

# The price formation of substitute markets: Theory and empirical application

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## Abstract

Two related issues are seldom jointly addressed in the cross market price discovery literature: i) a model that focuses on non-price parameter, ii) testing a non-price parameter model against a price parameter model. We have two objectives in this paper. First, develop a joint trade direction model (JTDM) from the single market model in Madhavan, Richardson and Roomans (1997). Second, estimate and test the JTDM against the Gonzalo and Granger (1995) VECM measure of price discovery. By doing so, we test the relevance of trade direction against quote change in cross-market price formation. The estimation of 20 Chinese twin-board firms reveal i) VECM and JTDM generate consistent ranking in 4 out of 10 A-H firms and 2 out of 10 A-B firms, all of which provide strong evidence of price discovery by the H or B boards; ii) Where VECM and JTDM generate conflicting rankings in 6 A-H firms, the Wald test and/or J-test rejects VECM in favor of JTDM; iii) Where VECM and JTDM generate conflicting rankings in 8 A-B firms, the Wald test and J-test rejects VECM (JTDM) in favor of JTDM (VECM) for 2(3) firms; neither model nor model selection tests are able to decide which board is more informative in 3 A-B firms. The less consistent results in the A-B sample group is not surprising given that the A and B boards were implicitly merged in 2001-2002.

*JEL classification:* G14, G15.

*Key words and phrases:* price discovery, trade direction, cross-listings.

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## Abstract

Two related issues are seldom jointly addressed in the cross market price discovery literature: i) a model that focuses on non-price parameter, ii) testing a non-price parameter model against a price parameter model. We have two objectives in this paper. First, develop a joint trade direction model (JTDM) from the single market model in Madhavan, Richardson and Roomans (1997). Second, estimate and test the JTDM against the Gonzalo and Granger (1995) VECM measure of price discovery. By doing so, we test the relevance of trade direction against quote change in cross-market price formation. The estimation of 20 Chinese twin-board firms reveal i) VECM and JTDM generate consistent ranking in 4 out of 10 A-H firms and 2 out of 10 A-B firms, all of which provide strong evidence of price discovery by the H or B boards; ii) Where VECM and JTDM generate conflicting rankings in 6 A-H firms, the Wald test and/or J-test rejects VECM in favor of JTDM; iii) Where VECM and JTDM generate conflicting rankings in 8 A-B firms, the Wald test and J-test rejects VECM (JTDM) in favor of JTDM (VECM) for 2(3) firms; neither model nor model selection tests are able to decide which board is more informative in 3 A-B firms. The less consistent results in the A-B sample group is not surprising given that the A and B boards were implicitly merged in 2001-2002.

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# 1 Introduction

The interest in modeling price formation to measure price discovery contribution by substitute markets e.g cross-listings, contract proliferation, spot-futures-option is not limited to just investors and regulators. For competing financial exchanges, reputations are at stake. Market  $X$  and Market  $Y$  are regarded as substitute markets if there exists a clear fundamental link between them e.g homogeneous securities or securities that are technically distinct but are linked by arbitrage forces.<sup>1</sup> Domowitz (1995) describes prices informativeness as a key service a financial exchange provides to facilitate resource reallocation. Fischel and Grossman (1984) stipulate that the quality of service provided by an exchange enhances its reputation, thereby entrenching liquidity. Noia (2001) suggests that for competing substitute markets, the exchange whose market performs more price discovery is able to use its reputation to charge a premium for data services and coverage access by the financial media.

Indeed, the microstructure literature offers an array of price formation models to measure price discovery, the process by which private information implicit in investor trading is revealed in subsequent price formation. These models differ in terms of the parameter(s) that each model emphasizes to depict trading activity. Examples include lagged return, lagged volatility, trade size in Easley and O'Hara (1987); Hasbrouck (1991), number/size of best bid and ask in Al-Suhaibani and Kryzanowski (2000), number/size of trades within a given time interval, trade direction in Madhavan, Richardson and Roomans (henceforth MRR) (1997)

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<sup>1</sup>This could refer to cross-listing, contract proliferation (e.g. Nikkei 225 index futures contracts of Osaka and Singapore) or spot-futures-option markets (e.g. Standard and Poors 500 futures and futures option markets of the Chicago Mercantile Exchange). It could also refer to a firm that is listed on multiple boards on a stock exchange (e.g. The Stock Exchange of Thailand manages both a main local board and a foreign board, where shares are trading at a premium).

and trade duration (time between consecutive trades) in Dufour and Engle (2000). Current research pursues one of three extension paths: i) Develop models focusing on a trading parameter that is not formally considered by an existing model; ii) Construct hybrids of existing models;<sup>2</sup> iii) Extend to multidimensional versions of existing single market models to measure cross-market price discovery.

A comprehensive modeling of intraday cross-market price formation considers interactions among trading parameters across markets. Two related issues are seldom addressed by existing price formation models: i) The role of non-price parameters in cross-market price formation and ii) the relevance of price versus non-price parameters in cross-market price formation. In this paper, we address both related issues. First, we formalize a suggestion by MRR (1997) to model trade direction<sup>3</sup> across assets or trading systems. Our joint trade direction model (henceforth JTDM) is a two-dimensional version of the single market MRR (1997) trade direction model. Second, we estimate and test the JTDM against the incumbent vector error correction model (henceforth VECM) measure, which is based on the Gonzalo and Granger (1995) common factor weights approach. The VECM measure assumes that price formation is entirely explained by price (quotes) parameters, while the JTDM assumes that price formation is entirely explained by non-price (trade direction) parameters. Hence a model evaluation between the VECM and JTDM constitutes an indirect test of the relevance of price versus non-price parameters to cross-market price formation.

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<sup>2</sup>E.g. Dufour and Engle (2000) is a hybrid of Hasbrouck (1991), which focus on signed trade size, and Engle and Russell (1998), which focus on trade duration.

<sup>3</sup>A trade inevitably involves a buying and selling side, such that trade direction gives a indication of the urgency of the two sides to consummate a trade. A trade executed at the bid (ask) price is classified as seller (buyer) initiated, since for that trade, the seller (buyer) is more eager to trade and accepts the lower bid (higher ask) price.

The two standard measures of price discovery contribution by multiple markets are the Gonzalo and Granger (henceforth GG) (1995) common factor weights approach and the Hasbrouck (1995) information share approach.<sup>4</sup> Our motivation to propose a new approach stems from the fact that both incumbent approaches assume that the price discovery process is driven entirely by price parameters. As such, both measures ignore the possibility of cross-market prices adjusting to the recent history of non-price parameters. Theoretically, non-price parameters have been the focus of existing single-market price formation models e.g trade size in Easley and O'Hara (1987); trade direction in MRR (1997); trade duration in Dufour and Engle (2000). Empirically, Engle and Patton (2004) estimate a comprehensive cointegrated bivariate system, where bid and ask quote changes are explained by lagged prices, spread, depth, trade direction, trade duration and trade size. Analyzing 100 NYSE stocks, they find evidence that the relevance of non-price trade flow parameters to quote change actually varies across stocks depending on the level of trading. To note, we regard the GG measure rather than the Hasbrouck (1995) measure as our model's benchmark because the idea behind the JTDM measure of cross-market price discovery is similar in context to the VECM measure. We elaborate on this in Section 2.

Estimating a cross-market model in event time, where progression through a sample is driven by (say) price change or trade, is not suitable as these events are highly non-synchronous across markets. Harris et al (1995) estimate a three equation VECM of IBM trade prices across NYSE, Pacific and Midwest Exchanges in event time. They address non-

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<sup>4</sup>These two approaches are so widely cited in cross market empirical studies that the editorial board of the *Journal of Financial Markets* devoted a special issue [2002, Vol 5(3)] just to discuss and contrast between them.

synchronicity by constructing a filtered sample of near-synchronized matched trade tuples.<sup>5</sup> Lehmann (2002) argues that the estimation of only matched trade tuples implies a study that measures price discovery only during “episodes of nearly contemporaneous trading activity”.<sup>6</sup> Besides, data processing work becomes mountainous when more firms are considered.

If there is sufficient trading across markets,<sup>7</sup> a model can be estimated with high frequency data without a major concern for non-synchronicity. As such, the JTDM provides incremental value to the VECM since the latter ignores the potential role of non-price parameters in price discovery. But if trading activity between markets is severely asymmetric, then the sample frequency needs to be minimized (say) 1-min intervals to reduce non-synchronicity. This causes the JTDM to impose numerous zero values on the trade parameters of the less liquid market. The possibility of quote prices adjusting to information in the absence of trading suggests that in such cases the VECM would be more appropriate. Accordingly, the relative performance between the VECM and JTDM is possibly case-specific and depends on the level of trading activity between the substitute markets. The main result in Engle and Patton (2004) that the relevance of trade parameters to quote change varies with the level of trading activity, supports this implication.

To ensure a comprehensive analysis of the competing models, the empirical estimation should consider an array of substitute markets with varying levels of trading activity on the different trading venues. In that regard, we examine the Chinese stock market since the

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<sup>5</sup>A trade tuple consists of trades in all three exchanges that occur within a pre-specified time of one another.

<sup>6</sup>To put differently, the Harris et al (1995) sampling methodology measures price discovery contribution when trading is triggered by heterogeneous inferences of (say) new macroeconomic announcements, and not private information per se. Thus it may be more suitable for the analysis of currencies, interest rates or market indices, but less appropriate for stocks.

<sup>7</sup>E.g. S&P 500 futures and futures option markets

analysis of cross-listings or competing derivative contracts across financial exchanges would restrict the number of firms or contracts and the extent of overlapping trading hours between markets. In stark contrast, the Chinese market offers a decent number of twin-board firms listed on the same exchange and/or time zone.<sup>8</sup> On either the Shanghai or Shenzhen stock exchange (henceforth SHSE and SZSE), a firm can list on the main A-board and/or either the B or H board. B-shares are traded mainly by foreign investors in USD (HKD) on the SHSE (SZSE). H-shares are traded in HKD on the Hong Kong Exchange (HKEx), which possesses a significant foreign institutional investor clientele. Either board offers a Chinese firm exposure to the foreign investment community.<sup>9</sup>

We estimate the competing models using a comprehensive sample of 10 A-H and 10 A-B twin-board firms covering various sectors of China's economy. When VECM and JTDM generate conflicting rankings, the Wald test and J-test are utilized to evaluate the two models. The main results show that in the A-H sample group, VECM and JTDM generate consistent ranking in 4 A-H firms. Both models provide strong evidence of more informative trading on the H-board. Subsequent Wald test and/or J-test rejects VECM in favor of JTDM for all remaining 6 A-H firms. While JTDM ranks the A-board above the H-board in 5 firms, these firms happen to pose the highest no-trade percentages in their H-sample. In the A-B group, VECM and JTDM generate consistent ranking in 2 A-B firms. Both indicate more

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<sup>8</sup>Also, as China's economy grows, her financial markets are attracting attention from the international investment arena. The Chinese stock market, with its multiple listing boards (A-B-H) on multiple exchanges (SHSE-SZSE-HKEx), is also generating interest among market microstructure researchers. Examining both A-B and A-H sample firms provide an opportunity to compare between the two groups, given that the B and H boards fulfill a somewhat similar role, which is to access foreign investor clientele. While attempts have been made to match up pairwise A-B and A-H firms based on industry and proportion of tradable capital, any comparison between the two subsidiary boards remains explorative.

<sup>9</sup>A firm can choose to list A, B, H, A-B or A-H shares. However, a firm is not allowed to issue both B and H shares, or to cross list on both SHSE and SZSE.

informative trading on the B-board. Subsequent Wald test and/or J-test rejects VECM (JTDM) in favor of JTDM (VECM) in 2 (3) firms. However, neither VECM/JTDM nor Wald/J-test are able to distinguish between the boards in 3 A-B firms. The less consistent results in the A-B sample group could stem from the blurring investor clientele due to the implicit merger between the A and B boards during 2001-2002. Our results do suggest potential efficiency gains by maintaining a single domestic listing board.

The theoretical models are presented in section 2. Empirical application of our model, data and sampling methodology are discussed in section 3. Results are reported and discussed in section 4. Section 5 concludes.

## 2 Measures of Cross-Market Price Discovery

In this section, we briefly describe the incumbent GG common factor weights approach. Next, we outline our extension of the MRR (1997) trade direction model to measure cross-market price discovery. Lastly, we discuss tests to evaluate the two competing approaches, which constitutes an indirect test of the relevance of quote change and trade direction in cross-market price formation.<sup>10</sup>

### *2.1 The common factor weights approach*

The GG common factor weights approach detects and calibrates informed trades in a VECM framework to measure cross-market price discovery. Harris et al (2002), Lehmann (2002)

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<sup>10</sup>To note, most price formation models take on a structural model that contains at least two price processes: An unobservable efficient price  $\mu_t$  and (at least) an observable price  $p_t$ . Information effects associated with a chosen parameter(s) are specified as part of  $\mu_t$ , while liquidity and/or microstructural effects associated with a chosen parameter(s) are specified as part of the  $p_t$  process. Deriving the reduced form of a structural model for estimation purposes involves an iterative substitution of  $\mu_t$  into  $p_t$ . Because of this, the reduced form model is always one equation less than the structural model.

and Covrig et al (2004) provide details. The GG approach decompose security price change into permanent and transitory components. Factor weights multiplied by each of the cointegrated prices is associated with a permanent common stochastic trend. The transitory error correction terms reflect adjustments by each security's price to disparities in idiosyncratic shocks in order to keep the price gap within arbitrage-free bounds. This decomposition implies the orthogonality between the common factor weights and the error correction coefficients in each security's price change equation.

In market microstructure, the implicit efficient price  $\mu_t$  in equation (1) is defined as the post-trade expected value of a tradable security conditional on all public information at time  $t$ ;  $\epsilon_t \stackrel{iid}{\sim} N(0, \sigma_\epsilon^2)$  represents random information arrival between  $\mu_t$  and  $\mu_{t-1}$ . By definition  $\mu_t$  fluctuates only in response to information, such that  $\epsilon_t$  introduces permanent shocks to  $\mu_t$  that accumulates over time as a stochastic trend  $\sum \epsilon_t$ . The observed prices of substitute markets  $\{p_{xt}, p_{yt}\}$  both contain  $\mu_t$ , such that  $\sum \epsilon_t$  is common to both  $\{p_{xt}, p_{yt}\}$ . However,  $\{p_{xt}, p_{yt}\}$  also contain idiosyncratic disturbances  $\{\xi_{xt}, \xi_{yt}\}$ . These disturbance terms capture an array of localized microstructure effects and transitory shocks e.g liquidity trading.  $\{\xi_{xt}, \xi_{yt}\}$  are assumed identically distributed over time, but may be serially correlated.

$$\begin{aligned} \mu_t &= \mu_{t-1} + \epsilon_t \\ p_{xt} &= \mu_t + \xi_{xt} \text{ and } p_{yt} = \mu_t + \xi_{yt} \end{aligned} \tag{1}$$

It is discussed in Hamilton (1994)<sup>11</sup> that if a linear combination of integrated I(1) variables is I(0), then by the Granger Representation Theorem for cointegrated variables,  $r_{xt} = p_{xt} - p_{x,t-1}$  and  $r_{yt} = p_{yt} - p_{y,t-1}$  can be estimated as a VECM. A two-market VECM is presented

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<sup>11</sup>For a reference, readers can refer to Hamilton (1994) Proposition 19.1 on page 582.

in equation (2), where the optimal lag length  $S$  can be determined based on (say) the Akaike Information Criterion (AIC) or a likelihood ratio test. Although  $\{p_{xt}, p_{yt}\}$  are non-stationary, but if they are cointegrated, a stationary error-correction variable  $Z_t = (p_{xt} - \tau p_{yt})$  can be introduced. While  $\tau = 1$  conveys a standard no-arbitrage equilibrium, it is widely documented that A-shares are systematically trading at a premium over those on the B or H boards. Sun and Tong (2000) and Wang and Jiang (2004) provide various explanations for the A-share premium. As such, the normalized cointegrating vector we apply for Firm  $i$  is  $[1, \tau_i > 1] \forall i$ . To note, the value of  $\tau$  is firm specific. The terms  $u_{xt}$  and  $u_{yt}$  are residuals generated from empirical estimation. The possibility of contemporaneous correlation  $Cov(u_{xt}, u_{yt}) \neq 0$  suggests the estimation of equation (2) using either full information maximum likelihood (FIML) or generalized methods of moments (GMM) estimation.

$$\begin{aligned}
r_{xt} &= \sum_{i=x,y} \sum_{s=1}^S (\beta_{xi,t-s} r_{i,t-s}) + \gamma_x Z_{t-1} + u_{xt} \\
r_{yt} &= \sum_{i=x,y} \sum_{s=1}^S (\beta_{yi,t-s} r_{i,t-s}) + \gamma_y Z_{t-1} + u_{yt}
\end{aligned} \tag{2}$$

As the name implies, the error-correction coefficients  $\gamma_x$  and  $\gamma_y$  reflect idiosyncratic adjustments by  $p_{xt}$  and  $p_{yt}$  in response to disparities in private value shocks, which cause the price gap to diverge. The common factor weights themselves cannot be estimated simply because  $\mu_t$  is unobservable. The idea behind the VECM measure is to infer the common factor weights from  $\gamma_x$  and  $\gamma_y$ . Intuitively, if  $r_{yt}$  responds to deviations from  $p_{xt}$ , but  $r_{xt}$  is exogenous to deviations from  $p_{yt}$ , it constitutes evidence of price discovery on Market  $X$ . This is reflected by a larger (smaller) and/or (in)significant  $\gamma_y(\gamma_x)$  from the estimation of equation (2).

