Trade Direction in Order-driven Markets – Definition, Inference, and Evidence

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ABSTRACT

This paper proposes a new definition for trade direction to capture the information effect in order-driven markets. To define trade direction, the existing literature uses quote-matching rules to identify whether it is the buyer or the seller who initiates or triggers a trade. The quote-matching rule is well suited for a quote-driven market, but not so for an order-driven market. In a continuous auction and order-driven market, orders that are submitted based on information, but do not trigger a trade, will not be counted using the quote-matching rule. In a call auction order-driven market, one also cannot identify who triggers the trade, because the timing of order clearance does not depend on the arrival of any specific order.

To deal with these issues, we propose to define trade direction based on the sign of the net order arriving between the two transactions, that is, the relative size of the buy and sell orders. If the buy order arriving between the two transactions is larger than the sell order, we say the trade is buyer dominated and define the trade direction to be positive. Based on the new definition, we develop ATT (Augmented Tick Test) rules to infer the trade direction.

To examine the validity of this new trade direction, we apply our ATT rules to transaction data observed in the Paris Bourse and the Taiwan Stock Exchange and find that ATT rules have information content. Furthermore, using the ATT rule and quote-matching rule together allows us to decompose the trade-related return into permanent and temporary components. The ATT rule is better at capturing the permanent component, while the quote-matching rule is better at capturing the temporary component.

Keyword: Trade direction, net order, order-driven, quote-driven, continuous auction, call auction, transaction data

JEL: G15, G19

1. Introduction

This paper proposes a new definition of trade direction that can capture the information effect in an order-driven market. Trade direction plays an important role in the microstructure literature. It can be used to estimate the total effective bid-ask spread, to separate the inventory and information components of the spread, and to estimate the price impact of trade that can have implications on asset pricing (Brennan and Subrahmanyam, 1996; Glosten and Harris, 1988; Hasbrouck, 1988, 1991).

Trade direction classifies trades into buy or sell. In an economy with information asymmetry, investors learn about other investors' private information by observing how they trade. Hence, investors treat buy orders totally different from sell orders. Practically, it is not always possible to observe orders directly, and investors and researchers have to use observed prices to infer trade direction.

There are several quote-matching rules used in the literature to infer trade direction. Using NYSE data, Lee and Ready (1991) compare the transaction price with the average of the prevailing bid and ask quotes from specialists to define trade direction. De Jong, Nijman, and Röell (1995) use a similar rule to define trade direction when they studied the Paris Bourse and London SEAQ. In their study of Tokyo Stock Exchange data, Lehman and Modest (1994) define trade direction by matching the transaction price with bid and ask quotes from the order book.

Although not exactly the same, these definitions share one common attribute. They all decide trade direction by trying to identify which side initiates a trade or which side is the last order to arrive. If the seller arrives after the buyer, who can be the specialist or other investors submitting a limit order, we say the seller initiates the trade and the trade direction is negative. On the other hand, if the buyer arrives after the seller, we say the seller initiates the trade and the trade direction is negative.

Trading mechanisms in different exchanges are not the same. The NYSE has specialists who have the obligation to post quotes and trade with investors who may have private information. Therefore, it does matter whether the investor who is trading with the specialist is buying or selling. However, in a purely order-driven market like the Paris Bourse or the Tokyo Stock Exchange, there are no designated market makers and all quotes come from investors. Since both the buyer and the seller in a transaction may have private information, it is not appropriate to assume that the last trader will possess better information. Hence, the quote-matching rule may not be appropriate for a continuous order-driven market.

Another way to look at this is through the order type. If one side of the transaction is a market order, then the quote-matching rule will give the trade direction of the market order. For example, if the market order is a sell order, then it will be matched immediately with the best bid and the trade direction will be negative. As a result, unless we think informed traders only submit market orders, there is no reason to decide trade direction based on market orders.

It is even more difficult to justify the quote-matching rule in a call auction order-driven market. In a call auction market, buy and sell orders accumulate over a period and, when orders are cleared, everyone pays or gets the same price regardless of their quotes. Under this mechanism, it is neither possible nor meaningful to decide which order initiates the trade. Many markets operate at least partially as a call auction market. For example, the opening of the New York Stock Exchange and Tokyo Stock Exchange is a call market. Some other markets, for example, the fixing A group of the Paris Bourse, the Mexican Intermediate Market, the Taiwan Stock Exchange, and the Kuala Lumper Stock Exchange, always operate as call markets.

In this paper we propose a new definition for trade direction to be used in an order-driven market, whether it is a continuous or a call one. The definition is based on the sign of the net order arriving between two transactions. If the buy order arriving is larger than the sell order, then we say the trade is buyer dominated and define the trade direction to be positive. A larger buy order implies a higher probability that investors are receiving good news. On the other hand, a larger sell order implies a higher probability that investors are receiving bad news. The net order, however, can be positive or negative at different prices. We choose to evaluate the net order at the most recent transaction price, because that reflects the most recent information.

Since orders are not observable to investors, we cannot decide the net order directly. Section 2 presents rules to infer trade direction. The empirical measure of trade direction will depend on the information set available to investors. We consider two different information sets in our sample. The first one, which is available to investors in the Paris Bourse, includes the transaction price, the best bid and its depth, and the best ask and its depth after the transaction. The second information set, available to investors in the Taiwan Stock Exchange, is smaller and only includes the transaction price, the best bid, and the best ask price. With the first information set, investors can always unambiguously infer trade direction, but not with the second information set.

To compare the newly-defined trade direction with the traditional one, we estimate the temporary and permanent responses to a shock in the trade direction. If one measure of the trade direction captures the information component better than other measures, then it should have a larger permanent response. On the other hand, if one measure of the trade direction only captures the bid-ask bounce, then it should only have a temporary response and no permanent response. Section 3 introduces the empirical methodology used to estimate the permanent and temporary responses.

The rest of the paper applies our definition to the Paris Bourse and the Taiwan Stock Exchange data to check its empirical validity. Based on their 1998 year-end capitalization, the Paris Bourse ranked fifth and the Taiwan Stock Exchange ranked fourteenth in the world (International Finance Corporation, 1999). However, based on the trading value, the Paris Bourse ranked eighth while the Taiwan Stock Exchange ranked fifth in the world. On the intraday trading mechanism, the Paris Bourse is a continuous order-driven market while the Taiwan Stock Exchange is a call order-driven market. Section 4 will discuss the institutional details and describe the sample for both exchanges. Section 5 will present empirical results for the Paris sample and Section 6 will do so for the Taiwan sample. Section 7 will conclude.

2. Trade direction

We define trade direction based on the sign of the net order arriving between the two transactions. If the buy order is larger than the sell order, then we say the trade is buyer dominated and define the trade direction to be positive. If the sell order is larger, then we say the trade is seller dominated and define the direction to be negative. A larger buy order will imply a higher probability that investors are receiving good news and that should be taken into account by other investors to revise upward their expectation of the true value.

Defining trade direction by the net order between two transactions focuses our attention on decisions based on new information. New orders, however, can be tricky to identify. On the one hand, we can treat every existing order as new since investors can always withdraw their orders as they wish and an order not cancelled is equivalent to a new order. On the other hand, some investors do not revise orders as new information arrives. These investors will leave their orders, which are based on outdated information, on the book. If we only define trade direction based on newly-arrived orders (net of cancelled orders), then this might reflect new information better. In the following, we will pursue both approaches: treating all existing orders as new or only newly-arrived orders as new orders.

The net order can be positive or negative at different prices. At higher prices, sell orders will be greater than buy orders and vice versa. Which price should we choose to evaluate the net order? A natural candidate is the most recent transaction price (P_{t-1}), because that reflects the most recent public information available to investors who submit orders after observing that transaction. The net order at P_{t-1} is the sum of buy orders which are willing to pay at least P_{t-1} minus the sum of sell orders asking at most P_{t-1}. Although intuitively appealing, there is no theoretical justification to evaluate the net order at P_{t-1} and future research is needed.

Usually we do not observe orders directly and, to infer trade direction, we have to use information available to investors. This paper derives the rule used to infer trade direction based on two different information sets. The first information set, which is available to investors in the Paris Bourse, includes the transaction price, the best bid, the best ask, and the associated order size out of the order book immediately after the transaction. The second information set, which is available to investors in the Taiwan Stock Exchange, is smaller and only includes the transaction price, the best bid, and the best ask.

2.1. All existing orders are new orders

We will first assume that all existing orders are new orders. Another interpretation is that the last transaction clears all existing orders and the order book becomes empty. Therefore, only orders arriving after the last transaction will decide the next price.

To derive the rule, we first describe the setting of an auction market at time t. Suppose the demand schedule D(P) gives the number of shares investors are willing to buy, while the supply schedule S(P) gives the number of shares investors are willing to sell at price P. The transaction price P_t is the price that can maximize the trading volume Q_t subject to demand and supply.[1] After the transaction, the best bid (B_t) is the highest bid price from unfilled buy orders; the best ask (A_t) is the lowest ask price from unfilled sell orders.

Taking Figure 1 as an example, there are only four possible prices (P_1 to P_4) at which buyers and sellers are willing to trade. Demand and supply intersects at P_3. Therefore, the transaction price P_t will be P_3 and the maximum shares that can be traded at this price is Q_t. At the transaction price, all buy orders that are willing to pay P_3 have been filled, but there are orders left unfilled that are willing to sell at P_3. Hence, the best bid B_t is P_2 and the best ask A_t is just the transaction price P_3.

If the last transaction price P_{t-1} is lower than P_3, then the net order at P_{t-1} must be positive and the trade direction is positive. On the other hand, if the last transaction price P_{t-1} is higher than P_3, then the net order at P_{t-1} must be negative and the trade direction is negative.

If the last transaction price P_{t-1} is equal to P_3, then the net order at P_{t-1} can be positive or negative. Given the best bid and ask, we can still decide trade direction. For example, in Figure 1 when the transaction price equals the best ask, there are sell orders left on the book. Therefore, the net order at P_3 is negative and the trade direction is negative. However, in Figure 2 the net order at the transaction price P_3 is positive and the trade direction is positive. One thing to notice in Figure 2 is that there

[1] If there are multiple prices that will give the same trading volume, then the exchange rule will decide the transaction price. For example, the Paris Bourse uses a continuous auction during the day. The new order will be matched with orders on the book, and the transaction price will be the price placed on the order in the book. On the other hand, the Taiwan Stock Exchange requires the transaction price to be the one closest to the last transaction price.

are orders willing to buy at the transaction price P3 that are left unfilled. Therefore, the best bid B_t equals the transaction price.

It is also possible that the net order is zero. In Figure 3 the last transaction price is equal to the current transaction price P_3. At the same time, all buy and sell orders willing to trade at P_3 are matched, the best ask is P_4, and the best bid is P_2. As a result, the net order is zero and the trade direction is zero.

