s) with BOX.

Brokers with high existing technical capability — online brokers in our sample — can connect more cost effectively to new electronic exchanges. Full service brokers have less IT in their basic business and have lower technical capabilities. This would mean that $p_i = 0 \forall i = \{1, \ldots, L\}$ and the average routing will be lower to the electronic exchanges for these brokers.

Hypothesis 2a (H2a): Online brokers will send a higher percentage of their customer orders to ISE than full service brokers.

Hypothesis 2b (H2b): Online brokers will send a higher percentage of their customer orders to BOX than full service brokers.

The third hypothesis is that brokers react to greater liquidity on an exchange with increased order flow. In our setting, the exchange’s liquidity in the previous quarter will have a positive impact on broker use in the current quarter. In the context of exchanges, these network effects are important for brokers since markets with greater liquidity have more competitive quotes. This is represented in our model in a manner similar to the affiliation discount: $\frac{\partial p_i}{\partial \lambda} = \frac{N-1}{2N} > 0$.

Hypothesis 3a (H3a): As ISE gains in overall liquidity, the percentage of orders that brokers send to ISE will increase.

Hypothesis 3b (H3b): As BOX gains in overall liquidity, the percentage of orders that brokers send to BOX will increase.
Therefore, as the liquidity of the exchange increases, the percent of orders sent to that exchange will increase because of the decreased implicit cost of trading in that exchange. When a new entrant opens for business, it is usually the case that the market shares of close rivals will decrease. We therefore expect a negative impact on brokers’ use of the ISE when BOX is launched.

**Hypothesis 4 (H4):** *The opening of BOX will reduce the fraction of order flow sent by brokers to the ISE.*

**DATA**

Our data set comes from several sources. First, the total number of contracts traded on each exchange for each quarter comes from the Options Clearing Corp. We use this data to calculate the market share for each exchange in each quarter. An exchange’s market share is a measure of the liquidity in that exchange relative to liquidity in all of the other exchanges. Figures 4(a) and 4(b) show the growth in the initial months at ISE and BOX were similar in terms of the number of contracts traded per day and market share of the exchange. For robustness we have checked the results using the average number of contracts per trading day in that quarter normalized by the average number of contracts per trading day in the quarter that the exchange opened. Results are qualitatively similar and available from the authors upon request.

The brokers’ membership and affiliation information comes from the ISE and BOX websites and correspondence with managers at the exchanges to determine dates at which firms became members. Third, Securities and Exchange Commission’s (SEC) Rule 606 (formerly called Rule 11Ac1-6) requires brokers to publish their routing of equity and option orders on a quarterly basis. The data is the percentage of orders sent to each exchange by each broker. This is reported quarterly beginning 3Q 2001 through 4Q 2006 for our sample of 24 of the largest US brokerage firms.\(^2\)

\(^2\)Rule 606 mandates that from third quarter 2001 firms must disclose the identity of the market centers that re-
Figure 4: Similar initial growth in the first 30 months after launch for ISE and BOX.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Mean</th>
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<tbody>
<tr>
<td><strong>Dependent Variables</strong></td>
<td></td>
<td></td>
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<tr>
<td>ise</td>
<td>Percent of orders routed to ISE</td>
<td>0.242</td>
</tr>
<tr>
<td>box</td>
<td>Percent of orders routed to BOX</td>
<td>0.015</td>
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<tr>
<td><strong>Independent Variables</strong></td>
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<td></td>
</tr>
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<td>olb</td>
<td>Online Broker Indicator</td>
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<td>ISE Primary Market Maker Indicator</td>
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<tr>
<td>prevqtrmsise</td>
<td>BOX Previous Quarter Market Share</td>
<td>0.040</td>
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Table 2: Mean of the dependent and independent variables used in our analysis.

