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Considering Market Microstructure At Seven US Stock Exchanges: A Methodological Note

Aleksandar Sevic, Chandrasekhar Krishnamurti and Zeljko Sevic*
Greenwich University, London.

ABSTRACT

This article questions the validity of regression models when high correlations exist between independent variables and presents the application of VAR as an alternative technique through the comparison of two groups of selected stocks that represent components of Dow Jones and S&P 500 indices, respectively. The results indicate that panel regressions face serious specification problems, while the impulse response function underlines that the shock to the volume innovation has a mostly positive impact on the volatility in both S&P and Dow Jones sample, but the tendency cannot be easily accounted for. The positive impact of volatility shocks on the intermarket depth is rather unexpected, but it may be associated with an increase in volume that does not enormously enhance the spread up to the point where it will be too costly for market-makers to trade, and accordingly, quickly narrows the spread to absorb new liquidity influx in the market. In the Granger causality tests Dow Jones stocks with comparatively larger average volume, depth values and price levels provide slightly stronger relations between analyzed variables compared to the stocks included in the S&P sample.

JEL Classification : C5; G15;

Keywords : Volatility, Market Depth, Volume, Correlation Matrix.

1. INTRODUCTION

The availability of high frequency data has only recently caused widespread studies on intraday market microstructure variables behavior. The foundation setting studies on volume and volatility were either based on interday patterns or provided theoretical foundations that could have been tested on low data frequency sets. Kim and Verrecchia (1991) model the impact of public announcement on the process of market

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* Corresponding author email : Z.Sevic@greenwich.ac.uk

participants, information gathering, which, in turn, influence price change, volume and the level of information asymmetry. Gallant et al. (1992) show that past volatilities can forecast trading volumes in equities. Lee et al. (1993) further notice that academic does not equally analyze the spread and the depth, as a respective price dimension and quantity dimension of volatility. For instance, Copeland and Galai (1983) model the determination of the bid-ask using the option pricing approach, while Glosten and Milgrom (1985) comprehensively examine the impact of asymmetric information on the spread value by ignoring depth. Kyle (1985) defines depth as the order flow required to move prices by one unit. In is model the depth changes with trading activity and claims that high market depth is more closely related to low market volatility and vice versa.

Lee et al. (1993) are the first to analyze both liquidity dimension by applying the event study. They prove that specialists and other liquidity suppliers reply quickly to public announcements by adjusting depth and spread. The authors also demonstrate that an increase in volume is reflected in larger spreads and smaller depths. Kavajecz's (1999) study brings up a further proof that depths are a strategic choice variable used by the specialists who are alerted by inventory and adverse selection concerns. Moreover, Noronha et al. (1996) discover the possibility of an increase in the depth following the dual listing of US firms. Unexpectedly, spreads remain unchanged.

Easley and O' Hara (1992) assume that volume shocks reduce volatility. In their model the specialist uses trading volume as a signal that information has occurred, but it does not encompass depth. Harris and Raviv (1993) imply that volume shocks denote the lack of consensus among market participants about the value of the asset, which originates in the different interpretation of public announcements. Campbell et al. (1993) claim that volume information helps distinguish price movements reflecting modifications prompted by public announcements. In the former case the change in volume is comparatively larger and market makers may adequately alter their perceptions about the expected return. Blurne et al. (1994) underline that volume provides information that cannot be deduced from the price statistics and demonstrate that traders using information that contained in volume have comparatively better performance. Chan et al. (1995) claim that if the trading volume has been divided by the trading frequency the ratio has virtually no incremental information content in explaining volatility. The number of transactions contains all necessary information to prices securities.

In the sphere of futures markets price volatility, trading volume, and market depth have been first accounted for by Bessembinder and Seguin (1993). They investigate whether the effect of volume or depth, proxied by the variables into expected and un-expected components. Positive shocks to volume have a strong impact on volatility. The unexpected level of open interest in eight selected markets is negatively related to volatility. The explanatory power of the market depth is persistent even after the inclusion of volume. Fung and Patterson (1999) explore dynamic relationships among return volatility, trading volume, and open interest for five currency futures markets. Their test indicates that volume and open interest influence return volatility. The authors also show that on currency futures markets volume is not exclusively positively related to returns. This is in contrast to previous findings since their model does not assume short-selling restriction that established the positive relationship that establishes the positive relationship between volume and return in non-futures markets.

Ahn and Cheung (1999) conclude that outside of US trades are preponderantly organized as order-driven markets without market makers. Using intraday data for the Stock Exchange of Hong Kong (30-minute interval) the authors point out that the trading pattern of limit order trades on the SEHK is similar to quote-posting behavior of a specialist on the NYSE. The intraday result show the persistence of U-shaped spread and the reverse U-shaped depth patterns. The larger spreads are followed by small market depths, while narrow spreads assume large depths. Finally, like specialists, limit order traders try to protect themselves from information asymmetry by widening spreads and thereby lowering depths. Brockman and Chung (1999) investigate inter-temporal and cross-sectional depth in an electronic, order-driven environment. The authors also observe SEHK and conclude that inter-temporal or liquidity. It has been found that it is significant depth increase disappear after controlling for changes in prices, volume and variance. The interday trading also shows the inverted U-shaped pattern of the market depth.

This paper tries to address the interrelationship between several market microstructure variables: market depth, volatility, volume and price, using both panel data and VAR, followed by the impulse response analysis. This mixture of applied procedure tries to appease differences in the applied methodology. In currency futures markets volatility, volume and market depth have been thoroughly examined by Fung and Patterson (1999) using VAR based on low frequency hourly data. On the contrary, Brockman and Chung (1999) in the analysis of the Stock Exchange of Hong Kong apply five minute intervals and incorporate price in the equation models assuming stationary caused by high frequency observation intervals.

The main contribution of this study is the elaboration of microstructure variables based on the quotes of selected S & P 500 and Dow Jones stocks that are simultaneously traded on Nasdaq, and six US stock auction markets comprising the National Market System (NMS). The trading is organized through the Internetmarket Trading System (ITS).

Even though there are opinions that liquidity providers manage depth to minimize uncertainty during volatile trading periods, there is no indisputable study on the relationship between volatile and depth in equity markets. In term of the (inter) market depth specification, this approach adds new dimension to the best NYSE quotes selection applied in Lee et al. (1993). The inclusion of best quotes in multiple trading places providers a viable substitute for the unavailability of the limit-order book quotes such as those in Ahn Cheung (1999).

2. DATA

Data for this study are collected from the Quote and Trade Intraday Database, that comprises intraday transactions data for all securities traded on the New York Stock Exchange, Nasdaq National Market system, American Stock Exchange and SmallCap issues, starting from 1994 until present day.

It is our intent to use high frequency data of approach duration. In previous studies, such as Dufour and Engle (2000) it is claimed that prices take 4 minutes before converging to the full information level if the trading intensity is high. The brief overlook of the data set shows that trading frequency widely varies across particular stocks and 4-5 minute intervals will not provide sufficient information. Therefore, we have arbitrary selected 10 minute intervals from 9:30 AM to 4:30 PM. In total, 39 time intervals are selected per day during April 1996.

Transactions are sequentially tracked for ten S & P 500 and ten Dow Jones stocks across seven exchanges: NYSE, Nasdaq, Midwest (Chicago Stock Exchange (CSE) since 1993), Pacific (trading in San Francisco and Los Angeles), Boston (BSE), Cincinnati (trading in Chicago) and Philadelphia. While CSE and BSE compete in terms of volume to cope with NYSE, all other stock markets have rather regional significance. The competition among them is fierce. They also tend to synchronize trading hours with those at NYSE in order to take full advantage of the Intermarket Trading System. For instance, hours of operation for equities floor at the Pacific Stock Exchange is from 6:30 AM – 1:30 PM Pacific time which coincides with the NYSE opening hours 9:30 AM – 4:30 PM Eastern time.[1] Therefore, non-synchronous trading does not pose problems in this study.

In order to present a focused study we have selected ten Dow Jones and ten S & P 500 stocks (after the exclusion of Dow Jones and split stocks). This result is biased towards stocks with the highest liquidity, but it provides good ad hoc estimates of the trading patterns and variables interrelationship. Moreover, it eliminates the effect of stale quotes.

3. METHODOLOGY

Volume (VOL) is calculated as the total number of shares traded in any of the seven exchanges during the specified 10-minute interval.

The price level is defined as the mid-point of the quoted highest bid and lowest ask prices observed during the 10-minute interval. Quoted price can change even if there is no trading activity and, accordingly, affect volatility. If, by contrast, the traded prices were used, probable bid-ask bounces would provided unsustainable results.

Price volatility (VOLAT) is denoted as the absolute value of the logarithmic transformation of the ratio between the price at time t and t-l, respectively. The intermarket depth (INMKTDPT) takes into account the variation in quotes among seven exchanges which provides a new approach in comparison to previous studies [Lee *et al.* : 1993]:

$$D=\sum_{j=1}^{7}\frac{\left(\frac{n_{bj}}{(p-Q_{bj})/p}+\frac{n_{aj}}{(p-Q_{aj})}\right)}{2},$$

where

n_{bj} is the number of shares looked for at the highest bid price at each of the seven exchanges during the 10-minute interval;
n_{aj} is the number of shares offered at the lowest ask price at each of the seven exchanges during the 0-minute interval;
p is the price eve;
Q_b is the highest bid price observed at each of the even markets
Q_a is the lowest price observed at each o the even markets.

The market depth measure is the average of the cumulative quantity measure is the average of the cumulative quantity measure in the nominator and cumulative distance measure presented in the denominator. It can be augmented by higher price levels, an

[1] Pacific Exchange- General Information, http://www.pacificex.com/about/abt_geninfo.html, 25-05-2001.

increase in the number of shares offered at the best bid and / or offer prices in each of the stock markets, or by the contraction of the quoted spread.