## 2.2 The Joint Trade Direction Model (JTDM)

Our proposed JTDM is based on the single-market MRR (1997) trade direction model. The MRR model focuses on trade direction  $\{X_t\}$  as the key parameter to explain intraday price formation. The indicator variable  $\{X_t\}$  is assumed to follow a general Markov process, and takes on the value  $\{+1, 0, -1\}$ . Other than buyer (+1) and seller (-1) initiated trades, the model considers a mixed direction  $X_t = 0$ . This situation arises when a trade occurs within the prevailing spread, thus causing a break in the Markov chain. Conceptually, limited inference is made from a mixed direction. Statistically, limited inference is drawn from zero.

$$\begin{aligned}
 \mu_t &= \mu_{t-1} + \theta(X_t - \mathbb{E}(X_t|X_{t-1})) + \epsilon_t \\
 p_t &= \mu_t + \phi X_t + \xi_t \\
 r_t &= \theta(X_t - \mathbb{E}(X_t|X_{t-1})) + \phi \Delta X_t + \Delta \xi_t + \epsilon_t
 \end{aligned} \tag{3}$$

Presented in equation (3), the structural form of the MRR model consists of an implicit efficient price process  $\mu_t$  and an observable price process  $p_t$ . In its single equation reduced form, intraday price change  $r_t = p_t - p_{t-1} = \Delta p_t$  is explained entirely by trade direction parameters. A revision in belief  $\Delta \mu_t$  is triggered by either non-trade public information  $\epsilon_t$  or an innovation (surprise) in trade direction  $X_t - \mathbb{E}(X_t|X_{t-1})$ . The latter adjustment occurs in the presence of asymmetrically informed investors learning from the trading activities of other investors.<sup>12</sup> The coefficient  $\theta \geq 0$  measures the permanent price impact of that

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<sup>12</sup>In MRR (1997), information asymmetry is what drives the adjustment in  $\mu_t$  in response to the recent history of trading activities i.e trade direction innovation. That is why MRR (1997) sometimes refer to  $\theta$  as a measure of information asymmetry. We argue that it is more appropriate to refer to  $\theta$  as a permanent price impact measure. To note, information asymmetry in the market may translate to a non-trivial  $\theta$ , reflecting the adjustment in  $\mu_t$ . However, a trivial  $\theta$  does not necessarily imply that a given market has low information asymmetry. A trivial  $\theta$  may reflect asymmetrically informed market participants learning from parameters other than trade direction.

innovation.  $p_t$  contains  $\mu_t$  plus transitory effects  $\phi \geq 0$  and  $\xi_t$ . The former may represent implicit trading cost e.g. inventory cost, risk bearing or return for market making services in a dealer's market. The residual  $\xi_t$  captures all transitory microstructural effects e.g. price discreteness. This is how the MRR model incorporates both information and microstructural effects in intraday price formation.

Additional structure is required for  $\mathbb{E}(X_t|X_{t-1})$  in order to estimate the reduced-form  $r_t$  process in equation (3). Denote  $\lambda = \mathbb{P}[X_{t-1} = 0]$  and  $\gamma = \mathbb{P}[X_t = X_{t-1}|X_{t-1} \neq 0]$ , such that  $\mathbb{P}[X_t \neq X_{t-1}|X_{t-1} \neq 0] = 1 - \lambda - \gamma$ .<sup>13</sup> The two key results of the MRR model are: i) first order serial correlation coefficient in  $X_t$  is  $\rho = 2\gamma - (1 - \lambda)$  and ii)  $\mathbb{E}(X_t|X_{t-1}) = \rho X_{t-1}$ .<sup>14</sup> This allows us to obtain the empirical model in equation (4), which shows that in the MRR (1997), intraday price formation is explained by the change in trade direction  $\Delta X_t$  and the autocorrelation  $\rho$  in  $\{X_t\}$ .

$$r_t = \Delta p_t = (\phi + \theta)\Delta X_t + \theta(1 - \rho)X_{t-1} + \Delta\xi_t + \epsilon_t \quad (4)$$

The focus on serial correlation in trade direction stems from stealth trading by informed institutional investors i.e. partitioning a large order into two or more smaller orders so as not to attract attention when submitted to the limit order book. While there is abundant theoretical and empirical justification to consider a size parameter in single market price formation e.g. signed trade size in Easley and O'Hara (1987), it is less clear if the same parameter is just as readily applicable in a cross-market setting. For example, if trading in one market is dominated by uninformed hedging or portfolio re-balancing, then size may not

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<sup>13</sup>A diagram illustrating the transition of  $X_t$  over time is available upon request.

<sup>14</sup>MRR (1997) does not contain the actual derivation of the two key results. The detailed derivations are available from us upon request.

necessarily matter. A good example is the Nikkei 225 futures trading between the Singapore Exchange (SGX) and Osaka Securities Exchange (OSE) discussed in Chng (2004). Although OSE hosts the lion share of trading volume, SGX performs the majority of price discovery.

Our JTDM focuses on the trade direction of Market  $X$  and Market  $Y$ . The mixed signal state of zero is ignored, such that  $\{X_t\}$  and  $\{Y_t\}$  are dichotomous variables. Put differently, all trades are assumed classifiable as either buyer or seller initiated. We offer three justifications. First, trading on non-American stock and futures exchanges are hosted by a central limit order book. With a limit order queue in place, the majority of trades occur at either the best bid or best ask quote. Even NYSE and Nasdaq are organized as quasi-order driven markets. Second, for quote driven and/or floor traded markets, there exist various causes for a trade be transacted within the prevailing spread.<sup>15</sup> Many of these are technical outcomes not normally associated with information effects. Moreover, the literature offers a variety of algorithms to infer the direction of trades, including the commonly used quote and tick rules outlined in Lee and Ready (1991) and hybrid rules proposed in Ellis, Michaely and O'Hara (2000). Third, the assumption makes the JTDM more tractable.<sup>16</sup>

The JTDM examines the cross-market price formation of a risky security that is traded

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<sup>15</sup>One example is on a pre-1997 quote-driven NASDAQ, where direct negotiation between dealer and a client on a large buy order could lead to a trade occurring at a price marginally below the dealer's quoted ask price. For another example, note that the time stamps on floor traded futures tick data refer to the time of recording, not time of occurrence. Consider two locals shouting a best bid of \$10 and best ask of \$10.20. When the bidding local's order is filled by a floor broker, their respective clerks will gather corresponding details for confirmation in the upstairs offices. Once confirmed, the trade is recorded at a price of \$10, but at a delay. While this is happening, another local could be announcing the next best bid at \$9.90. If this new bid is recorded ahead of the latest trade, then when order and trade data are consolidated and sorted according to the time stamps, the following sequence is observed: Spread is 10-10.2; spread widens to 9.90-10.20; a trade occurred within the prevailing spread at \$10. The reason why a given spread could actually widen in a floor environment is because prevailing quotes have very short term to maturity as they can easily be withdrawn or canceled.

<sup>16</sup>To note, the one-period transition of a 2-variables, 2-state generates a total of 16 possible joint states. The one-period transition of 2-variables, 3-states, increases the total number of possible joint states to 81.

on markets  $X$  and  $Y$  based on the joint trade variable  $\{X_t, Y_t\}$ . The latter is introduced into a bivariate system of cross-market price formation to gauge the price discovery between a pair of substitute markets. Since each is a dichotomy,  $\{X_t, Y_t\}$  has four possible states:  $\{(1, 1), (1, -1), (-1, 1), (-1, -1)\} := \mathcal{S}$ . Unlike the MRR model, which emphasizes more on  $\rho X_{t-1}$  and less on  $X_{t-1} = 0$ , our JTDM focuses more on the transition of the two middle states where conflicting trade directions are observed i.e.  $\{X_{t-1}, Y_{t-1}\} = (1, -1)$  or  $(-1, 1)$ . By modeling the transition of  $\{X_t, Y_t\}$  conditional on substitute markets generating mixed signals  $\{X_{t-1}\} \neq Y_{t-1}$ , this allows our JTDM to evaluate which market exerts more influence on  $\{X_t, Y_t\}$ . Specifically, our model gauges the tendency for  $\{X_t\}$  to persist in the same direction and for  $\{Y_t\}$  to reverse and follow the direction of  $\{X_t\}$  when  $\{X_{t-1}\} \neq \{Y_{t-1}\}$  is observed across the two markets. This forms the basis to measure price discovery between two markets based on non-price parameters, which constitutes our model's contribution to the existing literature on cross-market discovery measures.

$$\mu_t = \mu_{t-1} + \theta (X_t + Y_t - \mathbb{E}(X_t + Y_t | X_{t-1}, Y_{t-1})) + \epsilon_t \quad (5)$$

Our structural system has three price processes  $\mu_t$ ,  $p_{xt}$  and  $p_{yt}$ . Similar to equation (1),  $\mu_t$  in equation (5) is the post-trade expected value of a risky security that is updated by either of two sources. First, non-trade new public information released between  $t - 1$  and  $t$ , denoted as  $\epsilon_t \stackrel{iid}{\sim} N(0, \sigma_\epsilon^2)$ . Second,  $\mu_t$  is updated by the joint trade innovation  $X_t + Y_t - \mathbb{E}(X_t + Y_t | X_{t-1}, Y_{t-1})$ , where  $\{X_t, Y_t\}$  is assumed to follow a general Markov process. When traders are asymmetrically informed, the joint trade innovation is the surprise in the direction of trading jointly observed on  $X$  and  $Y$  at time  $t$ . The joint trade innovation elicits a revision in belief and an adjustment in  $\mu_t$  according to  $\theta$ , which measures the permanent

price impact of the joint trade innovation. Following Glosten and Milgrom (1985), we assume that buyer (seller) initiated trades induce upward (downward) revisions in beliefs, such that  $\theta \geq 0$ . A bigger  $\theta$  implies a larger revision in  $\mu_t$  for a given innovation, such that  $\theta$  measures the overall relevance of joint trade directions to cross-market price discovery.

Possible higher order trade direction autocorrelation raises a question as to whether modeling only first order dynamics is a reasonable depiction of cross-market price formation. The MRR (1997) trade direction model assumes a Markov process in  $\{X_t\}$  in order to solve the closed form for  $\mathbb{E}(X_t|X_{t-1})$ . Given that some NYSE stocks will display more persistent trade direction serial correlation than others, MRR (1997) could extend their theoretical model to consider 1st and 2nd order serial correlations. However, a similar question regarding 3rd order serial correlation could still be asked. Furthermore, since the JTDM is already a two-dimensional version of MRR (1997), the model becomes untractable if we model additional dynamics. The empirical results in Chung, Li and McNish (2005) show that while trade direction autocorrelation is significant up to 5 lags, the magnitude of the 1st order autocorrelation coefficient is about 3 times as large as the sum of coefficients for the 2nd-5th order autocorrelation.

$$\begin{aligned}
 p_{xt} &= \mu_t + \phi_x X_t + \xi_{xt} \\
 p_{yt} &= \mu_t + \phi_y Y_t + \xi_{yt}
 \end{aligned}
 \tag{6}$$

A pair of transaction prices  $p_{xt}$  and  $p_{yt}$  observed correspondingly on Market  $X$  and Market  $Y$  at time  $t$  are outlined in equation (6)<sup>17</sup>. As the same security is traded on two different

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<sup>17</sup>This is a general approach for expressing a non-stationary series into a random walk and a residual stationary component. Stock and Watson (1988) provides a comprehensive review

markets, we assume that  $p_{xt}$  and  $p_{yt}$  will encapsulate the common factor  $\mu_t$  while displaying idiosyncratic pricing errors. The pricing error of Market  $X$  ( $p_{xt} - \mu_t$ ) has two components. First,  $p_{xt}$  incorporates the transitory impact of the current trade direction  $\phi_x X_t$  since it is a regret-free price. That a current trade at the prevailing ask (bid) is expected to move the limit ask queue, thus lifting (lower) subsequent prices, is already impounded into  $p_{xt}$ . Second, all microstructure effects, e.g. tick size, price rounding, are manifested in the residual  $\xi_{xt}$ , where  $\xi_{xt} \stackrel{iid}{\sim} N(0, \sigma_{\xi_{xt}})$ .  $p_{yt}$  is described in a similar fashion.

$$\begin{aligned} r_{xt} &= \phi_x \Delta X_t + \theta(X_t + Y_t - \mathbb{E}(X_t + Y_t | X_{t-1}, Y_{t-1})) + \Delta \xi_{xt} + \epsilon_t, \\ r_{yt} &= \phi_y \Delta Y_t + \theta(X_t + Y_t - \mathbb{E}(X_t + Y_t | X_{t-1}, Y_{t-1})) + \Delta \xi_{yt} + \epsilon_t \end{aligned} \quad (7)$$

Substituting equation (5) into equation (6) yields the reduced-form JTDM in equation (7). As with the MRR model, additional structure is required for  $\mathbb{E}(X_t + Y_t | X_{t-1}, Y_{t-1})$  to estimate the JTDM. Since  $\{X_t, Y_t\}$  depends only on  $\{X_{t-1}, Y_{t-1}\}$ , there exist 16 possible transitions for  $\{X_t, Y_t\}$ . These can be evenly grouped into one of four categories outlined below. For example, full continuation could refer to one of four transitions:  $(1, 1) \rightarrow (1, 1)$ ,  $(-1, 1) \rightarrow (-1, 1)$ ,  $(1, -1) \rightarrow (1, -1)$  and  $(-1, -1) \rightarrow (-1, -1)$ . The other three categories are similarly described.<sup>18</sup>

1. Full continuation:  $\{X_t = X_{t-1}\} \cap \{Y_t = Y_{t-1}\}$
2. X-continuation:  $\{X_t = X_{t-1}\} \cap \{Y_t = -Y_{t-1}\}$
3. Y-continuation:  $\{X_t = -X_{t-1}\} \cap \{Y_t = Y_{t-1}\}$
4. Full reversal:  $\{X_t = -X_{t-1}\} \cap \{Y_t = -Y_{t-1}\}$

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<sup>18</sup>A diagram illustrating the transition of  $\{X_t, Y_t\}$  over time is available upon request.

Denote the probability of full continuation as  $\mathbb{P}(X_t = X_{t-1}, Y_t = Y_{t-1} | X_{t-1}, Y_{t-1}) = \gamma$ , the probability of  $X$ -continuation as  $\mathbb{P}(X_t = X_{t-1}, Y_t = -Y_{t-1} | X_{t-1}, Y_{t-1}) = \lambda_x$  and the probability of  $Y$ -continuation as  $\mathbb{P}(X_t = -X_{t-1}, Y_t = Y_{t-1} | X_{t-1}, Y_{t-1}) = \lambda_y$ . It follows that the probability of full reversal is  $\mathbb{P}(X_t = -X_{t-1}, Y_t = -Y_{t-1} | X_{t-1}, Y_{t-1}) = 1 - \gamma - \lambda_x - \lambda_y$ .

$$P = \begin{matrix} & \begin{matrix} (1, 1) & (1, -1) & (-1, 1) & (-1, -1) \end{matrix} \\ \begin{matrix} (1, 1) \\ (1, -1) \\ (-1, 1) \\ (-1, -1) \end{matrix} & \left( \begin{array}{cccc} \gamma & \lambda_x & \lambda_y & 1 - \gamma - \lambda_x - \lambda_y \\ \lambda_x & \gamma & 1 - \gamma - \lambda_x - \lambda_y & \lambda_y \\ \lambda_y & 1 - \gamma - \lambda_x - \lambda_y & \gamma & \lambda_x \\ 1 - \gamma - \lambda_x - \lambda_y & \lambda_y & \lambda_x & \gamma \end{array} \right) \end{matrix} \quad (8)$$

The  $4 \times 4$  transition probability matrix  $P$  is presented in equation (8). This is a doubly stochastic matrix with both row and column values summing to 1. It arises from how transitions are defined in the JTDM. The temporal behavior of  $\{X_t, Y_t\}$  is depicted in terms of whether it fully persists, partially persists or totally reverses direction from  $\{X_{t-1}, Y_{t-1}\}$ . In the current model, no distinction is made between (say)  $\mathbb{P}((X_t, Y_t) = (1, 1) | (X_{t-1}, Y_{t-1}) = (1, 1))$  and  $\mathbb{P}((X_t, Y_t) = (-1, -1) | (X_{t-1}, Y_{t-1}) = (-1, -1))$ .