A fourth source is Barron’s annual survey of online brokers in 2002-2005, which allowed us to separate the brokers into online and full-service categories.

to receive 5% or more of customers’ orders for: i) NYSE-listed securities, ii) Nasdaq-listed securities, iii) Amex-listed and regional exchange-listed securities, iv) exchange-listed options. The specific disclosures apply are the “Percentage of Customer Orders Having a Market Value Less Than $200,000” for securities, and for listed options, the “Percentage of Customer Orders Having a Market Value Less Than $50,000.”
Execution Fee Match / Exchange Floor Comparison Fee Total

<table>
<thead>
<tr>
<th>Exchange</th>
<th>Execution Fee (per contract)</th>
<th>Match / Comparison Fee</th>
<th>Exchange Floor Broker Fee</th>
<th>Total</th>
</tr>
</thead>
<tbody>
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<td>ISE</td>
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<td>$0.03</td>
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Table 3: Fees per contract traded in 2006 are comparable across the six exchanges and cost differentials are not significant in explaining market share gains at ISE or BOX.

Descriptive Statistics

Table 2 reports the mean of the dependent and independent variables in our sample. At the midpoint of our data collection in 2004, the ISE listed options on 646 securities. Its market is organized into 10 bins with about 60 stock options in each. A bin has one Primary Market Maker (ISEPMM), and as many as 16 Competitive Market Makers (ISECMMs). An ISEPMM must purchase or lease one of the 10 ISEPMM trading rights. In 2004, eight firms operated as ISEPMMs, with two firms covering two bins each. The second ISE membership category is Competitive Market Maker. In 2004, 23 firms operated as ISECMMs. An ISECMM must purchase or lease one of 160 ISECMM trading rights, entitling them to enter quotations in the options in a bin. For instance, ISECMM trading privileges for Bin 3 were bought for $1.5 million each on December 18, 2003. ISECMM rights were sold for $1.5 million again in 2008. In 2006, ISEPMM trading privileges for Bin 6 were sold for $7.9 million. ISEPMMs have greater obligations, but also greater privileges in ISE trading than ISECMMs. The third ISE membership type is an “Electronic Access Member” (ISEEAM). An ISEEAM is a broker/dealer that acts as an order flow provider, and unlike ISEPMMs and ISECMMs-is not required to purchase membership. There are no limits on the number of ISEEAMs, who pay a monthly access fee to send orders in all of the options traded on the ISE. ISEEAMs cannot enter quotations or otherwise engage in market making activities on the Exchange. In 2004, there were 126 ISEEAMs, and in 2009 there were...
In contrast, BOX doesn’t limit the number of market maker designations, nor does it require brokers to purchase seats. BOX Market Makers (BOXMM) are responsible for providing liquidity in the options they have been assigned to, but can freely enter or exit. The market makers on BOX are competing with any number of other market makers. The second BOX membership type is called a participant (BOXPRCT). Similar to the ISEEAM affiliation type, the BOXPRCT is not purchased but a registration requirement for trading on the exchange. The third BOX membership type is an investor (BOXINV). This is different to the other two affiliation types. An investor is a broker that also has an equity stake in BOX.

Data on explicit per trade exchange costs were collected, but the small differences turned out to have no relation to market share changes (Table 3).

**METHODOLOGY**

In general, a diffusion model explains the number of adopters in a given time period as a function of both adopter characteristics and external forces. In the context of electronic exchanges we explain the market share sent to a given exchange by a broker in each time period as a function of broker affiliation with an exchange (an firm characteristic), whether BOX is open (an external factor), and the liquidity of an exchange (an external factor).

We observe broker order routing to two exchanges simultaneously. If we were to estimate separate equation for the two exchanges the errors in corresponding observations may be correlated. We therefore estimate our models using seemingly unrelated regression (SUR) (Zellner, 1962).

We first consider a model in which a broker is considered affiliated with an exchange if it has any level of affiliation. In addition we include the exchange’s previous quarter total market share to measure the network effect and for the ISE equation the impact of BOX opening as the indepen-
dent variables.

\[ p^I_{jt} = \alpha^I + \beta^I_1 OLBJ_t + \beta^I_2 ISEAFF_{jt} + \beta^I_3 BOXAFF_{jt} \]
\[ + \beta^I_4 MS_{t-1} + \beta^I_5 BOXOPEN_t + \epsilon^I_{jt} \quad (11a) \]
\[ p^B_{jt} = \alpha^B + \beta^B_1 OLBJ_t + \beta^B_2 ISEAFF_{jt} + \beta^B_3 BOXAFF_{jt} \]
\[ + \beta^B_4 MS_{t-1} + \epsilon^B_{jt} \quad (11b) \]