3.1 The Panel Data Analysis

We follow the methodology presented from Brockman and Chung (1999) in which the authors examine 625 companies over the period of 330 days, listed in the Hong Kong Stock Exchange. In their model the number of total observations in the intertemporal analysis was 3,069,074 which is significantly larger than almost 154,000 observation per each variable for Dow Jones and S & P 500 samples in the cross sectional analysis to be implemented in this model.

Correlation matrix presented in the Brockman and Chung paper indicated 0.128 level of correlation between volume and variance, regard as explanatory variables, which was deemed as rather insignificant. Nevertheless for such a large sample this may be a significant result. Therefore, in the second part of this article VAR procedure will be used as an alternative method since it is more suitable for highly autocorrelated variables, that simultaneously express traits of high endogeneity.

The following regression model is to be evaluated in order to examine the intraday patterns while controlling for volume, variance, and price effects (1):

$$Int.market.depth_{it} = \alpha_i + \beta_1\, volume_{it} + \beta_2\, volatility_{it} + \beta_3\, price_{it} + \sum_{j=1}^{4} \gamma_j day_{i,\,jt} + \varepsilon_{it}$$

This model should indicate whether there exists a well-known inverted U-shape in the intermarket-depth patterns. In this case, seven markets are simultaneously trading during the day, and even though opening hours are similar the time of day may affect the willingness of investors to trade. For instance 1:30 PM in Los Angels may not have the same effect on the NYSE trading as the behavior of those based in Pennsylvania that is in the same time zone as New York.

3.2 VAR Analysis

Following the approach of Fung and Patterson (1999) who conduct an in-depth currency futures markets using hourly data, it is my intention to provide further rationale for the simultaneous trading in seven US stock markets by paying attention to high frequency observation.

In the Brockman and Chung (1999) model only contemporaneous relationship between variables has been analyzed. However, in the VAR approach it will be possible to examine the speed of information transmission among variables interactions: volatility, volume, price and market-depth.

The applied model is: $Y_t = a + \sum_{k=1}^{l} b_k Y_{t-k} + e_t$, (2), Y_t .It is a 4 x 1 column vector for volatility, volume intermarket depth, and price; a is 4 x 1 column vector of intercepts, while b_k is 4 x 4 matrix of cofficeints; l is the length of lags, while e_t is the 4 x 1 vector of serially uncorrelated error terms. It is important to note that the i^{th} component of is the innovation of the i^{th} variable that cannot be predicted from other variables of the system. This will be important in the impulse response function analysis. Since no previous studies determined the length of lags, it is necessary to compare the output of Akaike and Schwartz information criteria. If the results offer opposite conclusions the likelihood ratio test for the appropriate lag length will be applied.

Following the methodology of Sims (1980), we try to examine more thoroughly the dynamic relationship between variables. Accordingly, equation 2 can be transformed into: $Y_t = a + \sum_{k=1}^{l} b_k Y_{t-k} + e_t$, (3), which indicates that is linear combination of current and past one-step ahead forecast errors. The row i and column j of Ψ_k (moving average coefficient matrix) denotes the repercussions of a one-unit increase in the j^{th} variable's innovation at date t for the value of the i^{th} variable at time t + k, holding all other innovations at all dates constant. Ultimately the plot of the row i column j element of Ψ_k denotes as $\frac{\partial y_{i,t+k}}{\partial e_{it}}$ as a function of k is called the impulse response function.[2]

Standard statistical packages allow for the orthogonalizaiton of innovations. This makes them contemporaneously uncorrelated across equations $Y_i = \sum_{k=1}^{\infty} \Psi_k e_{t-k}$ (4), where V is a lower triangular matrix, and is the orthogonalizaiton innovations from

$$e = Vu \Rightarrow \begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \\ \vdots \\ e_{nt} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & \cdots & 0 \\ a_{21} & 1 & 0 & \cdots & 0 \\ a_{31} & a_{32} & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & 1 \end{bmatrix} \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \\ \vdots \\ u_{nt} \end{bmatrix}$$

(5). Ultimately, the plot of which is the estimate of $\frac{\partial \hat{E}(y_{t+k} / y_{jt}, y_{j-1,t}, \ldots, y_{1t}, x_{t-1})}{\partial y_{jt}}$ (6), denotes an orthogonolized impulse response function. The j_{th} column of the matrix V is represented by a_j.

Variance decomposition forecast error offers the percentage of unexpected variation in each variable that is produced by shocks from other variables. In econometric notation this indicates the contribution of the j^{th} orthogonolized innovation to the mean-squared errors of the k-period-ahead forecast:

$$Var(u_{jt}) \,.\, [a_j a`_j + \psi_1 a_j a`_j \psi`_1 + \psi_2 a_j a`_j \psi`_2 + \ldots\ldots\ldots\ldots + \psi_{k-1} a_j a`_j \psi`_{k-1}] \qquad (7),$$

and the magnitude depends on the ordering of the variables. In this article 15-period effects are analyzed, because it is assumed that this length is sufficient to explain the magnitude of the shocks.

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2 For more on the impulse-response function see: Hamilton J.D. (1994), Time Series Analysis, Princeton, New Jersey: Princeton University Press, pp. 318-323

Unit root test provides information on stationarity. The Augmented Dickey-Fuller approach controls for higher-order correlation by adding lagged difference terns of the dependent variable y to the right-hand side of the regression:

$$\Delta y = \alpha + \gamma \Delta y_{t-1} + \delta_1 \Delta y_{t-1} + \delta_2 \Delta y_{t-2} + \dots\dots\dots + \delta_{p-1} \Delta y_{t-p+1} + \varepsilon_t \quad (8)$$

and questions the hypotheses: $H_0 : \gamma = 0$ vs $H_0 : \gamma \neq 0$. Price and some other variables may be characterized by nonstationarity and, if necessary cointegration tests will be performed. E-views offers five estimation possibilities provided by Johansen (1995). Since we cannot predict the existence of the deterministic trends it is assumed that y has no deterministic trends and the cointegrating equations have only intercepts, i.e: $\Pi y_{t-1} + Bx_t = \alpha(\beta' y_{t-1} + \rho_0)$, where y_t, is a k-vector of non-stationary I (1) variables, while x is a d vector of deterministic variables. However, if only some of the variable observations are non-stationary, it will be transformed in order to make it of the same order as the rest of variables. At the same time, it is possible to examine response functions that included prices or their first differences, as is requested by the VAR analysis.

4. PRELIMINARY STATISTICAL OBSERVATIONS

Table 1 summarizes the descriptive statistics on the Dow Jones and S & P 500 for: a) market capitalization, b) the midpoint price between the lowest ask and highest bids over the 10-minute interval, c) the intermarket depth, d) volatility, e) volume, f) quoted spread, and g) capitalization weights.

In terms of the market capitalization a ten Dow Jones Stocks are, on average, more than four times larger than selected S & P 500 stocks, which exclude Dow Jones stocks and those that were split. Price level is higher for Dow Jones stock since it encompasses predominantly value stocks.

As expected, the intermarket-depth for the Dow Jones group is twice as large as the same indicator for the S & P index group. This is due to the assumed higher liquidity of those stocks. Trading volume is another good indicator of the attractiveness of Dow Jones stocks, that relative to the S& P sample have 2.9 times larger turnover. Finally, quoted spreads are lower for the former group, while the values of volatility are quite similar.

Table 1. The Summary of the Descriptive Statistics for Selected Dow Jones and S&P 500 Stocks

	Market Capitalization in million USD	Price	Intermarket Depth in 100 Shares	Volatality	Volume in 100 Shares	Quoted Spread
Dow Jones						
Total Average	62733.76	77.86	134666.43	0.001416	43958.27	0.1464
S&P 500						
Total Average	15091.03	67.9	64933.35	0.0014	15202.42	0.1614
Cross Comparison: Dow Jones/S&P 500						
Total Average	4.16	1.15	2.07	1.01	2.89	0.91

5. ANALYSIS RESULT

5.1 Panel Data Analysis

Since in previous studies through examination of casual linkages in various stock markets has not been performed, Granger causality test result have been preorder to monitor the stability of results.

5.1.1 *Intermarket-Depth*

In market microstructure theory intermarket depth is an important indicator of the ability of the market to absorb large volume of trades without having a large effect on price. We present the intermarket depth that accounts for the differences in the price levels at different markets. In the manner, market depth measures are made more accurate relative to the mere quantity change observations.

Intermarket depth causes volatility as well as price in 16 out of 20 calculations, at 5 per cent confidence level and eight lags. This is explained by the fact that volatility is inversely related to the market-depth movement. If the depth is large, it will be difficult for incoming order to strongly disturb the market and the volatility will be lower, and vice versa. The level of the price is inversely affected by the value of the market depth. Trading volume is affected in only 7 out 20 cases (5% confidence level – eight lags). In the market microstructure theory volume is used as an explanatory variable. Since the number of shares for the best ask and bid prices are incorporated in the nominator of the intermarket depth specification it is to be expected that their relationship is positive.

5.1.2. Volume

Trading volume comprises both liquidity and informed trading components. This prompt us to make a difference between noise and information related trading. Karpoff (1987) assumes that volume is a proxy for information flow, since liquidity traders appear randomly in the market. By contrast, informed trader posses quality knowledge about stocks and emerge more regularly at the market. At the same time it is necessary to make a difference between trading on information and trading as if the information is known, in the latter case this is just a proxy for noise (Black, 1985).

If one assumes that information flow is higher around specific moments in time it may be conjectured that price volatility also increases. Traders will also try to increase spreads in order to prevent deals with informed traders.

