Cyriel de Jong
RSM Erasmus University

Kees G. Koedijk
RSM Erasmus University and CEPR

Charles R. Schnitzlein
College of Business Administration, University of Central Florida

Stock Market Quality in the Presence of a Traded Option*

We use an economic experiment to examine the implications of asymmetric information for linkages between a stock and a traded option. We find the presence of the option splits price discovery across markets and changes the process by which conditional expectations are updated. The time series properties of the stock price depend directly on the intrinsic value of the option: when the intrinsic value of the option is positive, informational efficiency is higher in the market for the stock and volatility is lower. We provide evidence that the introduction of an option improves market quality in the underlying asset.

In this article we report the results from experimental asset markets designed to investigate the implications of asymmetric information for informational linkages between an asset market and a traded call option on that asset. Empirical evidence suggests that the presence of listed options is associated with higher market quality in the market for the underlying asset. A plausible explanation for this effect is that the presence of a correlated asset permits the sharing of effective price discovery across markets: if market makers in the stock learn from transactions in the option they can set more accurate prices. We explore this hypothesis by placing a market in which we observe all information sets under a microscope and examining the

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implications of the strategic interactions of an insider, demanders of liquidity, and suppliers of liquidity for the linkages between the two markets and the time series of prices in general.

The empirical evidence for informational linkages between the market for listed options and the underlying stock is mixed. For example, Vijh (1990) concludes that since very large options trades have limited effects on options prices, they are unlikely to be information based. This would preclude stock price discovery from occurring in the option market. Sheikh and Ronn (1994), however, find systematic patterns in options returns that are inconsistent with the view of options as redundant assets. They attribute these patterns to strategic behavior by informed and discretionary liquidity traders. Easley, O'Hara, and Srinivas (1998) find strong evidence that options markets are a venue for information-based trading and that properly defined option market volumes associated with "positive news" and "negative news" have predictive power for stock price movements. A recent surge in the number of insider-trading cases involving options also suggests an increasing importance of options markets as an outlet for information based-trade.[1]

There is a large body of empirical work that examines the influence of stock option listings on the time series properties of the market for the underlying asset. Much of this evidence suggests that the presence of listed options is associated with higher market quality in the market for the underlying stock. For example, Kumar, Sarin, and Shastri (1998) find that bid-ask spreads decline while quoted depth and informational efficiency increase subsequent to the listing of options. Numerous studies find that option listing causes a decrease in volatility, although in several other studies the results are mixed or insignificant,[2] and Mayhew and Mihov (2004) find that volatility increases with option listings in recent subperiods. Finally, Amin and Lee (1997) and Jennings and Starks (1986) study the effect of options trading on price discovery around earnings announcements. They provide evidence that the stock price adjustment to earnings announcements is faster for firms with traded options.

Theoretical evidence on the implications of listing traded options for market quality under asymmetric information does not provide clear guidance. For example, Biais and Hillion (1994) show that with asymmetric information and incomplete markets, the introduction of a nonredundant option has ambiguous consequences for informational efficiency. Although the option can help avoid a market breakdown, it enlarges the set of trading strategies the

1. See, e.g., "Where Have the Insider Traders Gone? Options Markets Are Their New Home," *Wall Street Journal*, April 23, 1997, C1. The recent growth in the multiple listings of options across exchanges with the accompanying reduction in bid-ask spreads suggests that options may become increasingly attractive venues for informed trading.

2. The following studies find a decrease in volatility: CBOE (1975, 1976), Trennepohl and Dukes (1979), Conrad (1989), Skinner (1989), Detemple and Jorion (1990), Damodaran and Lim (1991), Kumar et al. (1998). In the following the results are mixed or insignificant: Klemkosky and Maness (1980), Whiteside, Dukes, and Dunne (1983), Fedenia and Grammatikos (1992), Fleming and Ostdiek (1999).

insider can follow and can reduce informational efficiency by making it more difficult for market makers to interpret the information content of trades. Back (1993) extends the Kyle (1985) framework to include a call option and finds that the listing of an option leaves average volatility unchanged. John et al. (2000) use a single-period model to analyze the impact of option trading and margin rules on the microstructure of stock and option markets. They analyze opening quotes and show that the introduction of option trading improves the informational efficiency of stock prices irrespective of whether or not binding margin requirements are in place but is also associated with an increase in quoted spreads. The increase in the informativeness of the trading process results because with option trading private information can be inferred from two sources—order flow in the stock and option markets.

Our experimental design incorporates both an asset and a call option on that asset (for simplicity we refer to the asset as a stock). The framework is based on the Kyle model information structure with a single insider who knows the ex post liquidation value of the asset. Liquidity shocks in the stock and option are exogenously determined as in Back (1993), although we permit liquidity traders to act strategically in an attempt to minimize trading costs. We also employ a transparent quote-driven trading protocol, with all trades executed by competing dealers and all trades visible to all participants. We thus employ a standard trading mechanism and impose no constraints on the strategies of the insider, dealers, or liquidity traders.

One experimental approach would be to compare a market with a traded option to a market operating in isolation. We do not attempt this since it would introduce control problems as follows. Adding a traded option with dedicated option dealers would increase the supply of liquidity services and confound our attempt to isolate differences due to information flows. Adding a traded option without dedicated dealers (requiring the stock dealers to make a market in both the stock and the call simultaneously) would dramatically increase the difficulty of the dealers' task.

Rather than take this approach we focus on the role of the ex post intrinsic value of the option. We set the strike price of the option equal to the expected value of the stock. With the stock distribution approximately Gaussian, the option distribution is highly skewed around its expected value. When the intrinsic value of the option is positive, the linkage between the two markets is direct in the sense that knowing the liquidation value in one market is perfectly informative with respect to the liquidation value in the other. The potential for option trading to contribute to price discovery in the stock here is large. When the option's value is zero, knowledge of the option liquidation value only permits a truncation of the stock value distribution, with a corresponding decoupling of price discovery. Therefore the informational linkage between the two markets depends on the intrinsic value of the option. This allows an examination of how price discovery in the markets depends on the presence of a highly correlated asset. We argue below that differences in market quality for the underlying asset as a function of the ex post intrinsic value of the option will provide evidence for how and why the introduction of a traded option matters.

Our major findings are the following. The insider trades aggressively in both the stock and the option, and typically trades in the market that affords the most profitable trading opportunity. Liquidity traders concentrate their trades at the end of the trading period when trading costs are low, and insider trading patterns mimic those of liquidity traders. Price discovery with respect to intrinsic value takes place in both markets, and this leads to informational linkages: dealers in each market revise quotes in the direction consistent with an information story in response to trades in the other.

A strong set of results pertains to the effect of the intrinsic value of the option on liquidity and price efficiency in the market for the stock. When the intrinsic value of the option is positive, convergence to intrinsic value in the stock is faster, liquidity trader losses are smaller, and the volatility of transactions prices is lower than when the option's intrinsic value is zero. This appears due to the greater information content of trades in the option market in this case: this information is used by the dealers in the stock to more rapidly pinpoint intrinsic value. Of particular importance here is how differences in the dealers' conditional expectations for the stock and option values interact with the strategy of the insider to increase the message space of the dealers and help dealers more rapidly pinpoint fundamental value. This result is in sharp contrast with theoretical results in Back (1993) where average volatility is unaffected by option intrinsic value.

Although the experimental asset market literature is large and growing, there are relatively few studies that incorporate derivatives. Forsythe, Palfrey, and Plott (1984) find that in a private-value setting the inclusion of a futures market speeds convergence to informationally efficient pricing, although spot-price variability increases.[3] Friedman, Harrison, and Salmon (1984) also study the implications of incorporating a futures market in a private-value setting, but they find that spot-price variability declines and that there is only mixed evidence for efficiency gains.[4] Plott and Sunder (1988) compare private-value

3. In a private-value experimental setting, a motive for trade is induced by introducing a limited number of states (two or three) and giving two or three different trader types state contingent payoffs that are negatively correlated (e.g., trader type I receives a high payoff in state A and a low payoff in state B, while type II traders have payoffs that are reversed). Typically subsets of traders are given information with respect to which states can or cannot occur in a given period. Allocative efficiency measures the extent to which the trader type with the highest state contingent valuation holds the assets (which are in fixed supply) at the end of the period, and price efficiency measures the extent to which prices converge to the highest dividend in the realized state.

4. Forsythe et al. (1984) implement a market intended to study the influence of a futures market as follows. Two trader types are given inversely correlated dividends on assets A and B. There are two periods of trade. At the end of each period, each subject's dividends are a function of his joint holdings of the two assets. In the baseline setting, in the first period subjects may only trade assets A and B in combination. In the second period, subjects may only trade asset B. Forsythe et al. (1984) operationalize a futures market by allowing subjects to trade asset B along with A and B in combination in the first period. Friedman, Harrison, and Salmon (1984) employ a more complex design. There are three agent types, each of which receives a different

markets organized with two or three trader types and three states with two other types of markets. In the first there is a single trader type (common values), and in the second there are three option-like contingent claim securities, each paying off in one (and only one) state. They find that the contingent claims markets aggregate information better than the single security market and propose possible explanations, including the importance of knowledge of others' preferences as a necessary condition for the aggregation of diverse information. However, they conclude that their understanding of the issue is so incomplete that they cannot even provide a precise conjecture for why this effect obtains (1116). Finally, Kluger and Wyatt (1995) find that in a two-state private-value setting, an alternating asset market and option market (that are never open simultaneously) converge to equilibrium faster than an asset market alone. What distinguishes our experimental design from previous experimental work therefore is its focus on information flows in a common-value setting under asymmetric information. With the option market and the stock market open continuously we focus on feedback effects and their implications for market quality.