To summarize, we have rule ATT1 (Augmented Tick Test 1) as follows.[2]

Rule ATT1:

(1). If the current transaction price is higher than the previous price (uptick), then the current transaction is buyer dominated and the trade direction is positive.

(2). If the current transaction price is lower than the previous price (downtick), then it is seller dominated and the trade direction is negative.

(3). If the current transaction price is equal to the previous price, then the trade direction depends on the best bid and best ask as follows.

(3.1). If the transaction price equals the best bid, then the trade direction is positive.

(3.2). If the transaction price equals the best ask, then the trade direction is negative.

(3.3). If the transaction price falls between the best bid and best ask, then we cannot define the trade direction.

2.2. Only newly-arrived orders are new orders

In deriving the rule ATT1, we assume all existing orders are new, because investors can always choose to cancel their earlier orders when new information arrives. In reality, all investors do not revise their orders continuously. Some investors will leave their orders on the book even when new information suggests they should

[2] This rule can be seen as an extension of the tick test, which only checks an uptick or downtick of the price movement. That is why we call it the Augmented Tick Test.

cancel it. Therefore, in this part we will define trade direction based only on newly-arrived orders (net of cancelled orders) after the last transaction.

When we need to separate newly-arrived orders from stale orders, it becomes more complicated to infer trade direction. For example, in Figure 2 if P_3 is the last transaction price, the current transaction price, the last best bid, and the current best bid, can we still infer the trade direction to be positive?

The answer is no. When the best bid is P_3 at the last transaction, there are buy orders at P_3 left on the book. The trade direction will depend on the relative size of the remaining buy orders at the last and the current transactions. For example, if the number of buy orders left on the book at the last transaction is 500 shares and the number left at the current transaction is 600 shares, then buy orders arriving during this interval must be more than sell orders, and the trade direction is positive. On the other hand, if the number of buy orders left at the last auction is 700 shares instead of 500, then buy orders arriving during this interval is less than sell orders, and the trade direction is negative. Therefore, in this case we can infer the trade direction unambiguously only if investors have information on the order size at the best bid.

In other cases it is possible to decide the trade direction without knowing the order size. When the best bid is lower than the transaction price P_3 at the last auction, it must mean that there was no buy orders left on the book at P_3 after the last transaction. Nevertheless, there is buy orders left at P_3 after the current transaction, because the current best bid is P_3. Therefore, the newly-arrived buy orders must be greater than sell orders at P_3 and the trade direction is positive.

Similar logic gives us rule ATT2.

Rule ATT2:

(1). If the current transaction price is higher than the previous price (uptick), then the current transaction is buyer dominated and the trade direction is positive.

(2). If the current transaction price is lower than the previous price (downtick), then the current transaction is seller dominated and the trade direction is negative.

(3). If the current transaction price is equal to the previous price, then the trade direction is determined by the rule listed in Table 1. The trade direction will depend on the relation between the transaction price, the best bid, and best ask as well as their order size.

2.3. An example: The trade direction of a market order in a continuous auction market

After presenting two new rules to infer the net order or trade direction, we would like to compare them directly with the traditionally-used quote-matching rule (Q measure). To simplify matters, we will make the comparison for a market buy order of S shares in a continuous auction market such as the Paris Bourse. Table 2 lists all possible scenarios.

In counting net orders evaluated at the last transaction price (P_{t-1}), the relevant orders include all market orders, limit buy orders with a limit price no less than P_{t-1}, and limit sell orders with a price no higher than P_{t-1}. As a result, the trade direction depends on P_{t-1} and we will first examine the case where P_{t-1} equals the last best bid (B_{t-1}). If the market order is the only relevant order arriving after the last transaction, then the buy order will be matched against the best ask on the book (A_{t-1}).[3] Therefore, the current transaction price P_t cannot be less than A_{t-1} and will be greater than P_{t-1}. Both ATT1 and ATT2 will identify the trade direction to be positive, as will the Q measure.

If there is any relevant limit orders arriving before the market order and they did not trigger a transaction, then they must be buy orders with a limit price between B_{t-1}

(inclusive) and A_{t-1}. These buy orders will raise the best bid on the book, but will not affect the transaction price when the market buy order arrives. Both ATT measures will still identify the trade direction to be positive.

When the last transaction price is equal to the last best ask (A_{t-1}), ATT measures and the Q measure will give different results. If the market order is the only relevant order arriving and its size (S) is greater than the depth at the best ask $S_{A,t-1}$, then the transaction price will be decided by the trading rule of the exchange.[4] In the Paris Bourse, the market order cannot walk up the book.[5] After matching with the best ask A_{t-1}, any excess will be posted as a limit buy order with the bid price equal to A_{t-1}. Hence, the transaction price P_t will be equal to A_{t-1}, which is also the best bid after the transaction (B_t). Although the price does not change, according to rules ATT1 and ATT2, both ATT measures will still identify the trade direction to be positive.

If the market order is the only relevant order arriving and its size S is less than the depth at the best ask $S_{A,t-1}$, then the transaction price P_t will be A_{t-1}, which will also be the best ask after the transaction A_t. Since the depth at the best ask becomes smaller after the transaction, ATT2 will identify trade direction to be positive. In contrast, ATT1 will identify trade direction to be negative, because P_t equals to A_t. The difference between the two measures is that in ATT1 we assume any orders, including the sell orders represented by the best ask, left on the book are based on the most current information. Since the sell order at A_{t-1} is larger than the market buy order, ATT1 presumes that investors are more likely to have bad information. For the ATT2 measure, we assume the sell order at A_{t-1} is based on outdated information and

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[3] We use the subscript t-1 to make clear that A_{t-1} is the best ask after the transaction at t-1.
[4] To simplify matters, we will not discuss the possibility that the order size is exactly the same as the depth, but will list its result in Table 2.
[5] In some exchanges, a market order can walk up the book, that is, after matching with the best ask, the remaining buy order will be matched with the next best ask, and so on. The transaction price will then be higher than A_{t-1}. Since the price goes up, both ATT measures will identify trade direction to be positive.

only count the market buy order to decide trade direction. As for the Q measure, in a quote-driven market the quote comes from market makers who have no private information by assumption. Therefore, the Q measure only counts the market buy order, which might come from an informed investor, to decide the trade direction.

When P_{t-1} equals A_{t-1}, if there is any relevant limit orders arriving before the market order that do not trigger a transaction, then they must be sell orders with a limit price between B_{t-1} and A_{t-1}(inclusive). If these new limit orders are asking a price le ss than A_{t-1}, then they will be the first ones to match with the incoming market buy order.[6] The transaction price will then be less than A_{t-1} and both ATT measures will identify a negative trade direction.

To summarize, in a continuous auction market and a market order triggering a transaction, both ATT measures can give a trade direction different from the Q measure. The difference between ATT1 and Q is greater than the difference between ATT2 and Q. The difference is especially apparent when new limit orders arrived before the market order. The difference also has a particular pattern. For a market buy order, ATT measures tend to give a negative trade direction only when the last transaction price equals the best ask. The same logic implies that, for a market sell order, ATT measures tend to give a positive trade direction only when the last transaction price equals the best bid.

3. Methodology

To compare the ATT measure proposed here with the traditionally-used Q measure constructed from the quote-matching rule, we examine the permanent and temporary responses to a shock in the trade direction. Based on our earlier argument,

[6] The new limit order can also be asking a price at A_{t-1}. In this more complicated case, trade direction will depend on the relative size of the market order, the new limit order, and the existing limit orders.

ATT measures should capture the information component better and therefore should generate a larger permanent component.

If the transaction price only reflects new information, then its change will be permanent. In equation (3) the permanent change was decomposed into two parts: one is related to a trade (□O_t), and the other is not (v_t).

$$P_t - P_{t-1} = v_t + \hat{a}\, O_t \,. \qquad (1)$$

The transaction price includes not only the permanent information component, but it also has a temporary component that reflects the bounce between bid and ask quotes. In a continuous auction market such as the Paris Bourse, the transaction price can be equal to the existing bid if the incoming order is a sell or be equal to the asking price if the incoming order is a buy. If we denote the average of the existing bid and ask as P^*, then the transaction price P can be expressed as follows,

$$P_t = P_t^* + \frac{s}{2} O_t \,,\text{[7]} \qquad (2)$$

where O_t is the trade direction at time t, which equals 1 if the incoming order is a buy and equals -1 if the incoming order is a sell. The effective spread is denoted as s, which is also the difference between the best ask and the best bid.

To express the relation into the difference, the observed return contains a moving average component arising from the bid-ask bounce as the following.

$$P_t - P_{t-1} = P_t^* - P_{t-1}^* + \frac{s}{2} O_t - \frac{s}{2} O_{t-1} = \frac{s}{2} O_t - \frac{s}{2} O_{t-1} \,.\text{[8]} \qquad (3)$$

The coefficients on the current and lagged trade-direction variable have an opposite sign, but are equal in magnitude. A buy order will increase the current transaction price, but will not affect the future transaction price. In terms of returns, a buy order will increase the current return, but the increase will be reversed

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Table 2 gives the detail.
[7] All prices are expressed in logarithmic form.
[8] Assume the bid-ask average does not change.

immediately.

Combining both transitory and permanent components, the change in transaction price can be modeled as in equation (4),

$$P_t - P_{t\text{-}1} = v_t + \hat{a}\ O_t + \frac{s}{2} O_t - \frac{s}{2} O_{t\text{-}1} \qquad (4)$$

In equation (4) the coefficient on O_t is positive and the coefficient on O_{t-1} is negative. If the trade variable O_t is uncorrelated over time, then one can use coefficients on the current and lagged trade-direction variable (O_t) to decide the relative importance of the permanent and temporary responses to a shock from O_t. If there is only a temporary component, then the sum of the coefficients on O_t and O_{t-1} will be zero. If there is only a permanent component, then the coefficient on O_t will be positive and the coefficient on O_{t-1} will be zero. When both permanent and temporary components are present, the ratio of the absolute value of the coefficient on O_{t-1} relative to the coefficient on O_t will measure the relative importance of the temporary component.

This method will fail if v_t or O_t is autocorrelated or cross-autocorrelated. The return can be autocorrelated when the market has frictions such as transaction cost or price discreteness. Investors indeed may not react to information instantaneously, because the gain is not large enough to cover the transaction cost, or because they just need some time to absorb the information, or because they need to observe other people's behavior to learn the value implication. To deal with these complications, Hasbrouck (1991a, 1991b) propose a VAR (Vector Autoregression) approach.