Causality tests do not support this relationship in the dynamic setting. Contemporaneous relationship may still persist since volume may affect volatility only during specific intervals. The largest support for the impact of the volume is provided for price (8 vs. 12) and less for market-depth (3:17). Larger volumes are positively related market-depth.

5.1.3 Volatility and Price

The Granger causality tests alert that it is primarily necessary to find theoretical justification before accepting any conclusions. Therefore, strong support for the impact of volatility on other variables, especially for price (19 out of 20 observations at 5% confidence level, with eight lags) have to be examined with care (Table 2).

Table 2. Granger Causality Test on Intermarket Depth, Volume, Volatility and Price Variables (Ten Selected Dow Jones Stocks)

No. of lags	Probability	Depth Causes			Volume Causes			Volatility Causes			Price Causes		
		Volume	Volatility	Price	Depth	Volatility	Price	Depth	Volume	Price	Depth	Volume	Volatility
4	1%	1	8	9	0	1	2	1	7	7	3	8	7
	5%	2	1	1	0	0	0	2	0	2	1	1	2
	>5%	7	1	0	10	9	8	7	3	1	6	1	1
8	1%	1	7	9	0	0	2	1	6	9	1	7	9
	55	2	2	0	1	0	3	2	1	0	1	2	0
	>5%	7	1	1	9	10	5	7	3	1	8	1	1

Table 3. Granger Causality Test on Market Depth, Volume, Volatility and Price Variables (Ten Selected S&P 500 Stocks)

No. of lags	Probability	Depth Causes			Volume Causes			Volatility Causes			Price Causes		
		Volume	Volatility	Price	Depth	Volatility	Price	Depth	Volume	Price	Depth	Volume	Volatility
4	1%	1	8	9	0	1	2	1	7	7	3	8	7
	5%	2	1	1	0	0	0	2	0	2	1	1	2
	>5%	7	1	0	10	9	8	7	3	1	6	1	1
8	1%	1	7	9	0	0	2	1	6	9	1	7	9
	55	2	2	0	1	0	3	2	1	0	1	2	0
	>5%	7	1	1	9	10	5	7	3	1	8	1	1

Price level exhibits similarly convincing patterns. This may be the reason why, in spite of the assumed non-stationarity, market microstructure models regularly include this variable, but to lesser extent the market depth (6 vs. 14).

From the enclosed results it can be inferred that causality linkages are stronger in the Dow Jones sample that comprises stocks featuring larger volume, depth values and price levels compared to stocks sampled from the S & P 500 index.

The 2-tailed Pearson correlation matrix offers the following results:

Table 4. Correlation matrix for Dow Jones

	MKTDPT	*PRICE*	*VOLUM*	*VOLT*
MKTDPT	1			
PRICE	0.105**	1		
VOLUM	0.190**	0.207**	1	
VOLT	-0.091**	0.008**	0.372**	1

Table 5. Correlation matrix for S&P 500

	MKTDPT	*PRICE*	*VOLUM*	*VOLT*
MKTDPT	1			
PRICE	0.158**	1		
VOLUM	0.193**	0.057**	1	
VOLT	-0.124**	-0.068**	0.325**	1

** *Correlation is significant at the 0.01 level (2-tailed)*

The significance of pairwise correlations is high and a multicolinearity problem exists between all independent variables. There is a serious specification problem that may be circumvented by applying alternative estimation techniques such as VAR. In addition, the sign of correlation between volatility and price unexpectedly negative for S & P 500 sample.

5.1.4 Interday Patterns

Based on the following of descriptive statistics it is not possible to observe any particular pattern in interday market-depth. While in the S & P 500 sample market depth monotonically declines over the week in Dow Jones the behavioral pattern is interchangeable (Table 6).

Table 6. Weekday Intermarket Depth Values (in Mil. Shares)

	Monday	*Tuesday*	*Wednesday*	*Thursday*	*Friday*
S&P 500	6.71	6.60	6.54	6.30	6.13
Dow Jones	13.59	13.26	13.29	13.03	14.18

The following regression equation has been estimated:

$$Int.market.depth_{it} = \alpha_i + \beta_1\, volume_{it} + \beta_2\, volatility_{it} + \beta_3\, price_{it} + \sum_{j=1}^{4} \gamma_j day_{i,\,jt} + \varepsilon_{it}$$

Where the dummy variable for Wednesday has been excluded because of the intention to observe whether one can discern any particular weekday pattern of the market depth. The estimation techniques is generalized least squares with White heteroscedasticity consistent convariance.

For the Dow Jones sample, regression results with the common intercept and the exclusion of fixed or random effects are presented in table 7. It is indicative that it is impossible to discern any particular weekday patterns because only the coefficient for Friday is statistically significant. The signs of control variables are as expected. Volatility is negative correlated with market depth, while the other two have positive signs. All three are statistically significant. Nonetheless, it has to be noted that Durbin-Watson statistics does not reject the hypothesis of positive serial autocorrelation. Therefore, the validity of the model is rather questionable.

Table 7. The Results of the Panel Data Analysis for Ten S&P 500 Stocks (the Explained Variable Is Intermarket Depth)

Variable	*Coefficient*	*Std. Error*	*t-Statistic*	*Prob.*
C	7.406	0.532	13.912	0
PRICE	4.613	0.681	6.776	0
VOLATILITY	-10.269	0.745	-13.790	0
VOLUME	0.515	0.043	11.930	0
Dummy Monday	0.433	0.288	1.503	0.133
Dummy Tuesday	0.167	0.288	0.579	0.562
Dummy Wednesday	-0.217	0.296	-0.735	0.462
Dummy Thursday	1.053	0.346	3.041	0.002

Adjusted R^2 is 0.054, with Durbin-Watson statistics amounting to 0.91563

Fixed and random effect model render price variable insignificant. Similar results are obtained for the S & P 500 balanced panel regression. Due to low Durbin-Watson statistics and insignificant t-statistics value for two out of four dummy variables the results are not presented. Adjusted R^2 is slightly higher for S & P 500 sample.

5.2 Vector Autoregression Analysis

5.2.1. Augmented Dickey-Fuller Test

Regression results indicated high positive correlation and the price is assumed to be non-stationary. Therefore, Augmented Dickey-Fuller test is applied for all variables in the sample comprised of twenty stocks and the results are presented in Tables 8 and 9.

Table 8. Augmented Dickey-Fuller test applied for Dow Jones Stocks (four lags)

Company Name	*Price*	*Volume*	*Volatility*	*Intermarket Depth*
General Electric Co	-4.957*	-10.226*	-8.313*	-9.501*
Merck & Co Inc	-0.518	-9.318*	-9.984*	-12.184*
Philip Morris Cos Inc	0.227	-11.482*	-10.206*	-8.490*
Procter & Gamble Co	-3.887*	-9.406*	-8.940*	-8.957*
IBM	0.885	-10.659*	-10.757*	-11.211*
Du Pont EI De Nemours & Co	-3.618*	-10.244*	-9.298*	-7.665*
Exxon Mobil Corp	-0.251	-11.251*	-9.711*	-7.457*
Eastman Kodak Co	0.347	-11.152	-9.609*	-7.325*
American Express Co	0.058	-11.075*	-8.121*	-7.526*
Caterpillar Inc	4.426*	-9.592*	-11.859*	-9.392*

**Unit root hypothesis rejected at 1% significance level*
*** Unit root hypothesis rejected at 5% significance level*

In the Dow Jones sample it is ambiguous to claim that price is non-stationary since four out ten price patterns are strongly stationary at 1 percent significance level. By contrast, in S & P 500 sample only one price variable is stationary at the 5 percent significance level. The other three variables demonstrate high level of stationarity. Therefore, it is our sample there are four endogenous variables. Price is primarily assumed to exogenous, but with respect to the causality test results it seems more appropriate to change its specification and pool it together with the other three variables. ADF test results also indicate that some of the variables are integrated to different orders, and it seems necessary to change specification (Green, 2000). In this case, the first difference of the price will suffice in 15 cases where price is non-stationary. This will also allow us to control for changes in other variables when the price is assumed to be stationary or simply, transformed.

Table 9. Augmented Dickey-Fuller test applied for S&P 500 Stocks (four lags)

Company Name	*Price*	*Volume*	*Volatility*	*Intermarket Depth*
Bristol Myers Squib Co	0.670	-9.317*	-9.035*	-8.095*
Kimberly Clark Corp	2.292	-9.722*	-9.777*	-8.976*
Emerson Elec Co	-0.790	-8.826*	-9.644*	-7.866*
First Un Corp	-1.562	-10.117*	-8.811*	-9.555*
Medtronic Inc	1.760	-11.595*	-10.736*	-7.130*
Albertsons Inc	-2.966**	-8.870*	-8.454*	-6.616*
Georgia Pac Corp	1.563	-9.230*	-10.859*	-6.850*
Monsanto Co	-0.968	-11.905*	-11.695*	-9.757*
USX US Steel Group	-1.159	-10.408*	-9.612*	-8.845*
Pep Boys Manny Moe & Jack	-0.445	-11.136*	-8.994*	-8.170*

**Unit root hypothesis rejected at 1% significance level*
*** Unit root hypothesis rejected at 5% significance level*

The starting assumption is that the initial lag length is equal to four or more, since random preliminary VAR results indicate that most of the dynamic effects dissipate after four lags. The Akaike information criterion denoted as $-2l/n + k/n$ coroborates this stance (Table 10 and 11). However, the Schwartz criterion: $-2l/n + k \log n/n$ usually offers opposite conclusions. In order to pacify the differences between the two it is necessary to calculate the likelihood ratio test whose findings mostly justify the Akaike criterion. Therefore, one may assume that the Schwatz criterion is biased towards parsimonious lag lengths.