A barrier to experimental research that incorporates options is the necessary complexity of such markets. In order to ensure that our subjects could master the trading environment and employ sophisticated strategies we used only advanced finance students who were already familiar with options and their associated nonlinear payoffs. We also developed and employed custom software that aided subjects in mastering a setting that involves the trading of two interdependent assets. Finally, we relied on extensive training and multiple replications in order to verify the effect of experience on outcomes: each cohort of subjects was kept intact for a minimum of four experimental sessions in addition to an initial training session.

The plan of the article is as follows. In Section I we describe the experimental design and procedures. In Section II the data are presented and analyzed. In Section III we discuss our results in the context of theoretical models, and in Section IV we conclude.

I. Experimental Design, Subjects, and Procedures

A. Experimental Design Overview

Our experimental design is roughly based on the Kyle model information structure, generalized to include a single call option. There is a single insider who knows the intrinsic value of the stock and two liquidity traders who receive asset specific exogenous liquidity shocks in both the stock and the call. Three competing dealers maintain outstanding bids and asks for the stock, and three additional dealers make a market in the call.

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payoff in each of three periods. The asset may be traded in periods I and II. In addition, in sessions with a futures market, futures contracts can also be written in periods I and II for delivery in period III.

We impose no constraints on the timing, number, or direction of trades the insider may make in either market. For example, the insider is permitted to trade against her information in either market in an attempt to camouflage her information. We do not impose borrowing constraints or short-sales constraints, so leverage effects that might make options attractive to informed traders are not present in the experimental markets. The insider's choice to trade in the option or the stock is dictated entirely by the relative magnitude of profitable trading opportunities in the stock and the option, and the price responsiveness to order flow implied by the timing and direction of her trades. We do limit all trades to a single unit in order reduce the difficulty of the dealer's task and sharpen our ability to make inferences with respect to the informational content of the order flow.

As is standard in the microstructure literature (and more specifically in microstructure models that incorporate an option, e.g., Back [1993], Easley et al. [1998], and John et al. [2000]), we impose liquidity shocks in each market that are exogenous to intrinsic value. This avoids a "no trade" equilibrium as in Milgrom and Stokey (1982) and Biais and Hillion (1994).[5] An exogenous liquidity trading motive is particularly natural in options markets where many trades are hedging related and by their nature noninformational. We operationalize liquidity shocks by giving each liquidity trader a required end-of-period position in both the stock and the call. We make these demands inelastic by imposing penalties of sufficient magnitude that are proportional to the distance between a liquidity trader's final position and his required position. Although their required positions are exogenously determined each period, there are no constraints on how liquidity traders arrive to these positions: they are free to choose the timing of trades in both markets in order to minimize trading costs.[6] We also impose larger liquidity shocks on average in the stock market. This matches a feature of field markets and is a possible impediment to an equilibrium in which the insider trades the option.[7]

5. The imposition of exogenous liquidity shocks has also become a standard feature of market microstructure experiments. The use of computerized liquidity traders (Schnitzlein 1996, 2002; Bloomfield and O'Hara 1998; and Flood et al. 1999) has the advantage of reducing the required number of subjects while allowing the perfect control of the timing and size of liquidity shocks. In this study, subjects are employed in the role of liquidity traders to allow the examination of issues pertaining to their strategic timing of trades in order to minimize transactions costs. Other studies that employ strategic liquidity traders include Lamoureux and Schnitzlein (1997) and Cason (2000). Finally, Bloomfield and O'Hara (1999, 2000) employ both strategic and computerized liquidity traders.

6. We give each liquidity trader uncorrelated required positions in the stock and the option for experimental expediency: it reduces the number of agents required—an important consideration since our design required keeping cohorts of subjects intact for four sessions. This design feature does not change the incentives of liquidity traders to act strategically in order to minimize trading costs.

7. In Easley et al. (1998), whether an informed trader only uses stocks or trades both stocks and options depends in part on the fraction of liquidity traders in the option. Theory is silent on the relationship between the magnitude of liquidity shocks in the stock and option. Relative stock and option volumes suggest that noninformationally motivated trade is probably larger in absolute terms in stocks than options. We therefore match this feature of field markets with our experimental design.

We employ a transparent quote-driven trading protocol: dealers in the stock and dealers in the option maintain standing bids and asks in separate centralized limit-order books. This is a standard feature of many field markets and reduces the complexity of the task for subjects since they transact against known prices. A dealer is free to compete for order flow by adjusting his bid or ask at any time, and there are no constraints or costs associated with quote revisions. Unlike most theoretical models where dealers are assumed to be risk-neutral agents that set quotes equal to conditional expectations, dealers in the experimental markets are motivated to engage in price discovery in order to earn trading profits.

We include only one call option (and no put options) to create the following asymmetry. When the intrinsic value of the option is zero, knowledge of the option liquidation value only permits a truncation of the stock value distribution. When the intrinsic value of the option exceeds zero, the liquidation value in one market is perfectly informative with respect to the liquidation value in the other. This design allows us to analyze how the introduction of a correlated asset like an option affects market quality while enhancing experimental control: since the same group of subjects participates in multiple market periods when the intrinsic value of the option is either positive or zero, we control for the influence individuals might have on market quality as a function of (positive or zero) intrinsic option value.

B. Parameter Values and Variable Distributions

Agents begin the first market period of a session with a cash balance that differs across the type of agent. Cash balances and all other values are expressed in laboratory dollars (L$). The insider has a starting cash balance of L$450, the stock and option dealers of L$550, and the liquidity traders of L$900. The differences in starting cash balances are intended to minimize differences in profits by trader type. The starting cash balances average L$617. Trading profits (losses) are carried forward to subsequent periods. At the end of the final market period, the cash balances are multiplied by 0.08 to convert laboratory dollars to Dutch guilders (NLG),[8] and each subject is privately paid his earnings. Given the zero-sum nature of the trading game, cash payments (net of any penalties incurred by traders) average L$617 (NLG 50) per subject per session.

Each market period the stock value is known to be drawn from an approximate normal distribution with mean of L$100, standard deviation of L$12, and support on the whole laboratory dollars between L$50 and L$150, both inclusive. The value of the European call option with a strike of L$100 is $\max[\text{Stock} - 100, 0]$. A riskless asset (cash) is included that for simplicity pays an interest rate of zero.

8. One Dutch guilder equals approximately €0.45, or US$0.50 at the time the experiments took place.

C. Traders

Four different types of agents are present in each market period: one insider, two liquidity traders, three stock dealers, and three option dealers. We define a cohort to be the nine subjects who always trade together. Every cohort participates in four or five different sessions. Each session consists of between five and nine different market periods, with each market period defined by a different set of random draws for the asset values and liquidity shocks.

The insider is the only agent to learn the end-of-period stock and option value prior to the start of the trade. Each of the two liquidity traders is required to finish the trading period with a randomly determined position in the stock and the option. Each trader's required position is determined by an independent draw from a discrete uniform distribution. The draws range from -6 to $+6$ for the stock, and from -3 to $+3$ for the option, each integer-valued and excluding 0. If a trader does not meet this requirement, a penalty is assessed at the end of the period equal to L$100 times the absolute value of the deviation between the required position and the actual end-of-period position. The magnitude of the penalty ensures that demand is inelastic at the required position. Each period, total trading profits and losses of each trader are added to starting cash balances and carried forward to the next period. Therefore, traders have an incentive to minimize trading costs. Each liquidity trader privately learns his required position prior to the start of each market period.

Three stock dealers make a market in the stock, and three option dealers make a market in the option. The dealers have to provide quotes at all times, with the only restriction that they must lie in the interval [50, 150] for the stock and [0, 50] for the option. Dealers see the quotes reported by all other dealers and are allowed to revise their quotes at any time. Apart from providing bids and asks, they can initiate trades themselves as well, either in the market for which they provide quotes or in the other market. At the beginning of each market period, dealers do not learn either the end-of-period stock or option value nor the liquidity traders' required positions, and they do not receive required positions. All information pertaining to distributions, parameters, and the rules governing trade is common knowledge.

D. Communication and Computer Displays

All interactions among subjects are conducted on a series of networked personal computers with custom software. The computer screen in front of each subject contains continuously updated market information, including trade history, cash balance, stock and option positions, net market order imbalance (buyer-initiated trades less seller-initiated trades), current bids and asks, and the time remaining in the current trading period. The trade history shows the trades that have occurred, whether a buyer or seller initiated them, the price of the trade, and each agent's own transactions. In addition, the insider's screen shows the end-of-period value of both assets, and each liquidity trader's screen shows his end-of-period required positions for the stock and option.