Assume that return (R_t) and the trade-direction variable (O_t) follow a bivariate VAR(1) process:

$$R_t = \square_1 + \square_{02}\, O_t + \square_{11} R_{t\text{-}1} + \square_{12}\, O_{t\text{-}1} + v_{1t}$$

$$O_t = \square_2 + \square_{21} R_{t\text{-}1} + \square_{22}\, O_{t\text{-}1} + v_{2t}. \qquad (5)$$

The system includes the contemporaneous O_t in the R_t regression, but not vice versa, because orders decide the price, not the other way around. The VAR(1) process can be expressed in the vector and matrix form.

$$A_0 X_t = \alpha + A_1 X_{t-1} + v_t, \qquad (6)$$

where $X_t = \begin{bmatrix} R_t \\ O_t \end{bmatrix}, v_t = \begin{bmatrix} v_{1t} \\ v_{2t} \end{bmatrix}, \alpha = \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix}, A_0 = \left(I - \begin{bmatrix} 0 & \beta_{02} \\ 0 & 0 \end{bmatrix} \right), A_1 = \begin{bmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \end{bmatrix}.$

To measure the permanent and temporary responses, Hasbrouck uses the MA representation for the VAR process and estimates the impulse response function of v_{2t}. The MA representation expresses the dependent variable vector X_t as the infinite sum of the innovation vector v_t.

$$X_t = \square + \Psi_0 v_t + \Psi_1 v_{t-1} + \Psi_2 v_{t-2} + \ldots,$$

$$\text{where } \O_0 = A_0^{-1}, \O_i = A_0^{-1} A_1 \O_{i-1}, \text{ for } i = 1,2,\cdots. \qquad (7)$$

The number in row one and column two of the matrix Ψ_i ($\Psi_{i,12}$) measures the response of return at time t+i to a one-time shock in the trade variable at time t. The permanent response of the shock on the price is the infinite sum of responses from time t, $\sum_{i=0}^{\infty} \Psi_{i,12}$. The temporary response is the immediate response $\Psi_{0,12}$ minus the permanent response.

We can also interpret the temporary and permanent responses in terms of the transaction cost (Glosten and Harris, 1988; Hasbrouck, 1991; De Jong, Nijman, and Röell; 1996). The temporary response is the effective spread, or the transaction cost associated with the spread or bid-ask bounce. The permanent response is the transaction cost associated with information revealed by the trade.

4. Sample description

4.1.The Paris Bourse

By the end of 1998, the Paris Bourse (SBF) had 711 listed companies with a market capitalization of U.S.$991.5 billion, the fifth largest exchange in the world. In 1998, the total value traded was U.S.$572 billion, eighth in the world (International Finance Corporation, 1999). The exchange itself is fully computerized and is an order-driven market. Investors can submit market orders and limit orders. Orders start to accumulate from 8:30 a.m. and unexecuted orders will remain on the book until cancelled or go beyond the date specified in advance.

During the sample period, trading occurs from 10 a.m. to 5:05 p.m. Monday to Friday. Trading on the SBF involves two mechanisms: a periodic call auction used to open and close trading and a continuous auction used throughout the day. Price and time of orders decide the priority of the order execution.

To maintain price continuity, there is an intraday and daily price limit in the SBF. For shares in our sample, price changes are limited to –10% to 10% from the previous day's closing initially, followed by the range –5% to 5% for at most twice during the day. Therefore, the daily limit is –18.775% and 21.275%. When each limit is hit, trading is halted for 15 minutes.

The SBF disseminates information on the trade, the five best asks and bids to the public. However, the disclosed order may not reveal the true one on the book. In the SBF, investors can choose to hide a fraction of their limit orders from other traders (hidden order). The invisible fraction of the order retains its price priority, but not time priority. After the disclosed fraction is fully executed, another portion of the invisible order becomes visible.[9]

[9] Biais, Hillion, and Spatt (1995) gives a detailed description of the hidden order.

Our sample includes all intraday transactions for the 40 stocks included in the CAC40 index from June 1 to 30, 1999. The sample only includes transactions during the day, and does not include the daily opening and close. If several transactions are recorded at the same time (to the second), then we only use the last price.[10] The total number of observations is 570,756. For cross stocks, the number of observation ranges from 5,001 to 44,425, while the median number is 11,716. More than 40% of transactions have a time interval less than 10 seconds, and the median is 14 seconds. Although trading occurs very frequently, the trading volume per transaction is low.[11] The median number of shares traded is only 100.

4.2.Taiwan Stock Exchange

By the end of 1998, the Taiwan Stock Exchange (TSE) had 437 listed companies with a market capitalization of U.S.$260 billion, fourteenth largest in the world. What distinguishes Taiwan from other exchanges is that it has the highest turnover in the world. The turnover was 323% in 1998, which made the value traded in that year to be U.S.$884.7 billion, ranking fifth in the world (International Finance Corporation, 1999).[12]

There is no market maker in the TSE. The exchange is fully computerized and is an order-driven market. All orders are limit orders. Orders start to accumulate from 8:30 a.m. and unexecuted orders remain on the book until the end of the day.

During our sample period, trading occurs from 9 a.m. to 12 p.m. Monday to Friday and from 9 a.m. to 11:00 a.m. on Saturday. Trading on the TSE involves two mechanisms: a periodic call auction used to open trading and a batch call auction used

[10] The reason we use time rather than order to divide the sample is that the data d oes not allow us to distinguish whether these transactions come from the same order or from different orders.
[11] If several transactions are recorded at the same time, then the volume used is their sum.
[12] In 1998, the turnover is 106% for the U.S and 40% for Japan.

throughout the day. In either a periodic or a batch auction, orders accumulate and the computer sets a single market-transaction price at which all executed orders transact. Price and time of orders decide the priority of the order execution.

The electronic trading system of the TSE contains several terminals. In general, one terminal handles the trading of 12 to 16 stocks. The principle in allocating stocks to terminals is to smooth the computer workload and to give equal trading opportunity for different terminals. Therefore, each terminal handles both high and low volume stocks. There are many trading cycles in a given day. In one trading cycle, the terminal sequentially clears orders of the stock it handles. Each cycle lasts 40 to 100 seconds. In one trading cycle, in principle, all stocks will be cleared at least once, but active stocks can be cleared twice. For each stock, after the first clearing, the terminal will wait for 4 seconds, and then clear the stock again if there are any new orders submitted during this waiting period. Therefore, the timing of each call auction is random.

To maintain price continuity, there are two types of price limit in the TSE: daily and intraday price limit. No transaction price can occur beyond the limit. The daily price limit is 7% above or below the previous day's closing price. The intraday price limit is two ticks above or below the reference price.[13] The tick size in the TSE is a function of the price level. When the price level is between NT$5 and NT$15, the tick size is NT$0.05. When the price is between NT$15 (50) and NT$50 (150), the tick size becomes NT$0.1 (0.5).

The sample includes all intraday transactions for the 40 stocks with the largest market capitalization at the end of 1996. The sample period is June 1997. There are 194,014 observations, where 52% of transactions have a time interval between 40 and 80 seconds and 35% are less than 10 seconds. Therefore, although structured as a call market, the auction in the TSE is almost continuous.

5. Empirical results for the Paris sample

5.1. Basic results

Table 3 provides the summary statistics of return and three different measures of trade direction. The continuously-compounded return has a mean near zero and a standard deviation of 0.15%. The return is negatively autocorrelated at lag 1, but has no autocorrelation beyond the first lag. All three measures of trade direction have a weak, but persistent autocorrelation, and they are positively correlated with the return and with one another. The highest correlation 0.73 occurs between Q and ATT2, as ATT1 is only weakly correlated with the other two measures: 0.33 with ATT2 and 0.05 with Q.

To compare the performance of the three measures of trade direction, we first run a simple regression of returns against the current and lagged trade-direction variable as in equation (4). The coefficient on the current trade direction measures the immediate response, and the sum of coefficients measures the permanent response. Table 4 presents OLS estimates. The immediate response is very similar across different measures of trade direction: 0.084 for Q, 0.082 for ATT1, and 0.08 for ATT2. The difference between the three measures lies in the relative importance of the temporary and permanent components. Most of the response captured by the traditional measure Q is temporary. Out of the immediate response 0.084, 0.066 (78.6%) are reversed at the next transaction. In contrast, the ATT1 measure has the smallest temporary component. Out of the immediate response 0.082, only 0.016 (19.5%) are reversed at the next transaction. The measure ATT2 lies in between, with

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[13] Generally, the reference price is the transaction price.

a 43.8% temporary component. Therefore, the evidence is consistent with our claim that ATT measures can identify the information component better than the Q measure in order-driven markets.

The simple regression captures a significant proportion of return variation. The R^2 for the Q measure regression is 0.41, the highest among the three. The lowest R^2 is 0.30, which occurs for the ATT1 measure. The ranking for the R^2 is just opposite to the ranking for the temporary component. Apparently, the temporary component is an important element in modeling intraday returns.

A simple regression cannot capture the rich dynamics between return and the trade direction and provides biased estimates. To better capture the dynamics, we estimate a bivariate vector autoregression model (VAR, equation (5)) and its impulse response function (equation (7)).

Table 5 reports the estimated VAR(1) model. Although trade direction introduces a moving average component into returns, it is not enough to capture all the autocorrelation in returns. For the return equation, the coefficient on the lagged return is between –0.25 and –0.30. These numbers are less negative than the first autocorrelation coefficient (–0.38) found in Table 3, because the trade variable also captures some autocorrelation. Adding the lagged return term, however, does not improve the R^2 too much. For example, using the Q measure, the R^2 is 0.41 without the lagged return term and is 0.46 with it.

For the trade direction equation, we find that the trade direction is negatively correlated with the lagged return. There are two possible and nonexclusive explanations for this evidence. First, it reflects the bid-ask bounce. Given that the last transaction is triggered by the buy side, which makes the last return be positive, the current transaction will more likely come from the sell side. The other explanation is that it reflects the definition of the net order. We showed in Table 2 that both ATT measures tend to give a negative trade direction if the last transaction price is equal to the best ask, which makes the last return more likely to be positive.

Regarding the relative importance of temporary and permanent responses, evidence in Table 5 suggests that the ATT1 measure has the largest permanent response and that the Q measure has the largest temporary response. The immediate response to a shock in the trade direction is just the coefficient on the current trade variable. The immediate response is positive for all measures and the strongest one occurs for the Q measure (0.081). Out of the immediate response, only some will be permanent. The estimated permanent response is the cumulative response of returns from time t to t+10 given a shock at time t of trade direction. The choice of 10 periods is arbitrary, but justified empirically, because the cumulative response function levels off quickly.

The permanent response is positive for all three measures, suggesting that all measures can capture information. The largest permanent response is 0.072 for the ATT1 measure, about half of the standard deviation of returns. There is no reversal for the ATT1 measure, because the coefficient on the lagged ATT1 is positive. The largest temporary response comes from the Q measure, where 57% of the immediate response is reversed afterwards. Therefore, the Q measure mainly captures the bid-ask bounce and the ATT measures capture the information effect. In defining trade direction, the Q measure only relies on the last order arrived, while the ATT measures also consider orders on the book. Therefore, the evidence suggests that orders on the book have information content.

Given that all three measures contain information, the next step is to examine whether the in formation contained in the Q measure is a substitute or a complement to either the ATT1 or ATT2 measure. We estimate a trivariate VAR(1) process with the return, Q measure, and ATT1 or ATT2 as dependent variables. The estimates are reported in Table 6.