5.2.2. Variance Decomposition

In compliance with the calculated lag lengths the VAR has been performed consecutively on all twenty stocks. Following the procedure provided by Fung and Patterson (1990) the variance composition will be performed on the endogenous variables in the following order: volatility, volume, and intermarket depth.

Table 10. Akaike Information Criterion (Dow Jones)

Company Name	*Lag Length*	*Amount*
General Electric Co	7	-2.197
Merck & Co Inc	6	-2.191
Philip Morris Cos Inc	6	-3.847
Procter & Gamble Co	7	-4.256
IBM	5	2.072
Du Pont EI De Nemours & Co	2	-4.232
Exxon Mobil Corp	7	-3.676
Eastman Kodak Co	5	-4.192
American Express Co	2	-3.403
Caterpillar Inc	4	-4.170

Table 11. Akaike Information Criterion (S&P 500)

Company Name	*Lag Length*	*Amount*
Bristol Myers Squib Co	2	-2.322
Kimberly Clark Corp	4	-1.781
Emerson Elec Co	1	-6.623
First Un Corp	9	-6.759
Medtronic Inc	2	-4.067
Albertsons Inc	12	-10.140
Georgia Pac Corp	2	-3.645
Monsanto Co	2	-5.175
USX US Steel Group	4	-8.574
Pep Boys Manny Moe & Jack	2	-8.244

Price is primarily selected as an exogenous variable. However, with respect to Granger causality test result it seems plausible to include price as an endogenous variable. On the other hand price can regarded as the variable that should not demonstrate any endogenous interrelations. Pyndick and Rubinfeld (1998) suggest the inclusion of exogenous variables in the VAR procedure and testing it for its statistical explanatory power. If it does not perform well re-specification or its inclusion as the lagged variable may be considered. In multiple runs price performance was rather weak, but based on the previous findings of Granger causality it seemed plausible to include it in the system either in its basic from or as the first-difference. It will also allow for controlling the adequacy of the volatility specification.

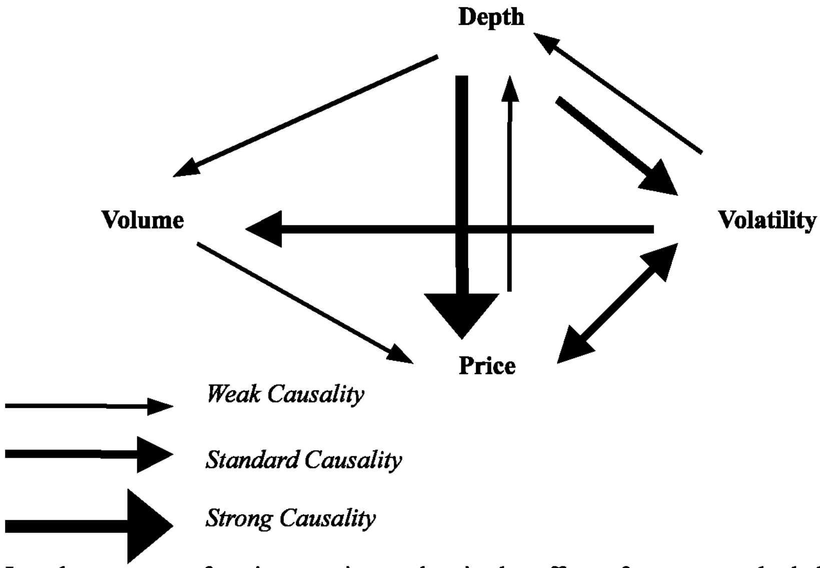
Result (Appendix I) indicate that the percentage of the forecast errors of volatility is apart from its own lagged values marginally accounted for by the intermarket depth. Price has rather weak, as expected, influence on volatility as well as all other variables, since it is primarily regarded as the exogenous variable. On the other hand, it provides us with an interesting insight since the price exhibits high levels of self-explanatory power after five periods, but when it is differenced, volatility preserves a substantial part of its explanatory power. This may be attributed to the way volatility is defined. However, the inclusion of the price does not significantly affect the similarity with the results provided by Fung and Patterson (1999).

Volume forecasting errors are significantly explained by volatility and this implies that the behavior of investors is affected by the level of return in the pervious period. The impact of the intermarket depth on the volume is rather weak. Intermarket depth preserves the highest level of self-explanatory power.

5.2.3. Impulse Response Function

The Granger causality test in Figure 1 is arbitrarily calculated as weak if there are 5-9 out of 20 observations in support of causality, 10-14 out of 20 as standard and 15-more out if 20 as strong. The results indicate that the only strong reciprocal relationship exists between volatility and price. De facto endogenous variables: Volatility, volume and intermarket depth do not indicate any strong reciprocal patterns.

Figure 1. Granger Causality Test Results



Impulse response function monitors what is the effect of a one standard deviation shock to one of the innovations on current and future values of the endogenous variables. As the results indicate (Appendix II) volatility mean reverts after 6-8 periods (lh – lh 20 min) in most of the observed cases after being exposed to the shock of its own innovation. Its impact is rather unusual on the intermarket depth that quickly takes up positive values in 16 out 20 cases even though its initial values are negative. It is stabilized, on average, after 14-16 periods (2h 20 min – 2h 40 min) even though in two cased it persists even 20 periods (3h 20 min).

Shock to volatility by volume innovations in most of the cases has a positive impact on volatility impact in both Dow Jones and the S & P 500 sample. Both positive and negative results are corroborated in the literature, but an average the tendency is rather inconclusive. In 15 out of 20 cases the shock to the volume innovations has stronger positive impact on the intermarket depth. The stabilization period ranges from 10 (lh 40 min) to slightly less than 20 (3h 20 min) periods.

6. CONCLUSION

The results indicate rather weak support for the inverted U-shape pattern of market depth during the weekdays. This may be explained by various trading patterns across seven US stock exchanges and delays in the electronic transmission of relevant data for highly liquid stocks. It is may have different behavioral approaches.

Control variables: a) price, b) volume, c) volatility have expected signs in GLS panel regressions and the t-statistic is significant. Nonetheless, fixed-and-random-effect models render price insignificant, and the Durbin-Watson statistics indicates strong positive autocorrelation.

Variance decomposition implies strong self-explanatory power of intermarket depth, which is in compliance with the findings of Fung and Patterson (1999). The impact of the lagged market-depth values in explaining forecast errors of volume is rather low, but it increases for price and volatility.

Also, price has rather small influence on forecast error, with the notable difference when impacting volatility. This may be explained by the way both variables are specified.

Impulse response function analysis implies that the stock to the volume innovation has mainly positive impact on volatility in the S & P 500 and Dow Jones stock sample. While the finding about the positive relations is in line Bessembinder and Sequin (1993) and Karpoff (1987), the opposite pattern is more related to the work of Conradetal (1994). In general, no specific behavior prevails.

It is also surprising that the shock to the volatility has rather posotive impact on the intermarket depth. Namely intermarket depth has a very steep increase and prevails in the positive area in three fourths of observed cases. This pattern may be theoretically corroborated by the impact on intermarket depth. A large increase in the spread following the shock to the volatility innovations may be quickly narrowed, while the volume persists and the market depth will take subsequently positive values before ultimate convergence. This may explain high level if absorption power of asymmetric information trading over the estimated period, as the principal cause of increased volatility.

Price is used more as a control variable and it does not coverage. However, its first difference follows the mean reversal pattern. In the market microstructure studies price should definitely be regarded as an exogenous variable in the intraday period studies due to its variance decomposition results.

This study compared the two competing approaches in the market microstructure analysis of intermarket depth. VAR clearly offers supportive results, but further model and/or variables modifications may render panel data competing in capturing the relationship between volatility, volume and intermarket depth.

