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Author(s): Thomas S. Y. Ho and Richard G. Macris
Source: *The Journal of Finance*, Vol. 39, No. 1 (Mar., 1984), pp. 23-45
Published by: Blackwell Publishing for the American Finance Association
Stable URL: http://www.jstor.org/stable/2327666
Accessed: 27/11/2009 07:37

THE JOURNAL OF FINANCE • VOL. XXXIX, NO. 1 • MARCH 1984

Dealer Bid-Ask Quotes and Transaction Prices: An Empirical Study of Some AMEX Options

THOMAS S. Y. HO and RICHARD G. MACRIS*

ABSTRACT

This paper, utilizing dealer's "trading book" information, presents some empirical evidence supporting the validity of a dealer pricing model. It shows that much of the transaction prices variation may be explained by the specialist's optimal determination of his bid and ask quotes. Furthermore, it demonstrates that the dealer's bid-ask spread is an important explanatory variable in the observed transaction return. Finally, it indicates that the dealer's inventory level may affect his quotes and thus the transaction prices and order arrivals. The paper provides insights into the relationship between transaction prices and equilibrium prices, which will permit more extensive use of transaction data in empirical investigations. It also provides a better understanding of optimal dealer pricing strategies, suggesting that the proposed empirical model may be used to evaluate a dealer's trading performance.

IN OUR PAPER, we derive an empirical model of a monopolistic dealer's optimal bid and ask quotes; we test the model utilizing the transaction prices and dealer inventory position information of some American Stock Exchange (AMEX) options. Such information which is available in the dealer's "trading book" has not been employed previously in microstructure literature. This paper shows that the approach taken can provide interesting insights into the transaction price formation process for thinly traded options on the AMEX.

Our study is motivated by the growing interest in empirical investigations of the formation of observed transaction prices. Oldfield et al. [13] addresses this problem by seeking a random return generating process which will best explain the transaction data. They propose a model for New York Stock Exchange stock returns composed of a calendar time diffusion process and a jump process where the magnitudes of the jumps may be autocorrelated. They conclude that a geometric Brownian motion process does not alone describe the data, and they hypothesize that stock returns follow an autoregressive jump process based on the sample means and variances of transaction returns. However, this approach, while being able to specify the generating process for transaction prices, fails to provide further economic insight into the formation of transaction prices for it does not incorporate micro-decisions of the market participants.

* Associate Professor of Finance, Graduate School of Business Administration, New York University, and Smith Barney, Harris Upham & Co. Inc., respectively. The authors would like to thank David Cohen of Cohen, Cohen, and Duffy for his assistance in helping the authors understand the function of an options specialist. They would also like to thank John Merrick, Anthony Saunders, Hans Stoll, and Seha Tinic, the referee, for their comments on the paper, and Neil Horrell for his computing assistance. We are responsible for the remaining errors.

Other empirical studies, for example Garbade and Leiber [4] and Stoll [15], follow an approach suggested by Niederhoffer and Osborne [12]. They propose that while the equilibrium returns may follow a Brownian motion process, the transaction prices may be determined by the dealer's quotes relative to the equilibrium prices.[1] However, these empirical investigations only study the implications of the dealer's micro-decisions on the transaction prices (for example, the bid-ask spread is shown to be related to the autocorrelation of transaction prices). They do not propose any specific model to study the determinants of the dealer's quotes and hence transaction prices, which is something that we do in this paper.

Specifically, in this study we provide some empirical evidence of the validity of the Ho and Stoll [8] dealer pricing model.[2] We show that the dealer's percentage spread is positively related to the asset risk and is larger than the percentage reservation spread; and that the dealer adjusts his quotes in response to his inventory position. He will lower both his buy and sell quotes when he has accumulated a positive inventory. Conversely, he will raise both his buy and sell quotes when his inventory level is below his optimal target. The implications of dealer pricing strategy on transaction prices are also discussed. The paper shows that the dealer's bid and ask spread is a significant explanatory variable in the observed transaction returns. Indeed, the dealer's spread may result in the observed autocorrelation in transaction prices; however, the random walk hypothesis for the "true" return cannot be rejected. Finally, since the dealer can induce trading, the empirical evidence suggests that the timing of a transaction and the nature of the transaction (a buy or a sell) may also depend on his inventory position.

The paper is organized as follows. Section I provides the institutional background of option trading for the later development of the paper. It describes the risks in trading options and the competitive position of the specialist. Section II discusses the theoretical dealer pricing model which forms the basis for the empirical model. The methodology that is employed in the tests is described in Section III and the data in Section IV. The main results of the paper are presented in Section V. It confirms the goodness of fit of the empirical model. The empirical model is then further analyzed. Section V *A* shows that the observed negative autocorrelation of transaction prices may be explained by the dealer's quotes while the "true" return may follow a "random walk." Section V *B* shows that the asset's risk is positively related to the percentage spread but not the bid-ask spread. The estimated bid-ask spreads are shown to be of reasonable magnitudes. Section V *C* demonstrates that the dealer's spread is significantly larger than his "reservation spread," and Section V *D* suggests that the dealer does utilize the quote adjustments to manage his inventory risks. Section V *E* incorporates nonstationary instantaneous rate of return into the model, and shows that the modified model does not provide better explanatory power. Finally,

[1] For a theoretical discussion on the difference between the equilibrium price and the transaction price see Goldman and Beja [6].

[2] While the empirical study is based on the Ho and Stoll [8] model, the results are also consistent with the Amihud and Mendelson model [1]. The lack of data does not permit empirically distinguishing the two models.

Section V *F* studies the impact of measurement errors in the inventory level on the empirical results. Section VI contains the conclusions. It suggests that the model may be utilized to evaluate the trader's performance in market-making.

I. Institutional Background

Options listed on the AMEX are traded in a specialist system. This system shares many similar characteristics with the equity specialist system at both the New York Stock Exchange and at the AMEX. Although options and equities have different characteristics as investment instruments, the determinants of the specialist's trading decisions are quite similar for both securities. For example, both depend on the price uncertainty of the asset traded, the intensity of the order flow, and the nature of other market participants. However, an option specialist does face a somewhat different set of circumstances from his equity counterpart.

There are several differences in the management of inventory risk by an option specialist and his equity counterpart. First, an option specialist is obligated to trade all the options of an underlying stock, and therefore, his trading portfolio consists of many issues highly correlated in returns and probably in order arrival. In holding an "undiversified" trading portfolio, the option specialist is subject to more return and transaction uncertainties in trading. Second, an option specialist can hedge his inventory risk by taking positions in the underlying stock. He can continuously monitor the underlying stock prices via a video display and he can transact at lower members' commission rates. However, he must transmit his order through a floor broker as he is not permitted to directly contact the specialist in the underlying stock. Equity specialists are not permitted to utilize the listed options on their assigned stocks as hedging or trading vehicles. Third, an option specialist can always exercise options that he is holding in order to alter his inventory position. This could be desirable in cases when the spread in the option market is significantly larger than the spread in the equity market and when the option is "in the money" resulting in insignificant premiums. Although an option specialist has methods for managing his inventory risks not available to an equity specialist, these methods are costly to implement. The extent that they may affect the specialist basic trading strategy is an empirical question; however, in a period when only relatively small transaction sizes are involved, one expects that these risk management methods will not be often used.