The following properties of  $\{X_t, Y_t\}$  under the steady state regime are derived in the appendix. We show that  $\mathbb{E}(X_t) = \mathbb{E}(Y_t) = \mathbb{E}(X_t Y_t) = 0$ ,  $\text{Var}(X_t) = \text{Var}(Y_t) = 1$ ,  $\text{Cov}(X_t, X_{t-1}) = 2(\gamma + \lambda_x) - 1 = \rho$  and  $\text{Cov}(Y_t, Y_{t-1}) = 2(\gamma + \lambda_y) - 1 = \delta$ . We also show that the stationary distribution of the Markov chain is  $\mathbb{P}((X_t, Y_t) = (i, j)) = 0.25$  for  $(i, j) \in \mathcal{S}$ , which has two justifications. First, there is no ex-ante reason for buyer-initiated trades to occur more frequently than seller-initiated trades for a given market over a given time period. Second, if all trades are information motivated, then consistent trade directions across two substitute markets should occur more frequently in the long run, such that

$\mathbb{P}((X_t, Y_t) = (1, 1) \text{ or } (-1, -1)) > \mathbb{P}((X_t, Y_t) = (1, -1) \text{ or } (-1, 1))$ . But since our price formation model allows for noise trading, there is no reason why substitute markets are more likely to give conforming than conflicting signals. Lastly, we show that the coefficient matrix  $\Sigma$  in the linear predictor  $\Sigma \begin{pmatrix} X_{t-1} \\ Y_{t-1} \end{pmatrix}$  for  $\begin{pmatrix} X_t \\ Y_t \end{pmatrix}$  is set to minimize

$$\mathbb{E} \left( \left( \begin{pmatrix} X_t \\ Y_t \end{pmatrix} - \Sigma \begin{pmatrix} X_{t-1} \\ Y_{t-1} \end{pmatrix} \right)^T \times \left( \begin{pmatrix} X_t \\ Y_t \end{pmatrix} - \Sigma \begin{pmatrix} X_{t-1} \\ Y_{t-1} \end{pmatrix} \right) \right),$$

has to satisfy:  $\Sigma = \begin{pmatrix} \text{Cov}(X_t, X_{t-1}) & \text{Cov}(X_t, Y_{t-1}) \\ \text{Cov}(Y_t, X_{t-1}) & \text{Cov}(Y_t, Y_{t-1}) \end{pmatrix} = \begin{pmatrix} 2(\gamma + \lambda_x) - 1 & 0 \\ 0 & 2(\gamma + \lambda_y) - 1 \end{pmatrix}$

The above result shows that  $\Sigma$  is actually a covariance matrix for trade directions. In the current model,  $\text{Cov}(X_t, Y_{t-1}) = \text{Cov}(Y_t, X_{t-1}) = 0$ . This outcome arises from imposing a doubly stochastic diagonal transition matrix in equation (8). Intuitively, since  $\{X_t, Y_t\}$  both center around zero and the fact that under the steady state,  $\mathbb{P}((X_t, Y_t) = (i, j)) = 0.25$  for  $(i, j) \in \mathcal{S}$ , the cross-products  $\text{Cov}(X_t, Y_{t-1})$  and  $\text{Cov}(Y_t, X_{t-1})$  will both be zero. However, this does not imply that substitute markets are not linked in the JTDM. The price processes  $\{p_{xt}, p_{yt}\}$  are linked simply because they share the same implicit efficient price  $\mu_t$ . This ensures that the JTDM allows  $\{r_{xt}\}$  to be explained by the trade direction of Market  $Y$ , and vice versa.<sup>19</sup> Solving for the conditional expected joint trade direction yields the result in equation (9), where  $\rho = 2(\gamma + \lambda_x) - 1$  and  $\delta = 2(\gamma + \lambda_y) - 1$ .

$$\mathbb{E}(X_t + Y_t | X_{t-1}, Y_{t-1}) = \rho(X_{t-1}) + \delta(Y_{t-1}) \quad (9)$$

We substitute equation (9) into equation (7) to obtain the empirical form of the JTDM in equation (10). Denote the residuals  $\Delta\xi_{xt} + \epsilon_t = \omega_{xt}$  and  $\Delta\xi_{yt} + \epsilon_t = \omega_{yt}$ . Equation

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<sup>19</sup>We thank an anonymous referee for raising this issue.

(10) shows the transaction price formation process of a given pair of substitute markets. Each price change process  $r_{xt}$  and  $r_{yt}$  is described by the change in trade directions,  $\Delta X_t$  and  $\Delta Y_t$ , as well as the lag one trade directions,  $X_{t-1}$  and  $Y_{t-1}$ , of both markets. In the absence of market imperfections ( $\theta = \phi_x = \phi_y = \xi_{xt} = \xi_{yt} = 0$ ), the observable prices  $(p_{xt}, p_{yt})$  both track the implicit efficient price perfectly. As there is no longer a need for cross-market price formation to incorporate dynamic adjustments to the recent history of trading activities, equation (10) reverts to the random walk definition of the efficient price change  $r_{xt} = r_{yt} = \Delta \mu_t = \epsilon_t$ .

$$\begin{aligned} r_{xt} &= (\theta + \phi_x)\Delta X_t + \theta\Delta Y_t + \theta(1 - \rho)X_{t-1} + \theta(1 - \delta)Y_{t-1} + \omega_{xt}, \\ r_{yt} &= (\theta + \phi_y)\Delta Y_t + \theta\Delta X_t + \theta(1 - \rho)X_{t-1} + \theta(1 - \delta)Y_{t-1} + \omega_{yt} \end{aligned} \quad (10)$$

Denote  $\boldsymbol{\pi} = (\theta, \phi_x, \phi_y, \rho, \delta)$  as the vector of JTDM coefficients. While  $(\phi_x, \phi_y)$  measures the transitory price impact of  $\{X_t, Y_t\}$  on cross market price formation,  $\theta$  measures the permanent price impact of joint trade directions. If institutional investors are active in Market  $Y$ , the order depth they bring to the limit order books of Market  $Y$  shares would be picked up by  $\phi_x > \phi_y$ . The coefficient  $\theta$  is also related to  $(\rho, \delta)$ . While  $\theta$  measures the overall relevance of  $\{X_t\}$  and  $\{Y_t\}$  to  $r_{xt}$  and  $r_{yt}$ ,  $(\rho, \delta)$  indicate the price leadership exerted by  $\{X_t\}$  and  $\{Y_t\}$  onto  $r_{xt}$  and  $r_{yt}$  when conflicting trade directions are observed at time  $t - 1$ . If trade direction is totally irrelevant to cross market price formation, such that  $\theta = 0$ , then both  $\rho$  and  $\delta$  are also irrelevant to  $r_{xt}$  and  $r_{yt}$ . This is shown in equation (10). Since  $\rho - \delta = 2(\lambda_x - \lambda_y)$ , such that  $\rho > \delta$  implies  $\lambda_x > \lambda_y$  and vice versa. For a given firm,  $\lambda_x < \lambda_y$  suggests that when the two boards are emitting conflicting trade directions at time  $t - 1$ , then it is more likely for Board  $Y$  to persist in the same direction and for Board  $X$  to

reverse its direction and follow Board  $Y$  at time  $t$ . Whether  $\lambda_x$  is greater or less than  $\lambda_y$  is suitably an empirical question. To note, the principle behind the JTDM measure is similar to the GG measure. That is why we regard the VECM rather than the Hasbrouck (1995) information share measure as the benchmark for our model.

$$\mathbb{E} \begin{pmatrix} \theta(X_t + Y_t - \rho X_{t-1} - \delta Y_{t-1})X_{t-1} \\ \theta(X_t + Y_t - \rho X_{t-1} - \delta Y_{t-1})Y_{t-1} \\ w_{xt}X_{t-1} \\ w_{xt}Y_{t-1} \\ w_{yt}X_{t-1} \\ w_{yt}Y_{t-1} \end{pmatrix} = 0$$

Following MRR (1997), we apply GMM to estimate equation (10). This procedure requires weak assumptions about the stochastic data generating process, although it does require a large sample size to generate consistent estimates.<sup>20</sup> The GMM procedure selects values for  $\pi$  to minimize a criterion function based on a set of moment conditions that  $\pi$  should satisfy. We specify six moment conditions, shown below, to estimate the JTDM. The first two moment conditions specify the orthogonality between the joint trade innovation at time  $t$  and each of the lagged trade directions  $\{X_{t-1}\}$  and  $\{Y_{t-1}\}$ . They convey the theoretical link between  $\theta$ , which measures the overall informativeness of joint trade directions, and  $(\rho, \delta)$ . The latter measure the price leadership that one board exerts over the other. The remaining four moment conditions describe the orthogonality between the residuals  $w_{xt}, w_{yt}$  and  $\{X_{t-1}, Y_{t-1}\}$ . Since  $\rho = 2(\gamma + \lambda_x) - 1$ ,  $\delta = 2(\gamma + \lambda_y) - 1$  and  $\gamma, \lambda_x$  and  $\lambda_y$  are probabilities, this implies  $-1 \leq \rho \leq 1$  and  $-1 \leq \delta \leq 1$ .<sup>21</sup>

<sup>20</sup>This should not pose a major hinderance since there are at least 15,000 observations per variable per firm per board.

<sup>21</sup>The fact that  $\rho$  and  $\delta$  are autocorrelation coefficients of  $\{X_t\}$  and  $\{Y_t\}$  respectively are proved in

### 2.3 The relevance of quote change and trade direction: VECM versus JTDM

We outline two approaches to test the JTDM against the VECM. Cross-market price formation is explained entirely by quote price and trade direction in the VECM and JTDM correspondingly. Hence a test between two non-nested models can be regarded as an indirect test of the relevance of price versus non-price parameters in cross-market price formation.

$$\begin{aligned}
 r_{xt} &= \sum_{i=x,y} \sum_{s=1}^S (\beta_{xi,t-s} r_{i,t-s}) + \gamma_x (p_{x,t-1} - \tau p_{y,t-1}) \\
 &\quad + (\theta + \phi_x) \Delta X_t + \theta \Delta Y_t + \theta(1 - \rho) X_{t-1} + \theta(1 - \delta) Y_{t-1} + u_{xt} \\
 r_{yt} &= \sum_{i=x,y} \sum_{s=1}^S (\beta_{yi,t-s} r_{i,t-s}) + \gamma_y (p_{x,t-1} - \tau p_{y,t-1}) \\
 &\quad + \theta \Delta X_t + (\theta + \phi_y) \Delta Y_t + \theta(1 - \rho) X_{t-1} + \theta(1 - \delta) Y_{t-1} + u_{yt}
 \end{aligned} \tag{11}$$

We apply a “top-down” approach based on artificial nesting of the two competing models. The unrestricted model is presented in equation (11), estimated using FIML. We apply the Wald test to measure how close equation (11) is to satisfy an array of model restrictions. As a robustness check, one may consider estimating equation (11) using the GMM procedure. But since the dynamics for some firms extends up to 8 lags, there is insufficient moment conditions to facilitate GMM estimation for all firms. Moreover, we argue that FIML estimation poses a bias against the non-price parameters, which are estimated using GMM in the JTDM. This makes it harder for the Wald test to favor the JTDM. First, we impose the restrictions  $\theta = \phi_x = \phi_y = \rho = \delta = 0$  to test the unrestricted model against the VECM. Second, we test the appendix. Consider a market where observed trades are described by  $\gamma + \lambda_x = 1(0)$ , such that  $\rho = 1(-1)$ . Since the transition of  $\{X_t, Y_t\}$  is solely depicted by either full or  $X$ -continuation (full reversal or  $Y$ -continuation),  $\{X_t\}$  is perfectly positively (negatively) autocorrelated.

the unrestricted model against the JTDM by imposing all the  $\beta$ 's being equal to 0 as well as  $\gamma_x = \gamma_y = 0$ . The appropriate restricted model (if any) that fits the data best is brought out by the Wald test statistics.

However, there is a possibility that the Wald test statistics may either reject or fail to reject both VECM and JTDM. To address this issue and to promote robustness, we complement the Wald test with a “bottom-up” approach using the J-test proposed by Davidson and MacKinnon (1981).<sup>22</sup> The J-test involves a pair of 2-step procedures. Consider a general expression of equation (11):  $\mathbf{Y} = \alpha(\mathbf{X}\boldsymbol{\beta}) + (1 - \alpha)\mathbf{Z}\boldsymbol{\pi} + \mathbf{u}$ , where  $\mathbf{X}$  is a vector of VECM variables and  $\mathbf{Z}$  is a vector of JTDM variables. The J-test involves an estimation of  $\mathbf{Y}$  on  $\mathbf{Z}\boldsymbol{\pi}$  followed by an estimation of  $\mathbf{Y} = \alpha_x(\mathbf{X}\boldsymbol{\beta}) + (1 - \alpha_x)\mathbf{Z}\hat{\boldsymbol{\pi}} + \mathbf{u}_x$ . The estimated  $\alpha_x$  reveals how relevant are VECM variables in explaining  $r_{xt}$  and  $r_{yt}$  in the presence of  $\mathbf{Z}\hat{\boldsymbol{\pi}}$  i.e. JTDM fitted values from the first step estimation. The reverse procedure is then applied, where an estimation of  $\mathbf{Y}$  on  $\mathbf{X}\boldsymbol{\beta}$  is followed by an estimation of  $\mathbf{Y} = \alpha_z(\mathbf{Z}\boldsymbol{\pi}) + (1 - \alpha_z)(\mathbf{X}\hat{\boldsymbol{\beta}}) + \mathbf{u}_z$ .<sup>23</sup>

### 3 Empirical Application

The empirical section involves the discussion of VECM and JTDM estimation results. This achieves the following. First, the empirical analysis demonstrates the use of the JTDM. Second, the estimation results provide some understanding of the price discovery mechanism between the main A-board and subsidiary B or H boards for Chinese twin shares. Some

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<sup>22</sup>The J-test is based on the encompassing principle formalized in Mizon and Richard (1986). As the name implies, the encompassing principle considers whether one model is able to encompass features of an alternative model.

<sup>23</sup>However, it is possible that the J-test rejects both or neither the VECM and JTDM. Nonetheless, Davidson and MacKinnon (1981) show that asymptotically, if the JTDM (VECM) is valid, then  $plim(\hat{\alpha}) = 1(0)$ .

comparisons can be made between the A-B and A-H group of results. Prior studies examine either A-B firms or A-H firms, but seldom both.<sup>24</sup> Third, the JTDM is tested against the benchmark VECM using an array of 20 firms. This allows us to investigate whether the relevance of price versus non-price parameters in cross-market price discovery depends on the proportion of trading on the twin boards, which in our sample varies from firm to firm. This complements Engle and Patton (2004), whose empirical findings are based on single market price formation.

*Prior studies and institutional background*

Lee and Rui (2000) and Sun and Tong (2000) consider firms potentially substituting between the B and H boards. Lee and Rui (2000) find little evidence of US or Hong Kong trades affecting mainland markets. In contrast, Sun and Tong (2000) find that increases in the number of listings on the H-board expands the A-B pricing gap, although their sample period predates the implicit merging between the A and B boards. From Feb 2001, mainlanders can use foreign currency accounts to trade B-shares. From Dec 2002, Qualified Foreign Institutional Investors (QFII) are allowed to trade A-shares. Wang and Jiang (2004) examine a daily sample from Jun 1995 to Dec 2001. The Feb 2001 reform may appear irrelevant since Wang and Jiang (2004) focus on A-H relative pricing. But mainlanders migrating between the A-B boards, which has been widely documented in the early months post reform, suggests their A-board sample may contain a structural shift. We address the preceding concerns by using minute-by-minute data from 4th Jan to 30th Sep 2005.

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<sup>24</sup>Yeh, Lee and Pen (2002) analyze the role of lagged pricing gap of A-share price over B-share price in affecting subsequent returns. Wang and Jiang (2004) examine factors that influence the pricing gap between A and H-share.

## INSERT TABLE 1

Both Sun and Tong (2000) and Wang and Jiang (2004) contain succinct yet informative institutional background on the Chinese stock market. Hence we provide only essential details in this paper. The SHSE and SZSE were established on 26th Nov 1990 and 11th Apr 1991 respectively. Table 1 provides basic listing details from Dec 2002 to Dec 2005. This includes market capitalization, turnover and number of listed firms on both the main and subsidiary boards. As at 31st Dec 2005, there are 824, 531 and 934 firms listed correspondingly on SHSE, SZSE and HKEx main boards. Trading on all three exchanges are divided into a morning and an afternoon session. For SHSE and SZSE, the pre-opening period is between 9:15am and 9:25am. The morning session is from 9:30am to 11:30am. Afternoon session trading is between 1:00pm and 3:00pm. On the HKEx, the pre-opening period is between 9:30am and 10:00am. Trading starts at 10:00am and breaks at 12:30pm. The market reopens at 2:30pm and closes for the day at 4:00pm.

## INSERT TABLE 2

Table 2 provides listing statistics on the A, B and H boards as at 31st Dec 2005. Shares listed on the SHSE or SZSE A-board are traded in Renminbi (RMB) and are restricted to mainlanders and (from Dec 2002) QFII.<sup>25</sup> As at 31st Dec 2005, there are 54 and 55 B-board firms listed on the SHSE and SZSE respectively. Trading on the B-board was restricted to foreign investors until Feb 2001, when mainlanders with legal foreign currency accounts (either USD or HKD) are allowed to trade B-shares. This, combined with the QFII rule, is

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<sup>25</sup>These are mainly global investment banks e.g. HSBC, JP Morgan Chase, Goldman Sachs, Standard Charter etc. As at Dec 2003, there are twelve licensed QFII with an aggregate investment quota of USD 1.7 billion.

a first step taken by the China Securities Regulatory Body (CSRB) to integrate the A and B boards. For a variety of reasons, the HKEx has a larger proportion of foreign investor participation than either SHSE or SZSE.<sup>26</sup> Thus listing on the H-board facilitates better access to foreign investors. Understandably, the H-board imposes more stringent listing and disclosure requirements. As at 31st Dec 2005, there are 80 H-board firms.