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APPENDIX I

Table 1. Variance Decomposition for Ten S&P Stocks

Explained variable	Variance period (in 10-minute intervals)	Bristol Myers Squibb Co*				Kimberley Clark Corporation				Emerson Elec. Corporation*			
		Volatility	Volume	Market-depth	Price	Volatility	Volume	Market-depth	Price	Volatility	Volume	Market-depth	Price
Volatility	1	100	0	0	0	100	0	0	0	100	0	0	0
	5	96.48	0.65	2.34	0.53	95.42	0.65	3.12	0.81	95.76	0.25	3.95	0.04
	10	96.11	0.67	2.68	0.54	93.77	0.77	4.62	0.85	95.38	0.25	4.33	0.04
	15	96.10	0.67	2.69	0.54	93.69	0.77	4.69	0.85	95.37	0.25	4.33	0.04
Volume	1	8.00	92.00	0	0	11.73	88.27	0	0	8.42	91.58	0	0
	5	12.23	86.61	0.17	0.99	12.79	86.06	0.44	0.71	9.62	90.03	0.26	0.09
	10	12.26	86.49	0.25	1.00	12.78	85.87	0.58	0.76	9.62	90.01	0.28	0.09
	15	12.26	86.49	0.25	1.00	12.78	85.86	0.59	0.76	9.62	90.01	0.28	0.10
Market-depth	1	0.93	1.68	97.40	0	0.65	0.16	99.19	0	0.01	4.31	95.68	0
	5	1.93	1.50	96.53	0.04	1.31	0.69	97.75	0.25	0.06	4.55	95.25	0.14
	10	2.46	1.54	95.96	0.05	1.48	0.69	97.56	0.27	0.07	4.52	95.28	0.14
	15	2.48	1.55	95.93	0.05	1.49	0.69	97.55	0.27	0.07	4.52	95.28	0.14
Price	1	14.40	0.35	0.01	85.24	33.25	0.06	0.44	66.26	40.85	0.41	0.15	58.60
	5	8.34	3.92	1.27	86.48	33.83	0.60	3.97	61.60	42.18	0.57	2.50	54.76
	10	6.70	5.32	2.60	85.39	33.90	0.64	4.14	61.32	42.18	0.57	2.50	54.75
	15	6.05	5.69	3.22	85.04	33.90	0.64	4.14	61.32	42.18	0.57	2.50	54.75
		First Un Corp				Medtronic Inc				Albetrtsons Inc			
Volatility	1	100	0	0	0	100	0	0	0	100	0	0	0
	5	94.88	0.59	2.73	1.80	92.62	0.08	4.09	3.20	94.62	0.91	3.78	0.69
	10	93.46	0.58	4.12	1.83	91.28	0.27	5.20	3.25	90.14	1.19	7.97	0.70
	15	93.38	0.58	4.19	1.85	91.12	0.28	5.34	3.26	89.37	1.18	8.74	0.71
Volume	1	7.59	92.41	0	0	21.74	78.26	0	0	15.77	84.23	0	0
	5	9.13	87.80	0.85	2.22	21.85	77.36	0.41	0.39	21.10	77.59	1.19	0.12
	10	9.13	87.35	0.94	2.58	21.83	77.24	0.54	0.39	21.13	76.69	2.05	0.13
	15	9.13	87.34	0.95	2.58	21.83	77.22	0.56	0.39	21.12	76.49	2.24	0.15
Market-depth	1	1.25	0.26	98.49	0	0.28	1.47	98.25	0	0.00	5.15	94.85	0
	5	1.86	0.65	94.90	2.59	0.66	2.64	95.87	0.84	1.67	3.91	94.10	0.32
	10	1.87	0.74	94.57	2.82	0.64	2.94	95.16	1.26	3.94	3.53	92.16	0.37
	15	1.88	0.74	94.56	2.82	0.64	2.98	95.05	1.34	4.51	3.49	91.62	0.38
Price	1	32.70	0.00	0.82	66.48	24.89	0.77	0.31	74.02	56.52	0.10	4.63	38.75
	5	28.56	1.67	5.24	64.53	24.58	0.91	3.36	71.14	34.21	0.37	1.92	63.49
	10	28.35	1.75	5.38	64.51	24.53	0.92	3.55	71.00	19.25	0.53	5.02	75.20
	15	28.35	1.76	5.38	64.51	24.53	0.92	3.55	71.00	12.38	0.39	7.70	79.54

Table 2. Variance Decomposition for Ten S&P Stocks (Continued)

Explained variable	Variance period (in 10-minute intervals)	Georgia Pac Corp				Monsanto Co*				USX US Steel Group			
		Volatility	Volume	Market-depth	Price	Volatility	Volume	Market-depth	Price	Volatility	Volume	Market-depth	Price
Volatility	1	100	0	0	0	100	0	0	0	100	0	0	0
	5	98.52	0.94	0.10	0.44	99.89	0.03	0.08	0.00	96.11	0.07	3.54	0.28
	10	98.36	0.95	0.17	0.52	99.89	0.03	0.08	0.01	93.92	0.08	5.73	0.28
	15	98.36	0.95	0.17	0.52	99.88	0.03	0.08	0.01	93.81	0.08	5.84	0.28
Volume	1	15.11	84.89	0	0	12.28	87.72	0	0	12.11	87.89	0	0
	5	16.27	80.00	2.00	1.73	12.37	87.19	0.42	0.01	15.18	83.28	1.07	0.46
	10	16.25	79.90	2.01	1.84	12.37	87.19	0.42	0.01	15.22	82.75	1.56	0.47
	15	16.25	79.88	2.01	1.86	12.37	87.19	0.42	0.01	15.21	82.71	1.60	0.47
Market-depth	1	0.03	4.48	95.49	0	0.75	0.63	98.62	0	0.02	5.78	94.20	0
	5	1.61	4.35	93.92	0.12	1.60	0.57	97.67	0.16	1.43	5.03	93.18	0.36
	10	1.83	4.34	93.71	0.13	1.60	0.57	97.67	0.17	1.43	4.98	93.22	0.36
	15	1.83	4.34	93.69	0.15	1.60	0.57	97.66	0.17	1.43	4.98	93.22	0.36
Price	1	32.23	0.49	0.72	66.56	32.45	0.01	0.72	66.82	61.03	0.10	0.69	38.18
	5	26.18	5.74	1.15	66.93	34.01	0.04	1.10	64.85	60.77	0.33	4.32	34.58
	10	26.09	5.86	1.15	66.90	34.01	0.04	1.10	64.85	60.75	0.33	4.42	34.49
	15	26.09	5.86	1.15	66.90	34.01	0.04	1.10	64.85	60.75	0.33	4.42	34.49
		Pep Boys Manny Moe & Jack*											
Volatility	1	100	0	0	0								
	5	93.89	0.40	4.42	1.29								
	10	92.21	0.46	6.04	1.30								
	15	92.13	0.46	6.11	1.30								
Volume	1	4.63	95.37	0	0								
	5	7.69	91.71	0.56	0.04								
	10	7.82	91.48	0.64	0.05								
	15	7.82	91.47	0.65	0.05								
Market-depth	1	1.23	1.07	97.70	0								
	5	1.48	1.11	97.16	0.25								
	10	1.56	1.12	97.07	0.25								
	15	1.56	1.12	97.07	0.25								
Price	1	48.82	0.08	1.61	49.49								
	5	47.52	1.11	3.64	47.73								
	10	47.82	1.10	3.66	47.41								
	15	47.83	1.10	3.67	47.40								

Table 3. Variance Decomposition for Ten Dow Jones Stocks

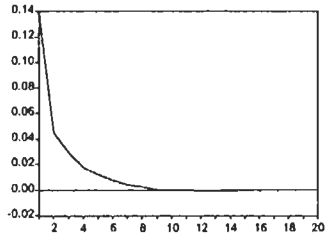
Explained variable	Variance period (in 10-minute intervals)	General Electrict Co				Merck & Co Inc				Philip Morris Cos Inc			
		Volatility	Volume	Market-depth	Price	Volatility	Volume	Market-depth	Price	Volatility	Volume	Market-depth	Price
	1	100	0	0	0	100	0	0	0	100	0	0	0
Volatility	5	88.04	0.63	7.05	4.27	87.60	0.17	5.02	7.21	90.76	0.40	5.27	3.56
	10	85.05	0.67	9.42	4.85	86.33	0.18	6.12	7.37	88.84	0.52	6.71	3.93
	15	84.91	0.67	9.56	4.86	86.32	0.18	6.13	7.37	88.80	0.53	6.75	3.93
	1	10.94	89.06	0	0	16.04	83.96	0	0	5.67	94.33	0	0
Volume	5	13.54	83.80	0.94	1.72	18.03	75.28	2.55	4.14	7.63	90.05	0.48	1.83
	10	13.77	83.13	1.20	1.90	17.89	74.53	3.30	4.28	7.61	89.51	0.79	2.09
	15	13.77	83.09	1.24	1.90	17.92	74.49	3.30	4.30	7.62	89.49	0.80	2.09
	1	0.32	0.19	99.49	0	0.30	1.78	97.92	0	0.01	3.22	96.77	0
Market-depth	5	0.60	0.34	99.05	0.02	2.00	1.93	95.56	0.51	1.17	3.11	95.30	0.41
	10	0.90	0.36	98.65	0.10	2.73	1.91	94.48	0.88	1.63	3.09	94.85	0.44
	15	0.93	0.36	98.57	0.14	2.74	1.91	94.46	0.89	1.64	3.09	94.81	0.47
	1	37.85	0.09	1.39	60.67	36.33	0.12	1.14	62.41	46.95	0.15	1.47	51.43
Price	5	13.96	1.46	2.44	82.13	36.34	1.06	5.64	56.97	46.64	1.32	5.40	46.64
	10	9.29	1.69	2.80	86.21	36.32	1.10	5.66	56.93	47.08	1.39	5.47	46.06
	15	7.62	1.74	2.66	87.98	36.31	1.10	5.66	56.93	47.08	1.39	5.49	46.05
		Procter & Gamble Co				International Business Mashine				Du Pont E I De Nemours & Co*			
	1	100	0	0	0	100	0	0	0	100	0	0	0
Volatility	5	92.55	0.66	4.86	1.94	98.38	0.05	0.55	1.02	97.01	0.12	2.87	0.00
	10	89.96	0.69	6.62	2.74	98.24	0.10	0.57	1.10	96.89	0.12	2.98	0.00
	15	89.90	0.69	6.65	2.76	98.23	0.10	0.57	1.10	96.89	0.12	2.98	0.00
	1	10.93	89.07	0	0	23.54	76.46	0	0	18.08	81.92	0	0
Volume	5	12.68	83.37	1.48	2.48	23.61	73.04	0.61	2.73	18.81	80.79	0.40	0.00
	10	12.63	82.65	1.81	2.91	23.62	72.89	0.65	2.84	18.81	80.78	0.41	0.00
	15	12.63	82.63	1.82	2.92	23.62	72.89	0.65	2.84	18.81	80.77	0.41	0.01
	1	0.01	5.71	94.29	0	0.36	3.72	95.92	0	0.15	0.25	99.60	0
Market-depth	5	1.01	6.33	91.48	1.18	0.56	3.91	95.27	0.26	0.12	0.19	99.69	0.00
	10	1.31	6.43	90.88	1.38	0.59	4.02	95.06	0.33	0.12	0.19	99.69	0.00
	15	1.31	6.43	90.87	1.39	0.59	4.02	95.05	0.34	0.12	0.19	99.69	0.00
	1	29.62	0.02	0.01	70.35	1.27	0.12	17.86	80.75	48.66	0.18	0.25	50.92
Price	5	8.10	0.47	6.96	84.47	1.92	1.78	22.48	73.81	32.50	0.14	5.33	62.04
	10	3.14	0.49	11.53	84.84	1.93	1.87	22.46	73.74	27.30	0.16	8.18	64.36
	15	1.89	0.43	13.16	84.51	1.93	1.88	22.45	73.74	25.43	0.17	9.24	65.16