The estimates show that almost all of the information components contained in the Q measure are contained in either one of the ATT measures, but not vice versa. In Table 6, the permanent response of the cumulative return to a shock of the measure Q is almost zero. The permanent response is 0.013 (17.3% of the immediate response) when the ATT1 measure is included and is 0.001 (1.9% of the immediate response) when ATT2 is included. In contrast, the permanent response to a shock from either one of the ATT measures is much larger. The permanent response to a shock of ATT1 is 0.066 and the response to a shock of ATT2 is 0.044. Therefore, both ATT measures are better than Q in capturing information.

Holding the Q measure constant, the temporary response from both ATT measures is negative. A negative temporary response means that there is a lagged response to a shock in ATT measures. The lagged response to an ATT1 shock is three times larger than the lagged response to an ATT2 shock.

To compare the performance between ATT1 and ATT2, ATT1 is better in capturing information. In terms of the R^2 of the return equation, using ATT1 gives a higher R^2 (0.567) than using ATT2 (0.491). Using ATT1 rather than ATT2 in the VAR process also identifies a stronger permanent response. The permanent response is 0.066 for ATT1 and is 0.044 for ATT2. Since the permanent response from Q is practically zero (0.001) when used with ATT2, but is positive (0.013) when used with ATT1, Q is thus complementary to ATT1 in capturing the information component. Furthermore, given Q and ATT1, ATT2 does not add additional explanatory power. The adjusted R^2 only increases from 0.567 to 0.573 when all three measures are included in the return equation.

By definition, ATT1 counts orders left on the book right after the last transaction and all the changes (new and cancelled orders) between transactions in order to decide the trade direction of the current transaction. ATT2, on the other hand, only considers changes during transactions to decide the trade direction. The better performance of the ATT1 measure in capturing information suggests that non-cancelled orders can provide new information into prices rather than only reflect outdated information.

The estimates in Table 6 can also provide an estimate for the transaction cost of a market buy order. Given that the market order is the only relevant order arriving, its transaction cost will be a function of the last transaction price and the order size submitted relative to the depth on the book. If the last transaction price is less than the best ask or the order submitted is greater than the depth, then both Q and ATT1 are equal to +1 (see Table 2). The expected total transaction cost will be 0.126%: 0.047% is temporary and 0.079% is due to the information revealed. On the other hand, if the last transaction price equals the best ask and the order submitted is less than the depth, then Q equals +1, but ATT1 is equal to –1. The expected total transaction cost will only be 0.024%: 0.077% is temporary and –0.053% is due to information. To fully explore the implication of this model on the transaction cost, of course, requires future research. Nevertheless, under this model it is certain that the transaction cost is not fixed, rather, it depends on the state of the price history and the order size submitted.

5.2.Further results

We have shown that both ATT1 and ATT2 measures can capture the information component better than the Q measure.

Choice of the lag of VAR

The discussions so far have been based on estimates from a VAR(1) model. The common practice in estimating a VAR model is to use some information criteria, for example, the Akaike Information criterion (AIC), to decide the best lag to use. Our sample, however, is so large that we choose an extremely large lag by using the AIC.

We instead show that estimates of the permanent and temporary responses are not sensitive to the choice of the lag.

Figure 4 plots the cumulative returns in response to a shock in trade direction variable. The cumulative response is estimated from a trivariate VAR model with the lag ranging from 1 to 5. The dependent variable used in the VAR model is the return, the Q measure, and ATT1 or ATT2. Qualitatively, the results are very similar across different lags. Therefore, changing the lag of the VAR process will not change the fact that both ATT1 and ATT2 measure the information component better than the Q measure.

Individual stocks

The results reported so far are based on a sample that includes both cross-sectional and time-series data. To examine whether results are similar across stocks, we also estimate the VAR process separately for each stock and summarize the estimated permanent and temporary response in Table 7.

For each and every individual stock, the Q measure captures the temporary response while the ATT measures capture the permanent response. Out of the immediate response to a shock of Q, the minimum proportion of temporary response is 58%. In contrast, out of the immediate response to a shock of ATT1 or ATT2, the minimum percentage due to the permanent response is 90%.

If we examine the combined response from Q and ATT, then it is also true that most of the temporary response comes from Q, and most of the permanent response comes from the ATT measures. For each and every stock, more than 90% of the temporary response comes from the Q measure, but the Q measure is only responsible for less than 40% of the permanent response.

Tick test

We have shown in section 2 that both the ATT1 and ATT2 measures can be viewed as an extension of the tick test used in the literature (Aitken and Frino, 1996; Finucane, 2000; Hasbrouck, 1988).[14] To appreciate the usefulness of the ATT measures, we need to show that there is explanatory power beyond the tick test. Accordingly, we define three new variables. The first variable TT is defined according to the tick test: it equals 1 if the price goes up, 0 if the price remains the same, and –1 if the price goes down. The second variable, RATT1 (Residual ATT1), is the difference between ATT1 and TT. The third variable, RATT2 (Residual ATT2), is the difference between ATT2 and TT.

Figure 5 plots the cumulative response function calculated from an estimated trivariate VAR(5) process. The variables included in the VAR are returns, TT, and RATT1 or RATT2. The tick test measure (TT) gives the strongest result: the immediate response is 0.14%, 0.06% are reversed and the permanent response is 0.08%. Apparently, most of the explanatory power of both ATT measures come from TT. After removing the effect from TT, the residual ATT2 offers very little additional impact. Neither the immediate response nor the permanent response exceeds 0.01%.

In contrast, the residual ATT1 offers a significant permanent response, but only with a lag. This explains the negative temporary response for ATT1 observed in Table 6. The immediate response from the residual ATT1 is –0.01%, but the permanent response is 0.04%. The reason that the residual ATT1 only has a lagged impact has to do with the its definition. Being the difference between ATT1 and TT, the residual ATT1 is non-zero only when the price remains the same. Therefore, by definition, there can be no contemporaneous correlation between returns and the residual ATT1.

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[14] When the price goes up or down, both ATT measures will give the same trade direction as the tick test.

Nevertheless, a positive residual ATT1 means a positive net order, which means that investors have good information. The good information, although not strong enough to move the price immediately, will be reflected in the following transactions and provides the additional explanatory beyond the simple tick test.

Signed volume

Trade direction is often used to sign the volume in the literature. The signed volume can be used to estimate the market depth and the extent of information asymmetry. Brennan and Subrahmanyam (1996) use the estimated market depth as a liquidity measure and examine its cross-sectional relation with asset returns.

To examine the explanatory power of the signed volume, we run a 5-variable VAR system, which includes return, Q, ATT, Q-signed volume, and ATT-signed volume. To make the coefficient on the signed volume easier to interpret, the volume used is the standardized logarithmic volume where the standardization is taken separately for each stock using its own standard deviation in the sample. Therefore, the unit of the signed volume is one standard deviation, which is similar to the unit of trade direction variable and will make comparison comparable.[15] Table 8 presents the estimated VAR system. The signed volume does not add any additional explanatory power for return. Using ATT1 as the measure, the R^2 of the return regression in the 3-variable VAR system is 0.567 and is 0.568 in the 5-variable VAR system.

As for the coefficients of the trade direction, the magnitude is smaller in the 5-variable system than in the 3-variable system. Part of the explanatory power of the trade-direction variable shifts to the signed volume variables. Nonetheless, the coefficient on the signed volume is much smaller in magnitude than the coefficient of the trade direction. For example, the current ATT1 coefficient is 0.051 in the

[15] From Table 3, we can see that the standard deviations of all trade direction variables are close to 1. Therefore, we can also treat trade direction variables as standardized ones.

3-variable system and falls to 0.043 in the 5-variable system. On the other hand, the coefficient on the signed volume using ATT1 is only 0.003, less than one-tenth of the coefficient on ATT1.[16] As a result, both permanent and temporary responses to a shock of the signed volume are much smaller than responses to a shock of trade direction.

A larger response to trade direction means that most of the transaction costs faced by investors are fixed costs, not a function of the trading volume. A large fixed cost for transaction will suggest that it is not worthwhile for investors to split orders.

The permanent responses to a shock of the signed volume are all positive. The permanent response is larger when Q is used than when ATT is used to sign the volume. The reason is that ATT measures represent the net order, whereas the Q measure represents the last order to arrive. Therefore, the signed volume using Q measures the size of the last order precisely, but the signed volume using ATT cannot measure the size of the net order.

6. Empirical results for the Taiwan sample

Table 9 provides the summary statistics of return and three different measures of trade direction of the Taiwan sample. In addition to measure ATT1 and ATT2 introduced in this paper, we also calculate measure Q. Since Taiwan is a call auction market, the Q measure in Taiwan does not have the same meaning as in Paris, which is a continuous auction market. In a call auction market, orders are cumulated over a time interval in order to get cleared. The transaction price is not required to be the price previously posted on the book. As a result, the Q measure in Taiwan does not have a clear meaning and we use it here only as a benchmark. Both the Q and ATT1

[16] Although the coefficient is small in magnitude, it is still statistically significant due to a very large sample size.

measures of trade direction are weakly, positively autocorrelated. The ATT2 measure is positively correlated with the other two measures (the correlation is 0.63 and 0.65). In contrast, the correlation between Q and ATT1 is weakly negative (-0.15).

Table 10 reports estimates for the bivariate VAR(1) model (equation (5)). The signs of coefficients in the Taiwan sample are exactly the same as the signs in the Paris sample, but the magnitude is generally larger in Taiwan. The larger magnitude may reflect the difference between a call and continuous auction or reflect the difference in the relative tick size. In deciding the transaction price, there are more orders involved in a call auction compared with a continuous auction. A larger number of orders will increase the precision of the information content and will increase the price impact (Garbade and Silber, 1979). For the same price change in the unit of ticks, a larger relative tick size will also increase the variability of returns. The relative tick size is larger in Taiwan than in Paris. If the stock price is between 15 and 50 in its own currency, then the tick size will be 0.1 in Taiwan and 0.01 in Paris. Given that more than 90% of all the price changes in our Taiwan sample are zero or one tick, the larger magnitude of coefficients in Taiwan is due to its larger relative tick size.

In comparing different trade measures, we find that measure ATT2 stimulates the largest immediate and permanent responses. It also produces the highest R^2 in the return regression. The differences are significant. For example, the R^2 in the return regression is 0.73 using ATT2, 0.58 using Q, and 0.37 using ATT1. The permanent response is 0.33% using ATT2, 0.23% using ATT1, and 0.09% using Q. The superior performance by ATT2 is even more significant given that ATT2 is measured with error in Taiwan. The measurement error exists because the exchange does not disclose the depth at the best bid and ask (see Table 1).

In the Paris sample measure ATT1 stimulates the largest permanent response. The difference between Paris and Taiwan is due to their trading mechanisms. In Paris the number of newly-arrived orders between two transactions is small, because the exchange uses a continuous auction. A small number of orders will reduce the information content conveyed in the measure ATT2. However, in Taiwan the number of newly-arrived orders between two transactions is relatively large, because the exchange uses a call auction. A large number of orders will increase the information content conveyed in the measure ATT2.

