

Ershi Qi
Jiang Shen
Runliang Dou *Editors*

The 19th International Conference on Industrial Engineering and Engineering Management

Engineering Management

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Ershi Qi · Jiang Shen · Runliang Dou
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Chapter 1

A New Estimation Method of the Probability of Informed Trading

Chun-lian Xiong and Hua-gui Duan

Abstract The measure of asymmetric information is an important problem in the market microstructure theories. This paper uses MMPP model to model the number of transactions, then the model is used to estimate the probability of informed trading. Our methodology extends the EKOP framework by allowing the arrival rates of traders to vary over time and the probability of news to vary. It can be used to estimate higher frequency PIN, such as daily PIN. Our estimation of PIN can also be applied to stocks with large number of transactions.

Keywords Informed trading · Markov-modulated poisson process · PIN · Uninformed trading

1.1 Introduction

The measure of asymmetric information is an important problem in the market microstructure theories. It helps us understand the risk of information and the related problem of asset pricing.

In the early period, the literatures measured asymmetric information indirectly by some proxy variables. However, since Easley et al. (1996a, b, 1997, EKOP, hereafter), the theoretical foundations of the probability of informed trading (PIN) were established and we can measure the asymmetric information directly by the transaction data. So far, the model of EKOP has become the classical model of the

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measurement of asymmetric information. Since then, many empirical applications of PIN have appeared in the financial literatures. For example, Easley et al. (1996b) used PIN to explain observed differences in spreads for actively and infrequently traded stocks. Easley et al. (2001) employed PIN to study whether stock split reduce information asymmetries. Easley et al. (2010) examined the relationship between the information risk and asset pricing. Recently, Duarte and Young (2009) demonstrated that PIN can be decomposed into two components, which are related to asymmetric information and illiquidity. They examined the relation between PIN and the cross-section of expected returns. Aslan et al. (2011) used PIN to study the link between microstructure and asset return. Chen and Zhao (2012) investigated the effect of PIN in determining price momentum.

Recently, with the widespread applications of PIN, some researchers have begun to examine its properties. Aktas et al. (2007) documented that the PIN decreases before announcements of M&A and increases after the announcement, however there are considerable evidence of illegal insider trading or information leakage prior to such M&A announcement (Dennis and McConnell 1986; Keown and Pinkerton 1981; Meulbroek 1992).

In fact, the EKOP methodology suffers several serious shortcomings. First, the method fails to deliver PIN estimation to all stocks. When the number of buy and sell orders is very large for some actively traded stocks, the estimation of PIN generates overflow error or underflow error.

Second, in the EKOP framework, the trading day and the event day are independent. In fact, the assumption of independence among trading days and among event days is problematic.

Third, the assumption of the arrival rates as constants isn't accord with the financial market. In fact, Easley et al. (2008) proposed a dynamic model to study how the arrival rates of informed and uninformed trading vary over time.

In this paper, to estimate PIN, we design a new methodology that could be viewed as an extension of EKOP, because their definition of the PIN is adopted directly. The new method overcomes the above shortcomings suffered by the EKOP. Our method offers several advantages over the current one. First, the method to estimate PIN can be applied to all the stocks. Second, we can estimate daily PIN and even intraday PIN, in contrast, EKOP can only estimate quarterly PIN at the highest frequency. Third, We not only allow arrival rates to vary over time, but also allow the probability of information to vary.

1.2 EKOP Model and Our Methodology

1.2.1 EKOP Model

In this section, we introduce EKOP model. The model views the trading of a financial asset as a repeating game between a market maker and traders. Nature decides the occurrence of an information event every day. The probability that an

information event occurs is denoted by α . If the information event occurs, information is further classified as being either “bad” with the probability δ or “good” with the probability $1 - \delta$. EKOP model the aggregate number of buyer-initiated and seller-initiated orders each day as independent Poisson variables, with different arrival rates for days with good news, no news and bad news. Uninformed traders with no information submit buy orders and sell orders at the arrival rate ε_b and ε_s respectively. On the day when good information event occurs, informed traders submit buy orders at the arrival rate μ and when bad information event occurs, informed traders submit sell orders also at the arrival rate μ . The characterization of each trading day is unknown, and the likelihood of the numbers of buy and sell orders is based on the mixture-of-Poisson distribution. The daily conditional probability of observing buy orders B_i and sell orders S_i on each trading day i equals:

$$\begin{aligned} L(\theta|B_i, S_i) = & \alpha(1 - \delta)e^{-(\mu + \varepsilon_b)} \frac{(\mu + \varepsilon_b)^{B_i}}{B_i!} e^{-\varepsilon_s} \frac{\varepsilon_s^{S_i}}{S_i!} \\ & + \alpha\delta e^{-\varepsilon_b} \frac{\varepsilon_b^{B_i}}{B_i!} e^{-(\mu + \varepsilon_s)} \frac{(\mu + \varepsilon_s)^{S_i}}{S_i!} \\ & + (1 - \alpha)e^{-\varepsilon_b} \frac{\varepsilon_b^{B_i}}{B_i!} e^{-\varepsilon_s} \frac{\varepsilon_s^{S_i}}{S_i!}, \end{aligned} \quad (1.1)$$

where $\theta = (\alpha, \delta, \varepsilon_b, \varepsilon_s, \mu)$ is the set of parameters in the EKOP model. EKOP assume that the trading days are independent, and construct the aggregate log likelihood function on the time series of buys and sells for T days as a sum of the logarithm of the above daily conditional probabilities:

$$L[\theta|M] = \sum_{i=1}^T \ln L(\theta|B_i, S_i), \quad (1.2)$$

where $M = ((B_1, S_1), \dots, (B_T, S_T))$ represents the observing dataset. The probability of informed trading (PIN) is defined as follows:

$$PIN = \frac{\alpha\mu}{\alpha\mu + \varepsilon_b + \varepsilon_s}. \quad (1.3)$$

From the definition, we know PIN measures the ratio of the number of transactions from informed traders divided by the number of transactions from all traders. Maximizing the log probability in Eq. (1.2) over the parameters, we can have the estimation of these structural parameters. However, because no closed-form solution is available to the maximization problem, a numerical maximization technique must be used to obtain a solution. When the trading number is large, it will cause underflow or overflow problems in the maximization process.

1.2.2 Our New Methodology to Estimate PIN

1.2.2.1 Modeling the Number of Trades Based on Markov-Modulated Poisson Process

A Markov-modulated Poisson process (MMPP) is a Poisson process whose instantaneous rate is itself a stationary random process which varies according to an irreducible n -state Markov chain. If n is 1, then the process is just a Poisson process. Points from the MMPP are often referred to as the observed data and the underlying Markov chain as the hidden data. MMPP is widely used in modeling time-varying intensity rate processes such as traffic flows of communication networks, internet traffic flows and queuing systems.

EKOP argues that the arrival rate obeys to Poisson processes throughout the day and the daily arrival rate is constant. However, this is not the case for financial markets. The time series of the number of transactions reflect the underlying hourly, daily, and weekly rhythms of uninformed traders' activity. At the same time, the time series are often corrupted by information events corresponding to burst of unusual informed trading behavior. Trading from informed traders is determined by whether there is new information; however, the information event obeys to one order hidden Markov process.

From the above analysis, we can consider the time series of the number of transactions as from MMPP and model it by Scott and Smyth (2003) nonhomogeneous Markov-modulated Poisson process. The following is the process to model the time series of the number of transactions.

Let us assume that

$$N(t) = N_0(t) + N_E(t), \quad N(t) \geq 0,$$

where $N_0(t)$ is the number of transactions from uninformed traders at time t , $N_E(t)$ is the number of transactions from informed traders at time t .