E. Trading Procedures

Before the trading interval can begin, each dealer in the stock and each dealer in the option must submit a bid and an ask.[9] A dealer's bid represents the price at which he or she is willing to buy a single unit of the risky asset, while a dealer's ask represents the price at which he or she is willing to sell a single unit. Only the stock dealers submit quotes in the stock market, and only the option dealers submit quotes in the option market. After all dealers have entered their quotes, the markets open and the trading interval clock begins a 60-second countdown. Each dealer does not observe the other dealers' quotes until the market opens. During the trading period traders are free to hit inside quotes in both markets, and each dealer is free to revise his or her outstanding quotes at any time. The quotes are displayed on each agent's computer screen so that bids are in ascending order and asks are in descending order, with the inside quotes highlighted. A dealer can move to the "inside" on either side of the spread by improving on the current inside quote. When a trader initiates a trade at the inside bid or ask, all traders and dealers observe the transaction and the price, but they do not learn which trader initiated the trade. The market period clock is stopped while the dealers go through the process of resubmitting quotes. Therefore, the actual trading interval requires considerably more than 60 seconds: most took between 10 and 12 minutes. Trades represent a zero-sum game, with the profitability of each trade determined on the basis of the relation between the trading price and the end-of-period asset value. Trading profits on a trade are equal to the signed trade ($+1$ for a buy, -1 for a sell) times the end-of-period asset value less the transaction price. All transactions are for a single unit of the risky asset.

At the end of each market period each subject is informed of the actual end-of-period value of the stock and the option, personal trading profits (or losses), any penalties incurred (in case of the liquidity traders), and his final cash balance after liquidation of end-of-period positions at stock and option intrinsic value.

F. Subjects and Experimental Procedures

The participants in the experiments are students in the Rotterdam School of Management at Erasmus University. All were students with a specialization in finance (32 undergraduates and 4 graduate students). The first set of markets involving cohort 1 was conducted in September 1999, followed by a set of markets involving cohort 2 in January 2000. In order to verify our results, we formed cohorts 3 and 4 and ran an additional set of markets in March and April 2001.

Each cohort went through training in the information structure, variable distributions, and parameter values, and on average five market periods of

9. Starting bids and asks in the stock must bracket the expected value of L$100; starting bids and asks in the option must bracket the expected value of L$4.78.

trade. The training round lasted between 2 and 3 hours and ensured that subjects possess a good understanding of the rules of the market.

Each session was preceded by a review of trading rules, parameter values, and distributions. The review became progressively shorter as the subjects became more experienced. In the first session, subjects were randomly assigned to roles. In the second to fourth sessions, the roles of subjects were changed according to a predefined scheme of which they were unaware: subjects are insiders at most once, and liquidity traders, stock dealers, and option dealers at least once and at most twice. The benefit of this role-switching scheme is that it controls for differences across participants—we do not want those differences to drive differences between trader types—and it provides a deep understanding of the market setting that comes from assuming the roles of different agent types.[10]

II. Results

Each of the four cohorts participated in an initial training session and then four (or in one case, five) 2-hour sessions. Since subjects were assigned to new roles at the beginning of each session, we exclude the first two market periods from each session in order to allow subjects to refamiliarize themselves with their roles, the trading rules, and the software. This yields an initial data set of 17 sessions, 132 market periods, and 3,475 transactions.

Our initial data analysis revealed mild learning effects before the third session: dealer losses are sometimes large over the first two sessions, with the dealers on average incurring losses. In contrast, over the last two sessions the average dealer profits are positive in all four cohorts. Since dealers' quote-setting strategies are completely unconstrained (dealers may set bids and asks at the support of the asset value distribution—prices that cannot be unprofitable) dealer losses are clearly inconsistent with equilibrium behavior. Since our intention is to present "equilibrium" results, we therefore report analysis based on the last two sessions from each cohort. Our "experienced" data set consists of eight sessions, 62 market periods, and 1,630 transactions. As a robustness check we also performed the analyses that follow with all 17 sessions. Major results are unchanged, although on most dimensions behavior shows more variation when the initial sessions are included.

Each market period in each session is distinguished by a distinct set of random draws for the stock value, the option value, and the liquidity traders' demands. Summary statistics pertaining to these draws are reported in tables 1 and 2.

A principal finding that we analyze in detail below is that price efficiency in the market for the stock is higher when the intrinsic value of the option is positive (in the money). This effect is very strong, is present in all four cohorts,

10. Ball, Bazerman, and Carroll (1991) find that convergence to equilibrium strategies in bargaining games with adverse selection is speeded by rotating the roles of subjects.

TABLE 1 **Asset Values, Trading Activity, and Profitability**

			Average Asset Value		No. of Trades/Period				Profits					
					Stock		Option		Stock			Option		
Cohort	Session	No. of Periods	Stock	Option	Insider	Liquidity Traders	Insider	Liquidity Traders	Insider	Liquidity Traders	Stock Dealers	Insider	Liquidity Traders	Option Dealers
1	1	7	100.1	3.7	8.1	7.4	7.1	3.7	44.5	−70.7	25.5	11.4	−9.5	−2.2
	2	7	99.7	4.7	4.9	9.1	6.0	3.4	26.7	−35.9	9.6	11.1	−14.6	3.6
2	1	8	100.1	4.9	7.0	7.9	3.3	3.9	55.2	−64.9	8.8	17.2	−11.2	−5.1
	2	8	98.1	4.4	5.9	8.0	4.1	4.0	49.8	−66.4	16.8	22.8	−5.5	−13.5
3	1	8	104.1	8.6	9.3	7.4	3.1	3.6	33.4	−53.7	16.4	6.7	−12.9	15.6
	2	8	98.6	3.4	4.1	7.8	1.8	4.4	29.7	−13.7	−14.1	3.0	−3.7	.2
4	1	8	97.0	2.6	5.9	7.5	4.8	4.0	52.8	−99.7	42.4	8.1	−9.6	3.8
	2	8	97.3	3.8	4.5	7.3	5.5	4.1	20.8	−55.0	39.5	1.0	−11.3	10.2
Mean			99.4	4.5	6.2	7.8	4.4	3.9	39.1	−57.5	18.1	10.2	−9.8	1.6
SE (SD)			(11.7)	(6.5)					4.6	9.0	6.4	2.5	1.3	3.2

NOTE.—This table reports asset values, trading activity, and profitability for each of the 62 market periods, aggregated by session. Trading takes place in a stock and a call option on that stock. Before trading begins, each of the three stock dealers must submit a bid and an ask for a single unit of the stock, and each option dealer must submit a bid and an ask for a single unit of the option. The market then opens, and the trading interval begins a 60-second countdown. There are three traders: one insider and two liquidity-motivated traders. There are six dealers: three dealers in the stock and three dealers in the option. When the market is open, each of the subjects (traders and dealers) is free to hit inside quotes, and each dealer is free to revise his or her outstanding quotes at any time. When a subject initiates a trade, all traders and dealers observe the transaction price, whether it is a buy or a sell, and whether the trade was in the stock or the option. This information remains permanently on each subject's screen during a period. They do not learn who initiated the trade or which dealer took the other side of the trade. After each trade, the trading interval clock is paused while the dealer who took the trade goes through the process of resubmitting the quote that was hit. Therefore, the actual trading interval requires approximately 10–12 minutes. The monetary unit in all tables is laboratory dollars (L$ in the text). To convert to Dutch guilders (the currency in which subject payments were made), multiply the laboratory dollars by 0.08. The stock value is the realized draw from the distribution governing the stock value (approximately Gaussian, with unconditional expectation of 100, standard deviation of 12, and support on the integers). The option on the stock is a call option with exercise price of 100. The liquidity demands in the stock are drawn from a uniform distribution between −6 and 6, excluding 0. The liquidity demands in the option are drawn from a uniform distribution between −3 and 3, excluding 0. Each random draw is independent of other random draws.