The institutional arrangements affect not only the risk characteristics confronting the specialists but also the nature of the trading environment. One may argue that, as a result of the trading rules, an option specialist can maintain a monopolistic position in thinly traded options.[3] In general, the "upstairs traders" and "registered traders" play a significant role in the price formation function. "Upstairs traders" refers to persons who trade from locations off the Exchange floor. "Registered traders" are persons who trade for their own account on the

[3] The trading rules described in this Section may be found in the American Stock Exchange, Inc. Constitution and Rules (1982), Rule 170 and Rule 950.

floor but also have specific obligations to trade in the issues in which they are assigned when called upon by a floor official.

Upstairs traders cannot compete effectively with the specialist's dealer function. This is particularly true in options trading because the option specialist has access to a greater amount of floor information compared to that available to registered traders and upstairs traders. In the options market, the quote information disseminated to outside vendors provides only the current bid and offer prices (which are firm for one contract), the amount of last sale, and total volume of trading. It does not provide the ticker tape of prices and prices for larger transaction sizes to market participants off the floor as does the equity market. Therefore, with limited information depicting the depth and the breadth of the current market, upstairs traders are unlikely to be able to submit competing quotes, trade by trade, against the specialists.

Registered traders, being on the floor, can compete for the order flow with the specialists. However, there are several factors limiting their ability to compete in thinly traded issues. The rules of the Exchange forbid registered traders from intentionally or unintentionally dominating the market in any option. Therefore, in a thinly traded security, registered traders may only participate in a few trades. The rules also forbid registered traders to trade in a particular issue as dealers, and to execute off-floor orders in the same option as brokers in any one trading session. This restriction deprives the registered traders of commission revenue in any issue they trade in. To maintain profitability and to compete effectively, constrained by the exchange rules, the registered traders would have to monitor many options continuously. Such a monitoring cost may be prohibitively high. There are other complications imposed on the registered traders in their dealership role. When they place their orders on the specialist's books, they incur commission costs. If they place a quote without entering the specialist's books, any of their orders cannot retain parity or priority with off-floor orders at the same price. In contrast, the specialists are exempt from these rules, and they have in addition exclusive access to their order books which provide additional information of any imbalances in the buy and sell orders of the options; such information will enhance their dealer function.[4]

Because of these institutional arrangements, an option specialist's trading decision in thinly traded security may be appropriately described as that of a monopolistic dealer as modeled in Ho and Stoll [8] (for equity trading). While, as noted earlier, the nature of inventory risk differs somewhat from that specified in the theory, the model does serve as an appropriate benchmark for comparison. For these reasons, we base our empirical model (Section II) on the Ho and Stoll model; the implications of differing inventory risk related specifically to option trading on the empirical results are discussed in later sections.

II. Theory of the Dealer Bid and Ask Prices

The dealer in options is assumed to hold a monopoly position in providing the immediacy to trade to the public. He stands ready to trade a fixed amount ψ at

[4] Ho et al. [7] have shown that such information is valuable to the specialist in making a market. Better information would enable him to provide better quotes to the public orders.

his quotes:[5]

P_t^b is his buy/bid price (for a public sell order)

and

P_t^a is his sell/ask price (for a public buy order)

The dealer will set the quotes relative to what he believes is the equilibrium price P_t of the option at any time instant t. The dealer has a cash account C, at which he earns a constant rate of interest r. On the arrival of a sell order, he will buy the option from his cash account at price P_t^b. He may also borrow funds at the same rate of interest r. At any time, he holds an inventory I_t (which may be negative in a short position). We assume that there is no short selling restriction and the proceeds of the transaction are deposited in the cash account.

During the trading period, the dealer/specialist is subject to two sources of uncertainty as a result of holding a long or short inventory position in the security. He faces price uncertainty of the security, and he also faces an order arrival uncertainty, as he does not know when he will transact with the public. However, he can alter the probability of the order arrival at each instant of time by changing his quotes. This is modeled by assuming that he faces a downward sloping stochastic demand function to buy and an upward sloping stochastic supply function to sell.

We assume that the dealer seeks to maximize his expected terminal utility of wealth. Under these assumptions, Ho and Stoll [8] show that the dealer's quotes at each time instant depend on the inventory level (I) and the time to the end of the trade period (τ). Specifically, the buy quote (P_t^b) and the sell quote (P_t^a) are given by the following equations.

$$P_t^a = P_t(1 + a_t) \tag{1}$$

$$P_t^b = P_t(1 - b_t) \tag{2}$$

where a_t, b_t depend on his inventory position given by

$$a_t = \gamma - \beta I_t \tag{3}$$

$$b_t = \gamma + \beta I_t \tag{4}$$

and P_t = the "true" price, where γ and β are positive parameters describing the trading environment and the dealer's risk-aversion. They are given by

$$\gamma = A + \frac{Z}{2}\sigma^2\psi\tau \tag{5}$$

and

$$\beta = Z\sigma^2\tau \tag{6}$$

[5] In option trading, the specialist's quotes are firm for only one contract (i.e., $\psi = 1$). In practice, however, the specialist would also transact at his quote for some larger transaction sizes. For a sufficiently large transaction, however, the specialist would transact portions of it at his quote, and other portions at different prices.

where

A is some positive constant, depending on the market demand functions;
Z is a measure of the dealer's risk aversion (an approximation of his absolute risk aversion);
σ is the standard deviation of the rate of return of the option, and it represents the price risk involved in trading;
ψ is the transaction size for which the quotes are firm; and
τ is the trading time horizon.

While a detailed discussion of the model can be found in Ho and Stoll (H-S), some description of the model is in order to explain the derivation of the empirical model. First note that the dealer's spread is given by

$$S = P_t^a - P_t^b = P_t(a_t + b_t)$$

But Equations (3) and (4) imply that

$$\frac{S}{P_t} = 2\gamma \tag{7}$$

Equation (7) shows that the percentage spread $\left(\frac{S}{P_t}\right)$ depends on the security risk (σ). That is, the dealer would set the spread sufficiently large to ensure a trading profit for each transaction, net of compensation for the risks incurred on him for holding an inventory. At the same time, the spread should not be too large, which would reduce the frequency of order arrival for execution. When the dealer holds a positive inventory, the model shows that he will lower both his buy and sell prices. Consequently, he will induce public buy order arrival and reduce the probability of public sell order arrival. Conversely, when the dealer holds a negative inventory, he will raise both his buy and sell prices, which will induce public sell order arrival and reduce the likelihood of public buy order arrival.