Table 4. Variance Decomposition for Ten Dow Jones Stocks (Continued)

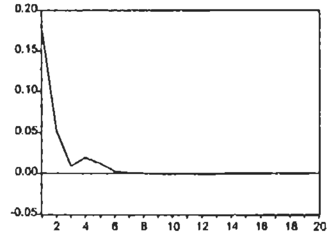
Explained variable	*Variance period (in 10-minute intervals)*	*Exxon Mobil Corp*				*Eastman Kodak Co*				*American Express Co*			
		Volatility	*Volume*	*Market-depth*	*Price*	*Volatility*	*Volume*	*Market-depth*	*Price*	*Volatility*	*Volume*	*Market-depth*	*Price*
	1	100	0	0	0	100	0	0	0	100	0	0	0
Volatility	5	94.69	0.25	3.73	1.33	92.46	0.07	4.79	2.67	97.10	0.35	1.66	0.89
	10	92.42	0.31	5.96	1.32	88.20	0.16	8.87	2.78	96.24	0.35	2.33	1.08
	15	92.28	0.33	6.07	1.32	87.98	0.17	9.07	2.77	96.14	0.35	2.43	1.08
	1	9.24	90.76	0	0	6.89	93.11	0	0	8.08	91.92	0	0
Volume	5	12.15	87.13	0.61	0.10	11.03	87.60	0.95	0.42	11.11	86.52	0.61	1.77
	10	12.14	86.92	0.84	0.11	10.96	86.78	1.80	0.46	11.26	86.15	0.74	1.85
	15	12.14	86.91	0.85	0.11	10.98	86.72	1.84	0.46	11.26	86.13	0.75	1.85
	1	0.81	3.27	95.92	0	1.16	1.46	97.38	0	0.87	1.76	97.37	0
Market-depth	5	1.39	4.46	94.14	0.01	1.76	1.80	95.70	0.74	1.10	3.32	95.31	0.26
	10	1.63	4.65	93.70	0.02	2.97	1.88	94.42	0.73	1.62	3.23	94.88	0.27
	15	1.64	4.66	93.67	0.02	3.05	1.88	94.33	0.73	1.77	3.22	94.72	0.28
	1	43.20	0.53	1.02	55.25	20.09	0.00	0.11	79.80	29.13	0.54	2.59	67.74
Price	5	44.24	0.99	5.39	49.38	20.04	0.20	4.08	75.68	28.59	1.12	4.69	65.60
	10	44.35	0.99	5.40	49.26	20.42	0.22	4.56	74.80	28.80	1.14	4.88	65.17
	15	44.35	0.99	5.40	49.26	20.46	0.22	4.56	74.76	28.81	1.15	4.88	65.16
		Caterpilar Inc											
	1	100	0	0	0								
Volatility	5	96.51	0.02	2.03	1.44								
	10	96.07	0.04	2.45	1.43								
	15	96.06	0.05	2.46	1.43								
	1	1.67	98.33	0	0								
Volume	5	1.85	97.62	0.34	0.19								
	10	1.85	97.47	0.48	0.20								
	15	1.85	97.45	0.51	0.20								
	1	0.01	1.20	98.80	0								
Market-depth	5	1.89	2.32	95.55	0.23								
	10	2.14	2.61	95.01	0.24								
	15	2.14	2.63	94.98	0.24								
	1	30.16	0.34	0.36	69.14								
Price	5	11.99	0.60	0.71	86.70								
	10	6.89	1.16	1.01	90.94								
	15	5.10	1.45	0.97	92.48								

APPENDIX II: *Impulse Response Function*
S&P 500: Shock to Volatility – Response of Volatility

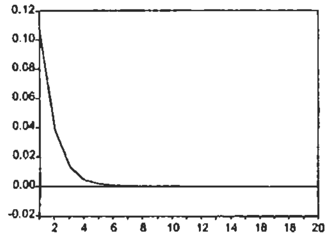
Response of VOLAT01 to One S.D. VOLAT01 Innovation



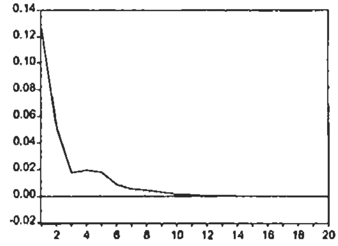
Response of VOLAT02 to One S.D. VOLAT02 Innovation



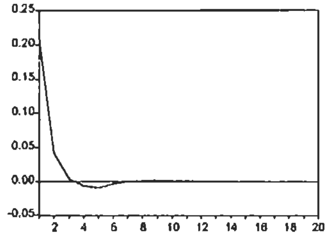
Response of VOLAT03 to One S.D. VOLAT03 Innovation



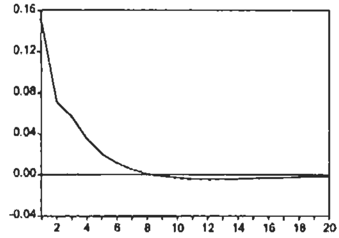
Response of VOLAT04 to One S.D. VOLAT04 Innovation



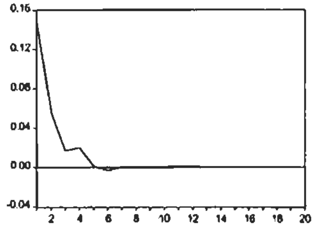
Response of VOLAT05 to One S.D. VOLAT05 Innovation



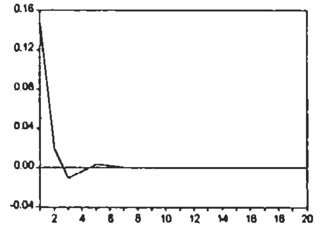
Response of VOLAT06 to One S.D. VOLAT06 Innovation



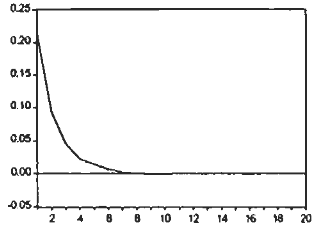
Response of VOLAT07 to One S.D. VOLAT07 Innovation



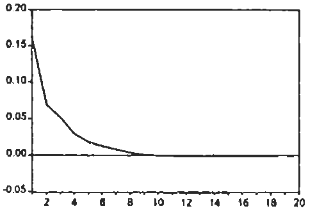
Response of VOLAT08 to One S.D. VOLAT08 Innovation



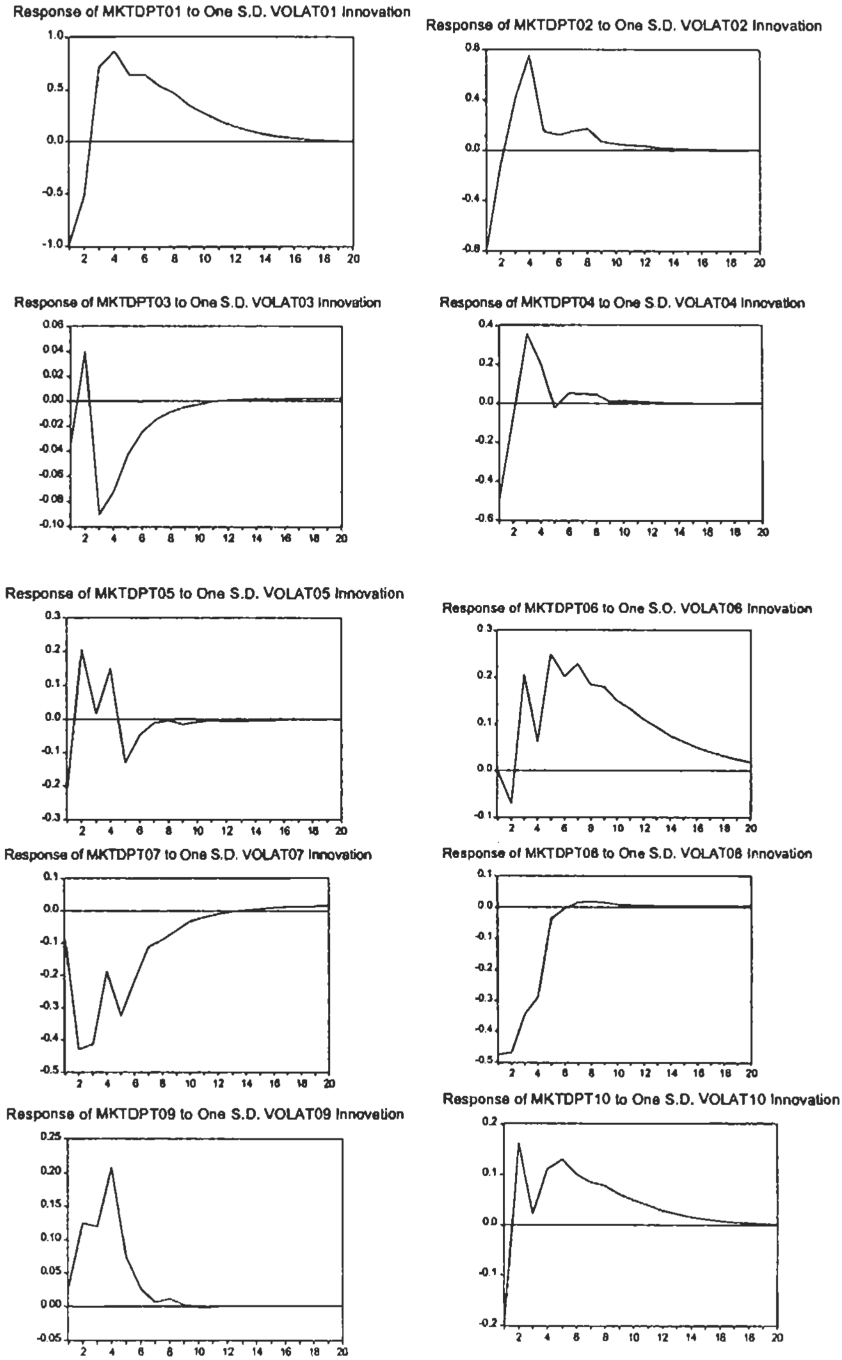
Response of VOLAT09 to One S.D. VOLAT09 Innovation