TABLE 2 Price Efficiency, Spreads, Volatility, and the Intrinsic Value of the Option

Cohort	Session	Periods	Average Stock	Stock Trades	Option Trades	PE_S (Price)	PE_S (Mid)	PE_C (Price)	PE_C (Mid)	PE_{SC} (Price)	PE_{SC} (Mid)	Stock Spread	Option Spread	ΔP_S (Mid)
			Panel A. Intrinsic Value of the Option Is Zero											
1	1	5	95.0	15.2	12.6	9.9	10.7	2.0	5.2	6.3	8.2	16.2	8.7	1.8
	2	4	91.3	18.8	8.8	6.7	8.2	3.6	4.7	5.7	7.1	11.1	6.7	1.3
2	1	4	90.5	18.8	8.8	11.2	11.9	5.5	7.5	9.4	10.5	9.9	9.0	1.2
	2	6	91.7	16.3	8.5	11.1	10.7	2.9	3.7	8.3	8.3	10.5	3.7	1.6
3	1	3	88.0	20.3	9.7	8.9	11.1	1.8	4.3	6.6	8.9	15.4	7.0	.9
	2	5	92.4	13.2	6.2	7.3	8.4	1.4	3.7	5.4	6.9	8.2	6.4	1.0
4	1	5	91.0	15.6	12.6	12.4	13.8	1.4	3.5	7.5	9.2	13.2	5.4	2.1
	2	5	89.6	12.8	12.6	9.3	9.8	2.8	4.2	6.1	7.0	17.3	5.9	.8
Average			91.2	16.4	10.0	9.6	10.6	2.7	4.6	6.9	8.3	12.7	6.6	1.3
			Panel B. Intrinsic Value of the Option Is Positive											
1	1	2	113.0	20.5	15.5	7.0	11.0	7.7	7.5	7.3	9.5	14.6	7.3	1.6
	2	3	111.0	10.3	12.0	4.3	3.4	3.9	6.4	4.1	5.0	10.6	9.4	1.1
2	1	4	109.8	15.3	9.5	5.8	7.3	4.5	5.5	5.3	6.6	10.3	7.6	1.0
	2	2	117.5	9.5	12.5	10.1	11.4	10.6	11.9	10.4	11.7	8.7	5.5	1.5
3	1	5	113.8	21.8	12.2	5.3	8.5	4.7	6.3	5.1	7.7	12.4	10.8	.8
	2	3	109.0	13.0	8.7	4.0	4.2	3.0	4.7	3.6	4.4	7.8	7.5	.7
4	1	3	107.0	14.3	14.3	13.0	9.9	5.4	5.3	9.2	7.6	17.3	6.2	1.0
	2	3	110.0	12.7	8.7	5.4	10.3	5.4	6.1	5.4	8.6	15.2	6.8	.6

Average	111.4	14.7	11.7	6.9	8.3	5.7	6.7	6.3	7.6	12.1	7.6	1.0
Difference		1.7	−1.7	2.7	2.3	−3.0	−2.1	.6	.7	.6	−1.0	.3
p-value: matched pairs *t*-test				.4%	3.0%	2.1%	7.2%	43.5%	49.7%	45.5%	14.9%	3.7%
p-value: matched pairs randomization test				.7%	5.8%	1.7%	3.5%	41.9%	47.8%	45.7%	15.9%	.0%

NOTE.—This table reports price errors, realized bid-ask spreads, and our measure of price volatility for each of the eight sessions. Panel A is based on the periods where the end-of-period intrinsic value of the option is zero; panel B is based on the periods where the end-of-period intrinsic value is positive. PE_S (price) is the mean of the absolute difference between the stock transaction price and the intrinsic stock value. PE_S (mid) also measures price errors in the stock, but relative to the midpoint of the bid-ask spread. PE_{SC} (price) is the mean of the absolute difference between the transaction price and the stock or option intrinsic value, depending on the asset traded, and is our measure of price efficiency in the aggregate. PE_{SC} (mid) is defined similarly. Stock (option) spread is the realized stock (option) bid-ask spread at the time of a stock (option) transaction. ΔP_S is the mean change in the midpoint of the bid-ask spread and is a measure of market volatility. In all cases, an average is calculated for each market period in a session, and then each market period is weighted equally. When option intrinsic value is positive, stock price errors and volatility are significantly lower, and option price errors are higher.

and is highly significant when we use a matched-pairs *t*-test to compare a single mean level of price efficiency for each cohort when the ex post value of the option is in the money, with a single mean when the option is out of the money ($t = 6.86$, $p < .01$).[11] A comparably strong result obtains for the effect of a positive intrinsic option value on stock price volatility ($t = 6.48$, $p < .01$). Later in this section we analyze the behavior that leads to these main results. This requires analysis on the level of the session, market period, and in some cases individual transactions. In order to account for possible session-level interdependencies in the data, we report all regressions with *p*-values that are based on GMM *t*-statistics that are consistent in the presence of heteroskedasticity and autocorrelation.[12] All reported *p*-values are for two-tailed tests.

A. Stock Market Quality and the Ex Post Intrinsic Value of the Option

In this section we characterize stock market quality as a function of whether the ex post intrinsic value of the option is positive or zero. Our initial measures of market quality are price efficiency, volatility, and liquidity trader losses.

We define price errors (*PE*) as the difference between intrinsic value and the transaction price, in absolute value. We also report price errors relative to the midpoint of the inside bid-ask spread (average of highest bid and lowest ask) in absolute value. Relative price errors provide a measure of how rapidly information in the order flow is incorporated into market prices in the presence of a strategic insider who chooses between transacting in the option and the stock.

When the intrinsic value of the option is positive, mean price errors in the stock market are significantly lower. This effect is very strong and is present at the level of cohorts, sessions, market periods, and individual transactions. We augment the cohort level analysis reported above by calculating for each session both a "within session" mean of the periods in which the intrinsic value of the option is zero and a "within session" mean when the intrinsic value is positive. In seven out of eight sessions mean price errors are smaller when the intrinsic value of the option is positive.[13] Both a matched pairs *t*-

11. We report both *t*-tests and results from the nonparametric randomization (permutations) test. With four cohorts, the randomization test yields the theoretical minimum *p*-value for a two-tailed test (.125).

12. Analysis on the level of the cohort is most conservative since observations across sessions are by definition independent. We test for cohort effects (dependencies across sessions within cohorts) by analyzing realized bid-ask spreads. We choose bid-ask spreads because although we change the roles of agents between sessions, the task of dealers is most complex and potentially subject to the influence of previously observed behavior. We test for dependencies by performing both parametric and nonparametric ANOVA on average session realized spreads in the option, with the data grouped by cohort. None of the tests approach even marginal significance. The variation in behavior across sessions is primarily due to the agents that assume the role of dealer and not to the cohort to which the dealers pertain.

13. The first session of cohort 4 is the only exception and can be explained as follows. In all three periods in which the option intrinsic value is positive, both liquidity traders had to sell the stock. As a result, all liquidity traders traded in the opposite direction from the insider, complicating price discovery.

test and the nonparametric randomization test yield a highly significant difference ($p < .01$).

Realized spreads in the stock (ask minus bid at the time of each transaction) are only slightly smaller when the intrinsic value of the option is positive. Aggregating on the level of the session as above, the difference is insignificant. The reduction in realized spreads does not explain the increase in price efficiency: the informational efficiency of the midpoint of the bid-ask spread also increases when the intrinsic value of the option is in the money ($p = .03$ and $p = .06$ for the *t*-test and randomization tests, respectively). Mean price errors measured relative to transaction prices and spread midpoints, and realized spreads by session are reported in table 2.

What causes the dramatic increase in price efficiency when the option is in the money? The short answer is that the insider's trades in the option are more informative when its ex post intrinsic value is positive. This in turn allows dealers in the stock market to benefit from price discovery in the option market. We analyze this phenomenon in detail in Section II.C.

Higher price efficiency when the intrinsic value of the option is positive is also associated with lower stock price volatility. Our measure of volatility is constructed as follows. First we calculate the change in the midpoint of the bid-ask spread for each transaction in a market period ($|mp_t - mp_{t-1}|$) and then compute the average for each market period. Spread midpoints are used in order to control for bid-ask bounce, with changes in the midpoint serving as a proxy for the transaction-induced revision in the conditional expectation of the intrinsic stock value.[14] Market period averages are calculated for each session and reported in table 2. Weighting each session equally, mean midpoint price changes are 27% less when the intrinsic value of the option is positive ($p = .04$ and $p < .01$ for the *t*-test and randomization tests, respectively). This effect is present in all eight sessions (and all four cohorts) and indicates a more direct convergence to intrinsic value in the stock.

Our third measure of stock market quality is the magnitude of liquidity trader losses. Liquidity traders have inelastic demands/supplies that are uncorrelated with intrinsic value and, as expected, incur large significant losses from their stock market activity. These losses decline by 44% when the intrinsic value of the option is positive (table 3). This effect occurs in six of the eight sessions and is due to liquidity traders on average trading at prices closer to intrinsic value. In the two sessions where it does not occur, it is explained by the average direction of liquidity trades relative to the intrinsic value of the stock (e.g., in the first session with cohort 4, in all three periods in which the option is in the money, both liquidity traders had to sell the stock, resulting in very large liquidity trader losses). In table 4 we present an analysis that controls for the direction of liquidity trades relative to the value of the stock and option, and we find a highly significant reduction in liquidity

14. Inventory effects may imply that this conditional expectation need not be centered at the spread midpoint. We assume these effects are of second order importance.