Thus far, we have described the dealer's optimal pricing strategy. In this trading environment, one can also determine his minimum sell price (reservation sell price) and his maximum buy price (reservation buy price). It has been shown elsewhere (see Ho and Stoll [10]) that the reservation buy price P_t^{Rb} and reservation sell price P_t^{Ra} are given by

$$P_t^{Ra} = P_t(1 + \gamma^R - \beta I_t) \tag{8}$$

$$P_t^{Rb} = P_t(1 - \gamma^R - \beta I_t) \tag{9}$$

where

$$\gamma^R = \beta\psi \tag{10}$$

In option trading, since the quotes are firm for one contract, we therefore require $\psi = 1$. Further, by definition, the reservation bid-ask spread is smaller than the optimal spread, and therefore we have $\gamma^R \leq \gamma$. Hence, we have shown that

$$\gamma \geq \gamma^R = \beta\psi = \beta \qquad \text{or} \qquad \gamma \geq \beta \tag{11}$$

III. The Empirical Model

In this section, we utilize the results presented in Section II to formulate the empirical framework. Let Y_t denote the transaction price (at which the specialist has traded) at time t. Let D_t^a and D_t^b be dummy variables defined as:

$$D_t^a = \begin{cases} 1, & \text{if the dealer sells at the transaction at } t \\ 0, & \text{if the dealer buys at the transaction at } t \end{cases}$$

$$D_t^b = \begin{cases} 1, & \text{if the dealer buys at the transaction at } t \\ 0, & \text{if the dealer sells at the transaction at } t \end{cases}$$

From Equations (1) and (2) from the previous section, it follows that the true price P_t is related to the transaction price Y_t, adjusting for the effects of the dealer quotes, and is given by

$$P_t = D_t^a(Y_t - P_t a_t) + D_t^b(Y_t + P_t b_t) \tag{12}$$

Substituting Equations (3) and (4) into (12), it can be shown that

$$P_t = D_t^a(Y_t - P_t\gamma + P_t\beta I_t) + D_t^b(Y_t + P_t\gamma + \beta I_t P_t)$$

In simplifying the above equation, and solving for the equilibrium price P_t, we get

$$P_t = \frac{Y_t}{(1 - \beta I_t - \gamma(D_t^b - D_t^a))} \tag{13}$$

Suppose we observe a sequence of transaction, and let t_i denote the calendar time of the ith transaction. Then the equilibrium rate of return between time t_i and t_{i+1} is given by $\ln\left(\frac{P_{t_{i+1}}}{P_{t_i}}\right)$. Since Equation (13) holds for any time t, it follows then

$$\ln\left(\frac{P_{t_{i+1}}}{P_{t_i}}\right) = \ln\left(\frac{Y_{t_{i+1}}}{Y_{t_i}}\right) + \ln\left(\frac{1 - \beta I_{t_i} - \gamma(D_{t_i}^b - D_{t_i}^a)}{1 - \beta I_{t_{i+1}} - \gamma(D_{t_{i+1}}^b - D_{t_{i+1}}^a)}\right) \tag{14}$$

Note $\ln(1 + x) \cong x$ for x sufficiently small. Thus for sufficiently small values of γ and β (and since the inventory position in absolute terms may also be small as the dealer seeks to minimize his inventory risk), the following equation holds approximately,

$$\ln\left(\frac{1 - \beta I_{t_i} - \gamma(D_{t_i}^b - D_{t_i}^a)}{1 - \beta_{t_{i+1}} - \gamma(D_{t_{i+1}}^b - D_{t_i}^a)}\right)$$

$$= \beta(I_{t_{i+1}} - I_{t_i}) + \gamma(D_{t_{i+1}}^b - D_{t_{i+1}}^a - D_{t_i}^b + D_{t_i}^a) \tag{15}$$

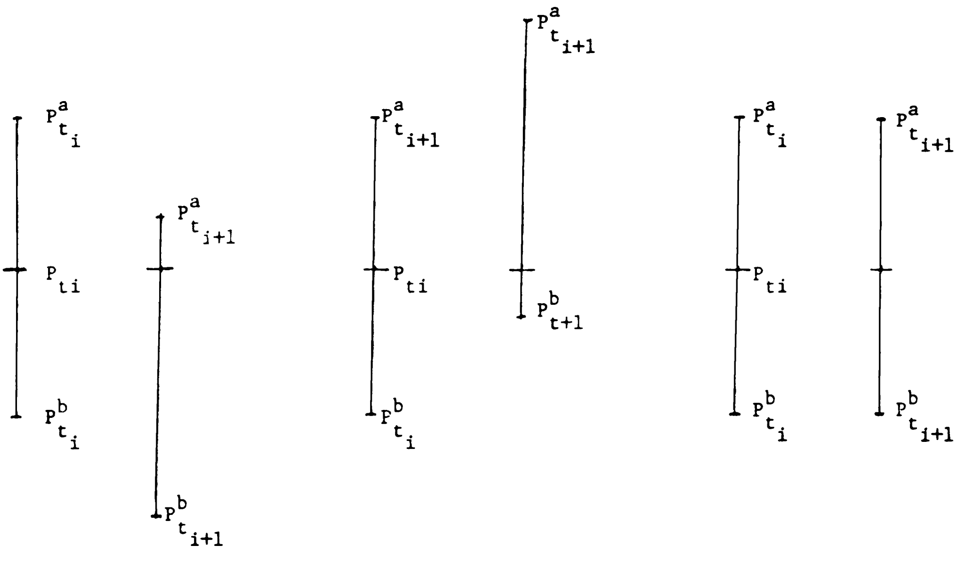
Combining Equations (14) and (15), we have finally related the observed return and the equilibrium return, and it is given by

$$\ln\left(\frac{Y_{t_{i+1}}}{Y_{t_i}}\right) = \ln\left(\frac{P_{t_{i+1}}}{P_{t_i}}\right) - \beta(I_{t_{i+1}} - I_{t_i}) - \gamma(D^b_{t_{i+1}} - D^a_{t_{i+1}} - D^b_{t_i} + D^a_{t_i}) \quad (16)$$

Equation (16) can be described intuitively. It shows that the observed rate of return deviates from the "true" rate of return as a result of two effects: the *inventory effect* and the *spread effect.*

The inventory effect (the second term) shows that if the dealer buys at t_i, and thus his inventory increases, the observed rate of return would underestimate the "true" rate of return. Referring to Figure 1a, when the dealer buys at t_i, the transaction price $P^b_{t_i}$ would be observed. At t_{i+1}, when he holds a positive inventory he would lower both his bid and ask quotes, and therefore when he buys at t_{i+1} the transaction price would be lower than the previous transaction price although the "true" price has not changed ($P^b_{t_{i+1}} < P^b_{t_i}$). Referring to Figure 1b, in this case, when he holds a negative inventory at t_{i+1}, both his bid and ask quotes would be raised, and the observed transaction price at t_{i+1} would be higher than that at $t_i(P^a_{t_{i+1}} > P^a_{t_i})$, although the "true" price remains unchanged. And hence the adjustment of the quotes depends on the change of inventory level between t_i and t_{i+1}.

The spread effect (the third term) captures the distortion of the observed rate of return due to the positive spread, isolated from the inventory effect. Referring to Figure 1c, in cases where a buy (sell) order is followed by a buy (sell) order, any observed price change, isolated from the inventory effect, would reflect the change in the "true" price. However, a dealer's sell followed by a dealer's buy



(1 a) (1 b) (1 c)

Figure 1. The Transaction Prices Relative to the Equilibrium Price

would bias downward the "true" return; meanwhile, a dealer's buy followed by a dealer's sell would lead to an overestimate of the "true" return.

Equation (16) presents an empirically testable hypothesis. It shows that the difference beween the "true" return and observed return depends (linearly) on the transaction size and knowledge of the transaction being a dealer's buy or sell. Such information is available in the dealer's trading "book." Furthermore, Equations (7) and (11) indicate the sign and relative magnitude of the coefficients β and γ, and the magnitude of γ. The tests of these hypotheses are presented in Section V.