where \( p^I_{jt} \) is the percentage of orders sent to the exchange by a given broker, \( OLBJ_t \) is a dummy variable taking the value of 1 when a broker is an online broker and 0 otherwise, \( ISEAFF_{jt} \) is a dummy variable taking the value of 1 when a broker has any level of affiliation with ISE and 0 otherwise, \( BOXAFF_{jt} \) is a dummy variable taking the value of 1 when a broker has any level of affiliation with BOX and 0 otherwise, and \( BOXOPEN_t \) is a dummy variable taking the value of 1 when a BOX is open. Following the SUR framework, \( \mathbb{E}[\epsilon^I_{jt}\epsilon^B_{js}|X] = 0 \) whenever \( t \neq s \) and \( \mathbb{E}[\epsilon^I_{jt}\epsilon^B_{js}|X] = \sigma_{IB} \).

Building on this model we relax the assumption that affiliation is a binary variable. This lets us examine if affiliation effects vary according to the affiliation level.

\[ p^I_{jt} = \gamma^I + \eta^I_1 OLBJ_t + \eta^I_2 ISEPMJM_{jt} + \eta^I_3 ISECMJM_{jt} \]
\[ + \eta^I_4 ISEEAM_{jt} + \eta^I_5 BOXINV_{jt} + \eta^I_6 BOXPRCT_{jt} \]
\[ + \eta^I_7 BOXMM_{jt} + \eta^I_8 MS_{t-1} + \eta^I_9 BOXOPEN_t + \nu^I_{jt} \quad (12a) \]
\[ p^B_{jt} = \gamma^B + \eta^B_1 OLBJ_t + \eta^B_2 ISEPMJM_{jt} + \eta^B_3 ISECMJM_{jt} \]
\[ + \eta^B_4 ISEEAM_{jt} + \eta^B_5 BOXINV_{jt} + \eta^B_6 BOXPRCT_{jt} \]
\[ + \eta^B_7 BOXMM_{jt} + \eta^B_8 MS_{t-1} + \nu^B_{jt} \quad (12b) \]

where \( ISEPMJM_{jt} \) is a dummy variable taking the value of 1 when a broker is an ISE Primary
Market Maker and 0 otherwise, $ISECM_{jt}$ is a dummy variable taking the value of 1 when a broker is an ISE Competitive Market Maker and 0 otherwise, $ISEEAM_{jt}$ is a dummy variable taking the value of 1 when a broker is an ISE Electronic Access Member and 0 otherwise, $BOXINV_{jt}$ is a dummy variable taking the value of 1 when a broker is an ISE Investor and 0 otherwise, $BOXPRCT_{jt}$ is a dummy variable taking the value of 1 when a broker is a BOX Participant and 0 otherwise, $BOXMM_{jt}$ is a dummy variable taking the value of 1 when a broker is a BOX Market Maker, $MS_{\theta,t}$ is the liquidity measure, and $\theta, j$ and $t$ reference the exchange, broker and time, respectively. All other variables are as described above. The relaxed model is also a SUR so that $E[\nu_{jt}^{I} \nu_{js}^{B} | X] = 0$ whenever $t \neq s$ and $E[\nu_{jt}^{I} \nu_{js}^{B} | X] = \sigma_{IB}^{'}$.

**RESULTS**

The results of the regressions are contained in table 4. The first two columns show the results for the model 11a and 11b.

Hypotheses H1a-H1d state that affiliation will impact the percentage of orders that brokers send to an exchange. Specifically we expect affiliation with an exchange to increase the percentage of orders sent to that exchange and decrease the amount sent to the other exchange. For example a broker that is affiliated with ISE will send more orders to ISE and less orders to BOX than a broker that is not affiliated with ISE.

We find support for hypothesis H1a and H1c as evidenced by positive and significant coefficients on ISEAFF in column 1 and BOXAFF in column 2. These estimates suggest that brokers send more to the exchange in which they are affiliated. Comparing the coefficients highlights a major difference between the exchanges. While ISE affiliates send nearly 10% more of their orders to ISE, BOX affiliates send only an extra 2% of their orders to BOX.