TABLE 3 Profitability by Trader Type and the Intrinsic Value of the Option

			Stock Profits			Option Profits			Total Profits			
Cohort	Session	Periods	Insider	Liquidity Traders	Stock Dealers	Insider	Liquidity Traders	Option Dealers	Insider	Liquidity Traders	Stock Dealers	Option Dealers
			Panel A. Option Intrinsic Value Is Zero									
1	1	5	41.1	−99.7	58.6	7.5	−10.7	2.7	48.6	−110.4	59.1	2.7
	2	4	46.5	−38.1	−9.2	4.1	−8.7	4.6	50.5	−46.8	−9.2	5.5
2	1	4	82.9	−100.1	24.5	15.2	−6.9	−5.8	98.1	−107.0	22.0	−13.0
	2	6	60.7	−86.9	26.4	7.3	−1.1	−1.1	67.9	−88.0	21.3	−1.3
3	1	3	42.6	−77.1	41.8	2.3	−9.2	4.1	44.9	−86.2	44.5	−3.2
	2	5	43.6	−6.2	−35.7	1.1	−4.5	2.8	44.7	−10.7	−35.1	1.1
4	1	5	73.7	−63.1	−18.8	5.1	−2.3	−1.6	78.7	−65.4	−20.0	6.7
	2	5	14.6	−78.9	72.6	−1.9	−5.2	7.2	12.7	−84.1	72.6	−1.1
Average			50.7	−68.8	20.0	5.1	−6.1	1.6	55.8	−74.8	19.4	−.3
			Panel B. Option Intrinsic Value Is Positive									
1	1	2	53.0	1.9	−57.4	21.0	−6.3	−14.6	74.0	−4.4	−57.6	−12.1
	2	3	.3	−33.0	34.7	20.4	−22.5	2.2	20.7	−55.5	34.7	.2
2	1	4	27.5	−29.8	−6.9	19.2	−15.5	−4.4	46.7	−45.3	−6.1	4.8
	2	2	17.0	−5.0	−12.0	69.3	−18.8	−50.6	86.3	−23.8	−12.0	−50.6
3	1	5	27.9	−39.7	1.1	9.3	−15.1	22.4	37.2	−54.8	−15.5	33.1
	2	3	6.7	−26.2	21.8	6.2	−2.4	−4.0	12.9	−28.7	22.1	−6.3

4	1	3	18.0	−160.6	144.5	13.0	−21.9	12.9	31.0	−182.5	140.5	11.0
	2	3	31.1	−15.2	−15.7	6.0	−21.3	15.3	37.1	−36.5	−15.7	15.0
1	1	2	53.0	1.9	−57.4	21.0	−6.3	−14.6	74.0	−4.4	−57.6	−12.1
	2	3	.3	−33.0	34.7	20.4	−22.5	2.2	20.7	−55.5	34.7	.2
2	1	4	27.5	−29.8	−6.9	19.2	−15.5	−4.4	46.7	−45.3	−6.1	4.8
	2	2	17.0	−5.0	−12.0	69.3	−18.8	−50.6	86.3	−23.8	−12.0	−50.6
Average			22.7	−38.5	13.8	20.6	−15.5	−2.6	43.2	−53.9	11.3	−.6
Difference			28.0	−30.3	6.3	−15.5	9.4	4.2	12.5	−20.9	8.1	.3
p-value: matched pairs t-test			3.0%	23.2%	85.0%	5.7%	2.2%	59.9%	30.6%	41.8%	80.7%	97.6%
p-value: matched pairs randomization test			3.9%	21.6%	86.6%	.0%	3.0%	66.4%	27.7%	40.9%	78.0%	96.5%

NOTE.—This table reports profitability by trader type for each of the eight sessions. Panel A is based on the periods where the end-of-period intrinsic value of the option is zero, and panel B is based on the periods where the end-of-period intrinsic value of the option is positive. Each session the number of market periods when the intrinsic value of the option is positive varies from two to five. Since averages are computed weighting each session equally, these averages do not directly correspond to those in table 1.

TABLE 4 Determinants of Profitability

Market	Trader Type	Constant	$OIV > 0$	*DEV*	*LIQ(S)*	*LIQ(O)*	*COR(S)*	*COR(O)*	Adjusted R^2 (%)
Stock	Insider	9.91	−36.20	3.93	−3.39	8.44	−.23	−.46	28.5
		(.30)	(−3.34)	(2.72)	(−1.50)	(2.11)	(−3.15)	(−1.96)	
Stock	Liquidity traders	3.53	25.12	.90	−10.45	.62	.70	.06	65.6
		(.19)	(3.10)	(2.46)	(−4.41)	(.13)	(6.96)	(.37)	
Stock	Dealers	−13.43	11.07	−4.83	13.84	−9.06	−.47	.40	46.9
		(−.43)	(.79)	(−3.38)	(3.84)	(−2.00)	(−3.42)	(1.54)	
Option	Insider	−7.25	11.55	.83	.89	−.43	−.04	−.18	20.1
		(−1.04)	(3.44)	(2.68)	(.93)	(−.24)	(−1.28)	(−2.22)	
Option	Liquidity traders	.87	−11.01	.02	.66	−3.23	.00	.29	42.1
		(.18)	(−5.49)	(.12)	(1.34)	(−2.20)	(−.15)	(5.42)	
Option	Dealers	6.38	−.54	−.85	−1.55	3.65	.04	−.11	8.7
		(.90)	(−.16)	(−2.35)	(−1.71)	(1.97)	(.95)	(−1.44)	
Stock and option	Insider	2.65	−24.65	4.76	−2.50	8.01	−.27	−.63	32.4
		(.08)	(−2.44)	(3.63)	(−1.11)	(2.06)	(−2.87)	(−2.94)	
Stock and option	Liquidity traders	4.40	14.11	.92	−9.79	−2.61	.70	.35	59.5
		(.21)	(1.53)	(2.27)	(−3.64)	(−.48)	(6.85)	(2.28)	
Stock and option	Dealers	−7.05	10.53	−5.68	12.29	−5.40	−.43	.29	40.6
		(−.22)	(.73)	(−4.19)	(3.20)	(−1.00)	(−2.71)	(1.02)	

NOTE.—In order to examine the determinants of profitability by trader type we estimate the following model with GMM (*t*-statistics that are consistent in the presence of heteroskedasticity and autocorrelation are reported in parentheses). Each of the 62 observations summarizes the random draws (asset values and liquidity shocks) for a single market period.

$$PROF_{type,market} = b_0 + b_1(OIV > 0) + b_2DEV + b_3LIQ(S) + b_4LIQ(O) + b_5COR(S) + b_6COR(O) + \varepsilon.$$

Variable definitions are as follows. $PROF_{type,market}$ is the per period profit of all subjects of the same type (insider, liquidity traders, or dealers) in a specific market (stock, option, or both). $OIV > 0$ is an indicator variable that takes on the value of one when the intrinsic value of the option is positive and zero otherwise. *DEV* is the absolute difference between the stock value and its unconditional expectation of 100. *LIQ(S)* is the number of liquidity trades in the stock. *LIQ(O)* is the number of liquidity trades in the option. *COR(S)* is the product of the net liquidity shock in the stock and the difference between the stock value and its unconditional expectation (a measure of the extent to which liquidity traders trade in the direction of the insider's information). *COR(O)* is the product of the net liquidity shock in the option and the difference between the stock value and its unconditional expectation.

trader losses in the stock in the presence of an option with positive intrinsic value ($p < .01$).

B. Overall Market Quality in the Presence of an Option

We show above that market quality is higher when the intrinsic value of the option is positive. We next consider whether the presence of a zero intrinsic value option might harm market quality relative to a market without a traded option, possibly offsetting the gains that occur when option intrinsic value is positive. A plausible mechanism by which this might occur is suggested by Biais and Hillion (1994): the presence of an option could make it more difficult for dealers to interpret the informational content of trades. There are important differences between their model and the experimental design, but it is conceivable that early liquidity trades (and possibly destabilizing insider trades) could significantly complicate the price discovery process when option intrinsic value is zero, damaging market efficiency relative to a market without a traded option.

We examine this possibility by isolating the impact of option trades on movements in the midpoint of the stock's bid-ask spread prior to a subsequent transaction in the stock or option when the option's intrinsic value is zero. Weighting each session equally, on average, trades in the option cause price changes in the stock midpoint that are in the direction of intrinsic value (that reduce price errors), although the magnitude of the movement is not significantly different from zero ($p = .87$). In these periods (where the option intrinsic value is zero) a larger percentage of trades in the option are due to liquidity traders because of less insider activity ($p < .01$), but insiders still earn significant profits in the option ($p < .05$). This indicates that on average insider trading activity aids price discovery (insider strategies are examined in Sec. II.C). We also analyze the effect of option trades on the bid-ask spread for the stock prior to a subsequent transaction. If trades in the option confuse dealers, they might widen spreads.[15] We find the opposite effect, however. Trades in the call when the option intrinsic value is zero lead to tighter spreads in the stock ($p = .03$). Finally, we also verify that when the intrinsic value of the option is zero, trades in the stock cause movements in stock quote midpoints in the direction of intrinsic value. This effect is highly significant ($p = .01$). When the intrinsic value of the option is positive, the effect is also present but is not statistically different ($p = .50$). In addition, the effect of stock transactions on the stock bid-ask spread does not vary as a function of option intrinsic value ($p = .95$).