*Hypothesis, data and sampling*

We outline three hypotheses below to explore potential differences in the trading characteristics between the A and B/H boards.<sup>27</sup> These differences stem from the distribution of local/foreign and retail/institutional clientele participation on the various boards and the assertion that foreign institutional investors in emerging markets are informed investors. Some of the differences between the A-B and A-H group of firms could be driven by the fact that the A and B boards have been implicitly merged.

The first hypothesis examines the transitory price impact of trade direction observed on each of the twin boards. Given a large proportion of foreign institutional trading on the H-board and the fact that the A and B boards were implicitly merged, we expect  $\hat{\phi}_A > \hat{\phi}_H$  but do not expect a robust relationship between  $\hat{\phi}_A$  and  $\hat{\phi}_B$ . The second hypothesis examines the overall informativeness of trade directions in a given firm. Given a higher percentage of foreign institutional trading in the A-H group of firms, we expect trade directions observed

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<sup>26</sup>First, HKEx has a longer history and is more well-established. It imposes more rigorous listing requirements on potential new firms and information disclosure requirements on listed firms. Second, the HKEx trading environment is more “foreign investor-friendly”. E.g. SHSE/SZSE English-version website contain only very basic information, and combined to equal roughly a quarter of the amount of information provided on the HKEx website. Third, English versions of financial reports, press releases and other basic media documents are not readily available and/or are not translated in detail.

<sup>27</sup>In this paper, we do not differentiate between Shanghai and Shenzhen listed A-B firms. That is suitably explored as a separate empirical paper.

across the A-H boards to be more informative. The third hypothesis examines price leadership exhibited by each of the twin boards on the overall market. The fact that there are more informed foreign institutional traders active on the H-board and the implicit merger between the A and B board suggest stronger (mixed) evidence of H-board (B-board) leading A-board.

**Hypothesis 1: Transitory price impact of trade directions**

*Given more retail trading on the A-board relative to the H board, we expect the transitory price impact of trading to be greater on the A-board i.e.  $\hat{\phi}_A > \hat{\phi}_H$ . But given the A and B boards are implicitly merged, we do not expect any robust relationship between  $\hat{\phi}_A$  and  $\hat{\phi}_B$ .*

**Hypothesis 2: Permanent price impact of joint trade direction**

*Given more (less) informed institutional (retail) trading in the A-H (A-B) sample group, the permanent price impact of joint trade directions is more (less) evident in the A-H (A-B) sample group i.e.  $\hat{\theta}_{AH} > \hat{\theta}_{AB}$ .*

**Hypothesis 3: Price leadership**

*Given more informed institutional trading on the H-board and the implicit merger between the A and B boards, the H-board should provide price leadership over the A-board i.e.  $\delta_H > \rho_A$ , but the B-board may not exert a robust price leadership over the A-board.*

We use minute-by-minute Reuters data for A-B and A-H firms over the sample period 4th Jan to 30th Sep 2005. For A-H shares, we consider only data for when both boards are trading simultaneously.<sup>28</sup> This corresponds to two hours worth of data per day: 10:00am to 11:30am; 2:30pm to 3:00pm.<sup>29</sup> To reduce potential market opening/closing effects, we exclude the first and last five minutes from both sessions. As such, our sample considers trading from 10:05am to 11:24am and from 2:35pm to 2:54pm. This gives a total of 100 observations per trading day (80 in the morning; 20 in the afternoon). For consistency, we restrict our analysis of the A-B sample group to the same trading hours. The actual number

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<sup>28</sup>There is no time zone difference between China and Hong Kong.

<sup>29</sup>To note, trading on the HKEx commences at 10:00am and recommences at 2:30pm. Conversely, SHSE/SZSE markets break at 11:30am and closes at 3:00pm.

of trading days differs slightly between the A-B and A-H groups since the A and H boards are hosted by different exchanges.

While our comparisons between the A-B and A-H group of firms is explorative, it is still necessary to promote compatibility between the two sample groups. We address three issues. First is the proportion of tradable capital. Many Chinese firms remain majority state-owned, with non-tradable shares averaging 60%-70% of total issued shares. Second is the allocation of tradable shares. For a study on cross-market price formation, it appears to be a futile exercise to analyze a firm that has (say) 90% of its tradable shares allocated to one board and only 10% on the other. Third is an appropriate firm attribute to match A-B and A-H firms e.g. size, industry/sector group and leverage etc. Attempts to match based on multiple attributes resulted in either or both the A-B and A-H group containing only one or two firms. While more firms are matched based on a single firm attribute, the tradeoff is that any subsequent results could be driven by size, industry or leverage effects.

### INSERT TABLE 3

Table 3 provides basic details of the firms included in the two sample groups. Three selection criteria are imposed. First, only firms with tradable capital that is at least 30% of issued capital (the overall average in the 2005 CSRC report) are considered. Second, a firm must have at least 10% of issued capital allocated to each board. In addition, the tradable capital on the smaller board is at least one-fifth the size of the larger board.<sup>30</sup> Third, pairwise A-B and A-H firms are matched based on industry/sector classification, and various sectors

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<sup>30</sup>Indeed, while these values are ad-hoc, but robustness checks can be easily performed by varying the minimum 10% issued capital and/or the one-fifth size criterions.

of the Chinese economy are considered. In sum, the overall sample contains a pair of A-B and A-H firms in each of ten sectors of the Chinese economy. Each firm has an A-board sample and a B or H board sample. Each board sample contains 100 minute-by-minute observations per day. The sample period contains 170 trading days.

## 4 Empirical Results

The percentage of buyer and seller initiated trades for each firm are reported in Table 4. If no trade occurs at time  $t$  for Market  $X$ , then  $X_t = 0$  and  $p_{xt} = p_{x,t-1}$  i.e.  $r_{xt} = 0$ . The same applies for Market  $Y$ . The proportion of buy, sell and no-trade averaged over ten firms of a given board are also reported. To note, our sampling methodology imposes the same sample size for the two listing boards of a given firm. Table 4 indicates a similar proportion of buyer and seller initiated trades occur on a given board for a given firm.<sup>31</sup> This is expected since there is no reason ex-ante to expect more buying than selling, or vice versa, for a given firm on a given board over a given time period.

INSERT TABLE 4

The bottom of Table 4 reports the average trade classifications for A-H and A-B firms. In the A-H group, the mean proportion of buy and sell trades on the A-board are fairly even at 40.1% and 38.4% respectively. Slightly wider on the H-board, the mean buyer and seller trades are 13.4% and 9.4% respectively. Similarly, in the A-B group, A-board

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<sup>31</sup>E.g. China Shipping Development A-share sample contains 48% and 46% buyer and seller initiated trades respectively. Similarly, its H-share sample consists of 26% buy and 22% sell trades. Inner Mongolia Cashmere has about the same proportion of buy and sell trades on its A-board and 20% buy and 16% sell trades on its B-board.

generates an average of 36.9% buy and 35.4% sell trades. Again, the discrepancy is wider on the B-board, with an average of 26.5% buy and 18.9% sell trades being handled. The percentage of no-trade is higher on the B and H boards relative to the A-board across all firms. Furthermore, the difference in percentage of no-trade between the main and subsidiary boards is comparatively larger in the A-H sample group. The mean proportion of no-trade on the H-board is 77.2% compared with 54.6% being observed on the B-board.<sup>32</sup>

INSERT FIGURE 1

We illustrate daily price movement across the twin boards in Figure 1 using Guangdong Kelon (A-B) and BOE Tech (A-H) as representative cases.<sup>33</sup> To note, the price series that are denominated in either USD or HKD are converted to RMB using the corresponding average cross rate i.e. RMB/USD or RMB/HKD over the sample period. The graphs show that both Guangdong Kelon and BOE Tech A-shares trade at a premium over their B and H share counterparts. This is true for all firms in our sample, although the A-share premium is firm-specific. Figure 1 also shows similar movements by  $p_{xt}$  and  $p_{yt}$ , suggesting that information linkages do exist between the twin boards.

Before estimating and testing the two competing models, it is important to perform diagnostic tests on the trading dynamics between twin boards. Not only do they provide insights into the data, but the results from such diagnostic tests would often complement subsequent discussions on model estimation results.<sup>34</sup> In this paper, we consider three di-

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<sup>32</sup>E.g. Tsingtao Brewery has a 45% and 86% no-trade classification in its A and H sample respectively. In contrast, Yantai Changyu Winery has a 55% and 60% no-trade classification on its A and B board samples correspondingly

<sup>33</sup>The daily price and volume graphs for all 20 firms are available upon request.

<sup>34</sup>We thank an anonymous referee for reaffirming to us the importance of such diagnostic tests.

agnostic tests. First, we test for the optimal lag specification of each firm. This involves estimating a bivariate VAR for  $p_{xt}$  and  $p_{yt}$ . We specify a sufficiently long dynamics with a VAR(12), then perform a lag-exclusion Wald test of joint significance to determine the appropriate lags to truncate.<sup>35</sup> The optimal lag length, which is firm-specific, is applied in all subsequent empirical analysis. Second, we perform the Johansen cointegration test on  $p_{xt}$  and  $p_{yt}$ . It is inappropriate to fit a VECM if the twin shares are not cointegrated in the first place. Third, we test for Granger causality between  $p_{xt}$  and  $p_{yt}$ . To a certain extent, Granger causality test statistics supplement subsequent discussions on the board rankings by VECM and JTDM.<sup>36</sup>

#### INSERT TABLE 5

The test statistics and corresponding p-values for both cointegration and Granger causality tests are reported in Table 5. The optimal lag specifications for the various firms are also reported. Due to space constraint, we do not report or discuss Wald test statistics and AIC used to determine optimal lag length.<sup>37</sup> We report both the trace and max eigenvalue statistics from the Johansen cointegration test. Both test statistics reject the null hypothesis of no cointegrating relationship between  $p_{xt}$  and  $p_{yt}$  for all firms. The normalized cointegrating coefficients  $\tau$  are also reported. Since the error correction term is defined as  $Z_t = p_{xt} - \tau p_{yt}$ , the A-share premium implies  $\tau > 1$  for all firms. And since the A-share premium is firm-

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<sup>35</sup>It is possible for the test to indicate e.g. 3rd lags are jointly insignificant, 4th lags are jointly significant, and 5th lags and onwards are all jointly insignificant. This occurs in 6 out of 20 firms. We contrast the Akaike Information Criterion (AIC) for e.g. the VAR(2) and VAR(4) to decide which lag specification is optimal.

<sup>36</sup>While unidirectional causality in the trading dynamics between boards provide an indication of the relative informativeness of one board over the other, evidence of bidirectional causality does not allow one to conclude which board performs more price discovery.

<sup>37</sup>Both test statistics and corresponding discussions are available upon request.

specific, our results show that  $\tau$  ranges from as low as 1.086 for Tsingtao Brewery to as high as 12.31 for Mongolia Cashmere. Pairwise Granger causality test statistics are also reported. We find evidence of bidirectional causality between the twin boards in 16 out of 20 firms. There is evidence of unidirectional causality in the 4 remaining firms (A to B/H board in 3 firms; H to A board for Guangdong Kelon). Results for these 4 firms may be useful later on if VECM and JTDM were to provide conflicting rankings between the two boards.

#### INSERT TABLE 6

VECM estimation results are reported in Table 6, which shows that the lag specification ranges from as short as 1-lag for Livzon Pharmaceutical to 7-lags for Zhenhua Port Machinery. For all firms,  $\gamma_x < 0$  and  $\gamma_y > 0$ . These are mechanical outcomes that correspond to the cointegrating vector being defined as  $p_{xt} - \tau p_{yt}$ . Intuitively, if  $p_{xt} - \tau p_{yt} < 0$  is caused by  $p_{yt}$  being too high, the error correction mechanism would involve a downward adjustment on  $r_{yt+1}$ . This is delivered by  $\gamma_y(p_{xt} - \tau p_{yt}) < 0$ . Similarly, if  $p_{xt} - \tau p_{yt} < 0$  is caused by  $p_{xt}$  being too low, the error correction mechanism is triggered by  $\gamma_x(p_{xt} - \tau p_{yt}) > 0$ . This would adjust  $r_{xt+1}$  upwards. The magnitudes of  $\gamma_x$  and  $\gamma_y$  will reflect the extent of error correction by  $r_{xt}$  and  $r_{yt}$ , which is the VECM's measure of cross-market price discovery.

There are 14 firms in our sample where both  $\gamma_x$  and  $\gamma_y$  are significant. In the other 6 firms, either  $\gamma_x$  or  $\gamma_y$  is significant. For Guangdong Electric, only  $\gamma_x$  is significant. This is consistent with the causality results in Table 5, which indicate Guangdong Electric as 1 of 3 firms where causality runs from the H to A board. The reverse description applies to BOE Tech. Table 5 indicates that causality runs from the A to B board. This is consistent with

the VECM estimation indicating that only  $\gamma_y$  is significant. For Huadian Power, causality runs from A to H board, and this is again picked by the VECM indicating an insignificant  $\gamma_x$ . Where only  $\gamma_x$  or  $\gamma_y$  is significant, their magnitudes are less relevant. The significance of (say)  $\gamma_x$  and insignificance of  $\gamma_y$  show that the error correction mechanism is relevant to  $r_{xt}$ , but not to  $r_{yt}$ , revealing the informational dominance of Market  $Y$  over Market  $X$ .<sup>38</sup>

#### INSERT TABLE 7

Results from JTDM estimation are reported in Table 7. For Hypothesis 1, the results show that  $\hat{\phi}_A > \hat{\phi}_H$  in 7 out of 10 firms. A higher proportion of institutional trading on the subsidiary H-board relative to the main board provides depth to the market, which resulted in lower transitory price impact of trading. For Guangzhou Shipyard and NE Electric, although  $\hat{\phi}_A < \hat{\phi}_H$ , neither of the coefficients are significant. Huadian Power is the only exception, with  $\hat{\phi}_A < \hat{\phi}_H$  and both are significant. For the A-B group,  $\hat{\phi}_A > \hat{\phi}_B$  in five firms;  $\hat{\phi}_A < \hat{\phi}_B$  in four firms and  $\hat{\phi}_A = \hat{\phi}_B$  for Hainan Airline. This also provides support for Hypothesis 1 that results on transitory price impact in the A-B group are mixed due to the blurring distinction between market participants on the A and B boards.

For Hypothesis 2,  $\hat{\theta}$  is positive and significant for all firms, constituting evidence that joint trade direction is relevant to cross market price formation. In 6 out of 10 sectors,  $\hat{\theta}_{AH} > \hat{\theta}_{AB}$ , which provides some evidence that trade direction in the A-H group of firms, which possess a higher proportion of institutional trading, is more informative. To reiterate, there is a link between  $\theta$ , which measures the overall relevance of joint trade direction on  $\{r_{xt}, r_{yt}\}$ , and the relative dominance of each of the twin-boards' trade direction on  $\{r_{xt}, r_{yt}\}$  as measured

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<sup>38</sup>This mirrors an earlier discussion on unidirectional and bidirectional causality.

by  $\rho$  and  $\delta$ . In 6 sectors, the price leadership outcomes differ between the two firms. E.g For Liquor, Transport and Telecommunication,  $\hat{\rho}_A < \hat{\delta}_H$  but  $\hat{\rho}_A > \hat{\delta}_B$ . For Pharmaceutical, Shipyard and R&D,  $\hat{\rho}_A > \hat{\delta}_H$  but  $\hat{\rho}_A < \hat{\delta}_B$ . Interestingly, if we contrast this with the results on  $\hat{\theta}$ , we find that for all 6 sectors where the H (B) board exhibits price leadership and the B (H) board does not, the joint trade direction has a larger permanent price impact for the A-H (A-B) firm i.e If  $\hat{\rho}_A < \hat{\delta}_H$  and  $\hat{\rho}_A > \hat{\delta}_B$ , then  $\hat{\theta}_{AH} > \hat{\theta}_{AB}$ , and vice versa.

For Hypothesis 3,  $\hat{\rho} < \hat{\delta}$  in 5 out of 10 firms in both the A-B and A-H sample groups. While this outcome is expected in the A-B sample group since the twin-boards have been implicitly merged, we did expect stronger evidence of price leadership by the H-board. Upon examining the results further, we notice that the 5 A-H firms where  $\hat{\rho}_A > \hat{\delta}_H$  include 3 of the most illiquid H-boards in the A-H group. From Table 4, they are Shandong Pharmaceutical (97% no-trade), Jingwei Textile (96% no-trade) and NE Electric (91% no-trade). At least for these three firms, the fact that there is a lack of H-share trading suggests limited potential for trade directions on the H-board to provide price leadership to the A-board.

#### INSERT TABLE 8

The last set of results, reported in Table 8, contrast the twin-board rankings by VECM and JTDM and in the process discuss Wald and J-test statistics when the competing models generate conflicting rankings. First, we discuss the twin-board rankings by VECM and JTDM for all firms. Second, we provide more discussions on group-specific results.

The models generate consistent ranking in 6 out of 20 firms. The latter consists of 4 A-H firms (China Shipping, Southern Airline, ZTE Corporation and Guangdong Kelon) and 2

A-B firms (Shandong Zhenhua and Livzon Pharmacy). For all 6 firms, VECM and JTDM are unanimous in ranking the B/H board above the A-board in price discovery. Interestingly, these 6 firms happen to possess some of the lowest percentage of no-trade observations in their B or H board samples: China Shipping (52%), Shanghai Zhenhua Port (36%), ZTE Corp (59%), Southern Airline (65%) and Guangdong Kelon (69%). These results show that while trading on the B or H boards do not match the A-board in terms of liquidity, but so long as there is some trading activity, the subsidiary boards do contribute to price discovery.