1. Modeling the Number of Transactions from Uninformed Traders $N_0(t)$

According to the EKOP model, we assume the number of transactions from uninformed traders obeys to Poisson process and use a nonhomogeneous Poisson process with a particular parameterization of the rate $\lambda(t)$ to consider the different arrival rates at different intraday time intervals. We decompose $\lambda(t)$ as

$$\lambda(t) = \lambda_0 \delta_{d(t)} \eta_{d(t), h(t)},$$

where $d(t)$ takes on values $\{1, 2, 3, 4, 5\}$ and indicates the day on which time t falls (so that Monday = 1, Tuesday = 2, and so on), $h(t)$ indicates the interval (e.g. 5 min for the paper) in which time t falls, $\sum_{j=1}^5 \delta_j = 5$ and $\sum_{i=1}^D \eta_{j,i} = D$, $\forall j$, D is the number of time intervals in a day (48 for the paper). We can ensure that the value λ_0 , δ , η are easily interpretable: λ_0 is the average rate of the Poisson process over a full week, δ_j is the day effect, or the relative change for day j , and $\eta_{j,i}$ is the

time of day effect, or the relative change in time period i on given day j . In the paper, we not only consider the change for a week, but also the change for a intraday, this makes it more in accord with the fact of financial markets.

By choosing conjugate prior distribution for these variables, we can ensure that the inference computation in the following section has a closed form:

$$\begin{aligned}\lambda_0 &\sim \Gamma(\lambda; a^L, b^L); \\ \frac{1}{5}[\delta_1, \dots, \delta_5] &\sim \text{Dir}(\alpha_1^d, \dots, \alpha_5^d); \\ \frac{1}{48}[\eta_{j,1}, \dots, \eta_{j,48}] &\sim \text{Dir}(\alpha_1^h, \dots, \alpha_{48}^h),\end{aligned}$$

where Γ is the Gamma distribution, and $\text{Dir}(\bullet)$ is a Dirichlet distribution with the specified parameter vector.

2. Modeling the Number of Transactions from Informed Traders $N_E(t)$

Information event causes informed trading $N_E(t)$, this makes the number of transactions increase. To model the behavior of informed traders, we use a double process $z(t)$ to indicate the present of an event, i.e.,

$$z(t) = \begin{cases} 0, & \text{if there is no event at time } t \\ 1, & \text{if there is event at time } t \end{cases}$$

Define the probability distribution over $z(t)$ to be Markov in time, with transition probability matrix

$$M_z = \begin{pmatrix} z_{00} & z_{01} \\ z_{10} & z_{11} \end{pmatrix}$$

We give the transition probability variables priors specified as

$$\begin{aligned}[z_{00}, z_{01}] &\sim \text{Dir}(z; [a_{00}^Z, a_{01}^Z,]), \\ [z_{10}, z_{11}] &\sim \text{Dir}(z; [a_{10}^Z, a_{11}^Z,]),\end{aligned}$$

where $\text{Dir}(\bullet)$ is the Dirichlet distribution.

Given $z(t)$, we can model the increase in the observation number of trading due to the event, $N_E(t)$, as Poisson process with rate $\gamma(t)$

$$N_E(t) \sim \begin{cases} 0, & z(t) = 0, \\ P(N, \gamma(t)), & z(t) = 1, \end{cases}$$

where $P(\bullet)$ is Poisson distribution, and $\gamma(t)$ as independent at each time t

$$\gamma(t) \sim \Gamma(\gamma, a^E, b^E)$$

In fact, $\gamma(t)$ may be marginalized over analytically, since $\int P(N; \gamma) \Gamma(\gamma; a^E, b^E) d\gamma = \text{NBin}(N, a^E, b^E/(1 + b^E))$ where $\text{NBin}(\cdot)$ is the negative binomial distribution.

Given $z(t) = Z(t)$, we can determine $N_E(t)$ and $N_0(t)$ by sampling. If $z(t) = 0$, we take $N_0(t) = N(t)$, if $z(t) = 1$ we draw $N_0(t)$ from the negative binomial distribution.

1.2.2.2 Estimating the Parameters and Sampling the Variables

We use Markov chain Monte Carlo (MCMC) method to estimate the parameters and sample the variables. There are four steps:

- Step 1: given $N_0(t)$, estimate the three parameters of λ_t , i.e., λ_0, δ, η . For the first estimation, we use the observed number of transaction to replace $N_0(t)$;
- Step 2: given $N(t), \lambda_t, M_z$, estimate $z(t)$. For the first estimation, the value of M_z is priors.
- Step 3: according to the value of $z(t)$ from step 2, we can count the frequency of the transition of different values of $z(t)$, so we can obtain the value of M_z , then we use it to replace M_z .
- Step 4: given $N(t), \lambda_t, z(t)$, we use MCMC method to sample $N_0(t), N_E(t)$.