The results that dealers in the stock (1) are not confused by option market activity when trading there is less informative, (2) use option market activity to facilitate price discovery when the intrinsic value of the option is positive, and (3) have a similar response to stock trades irrespective of option intrinsic

15. In the single-period model of John et al. (2000), the introduction of an option increases the stock bid-ask spread.

value suggest that informational efficiency in the aggregate will be improved by the presence of a traded option. Furthermore, tighter bid-ask spreads coupled with informational gains in the presence of the option suggest lower stock market volatility relative to a market without a traded option even when the intrinsic value of the option is zero.

C. Price Errors and Time

In this section we examine the role of the option's intrinsic value on the convergence to informationally efficient pricing in the stock using transactions level data and a parsimonious specification. In every market period, the trading activity of the insider causes stock and option prices to converge to intrinsic value by the end of the market period; our focus here is on how the intrinsic value of the option affects the speed of convergence to strong-form efficiency.

Recall that at the beginning of a market period, dealers know that the probabilities of the option being in or out of the money at the end of the period are roughly equal. We regress stock price errors on a constant, the absolute difference between the stock value and its unconditional expectation (*DEV*), the product of the net liquidity shock in the stock and the difference between the stock value and its unconditional expectation (*COR(S)*),[16] an indicator variable that indicates whether or not the insider initiated the trade (*INSIDER*), the transaction time (*TIME*), and the transaction time interacted with a variable that indicates whether or not the intrinsic option value is positive ($TIME \times OIV > 0$). To derive the transaction time we order the stock transactions and divide them by the total number of transactions in a period. This definition of time accounts for the clustering of transactions in clock time. The number of observations is 974 and the adjusted R^2 is 25.8%.

$$\begin{aligned} PE = {} & \underset{(9.09)}{10.32} + \underset{(2.62)}{0.20}DEV - \underset{(-4.57)}{0.03}COR(S) - \underset{(-4.83)}{3.51}INSIDER \\ & \underset{(-2.57)}{-3.79}TIME - \underset{(-3.41)}{4.87}(TIME \times OIV > 0). \end{aligned} \tag{1}$$

All parameter estimates have the expected sign and are significant at the 1% level (*t*-statistics are reported beneath the coefficient estimates). When the asset value is extreme, price errors are significantly higher: in this case convergence to informationally efficient pricing requires more time. When the net liquidity trade is in the direction of the insider's information, price errors are lower. This is due to fewer trades on the "high price error" side of the spread as price converges to intrinsic value and is a simpler information extraction problem for the dealers. When the insider transacts, price errors are lower because her trades are on the "low price error" side of the spread as insider activity moves price toward intrinsic value: it is the cumulative effect of insider trading that causes price errors to decline with time.

16. This variable measures the extent to which the liquidity traders trade in the same direction as the insider's information.

The coefficient on the time of trade variable interacted with the positive option value indicator is negative and highly significant. This indicates more rapid convergence when the option is in the money. This is because when the option is in the money, the option value is perfectly correlated with the stock value: trades in the option help dealers pinpoint the value of the stock. When the option is out of the money, trades in the option only aid the dealers in truncating the stock value distribution. We analyze in detail in Section II.F the informational linkages between the two markets.

D. Insider Profits and Behavior

Market period data on profitability by trader type are reported in table 1. Profits on each trade are $(V - P)Q$, where V is the end-of-period value of the asset, P is the transaction price, and Q is an indicator ($+1$ for a buy, -1 for a sale). An agent's market period profits are the sum of the profits on all transactions that agent participated in during that market period. Because the insider is the only agent who knows the terminal value of the stock and option, the behavior of the insider is critical in determining patterns in informational efficiency.

The profits earned by the insider are significantly greater than zero in both the stock market and the option market. In most market periods (56%) the insider earns profits in both the stock market and the option market. Over the 62 trading periods, the insider traded 384 times in the stock and 234 times in the option.

Most insider trades occur late in the trading period (fig. 1): on average, one-quarter of insider volume is not transacted until over two-thirds of the trading interval has expired. Temporal patterns in insider trading almost exactly match patterns in liquidity trading, with the correlation between the time of insider trades and liquidity trades 87% ($p < .01$). The temporal concentration of trades is consistent with the theoretical model of Admati and Pfleiderer (1988) in which both insiders and a subset of liquidity traders are given discretion over the timing of their trades. Unlike the model, most trading is concentrated late in the trading period. This important difference is due in part to the complete absence of ex ante constraints on when liquidity traders must trade in the experimental markets. With absolute discretion over the timing of trades, liquidity traders prefer to trade late when bid-ask spreads are more closely centered on intrinsic value.

The insider infrequently engages in unprofitable trades (3.7% of all insider trades). The majority of these trades are in the option in the opposite direction of the insider's information. This is evidence that these trades are intended to mislead dealers, since in most trading periods this is the least unprofitable trade when an insider trades in the opposite direction of her information.[17] At

17. Bloomfield and O'Hara (2000) is an experimental study that investigates whether transparent markets can survive in the presence of less transparent markets. In their design, both a liquidity trader and an insider may conceal their trades by trading with a low transparency dealer.

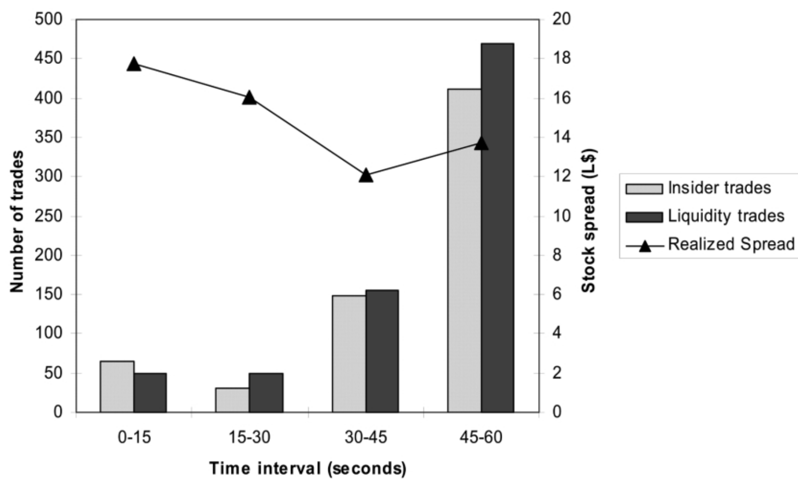

FIG. 1.—Temporal patterns in trading activity and the bid-ask spread. This figure shows the concentration of both insider and liquidity trader activity at the end of the trading period and the temporal decline in realized bid-ask spreads. The temporal consolidation of trading is consistent with the theoretical model of Admati and Pfleiderer (1988), in which both insiders and a subset of liquidity traders are given discretion over the timing of their trades. Liquidity traders prefer to trade when the market is deep (when trades have little impact on price). This in turn gives liquidity traders strong incentives to trade together. The insider also prefers to trade when the market is deep. The tendency of spreads to narrow over time is also observed in another dealer market experiment (Lamoureux and Schnitzlein 1997). This type of disequilibrium behavior is roughly consistent with the ad hoc price adjustment rule posited by Bulow and Klemperer (1994).

the time of most insider trades (72.6%) the insider can trade profitably in either the stock or option market. In most of these cases (86.3%) the insider chooses to transact in the market that at that instant offers the more profitable trading opportunity. When the option is in the money, insiders make 51.4% of their trades and earn 44.0% of their trading profits by transacting in the option. When the option is out of the money, insiders make 34.5% of their trades and earn only 8.8% of their profits from trading in the option: the option market's role in the price discovery process is more limited in this case.

We decompose insider profits by regressing insider profits on a constant, an indicator that takes on the value of one when the liquidation value of the

They conclude that strategic trading does not play an important role in their markets and traders are unwilling to pay a premium to have their trades concealed, although there is evidence that insiders sometimes trade against their information with transparent dealers in order to fool the market. The strategy space is rich in the sense that traders can choose among multiple trade sizes; however, they have limited ability to choose the timing of trades: all trades are executed simultaneously at one of eight trading rounds each period, and therefore time per se does not play an explicit role.

option is positive ($OIV > 0$), the distance of the stock value from its unconditional expectation (*DEV*), the number of liquidity trades in the stock (*LIQ(S)*), the number of liquidity trades in the option (*LIQ(O)*), the product of the net liquidity shock in the stock and the difference between the stock value and its unconditional expectation (*COR(S)*), and a similar statistic for the option (*COR(O)*).

$$\begin{aligned} PROF_{INSIDER-STOCK} = {} & b_0 + b_1 OIV > 0 + b_2 DEV \\ & + b_3 LIQ(S) + b_4 LIQ(O) \\ & + b_5 COR(S) + b_6 COR(O) + \varepsilon. \end{aligned} \tag{2}$$

The results (table 4) indicate that insider profits are increasing in the distance between the stock value and its unconditional expectation ($p < .01$). Profits are also higher when the net liquidity shock in the stock is in the opposite direction of the insider's information: the insider can more easily disguise her information while making profitable trades ($p < .01$). A similar effect obtains for the net liquidity shock in the option ($p = .06$). When the end-of-period option value is positive, the insider earns lower profits in the stock ($p < .01$). This is due to a greater number of profitable trades in the option (which stock dealers learn from). A regression identical to (2) but where the dependent variable is insider profits in the option (table 4) indicates that insider profits in the option are higher when the end-of-period option value is positive ($p < .01$).