For the remaining 14 firms, we apply the Wald test and J test statistics. If either or both tests reject one model in favor of another, then this constitutes evidence of one model providing a better fit and thus a more accurate ranking of the twin boards. If both tests fail to indicate a preferred model<sup>39</sup>, then we would be unable to conclude as to board is more informative. For Yangtai Winery and Huadian Power, the Wald test and J-test both reject VECM in favor of JTDM. For both firms, JTDM ranks the A-board above the B and H boards. For 9 firms, one test is able to reject one model over the other, while the other test is inconclusive. Of these firms, JTDM is the preferred model in 6 firms, and ranks the A-board above the B or H board in 4 of the 6 firms. The VECM is the preferred model in 3 firms, and ranks the B-board above the A-board in 2 of the 3 firms. For the 3 firms that remain, VECM and JTDM provide conflicting rankings and both the Wald nor J-test are unable to reject one model in favor of the other. They are Hainan Airline, Mongolia Cashmere and BOE Tech, all of which are A-B firms

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<sup>39</sup>This arises when both Wald and J-Test statistics reject or fail to reject the VECM and JTDM, or when the Wald test statistic rejects the VECM (JTDM) and the J-test statistic rejects the JTDM (VECM).

In the A-H sample group, the A and H boards are evenly matched in the A-H sample group with one board performing more price discovery than the other in 5 firms. In Table 4, note that the 5 A-H firms for which the A-board performs more price discovery happen to possess the highest percentage of no-trades on their H-boards (Shandong Xinhua (97%), Jingwei Textile (96%), NE Electric (91%), Guangzhou Shipyard (79%) and Huadian Power (78%)). In terms of model performance, VECM and JTDM generate consistent rankings in 4 A-H firms, with the Wald and/or J-test favoring the JTDM over the VECM in the remaining 6 A-H firms. From the Granger causality results, there are 4 firms where only unidirectional causality is detected. For Huadian Power and NE Electric, there is causality running from the A to H board. In the board and model ranking results for both firms, JTDM (VECM) ranks the A (H) board above the H (A) board, and both Wald and/or J-test rejects VECM in favor of JTDM. For Guangdong Kelon, causality runs only from H to A board. Both VECM and JTDM ranks H above A as well.

In the A-B sample group, B-board is ranked above A-board in 5 firms; A-board ranks higher in 2 firms; both board and model rankings are inconclusive for the 3 remaining A-B firms. In terms of model performance, VECM and JTDM generate consistent ranking in 2 A-B firms; the Wald and/or J-test favors JTDM over the VECM in 2 firms and the VECM over JTDM in 3 firms. In relation to the A-H sample group, the preceding results reveal inconsistencies in terms of which is the preferred model. In the 8 firms where the models generate conflicting rankings, VECM is preferred in 3 firms, JTDM is preferred in 2 firms and model test statistics are inconclusive in 3 firms.

In sum, JTDM is clearly the preferred model in the A-H sample group. In 6 firms where VECM and JTDM generate conflicting rankings, the Wald and/or J-test rejects VECM in favor of JTDM. Since JTDM focuses on trade direction parameters across the twin-boards, it incorporates possible institutional stealth trading in modeling cross-market price formation. While the A-board ranks above the H-board in 5 firms, these 5 firms suffer from severe illiquidity on their H-board. In the A-B sample group, results are not as consistent. We attribute this to the fact that with the A and B boards implicitly merged, it would be harder for models and model selection tests to distinguish between A and B samples simply because the A and B boards themselves are no longer distinct. To be sure, it is never our intent to replace the VECM measure. We propose the JTDM to complement the VECM measure by acknowledging the possibility that for certain markets, cross-market price discovery could be driven by non-price parameters. The results from the A-H sample group shows that JTDM is able to incorporate informed trading better than VECM by taking into account serial correlation in trade directions induced by institutional investor stealth trading.

## 5 Concluding Remarks

In this paper, we derive a two dimensional version of the single market MRR (1997) trade direction model. The mixed-signal state and corresponding transition probability  $\mathbb{P}(X_t = 0) = \frac{1-\lambda}{2}$  in the MRR model are less relevant to price discovery, given that a trade being straddled by the prevailing spread could be mechanically induced. In contrast, our JTDM considers the trade directions simultaneously observed on two substitute markets. Since  $X_t$  and  $Y_t$  are each a dichotomy, the mixed-signal states and their transition probabilities

$\mathbb{P}(X_t = X_{t-1}, Y_t = -Y_{t-1} | X_{t-1}, Y_{t-1}) = \lambda_X$  and  $\mathbb{P}(X_t = -X_{t-1}, Y_t = Y_{t-1} | X_{t-1}, Y_{t-1}) = \lambda_Y$  become a meaningful new measure of price leadership across two substitute markets. The emphasis of the JTDM is to measure the likelihood of one market following the other in the next state conditional on opposite trade directions being observed in the current state.

The empirical application on the Chinese stock market provides a platform to test the competing models to investigate the relevance of price versus non-price parameters in cross-market price discovery. In the A-H sample group, the VECM and JTDM provides consistent rankings in 4 firms, with both ranking the H-board above the A-board. JTDM is the preferred model for the remaining 6 A-H firms, revealing the model's ability to incorporate institutional investor stealth trading into subsequent cross-market price formation. JTDM ranks the A above the H-board in the 5 firms that exhibit a severe lack of trading on their H-boards. Results from the A-B sample group on rankings and model test statistics are both mixed. VECM and JTDM give conflicting rankings in 8 firms; VECM is the preferred model in 3 firms; JTDM is the preferred model in 2 firms; Wald and J-test are unable to distinguish between the two models for the remaining 3 A-B firms. We stipulate that this is not completely surprising given mainland investors are able to trade B-shares and foreign institutional investors are able to trade A-shares. The results do imply potential efficiency gains under a unified listing board.

There are two extensions for the JTDM. First, introduce non-zero off-diagonal terms to  $\Sigma$ . As the current model adopts a doubly stochastic transition matrix  $P$  that centers symmetrically around zero, the off-diagonal terms in  $\Sigma$  are always zero. One remedy is to make  $P$  asymmetric by allowing potential asymmetry price impact of buy versus sell trades.

Denote  $\mathbb{P}(X_t = Y_t = 1|X_{t-1} = Y_{t-1} = 1) = \gamma_b$  and  $\mathbb{P}(X_t = Y_t = -1|X_{t-1} = Y_{t-1} = -1) = \gamma_s \neq \gamma_b$  such that  $P$  becomes asymmetric, which then allows  $\Sigma$  to contain non-zero cross-serial covariance terms.<sup>40</sup> Second, expand the state space for  $X_t$  and  $Y_t$  to  $\{+1, 0, -1\}$  to formally acknowledge the no-trade scenario. This allows us to potentially construct a model that measures price discovery from the occurrence of trades as well as the absence of trades. The absence of trade and subsequent price formation is addressed in Easley and O'Hara (1993). Both theoretical extensions are currently being pursued as separate papers.

To reiterate, our results across 10 sectors of the Chinese economy show that when VECM and JTDM generate inconsistent rankings in 14 out of 20 firms, the Wald and J-test statistics rejects the VECM in favor of the JTDM in 6 A-H firms and 2 A-B firms. This suggests that trade direction is more informative than quote change history to cross-market price formation in some cases. The relevance of joint trade direction to cross market price discovery is case-specific and depends on the proportion of trading that the substitute markets handle. As such, the possible relevance of joint trade direction to cross-market price formation must be considered. This constitutes our motivation for deriving the JTDM, and represents this paper's key contribution to the existing literature. Whether a comprehensive theoretical model that incorporates both price and non-price parameters is able to outperform both VECM and JTDM remains to be seen.

**THE END**

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<sup>40</sup>We agree with the referee that this is an important feature for the JTDM to incorporate. In our previous attempts, the subsequent empirical form of the JTDM is close to 1-page long. We are currently working on a way to substitute  $\Sigma$  with non-zero off diagonal terms into equation (7).

## References

- [1] Al-Suhaibani, M., Kryzanowski, L., 2000. The information content of orders on the Saudi stock market. *Journal of Financial Research* 23, 145-156.
- [2] Chng, M., 2004. The trading dynamics of close-substitute futures markets: Evidence of margin policy spillover effects. *Journal of Multinational Financial Management* 14, 463-483.
- [3] Chung, K., Li, M., McInish, T., 2005. Information-based trading, price impact of trades, and trade autocorrelation. *Journal of Banking and Finance* 29, 1645-1669.
- [4] Covrig, V., Ding, D., Low, B., 2004. The Contribution of a Satellite Market to Price Discovery: Evidence from the Singapore Exchange. *Journal of Futures Markets* 24, 981-1004.
- [5] Davidson, R., MacKinnon, R., 1981. Several tests for model specification in the presence of alternative hypotheses. *Econometrica* 49, 781-793.
- [6] Dufour, A., Engle, R., 2000. Time and the price impact of a trade. *Journal of Finance* LV, 2467-2498.
- [7] Domowitz, I., 1995. Electronic Derivatives Exchanges: Implicit Mergers, Network Externalities, and Standardization. *Quarterly Review of Economics and Finance* 35, 163-175.
- [8] Ellis, K., Michaely, R., and O'Hara, M., 2000. The accuracy of trade classification rules. *Journal of Financial and Quantitative Analysis* 35, 529-551.
- [9] Engle, R., Patton, A., 2004. Impacts of trades in an error-correction model of quote prices. *Journal of Financial Markets* 7, 1-25.
- [10] Engle, R., Russell, J., 1998. Autoregressive conditional duration: A new model for irregularly spaced transaction data. *Econometrica* 66, 1127-1162.
- [11] Easley, D., O'Hara, M., 1987. Price, trade size, and information in securities markets. *Journal of Financial Economics* 19, 69-90.
- [12] Easley, D., O'Hara, M., 1992. Time and the process of security price adjustment. *Journal of Finance* 47, 576-605.
- [13] Fishel, D., Grossman, S., 1984. Customer Protection in Futures and Securities Markets. *Journal of Futures Markets* 4, 273-295.
- [14] Gonzalo, J., Granger, C., 1995. Estimation of common long memory components in cointegrated systems. *Journal of Business and Economic Statistics* 13, 27-35.
- [15] Glosten, L., Milgrom, P., 1985. Bid, ask and transaction prices in a specialist market with heterogeneously informed investors. *Journal of Financial Economics* 13, 71-100.

- [16] Hamilton, J., 1994. *Time Series Analysis*. Princeton University Press.
- [17] Harris, F., McInish, T.H., Shoesmith, G., Wood, R., 1995. Cointegration, error correction and price discovery in Informationally Linked Security Markets. *Journal of Financial and Quantitative Analysis* 30, 563-579.
- [18] Harris, F., McInish, Wood, R., 2002. Security price adjustment across exchanges: An investigation of common factor components for Dow stocks. *Journal of Financial Markets* 5, 277-308.
- [19] Hasbrouck, J., 1991. The summary informativeness of stock trades: An econometrics analysis. *Review of Financial Studies* 4, 571-595.
- [20] Hasbrouck, J., 1995. One security, many markets: Determining the contributions to price discovery. *Journal of Finance* 50, 1175-1199.
- [21] Lee, C., Rui, O., 2000. Does trading volume contain information to predict stock returns? Evidence from China's stock markets. *Review of Quantitative Finance and Accounting*, 14, 341-360.
- [22] Lehmann, B.N., 2002. Some desiderata for the measurement of price discovery across markets. *Journal of Financial Markets* 5, 259-276.
- [23] Lee, C.F., Ready, M., 1991. Inferring trade direction from intraday data. *Journal of Finance* 46, 733-746.
- [24] Mizon, G., Richard, J., 1986. The encompassing principle and its application to testing nontested models. *Econometrica* 54, 657-678.
- [25] Madhavan, A., Richardson, M., Roomans, M., 1997. Why do security prices change? A transaction-level analysis of NYSE stocks. *Review of Financial Studies* 10, 1035-1064.
- [26] Noia C Di., 2001. Competition and Integration among Stock Exchanges in Europe: Network Effects, Implicit Mergers and Remote Access. *European Financial Management* 7, 39-72.
- [27] Stock, J.H., Watson, M.W., 1988. Variable trends in economic time series. *Journal of Economic Perspective* 2, 147-174.
- [28] Sun, Q., Tong, H.S., 2000. The effect of market segmentation on stock prices: The China syndrome. *Journal of Banking and Finance* 24, 1875-1902.
- [29] Wang, S., Jiang, L., 2004. Location of trade, ownership restrictions, and market illiquidity: Examining Chinese A-H shares. *Journal of Banking and Finance* 28, 1273-1297.
- [30] Yeh, Y., Lee, T., Pen, J., 2004. Stock return and volatility under market segmentation: The case of Chinese A and B shares. *Review of Quantitative Finance and Accounting* 18, 239-257.

# Appendix

Notations

$\mu_t$ : Implicit efficient price

$\theta$ : Permanent price impact of joint trade innovation

$\phi(\delta)$ : Serial correction in trade direction  $X_t(Y_t)$

$\phi_x(\phi_y)$ : Transitory price impact of trade direction  $X_t(Y_t)$

$p_{xt}(p_{yt})$ : Observed traded price on Market  $X(Y)$

$\xi_{xt}(\xi_{yt})$ : Transitory microstructural effects on Market  $X(Y)$

$$m_t = m_{t-1} + \theta(X_t + Y_t - \mathbb{E}(X_t + Y_t | X_{t-1}, Y_{t-1})) + \epsilon_t$$

$$p_{xt} = m_t + \phi_x X_t + \xi_{xt}$$

$$p_{yt} = m_t + \phi_y Y_t + \xi_{yt}$$

## Derivation of the JTDM

$$\begin{aligned} \mathbb{E}(X_t + Y_t | X_{t-1}, Y_{t-1}) &= (2(\gamma + \lambda_X) - 1)X_{t-1} + (2(\gamma + \lambda_Y) - 1)Y_{t-1} \\ &= \rho(X_{t-1}) + \delta(Y_{t-1}) \text{ (derived below)} \end{aligned}$$

$$\begin{aligned} \Delta p_{xt} &= \theta(X_t + Y_t) - \theta(\mathbb{E}(X_t + Y_t | X_{t-1}, Y_{t-1})) + \phi_x(\Delta X_t) + \Delta \xi_{xt} + \epsilon_t \\ &= \theta(X_t + Y_t) - \theta(\rho X_{t-1} + \delta Y_{t-1}) + \phi_x(\Delta X_t) + \theta(X_{t-1}) - \theta(X_{t-1}) \\ &\quad + \theta(Y_{t-1}) - \theta(Y_{t-1}) + \Delta \xi_{xt} + \epsilon_t \\ &= (\theta + \phi_x)(\Delta X_t) + \theta(\Delta Y_t) + \theta(1 - \rho)X_{t-1} + \theta(1 - \delta)Y_{t-1} + \Delta \xi_{xt} + \epsilon_t \end{aligned}$$

$$\begin{aligned} \Delta p_{yt} &= \theta(X_t + Y_t) - \mathbb{E}(X_t + Y_t | X_{t-1}, Y_{t-1}) + \phi_y(\Delta Y_t) + \Delta \xi_{yt} + \epsilon_t \\ &= \theta(X_t + Y_t) - \theta(\rho X_{t-1} + \delta Y_{t-1}) + \phi_y(\Delta Y_t) + \theta(X_{t-1}) - \theta(X_{t-1}) \\ &\quad + \theta(Y_{t-1}) - \theta(Y_{t-1}) + \Delta \xi_{yt} + \epsilon_t \\ &= (\theta + \phi_y)(\Delta Y_t) + \theta(\Delta X_t) + \theta(1 - \rho)(X_{t-1}) + \theta(1 - \delta)(Y_{t-1}) + \Delta \xi_{yt} + \epsilon_t \end{aligned}$$

Using transition matrix equation (8) we have  $\mathbb{P}(X_t, Y_t) = (i, j) = \frac{1}{4}$ ,  $\mathbb{P}(X_t = 1) = \mathbb{P}(X_t = -1) = \frac{1}{2}$ , which means  $\mathbb{E}(X_t) = 0$ ,  $\text{Var}(X_t) = 1$

By symmetry,  $\mathbb{E}(Y_t) = 0$ ,  $\text{Var}(Y_t) = 1$  and

$$\text{Cov}(X_t, Y_t) = \mathbb{E}(X_t Y_t) = \mathbb{P}(X_t = Y_t = 1) + \mathbb{P}(X_t = Y_t = -1) - 2\mathbb{P}(X_t \neq Y_t) = 0.$$

$$\begin{aligned}
\mathbb{P}(X_t = X_{t-1} = 1) &= \mathbb{P}(X_t = X_{t-1} = Y_t = Y_{t-1} = 1) + \mathbb{P}(X_t = X_{t-1} = 1, Y_t = Y_{t-1} = -1) \\
&\quad + \mathbb{P}(X_t = X_{t-1} = 1, Y_t = 1, Y_{t-1} = -1) + \mathbb{P}(X_t = X_{t-1} = 1, Y_t = -1, Y_{t-1} = 1) \\
&= \frac{1}{4}[\mathbb{P}(X_t = 1, Y_t = -1 | X_{t-1} = 1, Y_{t-1} = -1) + \mathbb{P}(X_t = 1, Y_t = -1 | X_{t-1} = 1, Y_{t-1} = 1) \\
&\quad + \mathbb{P}(X_t = 1, Y_t = 1 | X_{t-1} = 1, Y_{t-1} = -1) + \mathbb{P}(X_t = 1, Y_t = 1 | X_{t-1} = 1, Y_{t-1} = 1)] \\
&= \frac{1}{2}(\gamma + \lambda_x) = \mathbb{P}(X_t = X_{t-1} = -1)
\end{aligned}$$

which implies  $\mathbb{P}(X_t = X_{t-1}) = \gamma + \lambda_x$ .