---

3When a broker affiliates during a quarter, we scale the 0-1 to reflect the portion of the quarter remaining, e.g. 0.5 if an ISEPMM seat was acquired midway through the quarter.
<table>
<thead>
<tr>
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<th>(2)</th>
<th>(3)</th>
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<td>BOX</td>
<td>ISE</td>
<td>BOX</td>
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<td>MODEL 11b</td>
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<tr>
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**Table 4:** Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
We find no support for hypothesis H1b and H1d as evidenced by insignificant coefficients on BOXAFF in column 1 and ISEAFF in column 2. This suggests that affiliation with an exchange is important but affiliation with other exchanges is not important to brokers when they decide where to route orders. To investigate whether individual affiliation levels are more important than others, we now examine hypotheses H1a-H1d using results based on model 12a and 12b where the affiliation impact can vary across the different levels. The results of the regression for these models are in columns 3 and 4 of table 4.

The coefficients on the individual affiliation variables may understate the effects affiliations have on brokers’ use of the two electronic exchanges. Since brokers who purchase the expensive affiliations typically obtain the less expensive as well, we can consider the true impact of the expensive affiliations as the cumulative impact of all affiliations. Table 5 shows the probability of being in one affiliation group conditional on being in the other affiliation groups. The upper right of the matrix shows the probability of being in a less expensive affiliation conditional on being in the more expensive affiliations. This further supports hypotheses H1a and H1b. For example, a broker that is an ISEPMM is also likely an ISECMM and ISEEAM (100% and 99.3% in our sample). The coefficients for model 12a suggest that this broker is predicted to send an additional $4.49\% + 3.07\% + 15.1\% = 22.68\%$ to ISE than a completely unaffiliated broker. To account for
this we ran tests on the linear combination of coefficients for the affiliation levels. The results of the tests are shown at the bottom of columns 3 and 4 in table 4.

We first consider the impact that a broker affiliating with an exchange has on the percentage of orders sent to that exchange. Hypothesis H1a and H1c are again supported in the data. However there is a difference between affiliation levels and subsequent order routing. Brokers that purchase the more expensive affiliation levels submit a larger percentage of their orders to that exchange than brokers who purchase a cheaper affiliation membership.

We now consider the effect that a broker affiliating with an exchange has on the percentage of orders sent to the other exchange. There is minimal support for hypothesis H1c and no support for hypothesis H1d. It appears that the only brokers which act in the way predicted by this hypothesis are those that have large affiliation ties with BOX. These brokers, which are BOX participants, market makers and investors, send a significantly lower percentage of their orders to ISE. No other combination of affiliation levels seen in the data shows support for these hypotheses. The results suggest that the negative impact of affiliation with another exchange is more detrimental to ISE than to BOX.

Hypotheses 2a and 2b state that online brokers will send a higher percentage of their customer orders to ISE and BOX than full service brokers. There is strong support for these hypotheses with coefficients that are positive and significant in both models estimated. The results again highlight the difference between ISE and BOX. While OLBs send an additional six or seven percent of orders to ISE relative to full service brokers, they only send an additional two percent of orders to BOX.

Hypotheses 3a and 3b state that as an exchange achieves higher liquidity relative to other exchanges, the percentage of orders that brokers send to that exchange will increase. There is strong support for these hypotheses with positive and significant coefficients across the models esti-
Table 6: Relative impact of independent variables on the dependent variable, percentage of orders sent to each exchange, expressed in percentage of influence. The left hand side uses all of the coefficients from models 12a and 12b while the right hand side uses only the coefficients on OLB, liquidity, and affiliation with the exchange in the dependent variable. To arrive at these values we first multiply the coefficient with the applicable variable’s average. We then divide this number by the sum of all values to get the relative impact in percentage terms. The values in the final column do not sum to 100 due to rounding.

Hypothesis 4 states that the opening of BOX as a competitor to ISE will decrease the percentage of orders brokers send to ISE. To find support for hypothesis 4 we would expect to see a significantly negative coefficient on BOXOPEN. However, the coefficient on BOXOPEN is positive and significant in both model formulations. This indicates that the opening of BOX had a beneficial impact on ISE’s market share. This may at first seem counter-intuitive, however this can be interpreted as a “legitimation” effect. Before BOX enters the electronic exchange market, brokers are unsure if electronic trading is a fad or a long term paradigm shift. When BOX opens it legitimizes the technology used by ISE and therefore the percentage of orders sent to ISE increases.