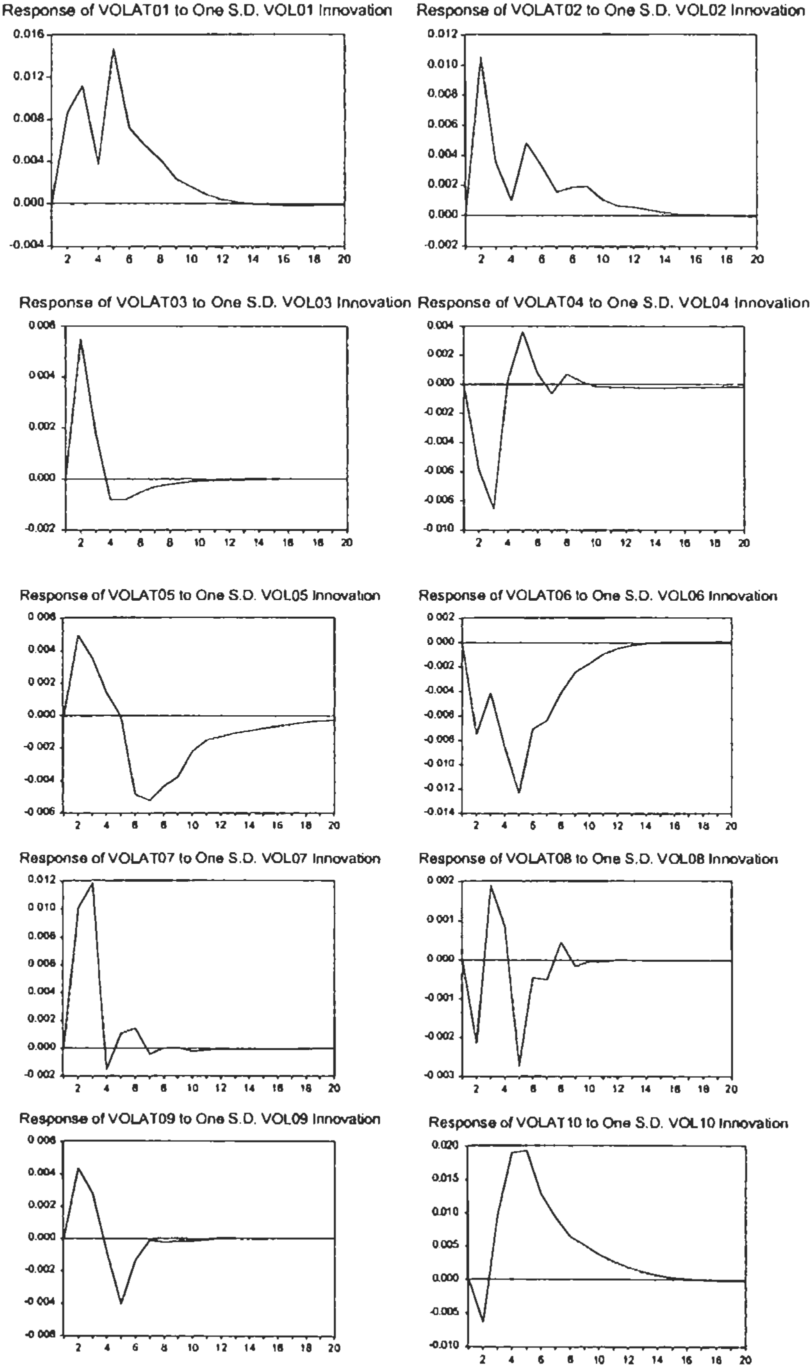
Response of VOLAT10 to One S.D. VOLAT10 Innovation



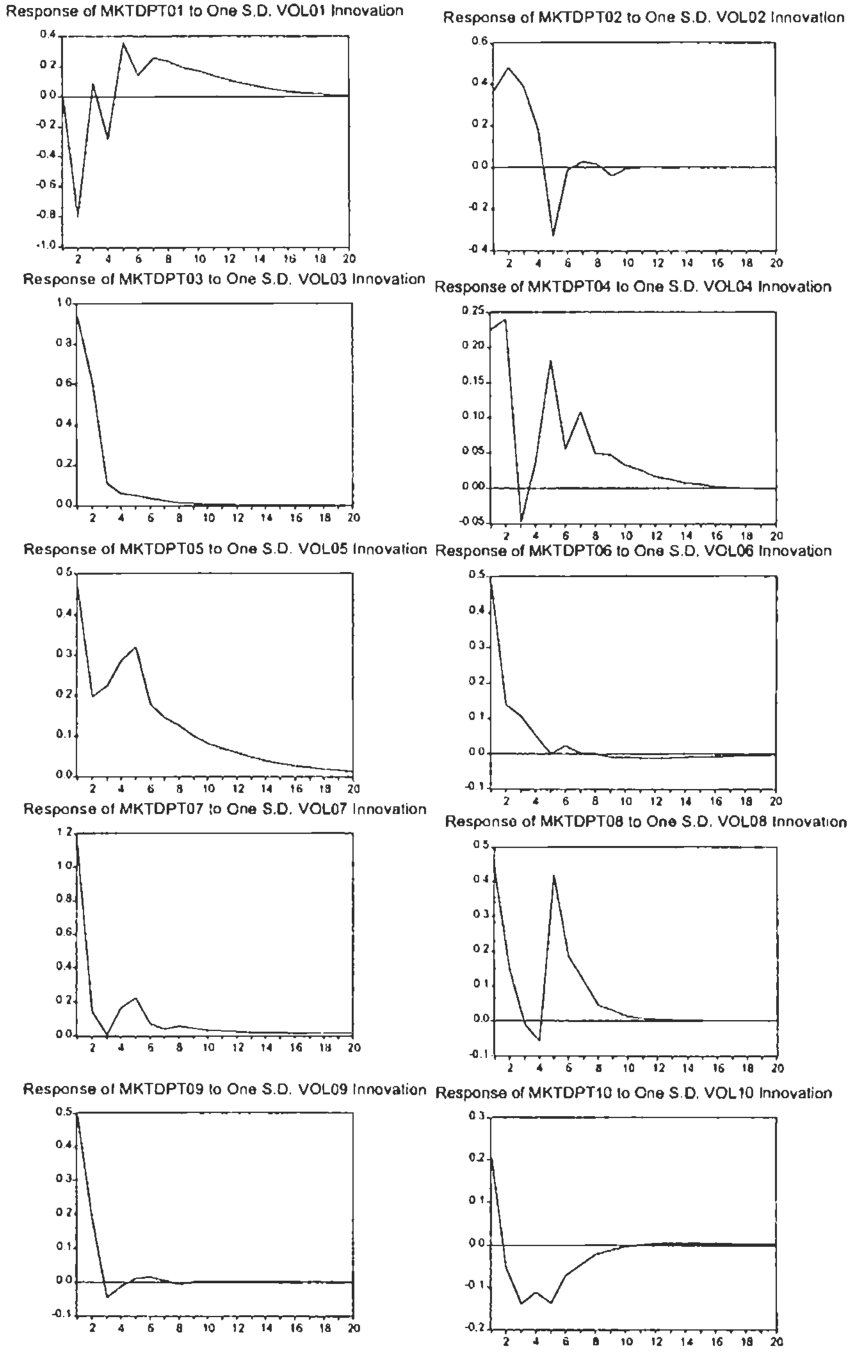
S&P 500: Shock to Volatility – Response of Market Depth