Similarly, we have  $\mathbb{P}(X_t = 1, X_{t-1} = -1) = \mathbb{P}(X_t = -1, X_{t-1} = 1) = \frac{1}{2}(1 - \gamma - \lambda_x)$  such that  $\mathbb{P}(X_t \neq X_{t-1}) = 1 - \gamma - \lambda_x$ . Hence  $\text{Cov}(X_t, X_{t-1}) = \mathbb{E}(X_t X_{t-1}) = \mathbb{P}(X_t = X_{t-1}) - \mathbb{P}(X_t \neq X_{t-1}) = 2(\gamma + \lambda_x) - 1 = \rho$ .

The proof for  $Y_t$  is similar, such that we obtain:

$$\begin{aligned}
\mathbb{P}(Y_t = Y_{t-1} = 1) &= \mathbb{P}((Y_t = Y_{t-1} = -1) = \frac{1}{2}(\gamma + \lambda_y), \\
\mathbb{P}(Y_t = 1, Y_{t-1} = -1) &= \mathbb{P}(Y_t = -1, Y_{t-1} = 1) = \frac{1}{2}(1 - \gamma + \lambda_y), \\
\text{Cov}(Y_t, Y_{t-1}) &= \mathbb{E}(Y_t Y_{t-1}) = 2(\gamma + \lambda_y) - 1 = \delta.
\end{aligned}$$

Set the linear predictor  $\Sigma \begin{pmatrix} X_{t-1} \\ Y_{t-1} \end{pmatrix}$  for  $\begin{pmatrix} X_t \\ Y_t \end{pmatrix}$  to minimize

$$\mathbb{E} \left( \left( \begin{pmatrix} X_t \\ Y_t \end{pmatrix} - \Sigma \begin{pmatrix} X_{t-1} \\ Y_{t-1} \end{pmatrix} \right)^T \times \left( \begin{pmatrix} X_t \\ Y_t \end{pmatrix} - \Sigma \begin{pmatrix} X_{t-1} \\ Y_{t-1} \end{pmatrix} \right) \right),$$

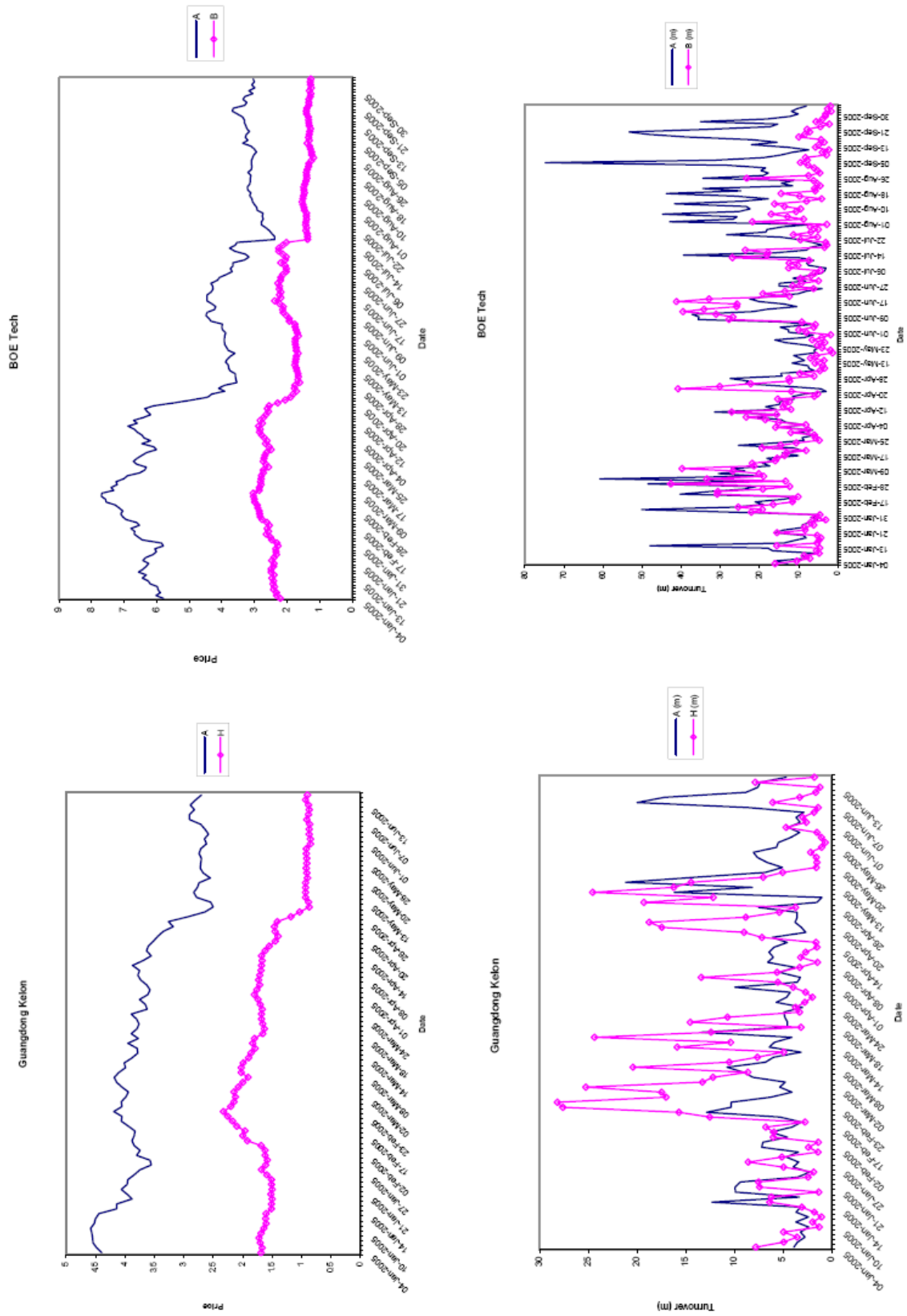
where  $\Sigma$  satisfies:

$$\Sigma \begin{pmatrix} \text{Cov}(X_t, X_{t-1}) & \text{Cov}(X_t, Y_{t-1}) \\ \text{Cov}(Y_t, X_{t-1}) & \text{Cov}(Y_t, Y_{t-1}) \end{pmatrix} = \begin{pmatrix} 2(\gamma + \lambda_x) - 1 & 0 \\ 0 & 2(\gamma + \lambda_y) - 1 \end{pmatrix},$$

which implies

$$\begin{aligned}
\mathbb{E}(X_t + Y_t | X_{t-1}, Y_{t-1}) &= (2(\gamma + \lambda_x) - 1)X_{t-1} + (2(\gamma + \lambda_y) - 1)Y_{t-1} \\
&= \rho X_{t-1} + \delta Y_{t-1}.
\end{aligned}$$

Figure 1: Daily price and turnover volume graphs for the twin boards



**Table 1:** Basic listing details on each of the three stock exchanges

	As at 30 <sup>th</sup> Dec 2005	30 <sup>th</sup> Dec 2004	30 <sup>th</sup> Dec 2003	30 <sup>th</sup> Dec 2002	30 <sup>th</sup> Dec 2005	30 <sup>th</sup> Dec 2004	30 <sup>th</sup> Dec 2003	30 <sup>th</sup> Dec 2002
<b>Panel A: HKEx</b>								
	<b>Main Board</b>				<b>GEM</b>			
No. of listed companies	934	892	852	812	201	204	185	166
No. of listed H shares	80	72	64	54	40	37	28	20
No. of listed red-chips stocks	86	81	72	71	3	3	0	1
Total no. of listed securities	2448	1971	1598	1416	201	205	187	170
Total market capitalisation (bil)	HKD 8,113	HKD 6,629	HKD 5,478	HKD 3,559	HKD 67	HKD 67	HKD 70	HKD 52
Total negotiable capitalisation (bil)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Average P/E ratio (Times)	15.57	18.73	18.96	14.89	22.94	28.65	38.79	21.75
Total turnover (m shares)	21104	20122	6504	2943	106	52	116	68
Total turnover (m)	HKD 18,500	HKD 9,724	HKD 10,921	HKD 1,693	HKD 85	HKD 33	HKD 98	HKD 37
<b>Panel B: SHSE</b>								
	<b>A-Share</b>				<b>B-Share</b>			
No. of listed companies	824	827	770	705	54	54	54	54
Total market capitalisation (bil)	RMB 2,286	RMB 2,571	RMB 2,940	RMB 2,492	RMB 24	RMB 30	RMB 40	RMB 44
Total negotiable capitalisation (bil)	RMB 651	RMB 705	RMB 780	RMB 702	RMB 24	RMB 30	RMB 40	RMB 44
Average P/E ratio (Times)	16.38	24.29	36.64	34.5	12.4	20.15	30.32	30.61
Total turnover (m shares)	1980	810	1428	633	23	21	28	18
Total turnover (m shares)	RMB 10,128	RMB 4,624	RMB 11,004	RMB 5,752	RMB 68	RMB 74	RMB 145	RMB 81
<b>Panel B: SZSE</b>								
	<b>A-Share</b>				<b>B-Share</b>			
No. of listed companies	531	522	491	496	55	56	57	56
Total market capitalisation (bil)	RMB 895	RMB 1,060	RMB 1,212	RMB 1,247	RMB 36	RMB 42	RMB 50	RMB 34
Total negotiable capitalisation (bil)	RMB 351	RMB 395	RMB 451	RMB 463	RMB 35	RMB 37	RMB 44	RMB 30
Average P/E ratio (Times)	16.96	0	0	0	9.11	0	0	0
Total turnover (m shares)	1137	517	635	374	25	42	74	13
Total turnover (m shares)	RMB 5,629	RMB 2,850	RMB 4,551	RMB 3,079	RMB 88	RMB 185	RMB 402	RMB 48

**Table 3:** Selected firms, number (millions) and proportion of issued capital shares

Industry	Matched AB-AH firms	RIC code	Total	A	B/H	Non-tradable
Heavy machinery	China Shipping Development	600026.SS	3326	451	1296	1579
		1138.HK	(100%)	(14%)	(39%)	(47%)
	Shanghai Zhenhua Port Machinery	600320.SS	1541	435	330	776
		900947.SS	(100%)	(28%)	(21%)	(51%)
Liquor	Tsingtao Brewery	600600.SS	1308	200	655	453
		168.HK	(100%)	(15%)	(50%)	(35%)
	Yantai Changyu Pioneer Wine	000869.SZ	406	50	137	219
		200869.SZ	(100%)	(12%)	(34%)	(54%)
Transport	China Southern Airline	600029.SS	4374	1000	1174	2200
		1055.HK	(100%)	(23%)	(27%)	(50%)
	Hainan Airline	600221.SS	730	372	185	173
		900945.SS	(100%)	(51%)	(25%)	(24%)
Pharmacy	Shandong Xinhua Pharmaceutical	000756.SZ	457	76	150	231
		719.HK	(100%)	(17%)	(33%)	(51%)
	Livzon Pharmaceutical	200513.SZ	306	116	122	68
		000513.SZ	(100%)	(38%)	(40%)	(22%)
Textile	Jingwei Textile Machinery	000666.SZ	604	203	181	330
		350.HK	(100%)	(34%)	(30%)	(36%)
	Inner Mongolia Cashmere	600295.SS	1032	192	420	420
		900936.SS	(100%)	(18%)	(41%)	(41%)
Telecom	ZTE Corporation	000063.SZ	960	376	160	424
		763.HK	(100%)	(39%)	(17%)	(44%)
	Eastern Communications	600776.SS	628	118	150	360
		900941.SS	(100%)	(19%)	(24%)	(57%)
Utility	Huadian Power	600027.SS	5590	569	1431	3590
		1071.HK	(100%)	(10%)	(26%)	(64%)
	Heilongjiang Energy	600726.SS	1126	195	432	499
		900937.SS	(100%)	(17%)	(38%)	(45%)
Shipyard	Guangzhou Shipyard	600685.SS	495	126	157	212
		317.HK	(100%)	(25%)	(32%)	(43%)
	Shenzhen Chiwan Wharf	000725.SZ	645	85	180	380
		200725.SZ	(100%)	(13%)	(28%)	(59%)
Electrical	Guangdong Kelon Electrical	000921.SZ	992	195	460	337
		921.HK	(100%)	(20%)	(46%)	(34%)
	BOE Tech Group	000725.SZ	2196	262	1116	818
		200725.SZ	(100%)	(12%)	(51%)	(37%)
R&D	NE Electric Development	000585.SZ	873	144	258	471
		42.HK	(100%)	(16%)	(30%)	(54%)
	Guangdong Electric Power Development	000539.SZ	2659	513	665	1481
		200539.SZ	(100%)	(19%)	(25%)	(56%)
Average (A-H firms)				21%	33%	46%
Average (A-B firms)				22%	33%	45%

**Table 4:** Basic trading features

Matched AB-AH firms	Total		Buyer-initiated trades		No trade		Seller-initiated trades	
	A	B/H	A	B/H	A	B/H	A	B/H
China Shipping Development	20,733 (100%)	20,733 (100%)	9,888 (48%)	5,356 (26%)	1,253 (6%)	10,741 (52%)	9,592 (46%)	4,636 (22%)
Shanghai Zhenhua Port Machinery	21,480 (100%)	21,480 (100%)	10,424 (48%)	7,670 (36%)	844 (4%)	7810 (36%)	10,212 (48%)	6,000 (28%)
Tsingtao Brewery	21,000 (100%)	21,000 (100%)	6,257 (30%)	1,700 (8%)	9,442 (46%)	18,035 (86%)	5,301 (25%)	1,265 (6%)
Yantai Changyu Pioneer Wine	21,360 (100%)	21,360 (100%)	5,128 (24%)	5,266 (25%)	11,795 (55%)	12,832 (60%)	4,437 (21%)	3262 (15%)
China Southern Airline	20,880 (100%)	20,880 (100%)	10,121 (48%)	4274 (20%)	656 (4%)	13,533 (65%)	10,103 (48%)	3,073 (15%)
Hainan Airline	21,360 (100%)	21,360 (100%)	8,412 (39%)	2,571 (12%)	4,104 (19%)	17,194 (80%)	8,844 (42%)	1,595 (8%)
Shandong Xinhua Pharmaceutical	21,000 (100%)	21,000 (100%)	6,533 (31%)	457 (2%)	8,727 (42%)	20,333 (97%)	5,740 (27%)	210 (1%)
Livzon Pharmaceutical	21,840 (100%)	21,840 (100%)	6,763 (31%)	5,839 (27%)	8,917 (42%)	11,151 (51%)	6,160 (28%)	4,850 (22%)
Jingwei Textile Machinery	20,760 (100%)	20,760 (100%)	7,709 (37%)	567 (3%)	5,438 (26%)	19,991 (96%)	7,613 (37%)	202 (1%)
Inner Mongolia Cashmere	21,720 (100%)	21,720 (100%)	7,448 (34%)	4,435 (20%)	7,418 (34%)	13,876 (64%)	6,854 (32%)	3,409 (16%)
ZTE Corporation	20,760 (100%)	20,760 (100%)	9,185 (44%)	5,354 (26%)	3,283 (16%)	12,192 (59%)	8,292 (40%)	3,214 (15%)
Eastern Communications	21,480 (100%)	21,480 (100%)	8,474 (39%)	3,471 (16%)	4,936 (23%)	15,854 (74%)	8,070 (38%)	2,155 (10%)
Huadian Power	18,120 (100%)	18,120 (100%)	8,564 (47%)	2,239 (12%)	350 (2%)	14,133 (78%)	9,206 (51%)	1,748 (10%)
Heilongjiang Energy	21,480 (100%)	21,480 (100%)	7,420 (35%)	4,984 (23%)	6,787 (32%)	12,820 (60%)	7,273 (34%)	3,676 (17%)
Guangzhou Shipyard	20,880 (100%)	20,880 (100%)	8,195 (39%)	2,628 (13%)	4,851 (23%)	16,650 (79%)	7,834 (38%)	1,602 (8%)
Shenzhen Chiwan Wharf	21,600 (100%)	21,600 (100%)	6,798 (31%)	6,510 (30%)	9,884 (45%)	11,222 (52%)	4,918 (23%)	3,868 (18%)
Guangdong Kelon Electrical	11,400 (100%)	11,400 (100%)	4,722 (41%)	2201 (19%)	2,157 (19%)	7,909 (69%)	4,521 (40%)	1,290 (12%)
BOE Tech Group	21,000 (100%)	21,000 (100%)	9,751 (46%)	9,578 (46%)	1,422 (7%)	4,434 (21%)	9,827 (47%)	6,988 (33%)
NE Electric Development	6,360 (100%)	6,360 (100%)	2,284 (36%)	339 (5%)	2,038 (32%)	5,776 (91%)	2,038 (32%)	245 (4%)
Guangdong Electric Power Development	21,480 (100%)	21,480 (100%)	8,960 (42%)	6,484 (30%)	3,583 (17%)	10,203 (48%)	8,937 (41%)	4,793 (22%)
	Average (A-H firms)		40.1%	13.4%	21.5%	77.2%	38.4%	9.4%
	Average (A-B firms)		36.9%	26.5%	27.9%	54.6%	35.4%	18.9%