So far we have observed that successful launch of an electronic exchange requires (1) gaining liquidity, (2) attracting brokers with the greatest propensity to trade electronically, and (3) creating affiliation structures that benefit member brokers through revenues from designated market
maker roles. Table 6 shows the relative impact that each variable has on the percentage of orders sent to an exchange by a given broker using models 12a and 12b. In the left side of the table, we notice that affiliation effects account for 43.3 percent of the predicted broker market share to ISE compared to 41.0 percent for BOX. These numbers exclude the OLB effect that accounts for 9.9 percent for ISE and 21.3 percent for BOX. Furthermore, network effects account for 34.3 percent of the predicted broker market share to ISE and 37.7 percent for BOX. Finally, the legitimation effects account for the remaining 12.6 percent of the predicted broker market share to ISE.

An exchange has little or no control over new exchanges entering the market or whether brokers affiliate with other exchanges. If we set these variables to zero and re-calculate the relative influence of the regressors, we obtain the results on the right side of Table 6. This tells us that for ISE (and BOX), OLB identity, broker membership affiliation, and the exchange’s lagged market liquidity account for 13.0 (27.2) percent, 42.2 (24.8) percent, and 44.8 (48.1) percent of brokers’ predicted market share of the new exchange.

ISE and BOX markets had similar diffusions. The factors with the most positive and significant coefficients for ISE’s market share model were significant, but less positive for BOX. At the broker level, there are several explanations for why BOX has not achieved a higher level of market share including: (1) brokers never used BOX, (2) brokers used BOX but with not enough volume, and (3) brokers used BOX for a time but then stopped using BOX.

In order to examine adoption and transitions in the highly sensitive early quarters, we first categorize the brokers into four types:

1. Continuing brokers (C) are those which submitted orders to the exchange in both the previous and the current quarter.

2. Entering brokers (E) are those which didn’t submit orders in the previous quarter but did in the current quarter.
3. Exiting brokers (X) are those which submitted orders to the exchange in the previous quarter but not in the current quarter.

4. Waiting brokers (W) are those which didn’t submit orders in either the previous or the current quarter.

If an exchange does not attract enough order flow, it could be the result of brokers not continuing usage (too many brokers exiting the user group), or brokers not entering the user group (too many brokers delaying adoption), or a combination. We have put each broker into one of these categories for each of the first 12 quarters from when an exchange opened. This enables us to compare the exchanges on equivalent time spans. In addition, we only consider brokers for which we have order information for all 12 quarters following exchange opening. This prevents overestimation of the impact of each category due to missing data. Figures 5(a) and 5(b) show the breakdown of brokers in each of the first three types for both exchanges. Immediately evident is that ISE has fewer exiting brokers than BOX in almost all quarters. However, with the exception of the final quarter BOX had more continuing brokers than ISE.

Table 7 shows the number of brokers in each category across quarter 2 to 12 for each exchange as well as for the two exchanges pooled together. In addition, it shows the relative percentage of
brokers in each category. Using this information we perform chi-squared tests to determine if the number of brokers in each category for the exchanges are significantly different from the number of brokers in each category for the pooled data. The results of the tests confirm that both ISE and BOX broker categorizations are statistically different than the pooled broker categorizations ($\chi^2 = 100.35, p < 0.001$ for ISE and $\chi^2 = 147.01, p < 0.001$ for BOX). We conclude that the overall distribution of brokers in each of the categories is different between the two exchanges.

We can also use the data in table 7 to calculate the probability of a broker switching their using in the current quarter given their usage in the previous quarter. For example, a broker who routed a positive percentage of their orders to an exchange in the previous quarter is either a continuing broker (if their usage is positive in the current quarter) or an exiting broker (if their usage is zero in the current quarter). Similarly a broker who did not route any orders to an exchange in the previous quarter is either an entering broker (if their usage is positive in the current quarter) or a waiting broker (if their usage is zero in the current quarter). Table ?? shows these probabilities for ISE and BOX. These calculations emphasize the drastic differences between the two

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<th>Exiting</th>
<th>Waiting</th>
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<td></td>
<td>74.6%</td>
<td>8.1%</td>
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<td>POOLED</td>
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<td>14</td>
<td>60</td>
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<td></td>
<td>72.7%</td>
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<td>3.7%</td>
<td>16.0%</td>
</tr>
</tbody>
</table>

Table 7: Number and percentage of broker-quarters in each category for each exchange.