We iterate between drawing samples of the hidden variable $\{z(t), N_0(t), N_E(t)\}$ and parameters until the sampler converges, where convergence is informally assessed by monitoring the parameters values and values of the marginal likelihood.

1.2.2.3 Our New Estimation Method of PIN

From the EKOP model, PIN is defined by

$$PIN = \frac{\text{the expected number of transactions from informed traders}}{\text{the expected total number of transactions from all traders}}$$

According to the definition, and use MMPP model, we have:

$$\begin{aligned} PIN &= \frac{\hat{\text{the mean of the number of transactions from informed traders}}}{\text{the mean of the total number of transactions from all traders}} \\ &= \frac{\overline{NE}}{\overline{Nt}} \end{aligned}$$

where $\overline{NE}$ can be obtained by MMPP model, while $\overline{Nt}$ is the observed number of transactions. When $\overline{NE}$ and $\overline{Nt}$ is the daily number, we can obtain the daily PINs. Because $\overline{NE}$ and $\overline{Nt}$ is different for different days, the daily PINs is also different. This is contrast to EKOP model, which PIN is the same for the whole sample period. When $\overline{NE}$ and $\overline{Nt}$ is the number for the whole sample period, we have the PIN for the whole sample period. In fact, we can obtain different frequency of

PINs for different frequency of $\overline{NE}$ and $\overline{Nt}$. The following is the specific steps to obtain daily PINs by our new method. We denote our method as MMPP_PIN model.

- Step 1: We sum the number of transactions by every 5 min per day during the time of 9:30–11:30 a.m. and 13:00–15:00 p.m. Thus, we have 48.05 min data every day.
- Step 2: We use MMPP model to separate $\overline{NE}$ from the observed number of transaction.
- Step 3: We count the mean of daily $\overline{NE}$ and $\overline{Nt}$, then the daily PIN equals to $\overline{NE}$ divided by $\overline{Nt}$.

If we expect to have the PIN for the whole sample period, we only need to replace the mean of daily $\overline{NE}$ and $\overline{Nt}$ by the mean of $\overline{NE}$ and $\overline{Nt}$ for the whole sample period.

The PIN estimated by our method is different from EKOP model, because we allow the probability of information is dynamics, i.e., using the transition probability matrix to indicate it. We also allow the arrive rates of informed traders and uninformed traders are time varying. These hypotheses make the model more accurate to the real financial markets.

1.3 Empirical Results

1.3.1 Data

We apply our new estimation method of PIN (PIN_MMPP model) to 10 companies listed in Shanghai Stock Exchange, which are most actively traded. These stocks code are 600010, 600016, 600030, 600050, 600383, 600795, 601668, 601766, 601818, 601899. The tick by tick data are obtained from Shanghai Stock Exchange, we use the data from January 10, 2011 to April 29, 2011. We extract three variables on each stock: time of transaction, transaction price, and direction of transaction. We don't need to use the Lee and Ready algorithm to determine the daily numbers of buys and sells, because the data directly record the trade directions.

Some summary statistics of the data are given in Tables 1.1 and 1.2. The number of buy and sell is substantially large. The mean and median of the number of buy and sell are both more than 11,000, the maximum of the number of buy and sell are 139,039 and 116,398, the minimum of the number of buy and sell are 1 and 0. For this huge number of trades, EKOP model can't estimate PIN because of the underflow or overflow problems in the maximization process.