IV. Data

The data is from an AMEX option specialist's trading book which we obtained from a specialist firm on the American Stock Exchange for the complete class of options. The data obtained were for the listed options on Philip Morris and Bausch and Lomb common stock; it contains information on 3 Calls and 3 Puts of Bausch and Lomb and 4 Calls and 3 Puts of Philip Morris. Other series were eliminated because they contained insufficient observations. The data covers mainly transactions for the period of August–September of 1981. The specialist's trading book for each option gives the following information about the transactions relevant to our empirical tests:

1. A time and date sequence (t_i) of all the transactions that the specialist participates in during the period under study. The study of each transaction is recorded to the nearest minute;
2. The transaction prices (Y_i);
3. Specification of each transaction being a dealer's buy or sell;
4. The dealer's inventory position at the time of each transaction (but before the transaction is consumated), I_t.

The lengths of the sample periods chosen for the study averaged approximately 2 weeks. The periods were kept short to minimize the variation of the options' expected rates of return during the sample period. In avoiding the empirical problem of the overnight returns, the observation of overnight returns was not considered. Most of the samples used in the study contained about 40 observations of rate of return. A detailed description of the data is given in Table I. Throughout the remainder of this paper the options will be referred to by the numerical classification given in the first column of Table I.

V. Procedure and Results

We shall assume that option equilibrium rate of return follows a Wiener process with drift, such that for any ith and $(i + 1)$th transactions

$$\ln\left(\frac{P_{t_{i+1}}}{P_{t_i}}\right) = \mu(t_{i+1} - t_i) + \sqrt{(t_{i+1} - t_i)}\tilde{\epsilon}_i \tag{17}$$

where $\tilde{\epsilon}_i \sim N(0, \sigma^2)$, a normal distribution with zero mean and variance σ^2;

Table I

Data Description

Numerical Classification	Code[a]	Classification	Number of Observations	Number of Trading Days	Time Span of Sample in 1982	Average Option Price[b]
1	PBOL.MJ	Jan 50 put	40	18	9/14–10/08	5.8947
2	CMO.II	Sept 45 call	40	9	8/24–9/02	1.7109
3	CZMO.II[c]	Sept 45 call	40	11	9/02–9/17	1.1010
4	PMO.VI	Sept 45 put	40	22	8/10–9/09	0.5604
5	CMO.LI	Dec 45 call	40	8	9/08–9/17	2.9844
6	PMO.XI	Dec 45 put	34	22	8/11–9/18	1.3841
7	CMO.LJ	Dec 50 call	40	16	8/24–9/15	1.3188
8	PMO.XJ	Dec 50 put	33	16	8/17–9/10	4.1568
9	PBOL.MI	Jan 45 put	40	11	9/14–9/28	3.6594
10	CBOL.JJ	Oct 50 call	40	17	9/14–10/08	0.3797
11	PBOL.VJ	Oct 50 put	40	8	9/14–8/23	5.4954
12	CBOL.AI	Jan 45 call	29	23	8/17–10/16	4.7115
13	CMO.CJ	March 50 call	32	16	9/03–9/25	1.8776
14	CBOL.AJ	Jan 50 call	25	15	9/09–10/01	1.9063

[a] The code is a modification of the standard CBOE momenclature for listed options.
[b] The average option price obtained by taking an average of all the transaction prices in the sample.
[c] CMO.II and CZMO.II are, respectively, the first and second set of observations drawn from the trading book for Philip Morris September 45 calls.

furthermore ϵ_i and ϵ_{i+1} are not correlated, and the expected rate of return μ is constant.[6]

Substituting Equation (17) into Equation (16) we can derive an empirical model

$$\ln\left(\frac{Y_{i+1}}{Y_i}\right) = \mu(t_{i+1} - t_i) - \beta(I_{t_{i+1}} - I_i) - \gamma(D^b_{t_{i+1}} - D^a_{t_{i+1}} - D^b_{t_i} - D^a_{t_i}) + \sqrt{(t_{i+1} - t_i)}\tilde{\epsilon}_i \quad (18)$$

Note that if we define a dummy variable

$D_{t_i} = 1$ if the ith transaction is dealer buy,

$= -1$ if the ith transaction is a dealer sell,

then, $D_{ti} = D^b_{ti} - D^a_{ti}$.

Furthermore, if we let

$$y_i = \frac{\ln\left(\dfrac{Y_{t_{i+1}}}{Y_{t_i}}\right)}{\sqrt{t_{i+1} - t_i}} \quad (18a)$$

[6] Following Stoll [14], we shall assume that the dealer revises his trading horizon τ after each transaction such that τ remains constant over time. For the empirical test

$$(t_{i+1} - t_i) = \frac{\text{number of minutes between the } i\text{th and } (i+1)\text{th transaction}}{24 \times 60}$$

$$X_{1i} = \frac{I_{t_i} - I_{t_{i+1}}}{\sqrt{t_{i+1} - t_i}} \tag{18b}$$

$$X_{2i} = \frac{D_i - D_{i+1}}{\sqrt{t_{i+1} - t_i}} \tag{18c}$$

and

$$X_{3i} = \sqrt{t_{i+1} - t_i} \tag{18d}$$

then Equation (18) suggests the following empirical model,

$$y_i = \alpha + \beta X_{1i} + \gamma X_{2i} + \mu X_{3i} + \tilde{\epsilon}_i \tag{19}$$

And from Section II, we have shown that $\gamma > 0$. Moreover, if $\bar{s}$ is the average observed bid-ask spread and $\bar{P}$ is the mean true price during the sample period, Equation (7) shows that

$$\bar{s} = 2\gamma\bar{P} \tag{20}$$

Equation (20) gives the sign and magnitude of γ. Equations (6) and (11) show that the following bounds on β have to hold.

$$0 < \beta < \gamma \tag{20a}$$

And a significant level of β will indicate the inventory effect on transaction prices. Finally, the "random" walk hypothesis requires that the residuals are not serially correlated.

The results of the OLS estimate of Equation (19) for 14 option samples are given in Table II. They in general confirm the goodness of fit of the empirical model.[7] They show that both the spread and inventory effects are significant. Specifically, the spread effect ($\hat{\gamma}$) is significant for 13 of the options. The inventory effect ($\hat{\beta}$) is significant for 6 of the options. As one might expect, the time elapsed between transactions (X_{3i}) is not a significant explanatory variable since the underlying rate of return is not a dominant issue in a short time horizon. (The explanatory power of the instantaneous rate of return will be analyzed further in Section V *E*.) Further, the constant term is not shown to be significant, consistent with the theory. It is also interesting to note the stationarity of the estimated coefficients across the options. The estimated $\hat{\gamma}$ are at about 10^{-2} level of magnitude, while the estimated $\hat{\beta}$ are about 10^{-4} for all the options.

However, some cross-sectional variation of these estimates can be anticipated. Since different options have different price risks and stochastic demand functions, one might expect that the inventory and spread effects differ across options. Specifically, referring to Equations (5) and (6), the parameters σ^2 and A would be different across the options, even though all the options are traded by one specialist firm. Finally the adjusted $\bar{R}^2$ generally averages about 30%. The results indicate that the model is robust, and suggest that the simplifying assumptions

[7] In reporting the empirical results, for simplicity, we refer to the option samples as "options." Recall option (2) and option (3) are observations of the same option in different time periods.