**Table 5:** Cointegration and Granger Causality test statistics

<b>Heavy Machinery</b>	Johansen Cointegration Test			Granger Causality F-test	
	Trace statistics	Max Eigen statistics	$\tau$	A→B/H	B/H→A
<i>China Shipping Development (A-H): Fitted lag specification: 3</i>					
Statistics	193.58	192.40	1.297	3.119	30.873
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**
<i>Shandong Zhenhua Port Machinery (A-B): Fitted lag specification: 7</i>					
Coefficient	70.58	68.44	10.302	76.82	31.89
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**
<b>Liquor</b>	Trace statistics	Max Eigen statistics	$\tau$	A→B/H	B/H→A
<i>Tsingtao Brewery (A-H): Fitted lag specification: 1</i>					
Coefficient	220	219	1.086	2.284	5.37
p-value	(0.000)**	(0.000)**	(0.000)**	(0.044)*	(0.000)**
<i>Yantai Changyu Winery (A-B): Fitted lag specification: 1</i>					
Coefficient	214	212	1.546	5.756	66.51
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**
<b>Transport</b>	Trace statistics	Max Eigen statistics	$\tau$	A→B/H	B/H→A
<i>China Southern Airline (A-H): Fitted lag specification: 3</i>					
Coefficient	64.42	62.77	1.391	11.57	48.67
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**
<i>Hainan Airline (A-B): Fitted lag specification: 5</i>					
Coefficient	147	144	8.967	83.09	52.28
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)*
<b>Pharmacy</b>	Trace statistics	Max Eigen statistics	$\tau$	A→B/H	B/H→A
<i>Shandong Xinhua Pharmaceutical (A-H): Fitted lag specification: 7</i>					
Coefficient	81.67	80.73	2.617	3.902	2.12
p-value	(0.000)**	(0.000)**	(0.000)**	(0.002)**	(0.006)**
<i>Livzon Pharmaceutical (A-B): Fitted lag specification: 1</i>					
Coefficient	155.76	144.98	1.672	2.927	8.655
p-value	(0.000)**	(0.000)**	(0.000)**	(0.032)*	(0.000)*
<b>Textile</b>	Trace statistics	Max Eigen statistics	$\tau$	A→B/H	B/H→A
<i>Jingwei Textile (A-H): Fitted lag specification: 4</i>					
Coefficient	84.75	84.08	1.773	6.607	25.22
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)*
<i>Mongolia Cashmere (A-B): Fitted lag specification: 2</i>					
Coefficient	90.164	88.11	12.313	20.99	22.05
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)*

\*: 5% significant level

\*\*: 1% significant level

**Table 5 (cont):** Cointegration and Granger Causality test statistics

<b>Telecom</b>	Johansen Cointegration Test			Granger Causality F-test	
	Trace statistics	Max Eigen statistics	$\tau$	A→B/H	B/H→A
<i>ZTE Corporation (A-H) : Fitted lag specification: 6</i>					
Coefficient	231.31	230.85	1.101	105	4.978
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)*
<i>Eastern Communications (A-B) : Fitted lag specification: 6</i>					
Coefficient	240.45	236.5	13.92	9.985	25.18
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)*
<b>Utility</b>	Trace statistics	Max Eigen statistics	$\tau$	A→B/H	B/H→A
<i>Huadian Power (A-H) : Fitted lag specification: 3</i>					
Coefficient	104.77	104.01	1.426	2.641	0.762
p-value	(0.000)**	(0.000)**	(0.000)**	(0.007)**	(0.637)
<i>Heilongjiang Energy (A-B) : Fitted lag specification: 4</i>					
Coefficient	14.53	12.99	12.159	31.07	18.29
p-value	(0.043)*	(0.047)*	(0.000)**	(0.000)**	(0.000)*
<b>Shipyard</b>	Trace statistics	Max Eigen statistics	$\tau$	A→B/H	B/H→A
<i>Guangzhou Shipyard (A-H) : Fitted lag specification: 3</i>					
Coefficient	32.58	32.21	1.827	40.59	6.483
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)*
<i>Shenzhen Chiwan Wharf (A-B) : Fitted lag specification: 2</i>					
Coefficient	48.80	48.34	1.603	225	33
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)*
<b>Electrical</b>	Trace statistics	Max Eigen statistics	$\tau$	A→B/H	B/H→A
<i>Guangdong Kelon (A-H) : Fitted lag specification: 2</i>					
Coefficient	19.08	18.17	2.273	1.406	4.777
p-value	(0.003)**	(0.003)**	(0.000)**	(0.236)	(0.0289)*
<i>BOE Tech Group (A-B) : Fitted lag specification: 2</i>					
Coefficient	432.77	421.16	2.35	46.66	1.484
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.138)
<b>R&amp;D</b>	Trace statistics	Max Eigen statistics	$\tau$	A→B/H	B/H→A
<i>NE Electric Development (A-H) : Fitted lag specification: 1</i>					
Coefficient	24.75	24.73	3.51	3.218	1.322
p-value	(0.000)**	(0.000)**	(0.000)**	(0.035)*	(0.2514)
<i>Guangdong Electric Power (A-B) : Fitted lag specification: 4</i>					
Coefficient	97.64	96.11	1.266	5.028	2.610
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.016)*

\*: 5% significant level

\*\*: 1% significant level

**Table 6:** VECM estimation results

	Heavy Machinery				Pharmaceutical			
	China Shipping Development		Zhenhua Port Machinery		Shandong Xinhua		Livzon	
	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$
$\gamma(P_{xt-1} - \tau P_{yt-1})$	-0.02152 (-11.95)**	0.00195 (3.474)**	-0.00355 (-2.431)**	0.000127 (0.985)	-0.00465 (-4.803)**	0.0019 (6.691)**	-0.00035 (-1.052)	0.007567 (10.597)**
$r_{x,t-1}$	0.003633 (0.456)	0.01949 (7.830)**	-0.10466 (-9.675)**	0.01681 (17.59)**	-0.00404 (-0.519)	-0.0002 (-0.111)	-0.03155 (-4.210)**	0.016289 (1.0191)
$r_{x,t-2}$	0.010752 (1.347)	0.0267 (10.71)**	-0.04314 (-3.867)**	0.003521 (3.573)**	-0.04387 (-5.641)**	-0.0010 (-0.459)	~	~
$r_{x,t-3}$	0.010032 (1.254)	0.01209 (4.839)**	-0.06934 (-6.423)**	0.00078 (0.818)	0.000739 (0.095)	-0.0009 (-0.387)	~	~
$r_{x,t-4}$	~	~	-0.044 (-4.169)**	0.001167 (1.252)	-0.04503 (-5.793)**	-0.0004 (-0.162)	~	~
$r_{x,t-5}$	~	~	-0.17336 (-16.437)**	0.000867 (0.931)	0.048028 (6.181)**	-0.0002 (-0.076)	~	~
$r_{x,t-6}$	~	~	-0.21478 (-20.091)**	0.002898 (3.069)**	0.045471 (5.845)**	-0.0011 (-0.476)	~	~
$r_{x,t-7}$	~	~	-0.06808 (-6.206)**	0.003965 (4.092)**	-0.03903 (-5.018)**	-0.0011 (-0.469)	~	~
$r_{y,t-1}$	-0.00307 (-8.402)**	0.06673 (0.121)	0.866799 (7.085)**	-0.102543 (-9.487)**	-0.00187 (-0.0694)	0.0050 (0.638)	0.005651 (1.609)*	0.001286 (0.172)
$r_{y,t-2}$	-0.01807 (-5.017)**	-0.03976 (-0.712)	0.370661 (3.003)**	-0.024318 (-2.230)*	0.029144 (1.082)	0.0007 (0.088)	~	~
$r_{y,t-3}$	-0.00334 (-8.277)**	0.06541 (0.132)	0.564358 (4.664)**	-0.006041 (-0.565)	-0.00566 (-0.210)	0.0011 (0.148)	~	~
$r_{y,t-4}$	~	~	0.463596 (3.873)**	-0.009801 (-0.927)	0.034124 (1.267)	0.0004 (0.049)	~	~
$r_{y,t-5}$	~	~	2.332914 (19.49)**	-0.008393 (-0.794)	-0.04425 (-1.644)*	0.0005 (0.060)	~	~
$r_{y,t-6}$	~	~	2.536203 (20.75)**	-0.039619 (-3.668)**	-0.03432 (-1.275)	0.0018 (0.236)	~	~
$r_{y,t-7}$	~	~	0.538479 (4.281)**	-0.047986 (-4.318)**	0.036174 (1.346)	0.0025 (0.316)	~	~
<b>Liquor</b>								
	Tsingtao Brewery		Yantai Winery		Guangdong Electric		BOE Tech	
	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$
$\gamma(P_{xt-1} - \tau P_{yt-1})$	-0.00937 (-6.406)**	0.01036 (9.907)**	-0.01525 (-5.938)**	0.011823 (7.26)**	-0.00318 (-3.351)**	0.00039 (1.4776)	-0.00141 (-1.351)	0.017708 (18.92)**
$r_{x,t-1}$	0.086433 (10.547)	-0.00565 (-0.9641)	-0.02665 (-2.707)**	0.135189 (21.67)**	-0.14103 (-13.08)**	-0.00267 (-0.881)	0.007048 (0.877)	-0.044666 (-6.21)**
$r_{x,t-2}$	~	~	~	~	-0.01815 (-1.684)*	-0.01114 (-3.672)**	-0.03769 (-4.687)**	-0.002597 (-0.361)
$r_{y,t-1}$	-0.04629 (-4.059)	0.00439 (0.539)	0.021991 (1.419)	-0.1214 (-12.22)**	0.143718 (3.784)**	0.00662 (0.619)	-0.0029 (-0.325)	0.138337 (17.32)**
$r_{y,t-2}$	~	~	~	~	0.02229 (0.587)	0.13695 (12.812)**	0.012674 (1.412)	0.003133 (0.389)

t-statistics in parentheses  
 \*: 5% significant level  
 \*\*: 1% significant level

**Table 6 (cont):** VECM estimation results

	<b>Telecommunication</b>				<b>Transport</b>			
	ZTE Corporation		Eastern Communications		China Southern Airline		Hainan Airline	
	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$
$\gamma(P_{x,t-1} - \tau P_{y,t-1})$	-0.02421 (-12.858)**	0.00201 (3.022)**	-0.02313 (-8.528)**	0.000406 (2.328)*	-0.00546 (-5.492)**	0.00163 (3.173)**	-0.01065 (-4.517)**	0.000755 (3.037)**
$r_{x,t-1}$	0.012552 (1.576)	-0.01805 (-6.414)**	-0.02095 (-2.153)	0.000286 (0.457)	-0.00632 (-0.769)	-0.01663 (-3.914)**	0.000209 (0.0197)	0.008509 (7.611)**
$r_{x,t-2}$	0.012696 (1.593)	0.00194 (0.688)	-0.071 (-7.321)**	0.0041 (6.577)**	-0.03447 (-4.214)**	0.00021 (0.051)	0.004079 (0.391)	0.023837 (21.67)**
$r_{x,t-3}$	0.013344 (1.677)*	-0.00261 (-0.928)	-0.04134 (-4.245)**	0.000589 (0.941)	-0.03592 (-4.418)**	-0.00201 (-0.477)	-0.0157 (-1.4734)	0.002374 (2.114)*
$r_{x,t-4}$	0.013421 (1.686)*	0.05134 (18.251)**	-0.03041 (-3.129)**	0.002409 (3.856)**	~	~	-0.00257 (-0.241)	0.010491 (9.350)**
$r_{x,t-5}$	0.012205 (1.518)	0.04142 (14.581)**	-0.03048 (-3.167)**	0.000977 (1.579)	~	~	-0.1256 (-11.927)**	0.00081 (0.729)
$r_{x,t-6}$	0.010424 (1.290)	-0.00841 (-2.944)**	-0.03972 (-4.138)**	0.004703 (7.624)**	~	~	~	~
$r_{y,t-1}$	-0.00922 (-0.41)	0.16961 (21.366)**	0.705694 (4.666)**	-0.027246 (-2.803)**	-0.01029 (-0.648)	0.08395 (10.221)**	0.049889 (0.496)	-0.030881 (-2.9152)**
$r_{y,t-2}$	-0.00931 (-0.412)	-0.02761 (-3.455)**	0.936697 (6.198)**	-0.085131 (-8.763)**	0.191993 (12.051)**	-0.00717 (-0.8701)	-0.02461 (-0.247)	-0.164649 (-15.689)**
$r_{y,t-3}$	-4.99E-03 (-0.223)	0.0126 (1.5891)	0.480668 (3.163)**	-0.010492 (-1.074)	0.197016 (12.313)**	0.00613 (0.741)	0.220234 (2.198)**	-0.014427 (-1.3657)
$r_{y,t-4}$	-0.00726 (-0.324)	-0.037 (-4.668)**	-0.01688 (-0.111)	-0.032796 (-3.361)**	~	~	0.019589 (0.196)	-0.06897 (-6.532)**
$r_{y,t-5}$	-0.00832 (-0.371)	-0.02741 (-3.458)**	0.664772 (4.428)**	-0.020366 (-2.111)*	~	~	1.685668 (17.266)**	-0.003178 (-0.309)
$r_{y,t-6}$	-0.00872 (-0.395)	0.00946 (1.212)	0.382718 (2.553)**	-0.066683 (-6.919)**	~	~	~	~

	<b>Shipyard</b>				<b>R&amp;D</b>			
	Guangzhou Shipyard		Shenzhen Chiwan Wharf		NE Electric		Guangdong Electric	
	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$
$\gamma(P_{x,t-1} - \tau P_{y,t-1})$	-0.00346 (-4.597)**	0.00039 (2.335)**	-0.00108 (-2.133)*	0.002874 (5.747)**	-0.0076 (-4.375)**	0.00034 (2.289)*	-0.00291 (-1.929)*	0.007552 (5.305)**
$r_{x,t-1}$	-0.09007 (-11.62)**	-0.00036 (-0.209)	-0.02493 (-3.188)**	0.004496 (0.583)	0.006587 (0.479)	0.00053 (0.451)	0.025944 (2.415)**	-0.055687 (-5.504)**
$r_{x,t-2}$	-0.04492 (-5.782)**	0.00159 (0.926)	-0.01386 (-1.772)	0.00708 (0.919)	~	~	-0.205 (-19.028)**	0.001279 (0.126)
$r_{x,t-3}$	-0.02883 (-3.712)**	0.02405 (13.97)**	~	~	~	~	0.02105 (1.997)	-0.013567 (-1.367)
$r_{x,t-4}$	~	~	~	~	~	~	-3.94E-02 (-3.748)**	-0.002858 (-0.288)
$r_{y,t-1}$	0.07392 (2.116)*	0.00943 (1.218)	0.008151 (1.0267)	0.00098 (0.125)	-0.00368 (-0.023)	0.06929 (5.057)**	-0.03244 (-2.838)**	0.080137 (7.446)**
$r_{y,t-2}$	0.046207 (1.3315)	-0.00089 (-0.115)	0.009642 (1.2147)	0.000301 (0.038)	~	~	0.305108 (26.56)**	-0.001654 (-0.153)
$r_{y,t-3}$	0.017209 (0.496)	-0.02225 (-2.893)*	~	~	~	~	-0.03341 (-2.863)**	0.019604 (1.784)*
$r_{y,t-4}$	~	~	~	~	~	~	0.061316 (5.271)**	0.001804 (0.165)

t-statistics in parentheses  
 \*: 5% significant level  
 \*\*: 1% significant level

**Table 6 (cont):** VECM estimation results

	Textile				Utility			
	Jingwei Textile		Mongolia Cashmere		Huadian Power		Heilongjiang Energy	
	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$	$r_{x,t}$	$r_{y,t}$
$\gamma(P_{x,t-1} - \tau P_{y,t-1})$	-0.00889 (-7.876)**	0.00095 (2.152)*	-0.00901 (0.0024)	0.000307 (2.128)*	-0.00837 (0.831)	0.00302 (2.527)**	0.000134 (-6.872)**	3.77E-05 (6.657)**
$r_{x,t-1}$	-0.02516 (-3.159)**	-0.00029 (-0.093)	-4.97299 (0.00044)	0.008335 (9.408)**	0.009248 (1.126)	-0.00222 (-0.724)	-0.04267 (-5.496)	0.004099 (5.713)**
$r_{x,t-2}$	0.0025 (0.314)	-0.00011 (-0.035)	0.21815 (0.041)	0.003633 (4.121)**	0.005202 (0.633)	-0.00219 (-0.716)	-0.01226 (-1.576)	0.003118 (4.335)**
$r_{x,t-3}$	0.004216 (0.529)	0.00519 (1.672)	~ ~	~ ~	-0.02695 (-3.281)**	-0.00108 (-0.352)	-0.01398 (-1.796)*	0.002256 (3.136)**
$r_{x,t-4}$	0.003345 (0.422)	0.01568 (5.085)**	~ ~	~ ~	~ ~	~ ~	-0.0081 (-1.042)	0.001998 (2.782)**
$r_{y,t-1}$	0.254284 (12.558)**	0.00103 (0.130)	-0.0722 (0.518)	-0.184323 (-16.59)**	-0.00246 (-0.112)	0.00258 (0.315)	0.256381 (3.054)**	-0.057113 (-7.361)**
$r_{y,t-2}$	0.003028 (0.149)	0.00034 (0.043)	-0.03282 (-0.236)	-0.067593 (-6.101)**	-0.00284 (-0.129)	0.0005 (0.061)	0.167156 (1.987)*	-0.05283 (-6.796)**
$r_{y,t-3}$	-9.40E-03 (-0.4618)	-0.00442 (-0.558)	~ ~	~ ~	0.008032 (0.366)	0.00023 (0.029)	0.012294 (0.146)	-0.021707 (-2.793)**
$r_{y,t-4}$	-0.00823 (-0.405)	-0.14732 (-18.59)**	~ ~	~ ~	~ ~	~ ~	0.284817 (3.395)**	-0.020496 (-2.644)**

t-statistics in parentheses  
 \*: 5% significant level  
 \*\*: 1% significant level