We also find that the Q measure produces the largest temporary response out of the three measures in Table 10. The temporary response is 0.14%, which is 61% of the immediate response. Therefore, although the Q measure does not have a clear economic meaning in a call auction market, it still captures the temporary response better than ATT measures.

To examine the complementarity of the Q measure and ATT measures, we also estimate a trivariate VAR process using return, Q, and one of the ATT measures as dependent variables. Figure 6 reports the cumulative responses calculated from the estimated coefficients. Similar to the bivariate model reported in Table 10, the estimated trivariate model also shows that the Q measure captures the temporary component while the ATT measure captures the permanent component.

To further appreciate the ATT measure, we decompose them into the tick test (TT) measure and the residual ATT (RATT) measure. Figure 7 reports the cumulative response calculated from the estimated trivariate VAR(5) process using return, TT, and either one of the RATT measures as dependent variables. Given its definition that RATT is not zero only when the contemporaneous return is zero, the response to a RATT shock lags one period. The permanent response to a shock of residual ATT1 is 0.12% and is 0.27% to a shock of residual ATT2. In comparison, the permanent response to a shock of TT is 0.31% or 0.23% when RATT1 or RATT2 is included in the VAR process respectively. Therefore, the permanent response to either the RATT1 or RATT2 measure is important, supporting our argument that the net order evaluated at the last transaction price conveys important information and should be used as a measure of trade direction.

7. Conclusion

This paper proposes a new definition of trade direction to capture the information effect in an order-driven market. We argue that, due to a different trading mechanism, one should use the net order evaluated at the last transaction price as a new definition of trade direction. By using the net order, this new definition takes into account all relevant orders submitted between two transactions rather than only considering the last order arriving.

Based on the new definition, we derive two ATT measures that can infer the net order only using public information. The ATT measures are not substitute to the commonly-used quote-matching measure; they are complement. The evidence from Paris and Taiwan suggests that the quote-matching measure can better capture the temporary component while our ATT measures can better capture the permanent component.

Given that our measures of trade direction complement the traditional Q measure, we can provide a new estimate of transaction cost for order-driven markets. The previous literature uses the Q measure to identify both temporary (inventory or bid-ask bounce) and permanent (information) components of the transaction cost in quote-driven markets. The evidence presented here will suggest that we use the Q measure to identify the temporary (bid-ask bounce) component and use the ATT measure to identify the permanent (information) components of the transaction cost in order-driven markets.

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Table 1. The decision rule for the trade direction measure ATT2 given that $P_{t-1} = P_t$

The trade direction measure ATT2 is positive (negative) if the net order evaluated at P_{t-1} is positive (negative). The net order counts every order arriving or cancelled between the last and the current transactions. The sign + denotes a positive trade direction, - denotes a negative direction, and 0 denotes a zero net order. Term P_t is the transaction price at time t, B_t is the best bid right after the transaction at time t, A_t is the best ask right after the transaction at time t. Term S_A is the depth at the best ask, and S_B is the depth at the best bid.

<table>
<tr><td></td><td colspan="2">$B_{t-1} = P_{t-1} < A_{t-1}$</td><td>$B_{t-1} < P_{t-1} < A_{t-1}$</td><td colspan="2">$B_{t-1} < P_{t-1} = A_{t-1}$</td></tr>
<tr><td rowspan="3">$B_t = P_t < A_t$</td><td>$S_{B,t} > S_{B,t-1}$</td><td>+</td><td rowspan="3">+</td><td colspan="2" rowspan="3">+</td></tr>
<tr><td>$S_{B,t} = S_{B,t-1}$</td><td>0</td></tr>
<tr><td>$S_{B,t} < S_{B,t-1}$</td><td>-</td></tr>
<tr><td>$B_t < P_t < A_t$</td><td colspan="2">-</td><td>0</td><td colspan="2">+</td></tr>
<tr><td rowspan="3">$B_t < P_t = A_t$</td><td colspan="2" rowspan="3">-</td><td rowspan="3">-</td><td>$S_{A,t} > S_{A,t-1}$</td><td>-</td></tr>
<tr><td>$S_{A,t} = S_{A,t-1}$</td><td>0</td></tr>
<tr><td>$S_{A,t} < S_{A,t-1}$</td><td>+</td></tr>
</table>

Table 2. The trade direction of a market buy order in the Paris Bourse

Term Q is equal to 1 (-1) if a buy order (sell order) triggers the transaction. The trade direction measures ATT1 and ATT2 are +1 (-1) if the net order evaluated at P_{t-1} is positive (negative). The difference between ATT1 and ATT2 is that the former counts all existing orders in the net order, but the latter does not. The transaction price at time t is P_t and the best bid (ask) is B_t (A_t). Term S_A is the depth at the best ask, S_B is the depth at the best bid, and S is the size of the market order.

Panel A. The last transaction price equals the last best bid ($B_{t-1}=P_{t-1}<A_{t-1}$)
Market order is the only order or limit orders to buy between B_{t-1} and A_{t-1} arriving before the market order.

Order size	Current transaction	Q	ATT1	ATT2
$S>S_{A,t-1}$	$B_t=P_t=A_{t-1}<A_t$	+1	+1	+1
$S=S_{A,t-1}$	$P_t=A_{t-1}<A_t$	+1	+1	+1
$S<S_{A,t-1}$	$P_t=A_{t-1}=A_t$	+1	+1	+1

Panel B. The last transaction price equals the last best ask ($B_{t-1}<P_{t-1}=A_{t-1}$)
Market order is the only order arriving after the last transaction.

Order size	Current transaction	Q	ATT1	ATT2
$S>S_{A,t-1}$	$B_t=P_t=A_{t-1}<A_t$	+1	+1	+1
$S=S_{A,t-1}$	$B_t<P_t=A_{t-1}<A_t$	+1	0	+1
$S<S_{A,t-1}$	$P_t=A_{t-1}=A_t$, $S_{A,t}<S_{A,t-1}$	+1	-1	+1

New limit orders to sell S_l at A_{t-1} arriving before the market order.

Order size	Current transaction	Q	ATT1	ATT2
$S>S_{A,t-1}+S_l$	$B_t=P_t=A_{t-1}<A_t$	+1	+1	+1
$S=S_{A,t-1}+S_l$	$B_t<P_t=A_{t-1}<A_t$	+1	0	+1
$S_l<S<S_{A,t-1}+S_l$	$P_t=A_{t-1}=A_t$, $S_{A,t}<S_{A,t-1}$	+1	-1	+1
$S=S_l$	$P_t=A_{t-1}=A_t$, $S_{A,t}=S_{A,t-1}$	+1	-1	0
$S<S_l$	$P_t=A_{t-1}=A_t$, $S_{A,t}>S_{A,t-1}$	+1	-1	-1

New limit orders to sell S_l at a price between B_{t-1} and A_{t-1} arriving before the market order.

Order size	Current transaction	Q	ATT1	ATT2
$S>S_l$	$P_t=B_t<A_{t-1}=A_t$	+1	-1	-1
$S=S_l$	$B_t<P_t<A_{t-1}=A_t$	+1	-1	-1
$S<S_l$	$P_t=A_t<A_{t-1}$	+1	-1	-1

Table 3. Summary statistics of variables used in the Paris sample

The return is the continuously-compounded return in percentage terms. Volume is the log of the shares traded. Term Q is the trade direction variable defined by the quote-matching rule and is equal to 1 (-1) if a buy order (sell order) triggers the transaction. The trade direction measures ATT1 and ATT2 are +1 (-1) if the net order evaluated at P_{t-1} is positive (negative). The difference between ATT1 and ATT2 is that the former counts all existing orders in the net order, but the latter does not. The sample has 570,756 observations, which includes all transactions for stocks included in the CAC40 index in July 1999.

	Mean	Standard deviation	Minimum	Maximum	□ 1	□ 2	□ 3	□ 4	□ 5
RET	9.8×10^{-5}	0.148	-3.679	5.108	-0.383	-0.021	-0.004	-0.003	0.001
VOLUME	4.702	1.933	0	14.732	0.232	0.205	0.189	0.177	0.170
Q	-0.113	0.988	-1	1	0.209	0.185	0.163	0.150	0.139
ATT1	0.091	0.983	-1	1	0.106	0.091	0.084	0.082	0.080
ATT2	-0.077	0.982	-1	1	-0.020	0.077	0.071	0.066	0.062

Correlation coefficient

	Q	ATT1
ATT1	0.051	
ATT2	0.728	0.327

Table 4. OLS estimates from regressing returns against the current and lagged trade direction variables using the Paris sample

This table reports OLS estimates for the following regression,

$$R_t = \boldsymbol{a} + \hat{a}_0 O_t + \hat{a}_1 O_{t-1} + v_t .$$

Term R_t is the continuously-compounded return in percentage terms. The trade direction variable O has three different measures. The measure Q is defined by the quote-matching rule: Q is equal to 1 (-1) if a buy order (sell order) triggers the transaction. The trade direction measures ATT1 and ATT2 are +1 (-1) if the net order evaluated at P_{t-1} is positive (negative). The difference between ATT1 and ATT2 is that the former counts all existing orders in the net order, but the latter does not. The sample has 570,756 observations, which includes all transactions for stocks included in the CAC40 index in July 1999. The immediate response, which is the coefficient on O_t, measures the contemporaneous response to a shock of the trade direction. The temporary response is the absolute value of the coefficient on O_{t-1}. The permanent response is the sum of the coefficient on O_t and O_{t-1}.

	Trade direction variable		
Independent variable	Q	ATT1	ATT2
O_t	0.084*	0.082*	0.080*
O_{t-1}	-0.066*	-0.016*	-0.035*
R^2	0.406*	0.299*	0.342*
Immediate response	0.084	0.082	0.080
Temporary response	0.066 (78.6%)	0.016 (19.5%)	0.035 (43.8%)
Permanent response	0.018 (21.4%)	0.066 (80.5%)	0.045 (56.2%)

Table 5. Estimates of a bivariate (return and trade direction) VAR(1) model using the Paris sample

This table reports OLS estimates for the following VAR(1) system,

$$R_t = \square_1 + \square_{02} O_t + \square_{11} R_{t-1} + \square_{12} O_{t-1} + v_{1t}$$
$$O_t = \square_2 + \square_{21} R_{t-1} + \square_{22} O_{t-1} + v_{2t}. \qquad (5)$$

Term R_t is the continuously-compounded return in percentage terms. The trade direction variable O has three different measures. The measure Q is defined by the quote-matching rule: Q is equal to 1 (-1) if a buy order (sell order) triggers the transaction. The trade direction measures ATT1 and ATT2 are +1 (-1) if the net order evaluated at P_{t-1} is positive (negative). The difference between ATT1 and ATT2 is that the former counts all existing orders in the net order, but the latter does not. The sample has 570,756 observations, which includes all transactions for stocks included in the CAC40 index in July 1999. The immediate response is the coefficient on O_t, which is also the immediate response of return R_t to a v_{2t} shock. The permanent response is the cumulative response of return from R_t to R_{t+10} to a v_{2t} shock; the temporary response is the difference between the immediate response and the permanent response.