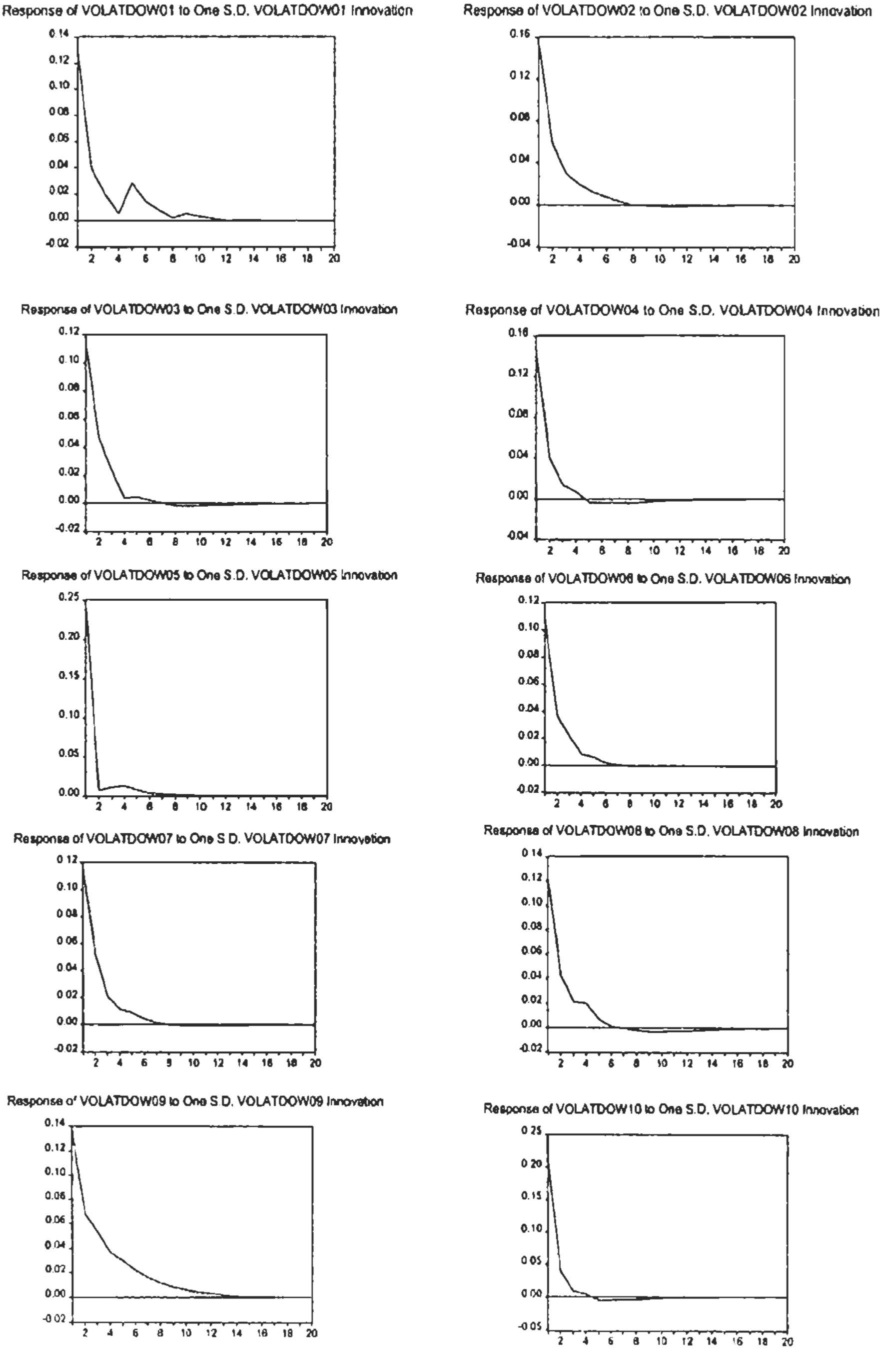
S&P 500: Shock to Volume – Response of Volatility



S&P 500: Shock to Volume – Response of Market Depth

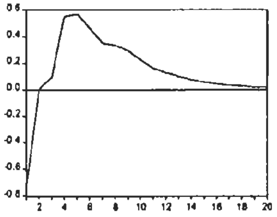


Dow Jones: Shock to Volatility – Response of Volatility

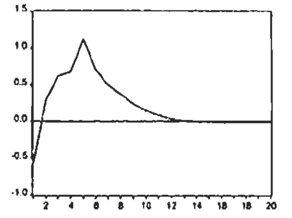


Dow Jones: Shock to Volatility – Response of Market Depth

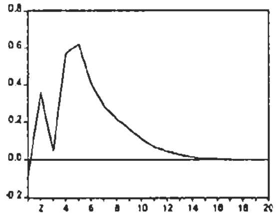
Response of MKTDPTDOW01 to One S.D. VOLATDOW01 Innovation



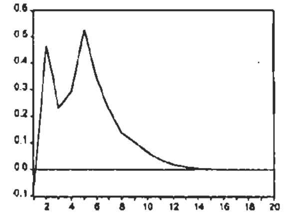
Response of MKTDPTDOW02 to One S.D. VOLATDOW02 Innovation



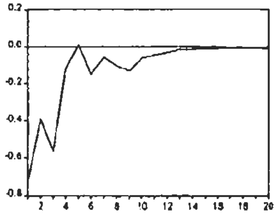
Response of MKTDPTDOW03 to One S.D. VOLATDOW03 Innovation



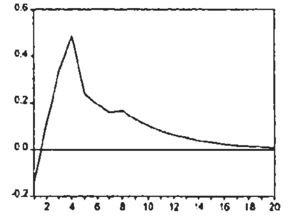
Response of MKTDPTDOW04 to One S.D. VOLATDOW04 Innovation



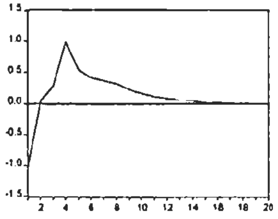
Response of MKTDPTDOW05 to One S.D. VOLATDOW05 Innovation



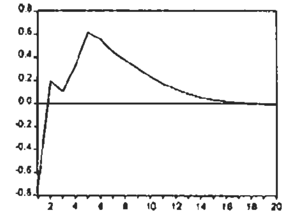
Response of MKTDPTDOW06 to One S.D. VOLATDOW06 Innovation



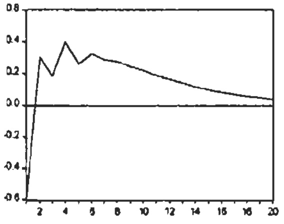
Response of MKTDPTDOW07 to One S.D. VOLATDOW07 Innovation



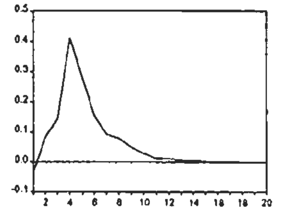
Response of MKTDPTDOW08 to One S.D. VOLATDOW08 Innovation



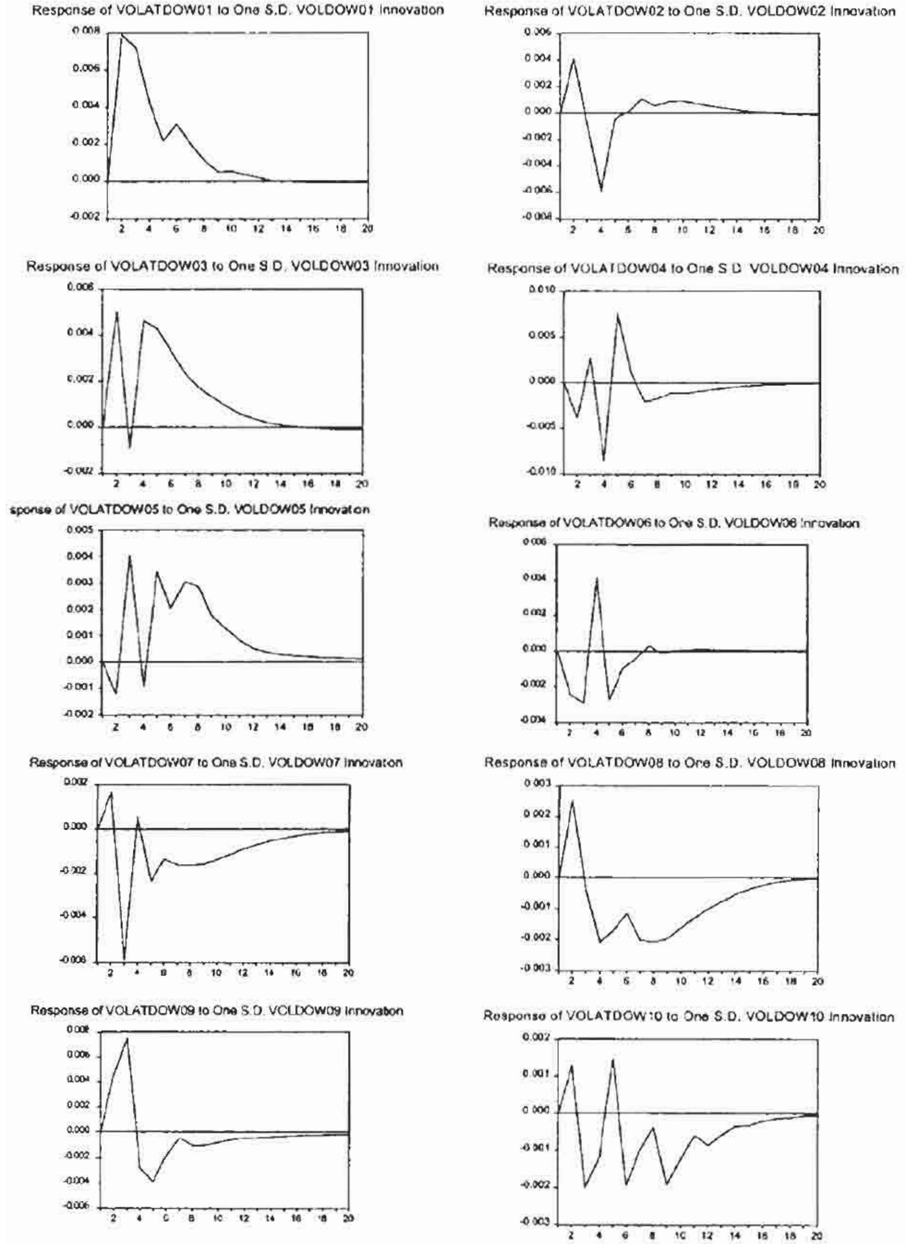
Response of MKTDPTDOW09 to One S.D. VOLATDOW09 Innovation



Response of MKTDPTDOW10 to One S.D. VOLATDOW10 Innovation



Dow Jones: Shock to Volume – Response of Volatility



Dow Jones: Shock to Volume – Response of Market Depth