**Table 2:** Description of the main classes of shares issued by Chinese firms

Share class	Origin of incorporation	Currency traded on Exchange	Ownership restriction	Liquidity	No. of listed firms on Dec 2005
A	Mainland China	RMB on SHSE & SZSE	Domestic; from Dec 2002: QFII	High	1223 firms (694 on SHSE, 529 on SZSE)
B	Mainland China	USD on SHSE HKD on SZSE	Foreign; from Feb 2001: domestic with foreign currency accounts (USD or HKD)	Low	111 firms 54 on SHSE (includes 39 A-B firms) 57 on SZSE (includes 43 A-B firms)
H	Mainland China	HKD on HKEx	Foreign	High	121 firms (includes 31 A-H firms) 80 on main board & 40 on GEM
Red chip	Incorporated/managed in Hong Kong; possess substantial business interest/connections to Mainland China	HKD on HKEx	Foreign	High	80 listed firms
N	Mainland China	USD on NYSE	Foreign	Low	12 firms on HKEx traded as ADR. (includes 5 H-N & 7 A-H-N firms)

**Table 7:** JTDM estimation results

<b>Heavy Machinery</b>	$\hat{\theta}$	$\hat{\phi}_x$	$\hat{\rho}$	$\hat{\delta}$	$\hat{\phi}_y$
<i>China Shipping Development (A-H)</i>					
Coefficient	0.8865	0.012	0.1043	0.2712	0.0146
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.139)
<i>Shandong Zhenhua Port Machinery (A-B)</i>					
Coefficient	0.486	0.0089	0.1222	0.1972	0.0391
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**
<b>Liquor</b>	$\hat{\theta}$	$\hat{\phi}_x$	$\hat{\rho}$	$\hat{\delta}$	$\hat{\phi}_y$
<i>Tsingtao Brewery (A-H)</i>					
Coefficient	0.1775	0.0329	0.2052	0.2262	0.0285
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.001)**
<i>Yantai Changyu Winery (A-B)</i>					
Coefficient	0.1355	0.009	0.0973	0.0736	0.018
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.013)*
<b>Transport</b>	$\hat{\theta}$	$\hat{\phi}_x$	$\hat{\rho}$	$\hat{\delta}$	$\hat{\phi}_y$
<i>China Southern Airline (A-H)</i>					
Coefficient	0.7762	0.0093	0.1447	0.2221	0.0113
p-value	(0.000)**	(0.008)**	(0.000)**	(0.000)**	(0.194)
<i>Hainan Airline (A-B)</i>					
Coefficient	0.6897	0.0145	0.1539	0.0611	0.0145
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.004)*
<b>Pharmacy</b>	$\hat{\theta}$	$\hat{\phi}_x$	$\hat{\rho}$	$\hat{\delta}$	$\hat{\phi}_y$
<i>Shandong Xinhua Pharmaceutical (A-H)</i>					
Coefficient	0.3131	0.0023	0.0861	0.0546	0.0094
p-value	(0.000)**	(0.017)*	(0.000)**	(0.011)*	(0.249)
<i>Livzon Pharmaceutical (A-B)</i>					
Coefficient	0.5322	0.0069	0.1163	0.1441	0.00845
p-value	(0.000)**	(0.003)**	(0.000)**	(0.000)**	(0.035)*
<b>Textile</b>	$\hat{\theta}$	$\hat{\phi}_x$	$\hat{\rho}$	$\hat{\delta}$	$\hat{\phi}_y$
<i>Jingwei Textile (A-H)</i>					
Coefficient	0.2120	0.0120	0.1101	0.0740	0.0111
p-value	(0.000)**	(0.000)**	(0.000)**	(0.015)*	(0.429)
<i>Mongolia Cashmere (A-B)</i>					
Coefficient	0.4045	0.0095	0.1115	0.0986	0.0029
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.406)

p-values in parentheses

\*: 5% significant level

\*\* : 1% significant level

**Table 7 (cont): JTDM estimation results**

<b>Telecom</b>	$\hat{\theta}$	$\hat{\phi}_x$	$\hat{\rho}$	$\hat{\delta}$	$\hat{\phi}_y$
<i>ZTE Corporation (A-H)</i>					
Coefficient	0.8191	0.0049	0.0686	0.0898	0.0004
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.680)
<i>Eastern Communications (A-B)</i>					
Coefficient	0.3833	0.0078	0.0999	0.0945	0.00798
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.008)**
<b>Utility</b>	$\hat{\theta}$	$\hat{\phi}_x$	$\hat{\rho}$	$\hat{\delta}$	$\hat{\phi}_y$
<i>Huadian Power (A-H)</i>					
Coefficient	0.9108	0.0111	0.1868	0.1397	0.0146
p-value	(0.000)**	(0.017)*	(0.000)**	(0.000)**	(0.007)**
<i>Heilongjiang Energy (A-B)</i>					
Coefficient	0.5531	0.0132	0.1226	0.0974	0.0090
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.005)*
<b>Shipyard</b>	$\hat{\theta}$	$\hat{\phi}_x$	$\hat{\rho}$	$\hat{\delta}$	$\hat{\phi}_y$
<i>Guangzhou Shipyard (A-H)</i>					
Coefficient	0.4026	0.0003	0.1215	0.0989	0.0058
p-value	(0.000)**	(0.834)	(0.000)**	(0.000)**	(0.177)
<i>Shenzhen Chiwan Wharf (A-B)</i>					
Coefficient	0.6313	0.0046	0.0834	0.0851	0.0022
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.036)*
<b>Electrical</b>	$\hat{\theta}$	$\hat{\phi}_x$	$\hat{\rho}$	$\hat{\delta}$	$\hat{\phi}_y$
<i>Guangdong Kelon (A-H)</i>					
Coefficient	0.6257	0.0022	0.1066	0.1885	0.0013
p-value	(0.000)**	(0.025)*	(0.000)**	(0.000)**	(0.000)**
<i>BOE Tech Group (A-B)</i>					
Coefficient	0.5957	0.0127	0.1610	0.1818	0.0151
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.009)**
<b>R&amp;D</b>	$\hat{\theta}$	$\hat{\phi}_x$	$\hat{\rho}$	$\hat{\delta}$	$\hat{\phi}_y$
<i>NE Electric Development (A-H)</i>					
Coefficient	0.4760	0.0031	0.1422	0.0734	0.0161
p-value	(0.000)**	(0.292)	(0.000)**	(0.032)*	(0.135)
<i>Guangdong Electric Power (A-B)</i>					
Coefficient	0.5168	0.0108	0.0979	0.1097	0.0039
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.035)*

p-values in parentheses  
 \*: 5% significant level  
 \*\*: 1% significant level

**Table 8:** VECM and JTDM rankings; Wald test and J-test statistics

<b>Heavy Machinery</b>	$\hat{\alpha}_{VECM}$	$\hat{\alpha}_{JTDM}$	Wald test (VAR)	Wald test (VECM)	Wald test (JTDM)	$\hat{\gamma}_x$	$\hat{\gamma}_y$	$\hat{\rho}$	$\hat{\delta}$	Rankings
<i>China Shipping Development (A-H)</i>										
Coefficient	0.99605	1.014	90.051	8.966	1829	-0.0215	0.002	0.1043	0.2712	<b>H-H<sup>^</sup></b>
p-value	(0.0014)*	(0.000)**	(0.000)**	(0.1104)	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	
<i>Shandong Zhenhua Port Machinery (A-B)</i>										
Coefficient	1.0376	0.8911	9.9594	6.4722	127235	-0.1046	0.00013	0.1222	0.1972	<b>B-B</b>
p-value	(0.000)**	(0.021)*	(0.191)	(0.263)	(0.000)**	(0.000)**	(0.165)	(0.000)**	(0.000)**	
<b>Liquor</b>	$\hat{\alpha}_{VECM}$	$\hat{\alpha}_{JTDM}$	Wald test (VAR)	Wald test (VECM)	Wald test (JTDM)	$\hat{\gamma}_x$	$\hat{\gamma}_y$	$\hat{\rho}$	$\hat{\delta}$	Rankings
<i>Tsingtao Brewery (A-H)</i>										
Coefficient	0.945	1.00169	943.65	1.8	7780	-0.0094	0.0104	0.2052	0.2262	<b>A-H</b>
p-value	(0.0129)*	(0.000)**	(0.000)**	(0.876)	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	
<i>Yantai Changyu Winery (A-B)</i>										
Coefficient	0.5979	0.9982	27.75	5.9347	249125	-0.0153	0.0118	0.0973	0.0736	<b>B-A</b>
p-value	(0.129)	(0.000)**	(0.000)**	(0.313)	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	
<b>Transport</b>	$\hat{\alpha}_{VECM}$	$\hat{\alpha}_{JTDM}$	Wald test (VAR)	Wald test (VECM)	Wald test (JTDM)	$\hat{\gamma}_x$	$\hat{\gamma}_y$	$\hat{\rho}$	$\hat{\delta}$	Rankings
<i>China Southern Airline (A-H)</i>										
Coefficient	0.9553	1.0298	10.769	0.6099	67555	-0.0055	0.0016	0.1447	0.2221	<b>H-H</b>
p-value	(0.000)**	(0.000)**	(0.149)	(0.988)	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	
<i>Hainan Airline (A-B)</i>										
Coefficient	0.9915	1.4101	3.4799	3.458	255814	-0.0107	8E-04	0.1539	0.0611	<b>B-A</b>
p-value	(0.000)**	(0.02)*	(0.837)	(0.630)	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	
<b>Pharmacy</b>	$\hat{\alpha}_{VECM}$	$\hat{\alpha}_{JTDM}$	Wald test (VAR)	Wald test (VECM)	Wald test (JTDM)	$\hat{\gamma}_x$	$\hat{\gamma}_y$	$\hat{\rho}$	$\hat{\delta}$	Rankings
<i>Shandong Xinhua Pharmaceutical (A-H)</i>										
Coefficient	0.4344	1.0082	57.37	49.2919	2203	-0.0047	0.0019	0.0861	0.0546	<b>H-A</b>
p-value	(0.004)**	(0.019)*	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.011)*	
<i>Livzon Pharmaceutical (A-B)</i>										
Coefficient	0.54954	1.1127	17.582	11.5483	2.9244	-0.00035	0.0076	0.1163	0.1441	<b>B-B</b>
p-value	(0.005)**	(0.001)**	(0.014)*	(0.042)*	(1.000)	(0.000)**	(0.000)**	(0.000)**	(0.000)**	
<b>Textile</b>	$\hat{\alpha}_{VECM}$	$\hat{\alpha}_{JTDM}$	Wald test (VAR)	Wald test (VECM)	Wald test (JTDM)	$\hat{\gamma}_x$	$\hat{\gamma}_y$	$\hat{\rho}$	$\hat{\delta}$	Rankings
<i>Jingwei Textile (A-H)</i>										
Coefficient	0.538	0.9929	2.9727	28.57	66425	-0.0089	0.001	0.1101	0.074	<b>H-A</b>
p-value	(0.135)	(0.008)**	(0.888)	(0.022)*	(0.000)**	(0.000)**	(0.008)**	(0.000)**	(0.015)*	
<i>Mongolia Cashmere (A-B)</i>										
Coefficient	0.9471	1.0777	161.95	149.267	55825	-0.00901	0.00031	0.1115	0.0986	<b>B-A</b>
p-value	(0.000)**	(0.007)**	(0.000)**	(0.000)**	(0.000)**	(0.256)	(0.001)*	(0.000)**	(0.000)**	

p-values in parentheses  
 \*: 5% significant level  
 \*\*: 1% significant level  
 ^: Rankings by VECM-JTDM

**Table 8 (cont):** VECM and JTDM rankings; Wald test and J-test statistics

<b>Telecom</b>	$\hat{\alpha}_{VECM}$	$\hat{\alpha}_{JTDM}$	Wald test (VAR)	Wald test (VECM)	Wald test (JTDM)	$\hat{\gamma}_x$	$\hat{\gamma}_y$	$\hat{\rho}$	$\hat{\delta}$	Rankings
<i>ZTE Corporation (A-H)</i>										
Coefficient	0.9662	0.9962	686.6	3.9155	171191	-0.0242	0.002	0.0686	0.0898	<b>H-H</b>
p-value	(0.016)*	(0.000)**	(0.000)**	(0.562)	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	
<i>Eastern Communications (A-B)</i>										
Coefficient	0.9488	1.1792	34.039	33.184	16238	-0.02313	0.00041	0.0999	0.0945	<b>B-A</b>
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.031)*	(0.000)**	(0.000)**	
<b>Utility</b>	$\hat{\alpha}_{VECM}$	$\hat{\alpha}_{JTDM}$	Wald test (VAR)	Wald test (VECM)	Wald test (JTDM)	$\hat{\gamma}_x$	$\hat{\gamma}_y$	$\hat{\rho}$	$\hat{\delta}$	Rankings
<i>Huadian Power (A-H)</i>										
Coefficient	0.7964	1.0916	10.457	0.52113	261	-0.0084	0.003	0.1868	0.1397	<b>H-A</b>
p-value	(0.000)**	(0.000)**	(0.164)	(0.991)	(0.000)**	(0.345)	(0.000)**	(0.000)**	(0.000)**	
<i>Heilongjiang Energy (A-B)</i>										
Coefficient	1.0039	1.0451	34.982	31.32	141475	-0.00013	0.0001	0.1226	0.0974	<b>B-A</b>
p-value	(0.000)**	(0.011)*	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	
<b>Shipyard</b>	$\hat{\alpha}_{VECM}$	$\hat{\alpha}_{JTDM}$	Wald test (VAR)	Wald test (VECM)	Wald test (JTDM)	$\hat{\gamma}_x$	$\hat{\gamma}_y$	$\hat{\rho}$	$\hat{\delta}$	Rankings
<i>Guangzhou Shipyard (A-H)</i>										
Coefficient	0.7458	1.0257	24.917	23.478	14149	-0.0035	0.0004	0.1215	0.0989	<b>H-A</b>
p-value	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.001)**	(0.000)**	(0.000)**	
<i>Shenzhen Chiwan Wharf (A-B)</i>										
Coefficient	1.0348	0.6891	145	114.45	20806	-0.0011	0.0029	0.0834	0.0851	<b>A-B</b>
p-value	(0.000)**	(0.037)*	(0.000)**	(0.000)**	(0.000)**	(0.016)*	(0.000)**	(0.000)**	(0.000)**	
<b>Electrical</b>	$\hat{\alpha}_{VECM}$	$\hat{\alpha}_{JTDM}$	Wald test (VAR)	Wald test (VECM)	Wald test (JTDM)	$\hat{\gamma}_x$	$\hat{\gamma}_y$	$\hat{\rho}$	$\hat{\delta}$	Rankings
<i>Guangdong Kelon (A-H)</i>										
Coefficient	0.9070	1.0938	12.992	12.341	37039	-0.0032	0.0004	0.1061	0.1885	<b>H-H</b>
p-value	(0.000)**	(0.072)	(0.072)	(0.030)*	(0.000)**	(0.000)**	(0.075)	(0.000)**	(0.000)**	
<i>BOE Tech Group (A-B)</i>										
Coefficient	1.0375	1.0683	13.174	12.5165	16046	-0.0014	0.0178	0.1610	0.1818	<b>A-B</b>
p-value	(0.000)**	(0.000)**	(0.068)	(0.028)*	(0.000)**	(0.011)*	(0.000)**	(0.000)**	(0.000)**	
<b>R&amp;D</b>	$\hat{\alpha}_{VECM}$	$\hat{\alpha}_{JTDM}$	Wald test (VAR)	Wald test (VECM)	Wald test (JTDM)	$\hat{\gamma}_x$	$\hat{\gamma}_y$	$\hat{\rho}$	$\hat{\delta}$	Rankings
<i>NE Electric Development (A-H)</i>										
Coefficient	0.3909	1.0892	145.77	145.41	313	-0.0076	0.00034	0.1422	0.0734	<b>H-A</b>
p-value	(0.000)**	(0.034)*	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.012)*	(0.000)**	(0.003)*	
<i>Guangdong Electric Power (A-B)</i>										
Coefficient	0.9423	1.0110	55.575	5.8606	458425	-0.0029	0.008	0.0979	0.1097	<b>A-B</b>
p-value	(0.102)	(0.000)**	(0.000)**	(0.032)*	(0.000)**	(0.024)*	(0.000)**	(0.000)**	(0.000)**	

p-values in parentheses

\*: 5% significant level

\*\*: 1% significant level