	Trade direction variable O					
	Q		ATT1		ATT2	
	Dependent variable					
Independent variable	R_t	O_t	R_t	O_t	R_t	O_t
R_{t-1}	-0.252*	-0.553*	-0.269*	-3.459*	-0.295*	-0.794*
O_t	0.081*		0.067*		0.076*	
O_{t-1}	-0.048*	0.248*	0.007*	0.386*	-0.011*	0.044*
Immediate response		0.081		0.067		0.076
Temporary response		0.046 (56.8%)		-0.005 (-7.5%)		0.025 (32.9%)
Permanent response		0.035 (43.2%)		0.072 (107.5%)		0.051 (67.1%)
R^2	0.455	0.049	0.341	0.205	0.404	0.011

Table 6. Estimates of a trivariate (return, Q, and ATT1 or ATT2) VAR(1) model using the Paris sample

This table reports OLS estimates for the following VAR(1) system,

$$R_t = \square_1 + \square_{02}\, Q_t + \square_{03}\, ATT_t + \square_{11} R_{t-1} + \square_{12}\, Q_{t-1} + \square_{13}\, ATT_{t-1} + v_{1t}$$

$$Q_t = \square_1 + \square_{21} R_{t-1} + \square_{22}\, Q_{t-1} + \square_{23}\, ATT_{t-1} + v_{2t}$$

$$ATT_t = \square_1 + \square_{31} R_{t-1} + \square_{32}\, Q_{t-1} + \square_{33}\, ATT_{t-1} + v_{2t}.$$

Term R_t is the continuously-compounded return in percentage terms. The trade direction measure Q is defined by the quote-matching rule: Q is equal to 1 (-1) if a buy order (sell order) triggers the transaction. The trade direction measures ATT1 and ATT2 are +1 (-1) if the net order evaluated at P_{t-1} is positive (negative). The difference between ATT1 and ATT2 is that the former counts all existing orders in the net order, but the latter does not. The sample has 570,756 observations, which includes all transactions for stocks included in the CAC40 index in July 1999. The immediate response is the coefficient on Q_t or ATT_t, which is also the immediate response of return R_t to a v_{2t} or v_{3t} shock. The permanent response is the cumulative response of return from R_t to R_{t+10} to a v_{2t} or v_{3t} shock; the temporary response is the difference between the immediate response and the permanent response.

	Trade direction variable					
	ATT1			ATT2		
	Dependent variable					
Independent variable	R_t	Q_t	ATT_t	R_t	Q_t	ATT_t
R_{t-1}	-0.347*	0.059*	-1.452*	-0.267*	-0.550*	-0.818*
Q_t	0.075*			0.052*		
Q_{t-1}	-0.012*	0.212*	-0.486*	-0.053*	0.249*	0.034*
ATT_t	0.051*			0.039*		
ATT_{t-1}	0.026*	-0.141*	0.248*	0.018*	-0.002*	0.021*
Immediate response		0.075	0.051		0.052	0.039
Temporary response		0.062 (82.7%)	-0.015 (-29.4%)		0.051 (98.1%)	-0.005 (-12.8%)
Permanent response		0.013 (17.3%)	0.066 (129.4%)		0.001 (1.9%)	0.044 (112.8%)
R^2	0.567	0.062	0.378	0.491	0.049	0.011

Table 7. Summary statistics of permanent and temporary responses to a shock of the trade direction estimated for each stock included in the CAC40 index using a trivariate (return, Q, and ATT1 or ATT2) VAR(1) model

For each stock included in the CAC40 index, we estimate the VAR(1) system,

$$R_t = \square_1 + \square_{02} Q_t + \square_{03} ATT_t + \square_{11} R_{t-1} + \square_{12} Q_{t-1} + \square_{13} ATT_{t-1} + v_{1t}$$

$$Q_t = \square_1 + \square_{21} R_{t-1} + \square_{22} Q_{t-1} + \square_{23} ATT_{t-1} + v_{2t}$$

$$ATT_t = \square_1 + \square_{31} R_{t-1} + \square_{32} Q_{t-1} + \square_{33} ATT_{t-1} + v_{2t}.$$

Term R_t is the continuously-compounded return in percentage terms. The trade direction measure Q is equal to 1 (-1) if a buy order (sell order) triggers the transaction. The trade direction variable ATT can be measure ATT1 or ATT2. The sample period is July 1999. The immediate response is the coefficient on Q_t or ATT_t, which is also the immediate response of return R_t to a v_{2t} or v_{3t} shock. The permanent response is the cumulative response of return from R_t to R_{t+10} to a v_{2t} or v_{3t} shock; the temporary response is the difference between the immediate response and the permanent response. The combined response is the sum of the response to Q and to ATT.

Shock	Response	Mean	Standard deviation	Minimum	Median	Maximum
Trade direction variable ATT is ATT1						
Q	Temporary	0.062 (72.4%)	0.015 (6.7%)	0.036 (58.0%)	0.061 (74.0%)	0.105 (83.7%)
	Permanent	0.024 (27.6%)	0.011 (6.7%)	0.010 (16.3%)	0.022 (26.0%)	0.057 (42.0%)
ATT1	Temporary	-0.005 (-9.6%)	0.004 (7.5%)	-0.017 (-25.4%)	-0.005 (-9.7%)	0.006 (9.2%)
	Permanent	0.060 (109.6%)	0.017 (7.5%)	0.028 (90.8%)	0.056 (109.7%)	0.101 (125.4%)
Combined	Temporary (% from Q)	0.057 (109.7%)	0.016 (8.2%)	0.031 (93.5%)	0.056 (109.2%)	0.103 (135.6%)
	Permanent (% from Q)	0.084 (28.0%)	0.027 (4.2%)	0.038 (19.8%)	0.079 (26.7%)	0.158 (37.5%)
Trade direction variable ATT is ATT2						
Q	Temporary	0.063 (96.4%)	0.016 (7.9%)	0.035 (76.1%)	0.062 (97.5%)	0.107 (109.2%)
	Permanent	0.003 (3.6%)	0.006 (7.9%)	-0.005 (-9.2%)	0.002 (2.5%)	0.026 (23.9%)
ATT2	Temporary	-0.003 (-8.0%)	0.004 (8.5%)	-0.018 (-32.9%)	-0.003 (-8.4%)	0.003 (5.9%)
	Permanent	0.045 (108.0%)	0.014 (8.5%)	0.018 (94.1%)	0.042 (108.4%)	0.079 (132.9%)
Combined	Temporary (% from Q)	0.059 (106.0%)	0.015 (7.3%)	0.035 (96.1%)	0.058 (104.8%)	0.104 (132.6%)
	Permanent (% from Q)	0.048 (3.7%)	0.019 (10.2%)	0.017 (-20.4%)	0.044 (3.8%)	0.105 (24.4%)

Table 8. Estimates of a five-variable (return, Q, ATT, Q-signed volume, and ATT-signed volume) VAR(1) model using the Paris sample

This table reports OLS estimates for the following VAR(1) system,

$$R_t = \square_1 + \square_{02}Q_t + \square_{03}ATT_t + \square_{04}Q_t{*}V_t + \square_{05}ATT_t{*}V_t + \square_{11}R_{t-1} + \square_{12}Q_{t-1} + \square_{13}ATT_{t-1} + \square_{14}Q_{t-1}{*}V_{t-1} + \square_{15}ATT_{t-1}{*}V_{t-1} + v_{1t}$$

$$Q_t = \square_2 + \square_{21}R_{t-1} + \square_{22}Q_{t-1} + \square_{23}ATT_{t-1} + \square_{24}Q_{t-1}{*}V_{t-1} + \square_{25}ATT_{t-1}{*}V_{t-1} + v_{2t}$$

$$ATT_t = \square_3 + \square_{31}R_{t-1} + \square_{32}Q_{t-1} + \square_{33}ATT_{t-1} + \square_{34}Q_{t-1}{*}V_{t-1} + \square_{35}ATT_{t-1}{*}V_{t-1} + v_{3t}$$

$$Q_t{*}V_t = \square_4 + \square_{41}R_{t-1} + \square_{42}Q_{t-1} + \square_{43}ATT_{t-1} + \square_{44}Q_{t-1}{*}V_{t-1} + \square_{45}ATT_{t-1}{*}V_{t-1} + v_{4t}$$

$$ATT_t{*}V_t = \square_5 + \square_{51}R_{t-1} + \square_{52}Q_{t-1} + \square_{53}ATT_{t-1} + \square_{54}Q_{t-1}{*}V_{t-1} + \square_{55}ATT_{t-1}{*}V_{t-1} + v_{5t}$$

Term R_t is the continuously-compounded return in percentage terms. The trade direction measure Q is equal to 1 (-1) if a buy order (sell order) triggers the transaction. The trade direction variable ATT can be ATT1 or ATT2. Term V is the standardized log volume, which is the raw log volume divided by its standard deviation calculated from each stock's log volume over the sample period. The sample has 570,756 observations, which includes all transactions for stocks included in the CAC40 index in July 1999. The immediate response is the coefficient on Q_t or ATT_t or signed volume, which is also the immediate response of return R_t to a shock of v_{2t} to v_{5t}. The permanent response is the cumulative response of return from R_t to R_{t+10} to a shock of v_{2t} to v_{5t}; the temporary response is the difference between the immediate response and the permanent response.

Independent variable	Dependent variable				
	R_t	Q_t	ATT_t	Q_t*V_t	ATT_t*V_t
Trade direction variable ATT is ATT1					
R_{t-1}	-0.349*	0.061*	-1.436*	0.142*	-3.507*
Q_t	0.070*				
Q_{t-1}	-0.009*	0.161*	-0.708*	0.007	-1.295*
ATT_t	0.043*				
ATT_{t-1}	0.028*	-0.178*	0.161*	-0.285*	0.213*
Q_t*V_t	0.002*				
$Q_{t-1}*V_{t-1}$	-0.001*	0.019*	0.085*	0.215*	0.060*
ATT_t*V_t	0.003*				
$ATT_{t-1}*V_{t-1}$	-0.001*	0.014*	0.029*	-0.024*	0.144*
Immediate response		0.070	0.043	0.002	0.003
Temporary response		0.073	-0.014	-0.005	0.000
Permanent response		-0.003	0.057	0.007	0.003
R^2	0.568	0.062	0.387	0.057	0.277
Trade direction variable ATT is ATT2					
R_{t-1}	-0.273*	-0.552*	-0.813*	-1.299*	-1.877*
Q_t	0.037*				
Q_{t-1}	-0.064*	0.192*	0.027*	0.095*	-0.168*
ATT_t	0.029*				
ATT_{t-1}	0.013*	0.050*	0.056*	0.101*	0.090*
Q_t*V_t	0.006*				
$Q_{t-1}*V_{t-1}$	0.004*	0.021*	0.002	0.218*	0.097*
ATT_t*V_t	0.004*				
$ATT_{t-1}*V_{t-1}$	0.002*	-0.020*	-0.013*	-0.049*	-0.024*
Immediate response		0.037	0.029	0.006	0.004
Temporary response		0.062	-0.005	-0.004	0.000
Permanent response		-0.025	0.034	0.010	0.004
R^2	0.498	0.049	0.011	0.047	0.009

Table 9. Summary statistics of variables used in the Taiwan sample

Term Return is the continuously-compounded return in percentage terms. Volume is the log of the shares traded. Q is the trade direction variable defined by the quote-matching rule and is equal to 1 (-1) if the transaction price equals the last ask (bid). The trade direction measures ATT1 and ATT2 are +1 (-1) if the net order evaluated at P_{t-1} is positive (negative). The difference between ATT1 and ATT2 is that the former counts all existing orders in the net order but the latter does not. The sample has 194,014 observations, which includes all transactions for the largest 40 stocks traded on the Taiwan Stock Exchange in June 1997.