Table II

Results of the OLS Test

Option	Constant Term	Inventory Response β	Spread Effect γ	Drift Term μ	$\bar{R}^2$
1	-2.0096×10^{-1}	2.252×10^{-3}	2.8964×10^{-2}	8.2973×10^{-1}	0.4595
	(−1.740)**[a]	(1.853)**	(5.795)**	(1.646)**	
2	-4.0095×10^{-1}	2.6241×10^{-3}	4.2626×10^{-2}	1.6952	0.3728
	(−1.331)*	(2.461)**	(5.089)**	(1.077)	
3	4.0759×10^{-1}	2.4255×10^{-4}	5.9061×10^{-2}	−1.8284	0.3825
	(1.264)*	(0.168)	(4.671)**	(−1.156)	
4	8.0098×10^{-1}	-2.2259×10^{-4}	4.8242×10^{-2}	−2.2821	0.3640
	(2.382)**	(0.254)	(4.343)**	(−1.675)**	
5	-4.7102×10^{-2}	-9.1513×10^{-4}	1.6908×10^{-2}	3.2454×10^{-1}	0.4783
	(−0.337)	(−4.160)**	(3.607)**	(0.406)	
6	4.2752×10^{-1}	-2.4697×10^{-3}	-9.9375×10^{-3}	−1.3662	0.2651
	(1.357)*	(−3.464)**	(−1.148)	(−1.144)	
7	-4.6298×10^{-1}	6.0471×10^{-5}	3.2850×10^{-2}	1.7709	0.0105
	(−0.937)	(0.101)	(1.510)*	(0.652)	
8	1.5500×10^{-1}	2.2619×10^{-3}	1.1082×10^{-2}	-2.6167×10^{-1}	0.0995
	(0.862)	(2.439)**	(1.207)	(0.360)	
9	5.7705×10^{-1}	6.2231×10^{-3}	5.7377×10^{-2}	−2.2016	0.2860
	(2.366)**	(3.258)**	(3.922)**	(−1.762)**	
10	3.2103×10^{-1}	5.6464×10^{-4}	1.0251×10^{-1}	−1.6233	0.4487
	(0.715)	(0.757)	(5.841)**	(0.724)	
11	1.5750×10^{-2}	1.4648×10^{-3}	2.2715×10^{-2}	2.2635×10^{-1}	0.2360
	(0.079)	(1.183)	(3.879)**	(0.211)	
12	3.244×10^{-1}	1.3143×10^{-3}	3.4880×10^{-2}	-8.3695×10^{-1}	0.2462
	(1.793)**	(2.110)**	(3.189)**	(−1.103)	
13	1.0479×10^{-1}	8.3029×10^{-4}	4.1881×10^{-2}	-4.4370×10^{-1}	0.6670
	(1.050)	(1.411)*	(7.690)**	(−1.068)	
14	-1.9477×10^{-1}	7.6316×10^{-3}	4.8042×10^{-2}	6.0037×10^{-2}	0.5036
	(−0.888)	(3.948)**	(4.713)**	(0.067)	
15a	-9.1033×10^{-2}	-4.1770×10^{-4}	1.8190×10^{-2}	5.1000×10^{-1}	0.2916
	(−0.588)	(−0.549)	(3.581)**	(0.599)	
16a	-8.4414×10^{-2}	—	1.3122×10^{-2}	3.0306×10^{-1}	0.0000
	(0.276)		(1.317)*	(0.246)	

[a] t-statistics are indicated in the parentheses.
* Significant at 10% level in the one-tail test.
** Significant at 5% level in the one-tail test.

we have made are not inappropriate for the options considered in the sample period.

The assumption that the dealer holds a monopolistic position is justified when the assets are thinly traded, as argued in Section I. For the option sample, the specialist participated in only 60 transactions in each option on the average. This number of transactions within a 2 to 3 week time frame is indicative of a thinly traded security. In addition there is evidence that the specialist was the dominant market maker. One can determine the percentage of transactions involving the specialist's participation as a dealer during the sample period for each option by identifying the specialist transactions reported in his "trading book" from the list of all the transaction reported in the "Fitch Sheets." This identification can be made as both the specialist "trading book" and the "Fitch Sheets" report the time (to the nearest minute), the amount, and the price of each transaction. The transactions not identified with those reported in the specialist's "trading book" are assumed to be transactions that did not involve the participation of the specialist as a dealer. Then, the percentage may be determined. These results are summarized in Table III, Column 1. Based on the sample studied, the results show that the average rate of specialist dealer activity was above 80% which indicates that he was the principal market maker.

Second, the model assumes that the specialist manages his inventory only by adjusting his quotes. Section I has argued that this assumption would not be invalid when the average transaction size is not large. Referring to Table III, Column 2, the total average transaction size is approximately 9 contracts which shows that most transactions did not involve large order sizes, and therefore, one would not anticipate that the specialist would actively hedge his positions in the equity market or liquidate his inventory by early exercise of his options during the sample period.

Third, the specialist is assumed to act as a dealer only to provide liquidity to the market. The model ignores his affirmative obligation to provide and maintain an orderly market. However, this assumption is not inappropriate if the price movements of the underlying stock do not exhibit excessive percentage changes during the sample period; stable stock prices and hence stable option prices indicate that the specialist's intervention in the market place is not called for. During the period August through October, Philip Morris reached a high of $51⅛ and a low of $45, while Bausch and Lomb reached a high of $50¾ and a low of $43¼. In addition, the maximum interday price change was only $1¾ for both stocks. These observations show that the sample covers a period of relatively stable prices; we can conclude that the pure dealer model is adequate to describe the specialist for the sample period. Now, we will proceed to analyze further the empirical model.

Table III

Further Statistical Results of the Options

Option Number	% of Dealer Participation in the Transaction	Average Transaction Size (in Contracts)	The Bid-Ask Spread ($2\hat{\gamma}\bar{P}$)	$\hat{\delta} = \hat{\gamma} - \hat{\beta}$ t value
1	89.39	3.96	0.3414	5.9375
2	85.71	8.94	0.1457	5.1162
3	85.00	8.25	0.1300	4.9614
4	64.52	10.11	0.0540	4.4873
5	96.15	7.75	0.1009	3.8167
6	80.00	9.82	0.0275	1.4402
7	71.25	16.96	0.0866	1.5170
8	90.91	6.76	0.0921	1.0018
9	77.14	6.76	0.4199	3.7417
10	71.05	12.62	0.0778	5.8671
11	79.44	5.04	0.2496	3.7908
12	91.23	10.75	0.1309	3.2142
13	84.75	8.44	0.1572	7.8411
14	85.11	6.25	0.1831	4.2128

Table IV

A Comparison of the Time Series Analyses of the Observed Rate of Return and the OLS Test Residuals

	The Observed Rate of Return		Analysis of the Residuals of the OLS Test		
Option	Auto-correlation	Standard Error	Durbin-Watson Statistics	Adjusted Box-Pierce Statistics for Lags	Number of Observations
1	−0.126	0.152	1.8636	13.91	40
2	−0.034	0.152	2.1846	10.48	40
3	−0.284	0.152*	2.0987	2.553	40
4	0.144	0.152	1.7402	2.519	40
5	−0.089	0.152	1.6123	9.205	40
6	0.306	0.166*	2.1513	10.87	33
7	−0.259	0.152*	2.0440	0.6323	40
8	−0.030	0.164	2.2844	4.176	33
9	−0.027	0.152	2.1310	5.044	40
10	0.101	0.152	1.6198	5.678	40
11	−0.244	0.152*	2.2597	9.322	40
12	0.011	0.176	2.2990	2.379	29
13	−0.530	0.169**	2.9241	13.46	32
14	0.137	0.189	2.1558	4.996	25

* Significant at 10% level in the one-tail test.
** Significant at 5% level in the one-tail test.