Aggregate insider profits (profits derived from trading in the stock and the option) are higher when the option is out of the money. Using session level data (table 3) the difference is not significant ($p = .32$ and $p = .29$ for the parametric and nonparametric test, respectively), however, the analysis in table 4 that controls for liquidity shocks and the asset values on the level of the market period suggests a significant difference ($p = .02$). If real, this result would be puzzling since the insider is free to forgo option trading. It is driven, however, by two unusual trading periods when the intrinsic value of the option is zero, and is not a robust result.[18]

18. In both of these trading periods, there is a large positive net liquidity shock. In one case, 11 consecutive liquidity trades in the stock and the option at the beginning of the period are purchases. Interspersed among these trades are additional (unusual) buy orders initiated by dealers that move price further away from intrinsic value. When the insider finally begins to trade, price moves very slowly toward intrinsic value: the dealers are apparently convinced by the initial 18 consecutive buy orders that the stock value is above its unconditional expectation. In the second case, a single dealer lowers the inside bid unusually slowly in the face of a large sell order imbalance. In the first case, insider profits exceed their mean by 3.9 standard deviations, and in the second by 4.8 standard deviations. The high insider profits in these two periods explain the significance of the ($OIV > 0$) coefficient estimate but seem unrelated to the relationship between the level of insider profits and the presence of a positive intrinsic value option. We verify this by repeating the regressions from table 4 but flagging these two periods with an indicator variable that takes on the value of one in these two periods and zero otherwise. The ($OIV > 0$) coefficient estimate becomes insignificant in the aggregate insider profits regression. Importantly, other qualitative results in the other eight regressions in the table are unchanged.

E. Liquidity Trader Profits and Behavior

Liquidity traders are free to choose the timing of trades, but the exogenous liquidity shocks are enforced by penalties that make liquidity demands (by the end of a market period) perfectly inelastic. Each liquidity trader receives an independent shock in the stock and the option. Over the 62 market periods, the liquidity traders never incurred a penalty for failing to exactly fulfill liquidity requirements.

As noted above, liquidity traders tend to trade late: 86.3% of liquidity trades are in the second half of the trading interval, when spreads are narrower. Requirements to sell options are on average satisfied earlier than requirements to buy options and to buy or sell units of the stock. This may be due to the fact that with the highly skewed unconditional option value distribution, price discovery is on average easiest for option sell orders. The desire of liquidity traders to trade near the unconditional asset value distribution therefore dictates earlier liquidity trading in this case, although two-thirds of these trades are still in the second half of the trading interval.

Liquidity traders suffer large significant losses in both the stock and option market (tables 1 and 3). As noted in Section II.A, average liquidity trader losses in the stock when the option intrinsic value is positive are lower than when the option's intrinsic value is zero, although this difference is only marginally significant. In order to control for other determinants of liquidity trader profitability, we regress liquidity trader profits in the stock on the liquidity shock variables, the extremeness of the asset draw, and the positive option intrinsic value indicator variable (table 4).

Overall liquidity trader profits are decreasing in the magnitude of the liquidity shocks but increasing in the correlation between the net liquidity shock and the insider's information: when the liquidity traders are required to trade in the direction of the insider's information, their profits are higher. Both of these effects are highly significant ($p < .01$). The extremeness of the asset value draw is also significant ($p = .02$). Finally, when the option's intrinsic value is positive, liquidity trader losses are lower ($p < .01$). This is because liquidity traders trade at prices closer to intrinsic value in this case.

F. Dealer Profits and Behavior

Recall that the three stock dealers are required to make a market in the stock. They are also permitted to transact against quotes submitted by other dealers in the stock and the option. The option dealers participate in 6.7% of the transactions in the market for the stock, and the stock dealers participate in 11.0% of the transactions in the option.

Since both stock and option dealers are permitted to trade in either asset we define dealer profits in the stock to be the sum of all stock dealers' profits in a market period, with option dealer profits similarly defined. Weighting each of the sessions equally, stock dealer profits are about half the magnitude of insider profits and are significantly greater than zero ($p = .03$ for both the *t*-test and the randomization test). Option dealer profits are positive, but lower, and are not significantly different from zero. In order to investigate the determinants of dealer profitability, we estimate the regression from (2) and report the results in table 4.

The results are similar when we use either stock market dealer profits or the sum of stock and call option dealer profits (aggregate dealer profits) as the dependent variable. Dealer profits are decreasing in the extremeness of the asset value draw and increasing in the magnitude of the stock liquidity shock. When stock dealer profits is the dependent variable, the negative coefficient on the *COR(S)* variable indicates that when the liquidity traders trade in the direction of the insider's information, stock dealer profits are lower. This is intuitive since in this state dealers take fewer highly profitable liquidity trades that are in the opposite direction of intrinsic value. When aggregate dealer profits is the dependent variable, the coefficient estimate for the *COR(S)* variable decreases in absolute value. This is because when the stock liquidity traders tend to trade in the direction of the insider's information, option dealers learn more rapidly from trades in the stock and earn higher profits. In general, dealer profits are not related to whether the intrinsic value of the option is positive. This is evidence that the dealer competitive dynamic accounts for the informational content of the order flow as a function of trading patterns (that depend on the intrinsic value of the option).

G. Informational Linkages between the Stock and Option Markets

In the previous sections we documented the impact of the intrinsic value of the option on price errors, volatility, and profitability by trader type. In this section we examine the informational linkages between the markets that give rise to these effects.

As noted earlier, the insider trades aggressively in both the stock and the option. This is consistent with the mixed strategy equilibrium in Easley et al. (1998) and indicates that a trade in one market will have informational implications for the other market. We document the informational linkages by examining changes in bid-ask spread midpoints induced by transactions (table 5). We define a quote midpoint price change as the difference in the midpoint of the inside bid and ask after a transaction and before a subsequent transaction. If there are multiple quote changes (by one or more dealers) that affect the inside quote, they are summed together.

Average quote changes are consistent with a strong informational linkage between the two markets. Quote midpoints in both markets are revised upward after a stock or option transaction at the ask and downward after a stock and option transaction at the bid.

Transaction-induced quote changes are not symmetric across the stock and option. First, a transaction induces larger quote changes in the stock than in the option. This is expected because the option's density covers only half the range of the stock's density. Second, the average responsiveness of

TABLE 5 Linkages between the Stock and Option Markets

	Stock Sell	Stock Buy	Option Sell	Option Buy
	Panel A. Changes in Stock Quotes in Response to a Stock or Call Transaction prior to the Subsequent Transaction			
No. of positive stock changes	45	311	33	72
No. of negative stock changes	339	37	86	20
Average	−1.12	.85	−.69	1.16
Standard error	.14	.09	.18	.24
	Panel B. Changes in Option Quotes in Response to a Stock or Call Transaction prior to the Subsequent Transaction			
No. of positive option changes	36	65	24	187
No. of negative option changes	119	68	229	33
Average	−.44	.20	−.61	.63
Standard error	.10	.11	.08	.09

NOTE.—This table documents the informational linkages between the option and stock market by reporting the responsiveness of quotes to trades in both markets. We report changes in the midpoint of "inside" bid-ask spreads (the average of highest bid and lowest ask). Panel A summarizes changes in stock quotes that occur after a transaction but before a subsequent transaction. The stock quote changes are broken out as a function of the direction of the transaction (buyer or seller initiated) and the market in which the transaction was made (stock or option). Panel B summarizes changes in option quotes. Both stock and option quotes change in the direction consistent with dealers in one market updating their beliefs with respect to intrinsic value on the basis of transactions in the other.

stock quotes in absolute value to an option purchase (L$1.16) is 68% larger (though not significantly, $p = .12$) than the responsiveness to an option sale (−L$0.69). The skewness of the option value distribution provides a logical explanation for this effect. In the beginning of the trading period, the insider can profitably buy options only when the true stock value is sufficiently larger than the unconditional expectation of 100, whereas the insider can always profitably sell options when the true stock value is 100 or lower. An option purchase therefore signals on average a more extreme stock value than an option sale, and this market feature seems to be well understood by the stock dealers.[19] Third, transactions in the option lead to larger quote changes in the option than in the stock market, a phenomenon consistent with the lower liquidity shocks (and hence greater informational content) of trades in the option.

III. Discussion

When the intrinsic value of the option is zero, the insider concentrates her trading activity in the stock. Stock dealers update their beliefs primarily on the basis of stock market order flow, and prices gradually converge to the informationally efficient level.

19. On average, opening asks in the stock and call, respectively, are L$110.43 and L$10.42. Average opening bids are L$91.52 and L$1.34.