	Mean	Standard deviation	Minimum	Maximum	□ 1	□ 2	□ 3	□ 4	□ 5
RET	-2.3x10^{-3}	0.358	-1.942	1.942	-0.426	-0.021	0.017	0.011	0.005
Q	-0.148	0.962	-1	1	0.245	0.239	0.220	0.202	0.172
ATT1	0.125	0.972	-1	1	0.201	0.112	0.144	0.133	0.116
ATT2	-0.016	0.679	-1	1	-0.204	-0.032	0.021	0.031	0.016

Correlation coefficient

	Q	ATT1
ATT1	-0.151	
ATT2	0.625	0.648

Table 10. Estimates of a bivariate (return and trade direction) VAR(1) model using the Taiwan sample

This table reports OLS estimates for the following VAR(1) system,

$$R_t = \square_1 + \square_{02}\, O_t + \square_{11} R_{t-1} + \square_{12}\, O_{t-1} + v_{1t}$$

$$O_t = \square_2 + \square_{21} R_{t-1} + \square_{22}\, O_{t-1} + v_{2t}. \qquad (5)$$

Term R_t is the continuously-compounded return in percentage terms. The trade direction variable O has three different measures. The measure Q is equal to 1 (-1) if the transaction price equals the last ask (bid). The trade direction measures ATT1 and ATT2 are +1 (-1) if the net order evaluated at P_{t-1} is positive (negative). The difference between ATT1 and ATT2 is that the former counts all existing orders in the net order, but the latter does not. The sample has 194,014 observations, which includes all transactions for the largest 40 stocks traded on the Taiwan Stock Exchange in June 1997. The immediate response is the coefficient on O_t, which is also the immediate response of return R_t to a shock of v_{2t}. The permanent response is the cumulative response of return from R_t to R_{t+10} to a shock of v_{2t}; the temporary response is the difference between the immediate response and the permanent response.

	Trade direction variable O					
	Q		ATT1		ATT2	
	Dependent variable					
Independent variable	R_t	O_t	R_t	O_t	R_t	O_t
R_{t-1}	-0.203*	-0.480*	-0.244*	-2.428*	-0.339*	-0.934*
O_t	0.233*		0.167*		0.402*	
O_{t-1}	-0.158*	0.339*	0.021*	0.720*	0.100*	0.205*
Immediate response		0.233		0.167		0.402
Temporary response		0.142 (60.9%)		-0.067 (-40.1%)		0.075 (18.7%)
Permanent response		0.091 (39.1%)		0.234 (140.1%)		0.327 (81.3%)
R^2	0.575	0.083	0.369	0.568	0.731	0.116

Figure 1. The transaction price is equal to the best ask

D (S) is the demand (supply) schedule. The transaction price is P_3, the best ask after the transaction is P_3, and the best bid after the transaction is P_2.

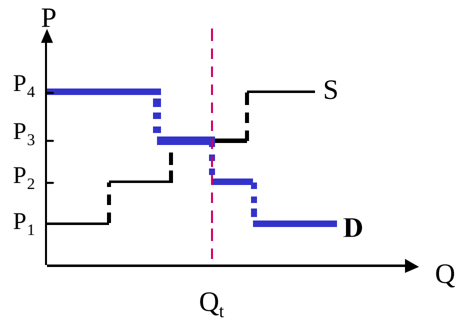


Figure 2. The transaction price is equal to the best bid

D (S) is the demand (supply) schedule. The transaction price is P_3, the best ask after the transaction is P_4, and the best bid after the transaction is P_3.

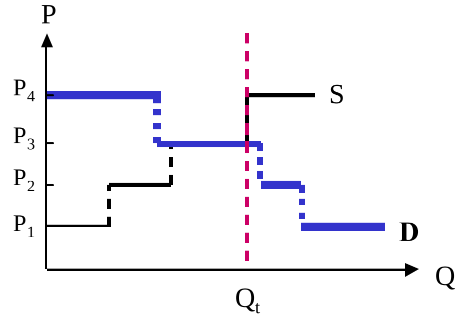


Figure 3. The transaction price is between the best bid and the best ask

D (S) is the demand (supply) schedule. The transaction price is P_3, the best ask after the transaction is P_4, and the best bid after the transaction is P_2.

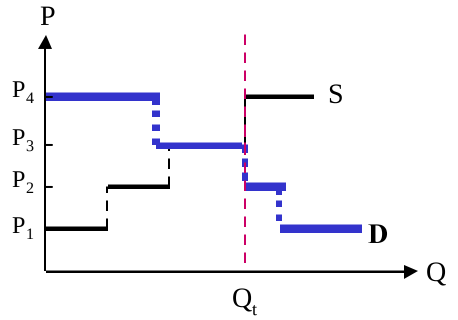


Figure 4. The response of cumulative return to a shock of the trade direction using the Paris sample

The cumulative response is estimated from the following trivariate VAR(I) system, I=1,…,5.

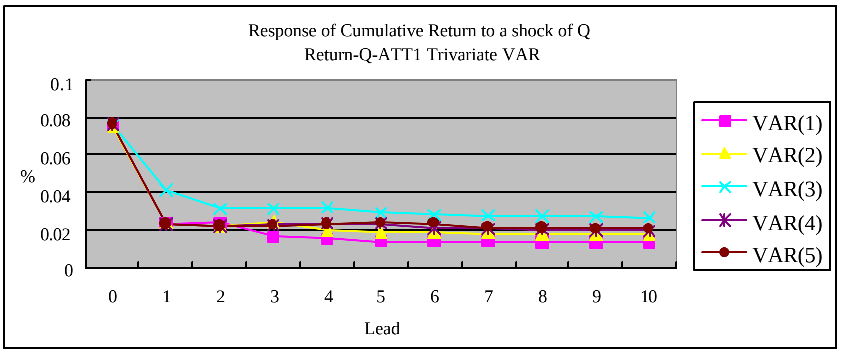
$$R_t = a_1 + b_{02}Q_t + b_{03}ATT_t + \sum_{i=1}^{I} b_{11i}R_{t-i} + \sum_{i=1}^{I} b_{12i}Q_{t-i} + \sum_{i=1}^{I} b_{13i}ATT_{t-i}$$

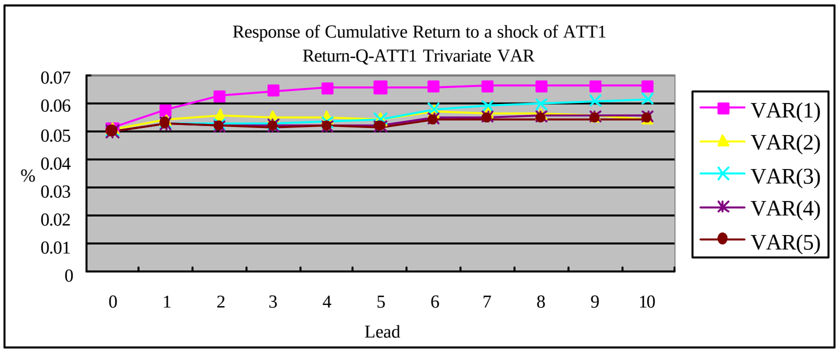
$$Q_t = a_2 + \sum_{i=1}^{I} b_{21i}R_{t-i} + \sum_{i=1}^{I} b_{22i}Q_{t-i} + \sum_{i=1}^{I} b_{23i}ATT_{t-i}$$

$$ATT_t = a_3 + \sum_{i=1}^{I} b_{31i}R_{t-i} + \sum_{i=1}^{I} b_{32i}Q_{t-i} + \sum_{i=1}^{I} b_{33i}ATT_{t-i}$$

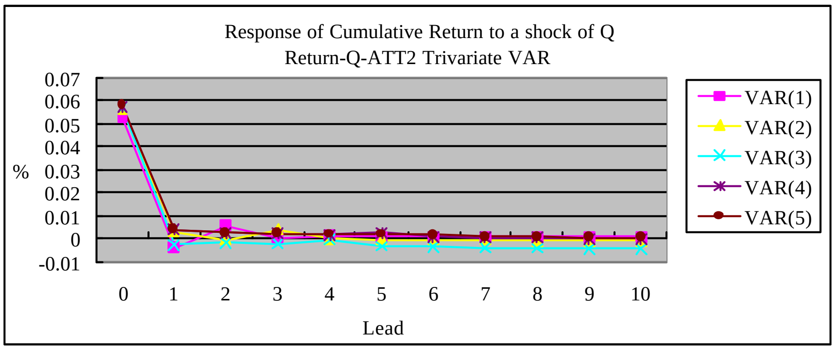
Term R_t is the continuously-compounded return in percentage terms. The trade direction measure Q is equal to 1 (-1) if a buy order (sell order) triggers the transaction. The trade direction variable ATT can be ATT1 or ATT2. The sample includes all transactions for stocks included in the CAC40 index in July 1999. The cumulative response of return to a shock of v_{2t} or v_{3t} is estimated from R_t to R_{t+i}, i=1,…,10.