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<tr>
<th></th>
<th>Panel A: ISE</th>
<th>Panel B: BOX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous Quarter</td>
<td>Zero</td>
<td>Positive 99.1%</td>
</tr>
<tr>
<td>Positive</td>
<td>22.9%</td>
<td></td>
</tr>
<tr>
<td>Zero</td>
<td>77.1%</td>
<td>0.09%</td>
</tr>
</tbody>
</table>

Table 8: Probability of a broker using ISE (Panel A) and BOX (Panel B) in the current quarter conditional on the previous quarter’s usage.
exchanges that we see in Figures 5(a) and 5(b). In particular, the chance of an ISE user remaining an ISE user the next quarter is 99.2% but it is only 92.3% for BOX as 7.7% of brokers fail to use BOX the quarter after reporting positive use of BOX.

It is not simply the number of brokers in the categories that determines why ISE reached the market share levels it did while BOX failed to achieve these levels. We must also consider the relative size of the brokers. If brokers start sending orders to an exchange, but only in small amounts, then the exchange may never reach the volume necessary to provide sufficient liquidity. A similar argument applies to brokers which are already sending orders to the exchange. If these brokers stop sending orders to the exchange or decrease the percentage of orders they send to the exchange then the volume could again be too small. In both cases the positive feedback loop of exchange volume was better engaged for ISE than BOX.

Figures 6(a) and 6(b) show the breakdown of changes in averages in each of the broker categories as well as the overall change in average shares. It seems that the average market share sent to ISE by entering brokers is higher than the average market share sent to BOX by entering brokers. In addition, the average change in market share sent to ISE by either continuing or exiting brokers is higher than the average change in market share sent to BOX by either continuing or exiting
Table 9 shows the results of two-sample t-tests assuming unequal variances for differences between the change in shares for different categorizations of brokers across exchanges. The results show that brokers who entered BOX did not submit a high enough percentage of their orders to match orders sent to ISE. Further, brokers continuing or exiting BOX were submitting a smaller percentage of their orders. These two results combine to show that ISE had larger entry and continuing usage which provided the liquidity advantages needed in order for an exchange to succeed.

BOX had a larger number of users than ISE. However, brokers’ lower usage levels and exits from usage of the exchange resulted in BOX not achieving the market share levels seen on ISE. From these results we propose that new electronic exchanges should attract a small number of highly committed users to achieve success. We leave the testing of this hypothesis to future work when data is available.

We conclude that at the time of launch electronic exchanges should strategically allocate their resources about equally between:

1. Attracting the segment of users with the greatest inclination to trade electronically - In the ISE and BOX cases this meant OLBs, who moved away from traditional practices most readily. Once a broker adopts the new exchange, maintaining the relationship and limiting drop outs contributes to the entrant exchange’s success.
2. Membership affiliation - Affiliates showed higher usage than non-affiliates, and membership categories should be designed to attract committed sources of order flow

3. General liquidity - While the two e-exchanges diffused faster in some segments of our sample of 24 firms, network effects and raising trading volumes from all sources drove subsequent usage growth

**DISCUSSION AND CONCLUSIONS**

Based on our panel of 462 quarterly disclosures from 24 major brokerage firms, we have demonstrated significant differences in the diffusions at the broker level of two new electronic options exchanges. The models we estimated allowed us to test four hypotheses that explain individual firms’ adoption levels and the drivers of new electronic markets’ growth. The different diffusions of the more and the less successful electronic exchanges can be attributed to characteristics of the broker-users.

We believe we are the first to compare two competing electronic markets by contrasting their diffusion models estimated from an empirical data set. We find support for sociological factors influencing diffusion, for instance whether a firm is an online broker, or whether it has an e-exchange membership or ownership role. Economic measures of the network externality effect also influenced the markets’ growth. In fact, prior period relative liquidity is shown to account for up to 48.1 percent of the e-markets’ diffusion explained by the model.