Table 1.1 Summary statistics of the number of buy

Code	Mean	Median	SD	Min	Max
600010	36,606	22,699	36,199	2,565	139,039
600016	16,656	12,519	13,519	4,550	65,139
600030	27,200	21,119	19,980	43	108,544
600050	11,980	10,241	6,852	19	36,011
600383	20,716	17,143	13,389	16	63,502
600795	12,021	8,983	10,117	7	56,370
601668	12,021	11,823	13,821	24	87,173
601766	23,463	21,282	14,091	1	69,205
601818	14,064	12,372	9,077	24	53,690
601899	25,461	20,694	18,561	51	87,173

Table 1.2 Summary statistics of the number of sell

Code	Mean	Median	SD	Min	Max
600010	34,892	23,634	34,369	0	116,398
600016	14,259	12,867	6,814	4,765	36,941
600030	28,848	25,513	15,356	0	93,730
600050	12,531	11,492	5,193	15	32,981
600383	21,253	20,774	10,587	15	59,964
600795	13,847	12,837	7,393	6	37,117
601668	13,722	12,085	7,434	8	49,687
601766	27,881	24,973	15,338	25	64,833
601818	15,904	14,459	6,710	13	35,401
601899	29,137	26,702	13,865	2	83,971

1.3.2 Results and Discussion

The results of the PIN_MMPP model are presented in Table 1.3. Table 1.3 is the result of daily PIN and the PIN for the whole sample period. It can be seen that the daily PIN of the stocks 600010, 601899 and 600030 are lower, while the stocks 600016, 600050 and 601818 are higher. The mean of daily PIN estimation varies from the lowest value of 0.075 for 600010, which is the stock with the most daily trading of buy and sell orders, to the highest value of 0.182 for 600050, which is the stock with the fewest daily trading of buy and sell orders. The result of the PIN is similarly the result of Tay et al. (2009) who estimated the PIN of five NYSE companies by PIN-AACD model. From the result of PIN for the whole sample period in Table 1.3, we can see that the stock 600010 have the lowest PIN, which is 0.089, while the stock 600016 have the highest PIN, which is 0.213.

Table 1.3 Summary statistics of the pins estimated by MMPP_PIN model

Code	Daily_PIN			ALL_PIN
	Mean	Median	SD	
600010	0.075	0.017	0.095	0.089
600016	0.175	0.161	0.137	0.213
600030	0.087	0.049	0.105	0.149
600050	0.182	0.141	0.142	0.206
600383	0.141	0.111	0.127	0.166
600795	0.132	0.106	0.110	0.154
601668	0.173	0.147	0.150	0.195
601766	0.109	0.090	0.109	0.148
601818	0.157	0.126	0.133	0.186
601899	0.091	0.057	0.104	0.119

Table 1.4 Daily correlation of PIN versus return volatility

Code	600795	601668	601766	601818	601899
Corr(RV, PIN)	0.11	-0.12	0.74	0.15	0.83
Code	600010	600016	600030	600050	600383
Corr(RV, PIN)	0.36	0.73	0.68	0.67	0.62

1.3.3 Evaluation of PIN Estimates

In this section, we study the correlation between daily PIN and daily return volatility, which is estimated by realize volatility, to understand the economic implications of our methodology for estimating PIN.

Wang (1993) demonstrated that asymmetric information increases return volatility. If PIN successfully measures the extent of asymmetric information, we would expect the positive correlation between PIN and return volatility. We denote RV as the realized volatility, computed as the sum of squared difference log mid-quotes. As PIN is predicted to be positively correlated with RV, the correlation between daily PIN and daily realized volatility would help us gauge the appropriateness of our methodology. Table 1.4 shows the correlations between PIN and RV range from -0.12 to 0.83 . While only the correlation of stock 601668 is negative, other stocks all have positive correlation, some have high correlation. For example, the correlation of stock 601899 is 0.83 . Overall, the result shows that our method of PIN estimation is effect.

1.4 Conclusions and Further Research

In this paper, we extend the EKOP model, and overcome several shortcomings suffered by the EKOP model. We relax the assumption of the constant arrival rates in the EHOP framework. Our enhanced methodology yields daily estimation for

the probability of informed trading, and allows the probability of information is dynamics. Our methodology also can be applied to all the stocks. We selected a sample of 10 actively traded stocks in Shanghai Stock Exchange to illustrate our method and also verify the improved economic implications of our methodology.

Our daily estimation of the probability of informed trading can be further used to study the impact of various events such as earnings announcements or merger activity on the level of informed trading. It also can be utilized to investigate the asset pricing implications of informed trading by our methodology.

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