Panel A. The trade direction is ATT1





Panel B. The trade direction is ATT2



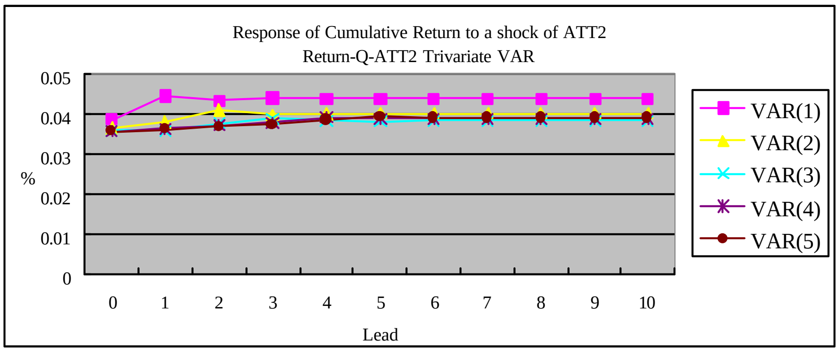


Figure 5. A decomposition of the cumulative response of returns to the ATT measure into TT (Tick Test measure) and residual ATT using the Paris sample

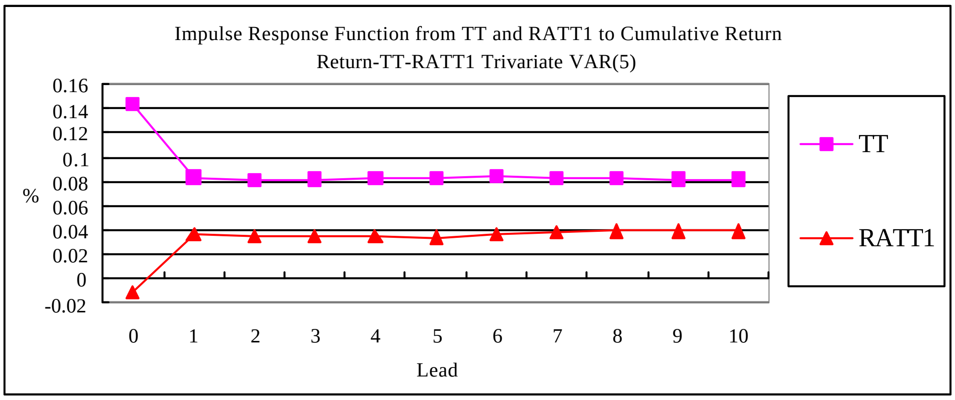
The cumulative response is estimated from the following trivariate VAR(5) system,

$$R_t = a_1 + b_{02}TT_t + b_{03}RATT_t + \sum_{i=1}^{5} b_{11i}R_{t-i} + \sum_{i=1}^{5} b_{12i}TT_{t-i} + \sum_{i=1}^{5} b_{13i}RATT_{t-i}$$

$$TT_t = a_2 + \sum_{i=1}^{5} b_{21i}R_{t-i} + \sum_{i=1}^{5} b_{22i}TT_{t-i} + \sum_{i=1}^{5} b_{23i}RATT_{t-i}$$

$$RATT_t = a_3 + \sum_{i=1}^{5} b_{31i}R_{t-i} + \sum_{i=1}^{5} b_{32i}TT_{t-i} + \sum_{i=1}^{5} b_{33i}RATT_{t-i}$$

Term R_t is the continuously-compounded return in percentage terms. Term TT is equal to 1 (-1) if the transaction price goes up (down), while RATT is the difference between TT and ATT, and ATT can be ATT1 or ATT2. The sample includes all transactions for stocks included in the CAC40 index in July 1999. The cumulative response of return to a shock of v_{2t} or v_{3t} is estimated from R_t to R_{t+i}, i=1,…,10.



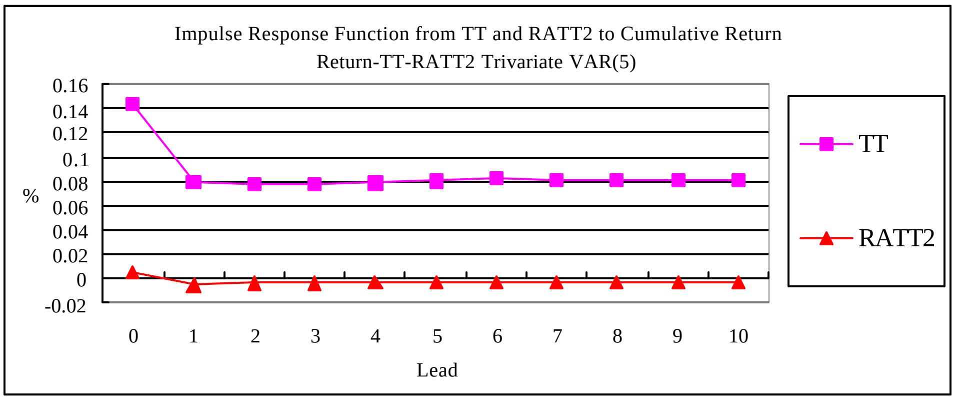


Figure 6. The response of the cumulative return to a shock of the trade direction using the Taiwan sample

The cumulative response is estimated from the following trivariate VAR(I) system, I=1,…,5,

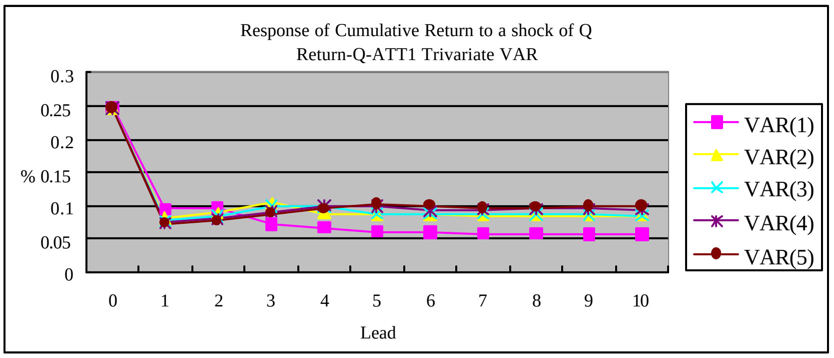
$$R_t = a_1 + b_{02}Q_t + b_{03}ATT_t + \sum_{i=1}^{I} b_{11i}R_{t-i} + \sum_{i=1}^{I} b_{12i}Q_{t-i} + \sum_{i=1}^{I} b_{13i}ATT_{t-i}$$

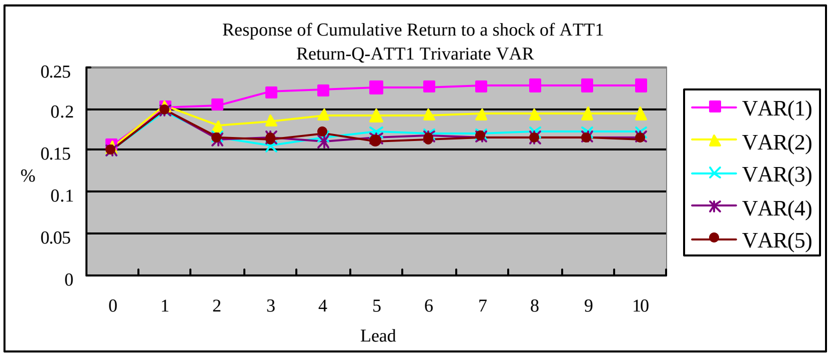
$$Q_t = a_2 + \sum_{i=1}^{I} b_{21i}R_{t-i} + \sum_{i=1}^{I} b_{22i}Q_{t-i} + \sum_{i=1}^{I} b_{23i}ATT_{t-i}$$

$$ATT_t = a_3 + \sum_{i=1}^{I} b_{31i}R_{t-i} + \sum_{i=1}^{I} b_{32i}Q_{t-i} + \sum_{i=1}^{I} b_{33i}ATT_{t-i}$$

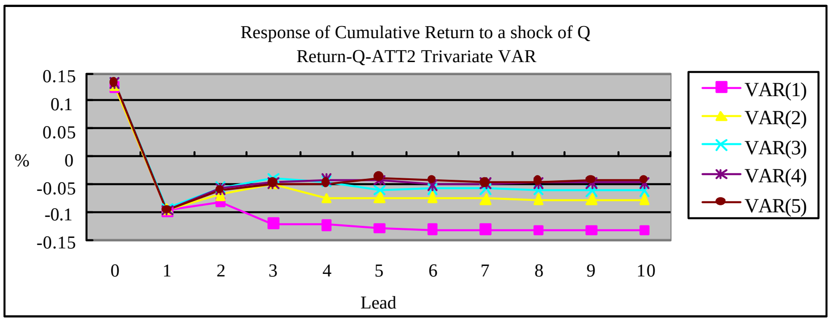
Term R_t is the continuously-compounded return in percentage terms. The trade direction measure Q is equal to 1 (-1) if a buy order (sell order) triggers the transaction. The trade direction variable ATT can be ATT1 or ATT2. The sample has 194,014 observations, which includes all transactions for the largest 40 stocks traded on the Taiwan Stock Exchange in June 1997. The cumulative response of return to a shock of v_{2t} or v_{3t} is estimated from R_t to R_{t+i}, i=1,…,10.

Panel A. The trade direction is ATT1





Panel B. The trade direction is ATT2



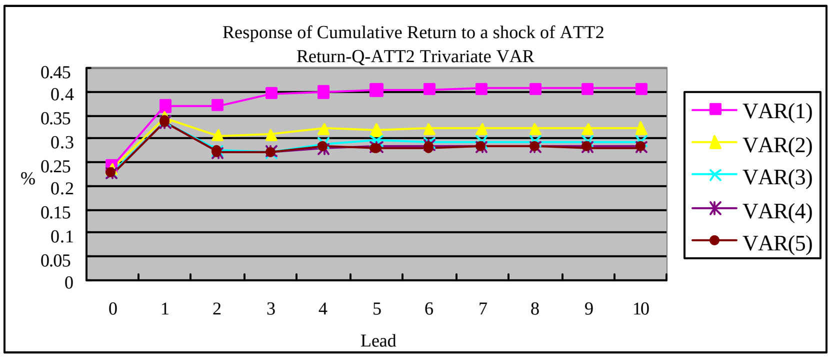


Figure 7. A decomposition of the cumulative response of returns to the ATT measure into TT (Tick Test measure) and residual ATT using the Taiwan sample

The cumulative response is estimated from the following trivariate VAR(5) system,

$$R_t = a_1 + b_{02}TT_t + b_{03}RATT_t + \sum_{i=1}^{5} b_{11i}R_{t-i} + \sum_{i=1}^{5} b_{12i}TT_{t-i} + \sum_{i=1}^{5} b_{13i}RATT_{t-i}$$

$$TT_t = a_2 + \sum_{i=1}^{5} b_{21i}R_{t-i} + \sum_{i=1}^{5} b_{22i}TT_{t-i} + \sum_{i=1}^{5} b_{23i}RATT_{t-i}$$

$$RATT_t = a_3 + \sum_{i=1}^{5} b_{31i}R_{t-i} + \sum_{i=1}^{5} b_{32i}TT_{t-i} + \sum_{i=1}^{5} b_{33i}RATT_{t-i}$$

Term R_t is the continuously-compounded return in percentage terms. Term TT is equal to 1 (-1) if the transaction price goes up (down), while RATT is the difference between ATT and TT, and ATT can be ATT1 or ATT2. The sample has 194,014 observations, which includes all transactions for the largest 40 stocks traded on the Taiwan Stock Exchange in June 1997. The cumulative response of return to a shock of v_{2t} or v_{3t} is estimated from R_t to R_{t+i}, i=1,…,10.