A. The True Rate of Return Follows a Random Walk

The empirical model suggests that the true rates of return follow a random walk while the observed rates of return are autocorrelated. This hypothesis can be explained intuitively. The model argues that when a positive rate of return is observed, it is likely that the dealer has just transacted at his sell price and that the previous transaction was consummated at his buy price. Now, the dealer is likely to induce a public sell order such that one anticipates a higher likelihood of a transaction at his buy price, which is lower than his sell price. One can anticipate an observed lower rate of return for the next transaction. Consequently the observed rates of return are negatively correlated in the first order.

Table IV shows that this hypothesis is consistent with the empirical evidence. The first-order autocorrelation of the observed rate of return $\ln(Y_{i+1}/Y_i)$ is calculated for all the options. 11 options out of the 14 options investigated show negative correlation, and 4 of them are significantly negative.[8] For option (6), the autocorrelation is significantly positive. An explanation of this result is given in later sections. However, when the Durbin-Watson test is applied to test the

[8] The result that the observed rate of return is negatively autocorrelated is consistent with previous literature. There has been much evidence (e.g., Cootner [2]) suggesting that the rates of returns on equities follow a random walk over weekly or monthly intervals. However, over shorter time intervals, stock returns are negatively autocorrelated.

serial correlation of the residuals from OLS test of Equation (19), the results indicate that the hypothesis of zero first-order correlation in the residuals cannot be rejected. Further, the Box-Pierce test shows that the null hypothesis of no serial correlation up to lag 5 cannot be rejected, indicating that the residuals may be white noise.[9]

B. Percentage Spreads and Bid-Ask Spreads

In Section II, we have shown that the estimate of the spread effect ($\hat{\gamma}$) can be used to estimate the percentage spread (Equation (7)) and the bid-ask spread of an option (Equation (20)). This section will discuss the goodness of these estimates for the options sample.

The model argues that the dealer, at each time instant (t), should maintain a positive spread (S_t) beween his bid and ask quotes. Moreover, his percentage spread (S_t/P_t), where P_t is the option price, should be positively related to the option price risk (σ) (see Equation (5)). Since the study is based on two classes of options on two stocks, the relative risk of the options can be inferred from the relative maturities and relative exercise prices. That is, the options specifications can provide a partial ranking of the option price risks, and hence a partial ranking of the percentage spreads. This ranking can then be compared to that which is estimated in the empirical model.

Specifically, we compare the risks of a put and a call option in the same series (which are options on the same stock with the same exercise date and price). When the underlying stock price is below the exercise price, the call option (which is out of the money) is riskier than the put option (which is in the money). Since, during the sample period, both stocks were selling below \$50, it follows that the call options are riskier than their corresponding put options (referring to Table V) for the months of October, December, and January, for options with an exercise price 50. Therefore, by the previous arguments, for these options the call option percentage spread should be higher than the corresponding put option percentage spread. Table V shows that the ranking of the estimated percentage spread is consistent with the theory.

Further, Galai and Masulis [3] show that the call option risk decreases with the time to maturity, ceteris paribus. This risk ordering is consistent with the ordering of the percentage spreads of most of the options in the sample. Table V shows that the percentage spread of option (3) is greater than that of option (2), which in turn is greater than that of option (5). And also option (10) has higher percentage spread than option (14). Only option (13) has a slightly higher percentage spread than option (7), contrary to the theory. Since the risk and maturity relationship is not known for American put options, we do not have an analogous discussion of the put options. Finally, consider the ordering of the options' bid-ask spreads. They are, in general, not consistent with the risk ordering, suggesting that the spread *per se* is not related to the asset risk.

Lastly, using Equation (20) we can estimate the bid-ask spread as opposed to the percentage spread of the options. The average "true" price $\bar{P}$ is estimated to

[9] Lag 5 has been quite arbitrarily selected for reporting. In fact, no significant serial correlation has been found for lag 10.

Table V

Price Risk and the Percentage Spread

		Underlying Stock (Exercise Date)				
Exercise Price	Option Type	Philip Morris (September)	Bausch and Lomb (October)	Philip Morris (December)	Bausch and Lomb (January)	Philip Morris (March)
		(4)[a]		(6)	(9)	
	put	9.6484[b]		1.9874	11.4754	
		0.0540[c]		0.0275	0.4199	
45		(2)		(5)	(12)	
	call	8.5252		3.3816	6.9760	
		0.1457		0.1009	0.1309	
		(3)				
		11.8122				
		0.1300				
			(11)	(8)	(1)	
	put		4.5430	2.2164	5.7920	
			0.2496	0.0921	0.3414	
50						
			(10)	(7)	(14)	(13)
	call		20.5020	6.570	9.6084	8.3762
			0.7784	0.0866	0.1831	0.1572

[a] Option numerical classification.
[b] The percentage spread = $2\gamma \times 100$.
[c] The bid-ask spread.

be the mean value of the observed transaction prices. The estimated spread ($\bar{s}$) for each option is presented in Table III, Column 3. The results show that most of the spreads lie between 1/16 and 1/2 with 8 option spreads priced more than 1/8, indicating that these estimates are reasonable.[10] It is important here to differentiate between the specialist's spread and the displayed spread (derived from his quotes displayed on the video monitor on the floor). At times of active trading, the actual specialist bid-ask quotes may not be reported at any instant of time because of the time it takes for the exchange reporter to enter the quotes into the market data system. It therefore may not be possible to "observe" the actual spread by examining displayed quotes. The model presented in this paper suggests a possible way to estimate this spread from a sequence of transaction prices.

C. A Comparison of the Dealer's Spread and the Reservation Spread

Recall that the percentage spread (2γ) derived in the model is priced by a monopolistic dealer. It is therefore larger than his reservation percentage spread. Ho and Stoll [10] have shown that the reservation percentage spread is given by (2β) (as discussed in Section II). We therefore require $\beta < \gamma$, providing a testable hypothesis. Specifically, let $\delta = \gamma - \beta$. Then, the t-test can be applied to the null

[10] Note that many options are traded in 1/16 units.

hypothesis H_0: $\delta > 0$.[11] Referring to Table III, Column 4, for the 14 options considered, they all show the correct sign and 13 options show δ positively significant, consistent with the theory. We point out that the fact that the observed spread is larger than the reservation spread can be explained by factors external to the model. For example, the dealer will require a surplus to cover the expenses incurred in trading, or he may demand compensation for providing the opposite side of the market to some better informed investors. In general, the specialist holds a less diversified trading portfolio in option market making than he does in equity market making (see Section I). Ho and Stoll [9] show that this leads to a higher reservation spread for the option specialist and an underestimation of the reservation spread. Therefore, when $\delta < 0$, if the dealer is not making significant monopolistic profit, the factors considered here must necessarily be important determinants of the dealer's optimal quotes.[12]

D. Dealer's Inventory Management and Pricing Strategy

Section II shows that when the dealer holds a long inventory position he will adjust both his quotes downwards in order to induce public buy orders on one hand and to charge a higher "fee" for public sell orders on the other. Likewise, when the dealer holds a short inventory position, he will adjust both his quotes upwards. According to the theory, this pricing strategy will lead to a significantly positive regression coefficient β in the OLS test described in Section III. The empirical results for the 14 options, in general, support the theory. Referring to Table II, the results show that $\hat{\beta}$ is positive for 11 of 14 options and is significantly positive at the 5% level for 6 of the option samples.