When the intrinsic value of the option is greater than zero, the insider splits her trading activity between the stock and the option. In this case stock dealers learn from both stock market order flow and price discovery in the option. This leads to a significant increase in stock market informational efficiency relative to the case where the intrinsic option value is zero (and most price discovery occurs in the market for the stock). Importantly, differences in opinion among stock and option dealers (and the insider response) are particularly informative and speed the price discovery process. This is an effect that is not a feature of theoretical models. Although the concentration of insider trading in the stock depends on the ex post moneyness of the option, the insider trades in both assets in both states, as in the mixed strategy equilibrium derived by Easley et al. (1998).

These results highlight the mechanisms by which the introduction of a traded option can improve the market quality of the underlying asset and are consistent with the theoretical result of John et al. (2000, 3): "Even though the addition of option trading enhances the ability of informed traders to disguise and profit from their trades, the informativeness of the trading process is greater because the market can now infer private information from two sources—order flow in the stock *and* option markets." We believe it is noteworthy that we find support for this result in a richer setting than their model since we allow both insiders and liquidity traders to be strategic. We also show the exact mechanism by which this occurs in a dynamic setting. Unlike John et al. (2000), we do not find evidence in support of bid-ask spreads increasing in the presence of options but, rather, an opposite effect.

Our experimental design corresponds on many dimensions to Back's (1993) model of a stock and a single call option. An important result in Back's model is that the introduction of the option leaves average volatility unchanged. We have argued above that the lower volatility when the intrinsic value of the option is positive is evidence for lower volatility in the presence of a traded option. This argument would be less persuasive if the same comparative static obtains in Back's model: lower volatility conditional on a positive intrinsic value option.

Back does not solve for stock volatility as a function of option intrinsic value, so we investigate this possibility by simulating results from his model using the same parameters as the experimental markets.[20] The simulations produced 20,000 time series, with each trading interval divided into 48 segments. Importantly, the simulations show that average volatility does not depend on option intrinsic value.

In figure 2 we compare results from these simulations with results from the experimental markets. Trading volume in the experimental markets is concentrated toward the end of the trading period (see fig. 1), so we divide the trading interval into four quartiles with equal trading volume and show that stock price convergence is faster when the option's intrinsic value is

20. We gratefully acknowledge Back's help in setting up the simulation.

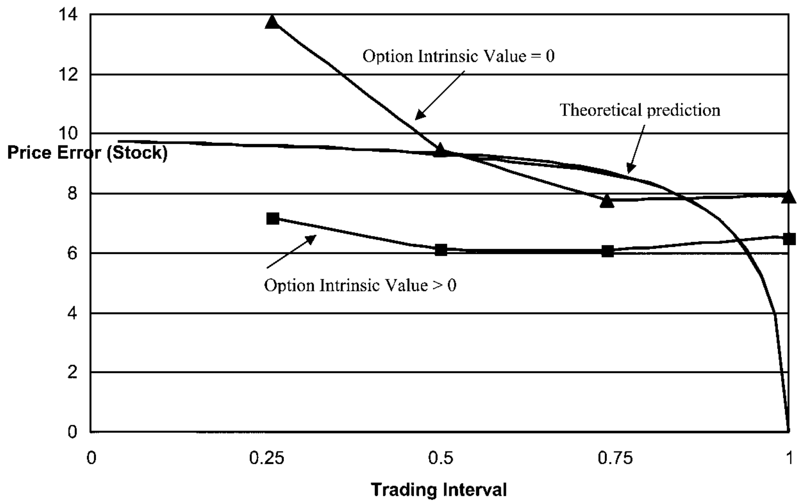

FIG. 2.—Price errors as a function of option intrinsic value relative to the theoretical prediction in Back (1993). This figure shows price errors in the stock as a function of the option intrinsic value relative to Back's continuous-time theoretical model. Back does not solve for price errors conditional on option intrinsic value, so the theoretical results are simulated assuming the same parameters as the experimental markets. The simulations produced 20,000 time series, with each trading interval divided into 48 segments. We draw below the average time series of price errors conditional on a positive option intrinsic value, and the average time series of price errors conditional on option intrinsic value equal to zero, with the length of the trading interval normalized to one. The two time series almost perfectly coincide, are statistically indistinguishable, and appear as a single time series in the graph below. We also show average price errors in the experimental markets conditioning on option intrinsic value. Trading volume in the experimental markets is concentrated toward the end of the trading period (see fig. 1), so we divide the trading interval into four quartiles with equal trading volume. For any portion of the trading interval, price errors are lower when the option intrinsic value is positive.

positive. We depict the simulation results by normalizing the length of the trading interval to one and drawing the average time series of price errors conditional on a positive option intrinsic value and the average time series of price errors conditional on option intrinsic value equal to zero. The two time series almost perfectly coincide, are statistically indistinguishable, and appear as a single time series in the graph. This is an important difference between our results and those of Back (1993).

There are many differences between the experimental design and the model that may contribute to this difference, including our quote-driven trading protocol, discrete pricing, and strategic liquidity trading. Perhaps most important is that agents in the experimental markets are not risk neutral. Risk aversion probably plays a role in the insider's propensity to trade in front of liquidity traders early in the market period (fig. 1) and to typically trade in the asset that affords the largest immediate profit (see Sec. II.D). The latter tendency plays an important role in the option's contribution to price discovery in the stock when its intrinsic value is positive and affects the rate of convergence. The theoretical result that the presence of a traded option should not affect volatility is a direct result of prices being martingales. Prices are not martingales in the experimental markets: the option intrinsic value influences the volatility in the stock market (table 2). This may be due to dealer risk aversion.[21] Evidence for dealer risk aversion is the significant level of dealer profits (see table 1).

Biais and Hillion (1994) focus on the introduction of a nonredundant option that completes the markets and find ambiguous consequences for the informational efficiency of the market. In their single-period model there are three states and three different types of liquidity traders with state-dependent endowments that trade in order to hedge their risk exposures. The introduction of the option can reduce the informational efficiency of the market by enlarging the set of strategies the insider can follow. This makes it more difficult for the dealers to interpret the informational content of trades.

As analyzed in Section II.B, we do not find evidence that the insider's larger strategy space in the presence of a traded option will reduce informational efficiency. This is most likely due to our dynamic setting with exogenous liquidity shocks in both the stock and the option: the insider uses the cover of liquidity trading to gradually but fully exploit profitable trading opportunities. Since the insider trades more aggressively in the call when it has a positive value, we find that the required number of trades in the stock to reach a given level of efficiency is less than when it expires worthless. Importantly, there is no evidence that the presence of the option harms the price discovery process when the intrinsic value of the option is zero. Thus, the sharing of price discovery strongly suggests a gain in price efficiency relative to a case without a traded option. We speculate that if we had incorporated multiple calls with different strike prices or both calls and puts, the range of informative signals would have been greater, implying additional gains in market quality. Calls and puts with multiple strike prices are features of most markets with traded options.

IV. Conclusion

We analyze the informational linkages between a stock market and a traded option by performing a controlled experiment. This allows the observation of all information sets and all actions in a setting based on the Kyle (1985) framework but with realistic features, including a quote-driven trading protocol

21. We thank an anonymous referee for pointing this out and, more generally, for suggesting this line of analysis.

and strategic liquidity traders. We examine the hypothesis that the presence of an option improves the market quality of the underlying asset by permitting the effective sharing of price discovery across markets.

We find that an insider trades aggressively in both the option and the stock, with most trades directed to the asset that affords the most profitable trading opportunity. This leads to price discovery occurring in both markets and, hence, important feedback effects: trades in the stock market imply quote revisions in the options market and vice versa. We believe that this result sheds light on why most empirical studies find an improvement in market quality after the introduction of traded options.

The focus of most related theoretical and empirical literature concerns the effect of the option on the time series properties of the price of the underlying asset. We find a significant relationship but one that varies dramatically with the ex post intrinsic value of the option: when the option is in the money the convergence to informationally efficient pricing is more rapid and the volatility of transaction prices is lower. This is due to option trades making a greater contribution to price discovery. Here the linkage between the two markets is direct in the sense that liquidation values are perfectly correlated. When the option is out of the money, price discovery in the option only helps truncate the stock value distribution. The dependence of market quality in the stock on the option's intrinsic value is very strong, and we thus demonstrate the implications of the presence of a correlated asset for price discovery. Importantly, the fundamental way in which information is extracted from order flow changes in the presence of an option with positive intrinsic values. Since stock and option dealers' expectations only gradually converge to stock and option intrinsic value, the tendency of insiders to trade where the magnitude of the profitable trading opportunity is greatest provides a richer set of signals to dealers than when there is a single asset in which the insider can trade profitably. We show therefore that not only does the presence of a correlated asset effectively split price discovery across markets; it also fundamentally changes the process by which conditional expectations are updated. We also show that the less strategic the insider (due to risk aversion, impatience, or [in field markets] noisy signals), the more powerful we expect this effect to be.

In this experiment, although the effective supply of dealer services is endogenous, the presence of an option and the absolute supply of dealer services are not. This experiment highlights the important role that the presence of a correlated asset and the supply of dealer services play in determining market quality.

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