We also have unexpectedly identified legitimation as a strong driver of electronic market growth. Our results have implications for market providers and firms that trade. Namely, the initial affiliations with the ISE appear to drive the market’s early volume, which then draws less active users to adopt. The factors were at work with BOX but with a weaker effect. Markets need to design their membership structures to ensure a solid base of motivated firms. Trading firms should recognize that new market entrants can offer advantages and benefits, but that some transition costs
are inevitable. It is important for firms to look to other categories of firms for innovative ideas, since full service brokers did not appear to benefit from ISE or BOX to the same degree as online brokers.

Our results demonstrate that firm-specific and network effects are evident in the growth of the ISE and BOX. However, while the network effects still impact BOX market share, the firm-specific effects appear to have a less important role in determining BOX’s market share. This could be the result of lower entry and exit costs for BOX affiliation. We analyze the propensity of a broker to stop using ISE or BOX and found withdrawals were high at 8% for BOX and less than 1% for ISE, which was more “sticky.” The commitment of ISE users to continue use of the exchange made up for the smaller number of ISE users in our sample. This reinforces the conclusion that exchanges require a base of dedicated users to compete successfully.

Based on our results, executives of new e-exchanges should allocate their resources strategically. High propensity users and early adopters, such as OLBs, are worth targeting. Broker affiliations and incentive schemes are important to building overall liquidity. We can conclude that exchanges should allocate their resources between attaining early and high propensity users and affiliation/membership incentives in approximately equal levels.

In a multi-firm setting such as the growth of new electronic exchanges, we believe the empirical methods presented are promising to management researchers in explaining the different responses to trading innovation, and are capable of generating important insights. In addition to the empirical results, we developed a model of competition in the presence of network effects. This model is not limited to analyzing electronic exchanges but, we expect, to many situations where competing firms also benefit from network effects.
References


Suppose \( X \) is an \( M \times M \) matrix of the form

\[
X = bH + (a - b) I
\] (13)

where \( H \) is an \( M \times M \) matrix of ones, \( I \) is the \( M \times M \) identity matrix, \( a \) and \( b \) are scalars and \( a \neq b \). We conjecture that the inverse of \( X \) has the same form

\[
X^{-1} = dH + (c - d) I
\] (14)

It follows that

\[
I = XX^{-1}
\]

\[
= [bH + (a - b) I] [dH + (c - d) I]
\]

\[
= bdH^2 + b(c - d)HI + dHI + (a - b)(c - d)I^2
\]

\[
= MbdH + b(c - d)H + dH + (a - b)(c - d)I
\]

which can be rewritten as

\[
\begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} Mbd + b(c - d) + d(a - b) & 0 \\ 0 & (a - b)(c - d) \end{bmatrix} \times \begin{bmatrix} H \\ I \end{bmatrix}
\] (15)

or

\[
0 = Mbd + b(c - d) + d(a - b)
\] (16a)

\[
1 = (a - b)(c - d)
\] (16b)
Solving 16b for \((c - d)\)

\[
(c - d) = \frac{1}{a - b}
\]  

(17)

and substituting 17 into 16a and solving for \(d\) yields

\[
0 = Mbd + \frac{b}{a - b} + d(a - b)
\]

\[
Mbd + d(a - b) = \frac{-b}{a - b}
\]

\[
d(Mbd + a - b) = \frac{-b}{a - b}
\]

\[
d = \frac{-b}{(a - b)(a + b(M - 1))}
\]  

(18)

Substituting 18 into 17 and solving for \(c\)

\[
c = \frac{1}{a - b} + d
\]

\[
= \frac{1}{a - b} + \frac{-b}{(a - b)(a + b(M - 1))}
\]

\[
= \frac{a + b(M - 1)}{a - b} + \frac{-b}{(a - b)(a + b(M - 1))}
\]

\[
= \frac{a + b(M - 1) - b}{(a - b)(a + b(M - 1))}
\]

\[
= \frac{a + b(M - 2)}{(a - b)(a + b(M - 1))}
\]  

(19)

**BROKER ORDER ROUTING DATA**
<table>
<thead>
<tr>
<th>Panel A: Percentage of contracts sent to ISE</th>
<th>Panel B: Percentage of contracts sent to BOX</th>
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Table 10: Market share OLBs sent to ISE (Panel A) and BOX (Panel B) in our dataset. NA means the data was not available.
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Table 11: Market share FSIBs sent to ISE (Panel A) and BOX (Panel B) in our dataset. NA means the data was not available.