However, for options (5) and (6), contrary to the theory, the estimated coefficients are significantly *negative.* A further investigation of these two options is in order. For option 5 during the sample period, of the nine trading days, nearly all transaction sizes were less than ten contracts. However, on one trading day, the specialist sold two contracts at 2½. Twenty five minutes later, he sold a large transaction of fifty contracts at a higher price 2⅝. Thus far, the pricing is consistent with the theory: that he will sell at a higher price to compensate for the increased inventory risk. However, one minute later, he sold two contracts at a lower price of 2½. One can project a possible explanation for this pricing behavior; after the second transaction, he hedged his position in the equity market which then allowed him to lower his quotes. Since the model does not seek to explain large transactions, one might expect such trades to affect the empirical results. Furthermore, since the transaction of fifty contracts is significantly larger than other transactions in that sample, it is possible that this one observation could significantly affect the empirical results. Indeed, when the

[11] The t-statistic is given by

$$t = \frac{\hat{\gamma} - \hat{\beta}}{\sqrt{\mathrm{Var}(\hat{\gamma}) - 2\,\mathrm{Cov}(\hat{\gamma}, \hat{\beta}) + \mathrm{Var}(\hat{\beta})}}.$$

[12] Section V *F* further suggests that significant inventory measurement error may offer another explanation for δ significantly larger than zero.

OLS test is repeated with this observation omitted, the result given in Table II (Row 5a) shows that the regressions constant β is no longer significantly negative.

For option (6), however, there is not any large transaction that might bias the results, and therefore the explanation must depend on considerations other than those used for option (5). The following considerations suggest that, for the option, the dealer may have taken speculative positions in some of the transactions in anticipation of price movements. He was not performing a pure market making role as described in the microstructure literature. Section V F shows that, for all the options, the observations X_{1i} and X_{2i} are negatively correlated which suggests a possible explanation for finding β significantly negative. Perhaps, while the dealer maintained a positive bid-ask spread he followed a risk-neutral pricing strategy, ignoring the inventory risk. This would lead to a misspecification of the model, resulting in a negatively significant inventory effect and an insignificant spread effect (option (6) is the only option showing an insignificant spread effect). However, when the OLS test is repeated for option (6), omitting the variable X_{1i}, the model has virtually no explanatory power (see Table II, Row 6a). Another possible explanation may be that the inventory positions are measured with significant errors, resulting in a bias in the estimation. However, Section V F will show that the bias should not result in an opposite sign, as is the case here.

E. Nonstationarity of the Instantaneous Rate of Returns of the Options

Thus far the model assumes that each option's expected instantaneous rate of return is constant during the sample period. However, the expected instantaneous return should depend crucially on the option price level and maturity. Therefore, one may expect that the rate of return may vary during the sample period. In this section, the empirical test is modified to incorporate the nonstationarity of the expected rate of return. By the Black and Scholes model, the instantaneous expected rate of return of a call option (r_C) is given by

$$r_C = r_f + (r - r_f)\,\frac{N(d)S}{C} \tag{21}$$

and the put option (r_P) (approximated by a European put option formula),

$$r_P = r_f - \frac{(r - r_f)N(-d)S}{P} \tag{22}$$

where

S = the stock price,
C = the call option price,
P = the put option price,
r = the expected instantaneous rate of return of the stock,
r_f = the risk-free rate,

$$d = \frac{\ln\left(\dfrac{S}{Xe^{-r_f t}}\right)}{\sigma\sqrt{t}} + \frac{\sigma\sqrt{t}}{2},$$

X = the exercise price,
σ^2 = the instantaneous variance of the rate of return on the stock, and
t = the time to maturity.

Equations (21) and (22) show that the elasticities of a call option

$$\eta_C = \frac{N(d)S}{C} \tag{23}$$

and a put option

$$\eta_P = \frac{N(-d)S}{P} \tag{24}$$

represent the nonstationary components of the expected rate of returns.

Utilizing Equations (23) and (24), the elasticities for the period between the ith and $(i + 1)$th transactions may be estimated by taking the stock price (S) to be the closing price on the date of the ith transaction; the call price (C) or put price (P) to be the ith transaction price; the standard deviation of the expected return (σ) estimated by using the daily realized rate of return of the stock during the year; the time to maturity (t) can be calculated directly; and the risk-free rates are taken to be the 3 month treasury bill rates.

Now, the OLS test may be modified to incorporate the elasticity component. Specifically, we have, for the call options

$$Y_i = \alpha + \beta X_{1i} + \gamma X_{2i} + \mu \eta_{Ci} X_{3i} + \tilde{\epsilon}_i \tag{25}$$

and for the put options

$$Y_i = \alpha + \beta x_{1i} + \gamma X_{2i} + \mu \eta_{Pi} X_{3i} + \tilde{\epsilon}_i \tag{26}$$

where the dependent variable Y_i and the explanatory variables X_{1i}, X_{2i}, and X_{3i} are defined by Equation (18a–d). The OLS tests of Equations (25) and (26) are summarized in Table VI. By incorporating the nonstationary expected rate of return into the empirical model, the results are not significantly different to that assuming constant instantaneous rate of return. The adjusted $\bar{R}^2$ have not been significantly increased and the drift term remains insignificant as an explanatory variable. This demonstrates that the assumption of a constant instantaneous rate of return during a short sample period of 2 to 3 weeks is not invalid.

F. Multicollinearity and the Estimation Bias

For the empirical model, Equations (18b), (18c), and (19), one may expect the variables X_{1i} and X_{2i} to be negatively correlated. From Equation (18c), X_{2i} is a dummy variable such that $X_{2i} < 0$ (> 0) when the ith transaction is a dealer sell (buy) and the $(i + 1)$th transaction a dealer buy (sell). Meanwhile, from Equation (18b), $X_{1i} < 0$ (> 0) when the dealer buys (sells) at the ith transaction (i.e., he raises (lowers) the quotes after a sell (buy) transaction). Therefore, the OLS test suffers a multicollinearity problem. The extent of correlation is given in Table VII, where the estimated correlation coefficients of X_1 and X_2 and the estimated correlation coefficients of the estimates of X_1 and X_2 are given. They confirm the significance of the correlation between X_1 and X_2.

Table VI

Results of the Modified OLS Test with Nonstationary Instantaneous Rate of Return

Option	Constant Term	Inventory Response β	Spread Effect γ	Drift Term μ	$\bar{R}^2$
1	-1.7767×10^{-1}	2.2781×10^{-3}	2.8810×10^{-2}	1.6538×10^{-1}	0.4481
	(−1.503)**[a]	(1.837)**	(5.708)**	(1.381)*	
2	-3.7159×10^{-1}	2.6479×10^{-3}	4.2543×10^{-2}	6.4204×10^{-1}	0.3655
	(−1.136)	(2.470)**	(5.012)**	(0.858)	
3	9.0019×10^{-2}	6.0065×10^{-4}	5.7471×10^{-2}	-1.1036×10^{-1}	0.3597
	(0.437)	(0.417)	(4.490)**	(−0.063)	
4	5.1855×10^{-1}	-5.098×10^{-4}	4.4586×10^{-2}	-2.7059×10^{-1}	0.3605
	(2.523)**	(−0.605)	(4.222)**	(−1.610)*	
5	-2.261×10^{-2}	-9.2969×10^{-4}	1.6964×10^{-2}	2.8296×10^{-2}	0.4765
	(−0.161)	(−4.218)**	(3.615)**	(0.206)	
6	4.5572×10^{-1}	-2.5302×10^{-3}	9.2643×10^{-3}	-2.7143×10^{-1}	0.3212
	(2.018)**	(−3.876)**	(1.115)	(−1.953)**	
7	-3.5421×10^{-1}	6.5164×10^{-5}	3.4515×10^{-2}	3.9387×10^{-2}	0.0037
	(−0.745)	(0.107)	(1.598)*	(0.420)	
8	1.0159×10^{-1}	2.1264×10^{-3}	9.9117×10^{-3}	-3.4063×10^{-3}	0.0956
	(0.611)	(2.271)**	(1.080)	(−0.023)	
9	5.8361×10^{-1}	6.2701×10^{-3}	5.7748×10^{-2}	-7.3492×10^{-1}	0.2916
	(2.444)**	(3.294)**	(3.759)**	(−1.848)**	
10	2.1235×10^{-1}	6.0158×10^{-4}	1.0126×10^{-1}	-6.0773×10^{-3}	0.4544
	(0.695)	(0.809)	(5.872)**	(−0.950)	
11	6.1518×10^{-2}	1.6180×10^{-3}	2.2619×10^{-2}	-1.0450×10^{-2}	0.2351
	(0.332)	(1.322)*	(3.863)**	(−0.051)	
12	3.2062×10^{-1}	1.2925×10^{-3}	3.4460×10^{-2}	-1.6054×10^{-1}	0.2493
	(1.651)*	(3.156)**	(2.082)**	(−1.151)	
13	1.2999×10^{-1}	8.4775×10^{-4}	4.1693×10^{-2}	-2.9842×10^{-2}	0.6751
	(1.309)*	(1.459)**	(7.744)**	(−1.366)*	
14	-1.7309×10^{-1}	7.619×10^{-3}	4.8035×10^{-2}	-1.9981×10^{-3}	0.5036
	(−0.943)	(3.935)**	(4.712)**	(−0.060)	

[a] t-statistics are indicated in the parentheses.

* Significant at 10% level in the one-tail test.

** Significant at 5% level in the one-tail test.

This multicollinearity problem may affect the empirical results beyond the loss of efficiency. In general, in a multiple linear regression model with one mismeasured independent variable, all coefficients are asymptotically biased in the presence of multicollinearity. In particular, for our model, the problem arises from the mismeasurement of the dealer's inventory positions.

During the trading day, it is likely for the specialist's clerk to record an incorrect transaction or transaction size in the trading book. This will result in an incorrect inventory figure at the end of the day. The accumulated error will be corrected the next morning when all the trades are compared and adjustments are made in the current inventory level. While this adjustment will erroneously measure the overnight return, it does not affect our test because we ignore the overnight return observations. However, the previous day's incorrect trades are not corrected so that the data we employed would show these errors. Since the extent of the clerical errors depends on the experience of the personnel at the

Table VII

Estimated Correlation Coefficients of X_1 and X_2 (ρ) and Estimated Correlation Coefficients of the Estimated Coefficients of X_1 and X_2 (ρ^*)

Option Number	ρ	ρ^*
1	−0.55	0.51
2	−0.59	0.57
3	−0.51	0.47
4	−0.38	0.45
5	−0.12	0.10
6	−0.13	0.10
7	−0.21	0.24
8	−0.34	0.45
9	−0.55	0.55
10	−0.26	0.25
11	−0.38	0.30
12	−0.80	0.80
13	−0.41	0.41
14	−0.41	0.40

post during the sample period, one cannot estimate the measurement error level. Assuming that there is a significant error, this section will analyze the bias that it may induce in our coefficient estimates. Further, it explores the possibility of using the measurement error to account for the option (6) results, which do not agree with the theoretical model (see Section V *D*).

Following Levi [11], we suppose X_1 (defined in Equation (18b)) is measured with error such that the observed data X_1^* is given by

$$X_1^* = X_1 + u$$

where $E(u) = 0$ and $E(uu') = \sigma_u^2 I$. Further we assume that all errors are uncorrelated with the true values of the variables and with each other. Then it can be shown that

$$\text{plim } \hat{\beta} = \beta\left(1 - \frac{\sigma_u^2 \Sigma_{11}}{|\Sigma| + \sigma_u^2 \Sigma_{11}}\right) \tag{27}$$

and

$$\text{plim } \hat{\gamma} = \gamma - \frac{\beta \sigma_u^2 \Sigma_{12}}{|\Sigma| + \sigma_u^2 \Sigma_{12}} \tag{28}$$

where

$\Sigma = \text{plim}\left(\dfrac{X'X}{T}\right)$,

$X = (X_1, X_2, X_3)$, and

T = the number of observations.

Notice that the following inequality always holds.

$$0 < \frac{\sigma_u^2 \Sigma_{11}}{|\Sigma| + \sigma_u^2 \Sigma_{11}} < 1$$

Therefore Equation (27) can be rewritten as

$$\text{plim } \hat{\beta} = \lambda \beta \quad \text{for} \quad 0 < \lambda < 1 \tag{29}$$

And also, since $\beta > 0$ and $\Sigma_{12} < 0$, we know that

$$\frac{\beta \sigma_u^2 \Sigma_{12}}{|\Sigma| + \sigma_u^2 \Sigma_{12}} < 0$$

Then Equation (28) can be rewritten as

$$\text{plim } \hat{\gamma} > \gamma \tag{30}$$

Equations (29) and (30) provide interesting insights into our empirical results. Equation (29) suggests that the empirical result may be understating the inventory effect but meanwhile Equation (30) suggests that the spread effect may be overstated. Therefore the magnitude of $(\hat{\gamma} - \hat{\beta})$ may be reduced, offering another explanation for the estimated spread being significantly larger than the estimated reservation spread (as discussed in Section V *D*). Next, Equation (19) shows that the measurement error does not alter the sign of the estimated coefficient. For this reason, the measurement error alone cannot explain the opposite sign of β obtained for option (6).

VI. Conclusions

This paper studies the implications of dealer quotes on the behavior of observed transaction prices of securities. It derives a relationship between transaction and equilibrium prices, and the theory is tested utilizing the "trading book" information of some options traded on the American Stock Exchange. The empirical results in general support the theory and thus provide insight into the formation of the transaction prices. Since the main results have been discussed in the introduction, they will not be repeated here.

It should be pointed out that while the paper focuses on the study of the return generating process of a security, the model may also have applications beyond the interest of microstructure literature. This literature tends to focus on the analyses of the design of trading arrangements. It assumes that market makers perform in an optimal way.[13] In contrast, the model presented in the paper can be used to evaluate the performance of the traders, without assuming that they trade optimally. Not unlike portfolio management, trading involves risks and returns, and therefore, observations of past returns of a trader alone cannot evaluate his ability. The model can describe the trader's bid-ask spread and his inventory management ability, identifying the main characteristics in market making performance. Therefore, the model may provide a more appropriate procedure to evaluate a trader's performance.

[13] The purpose of microstructure literature is clearly described in Garman [5].

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