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Title

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Technical Abstract

The day-of-the-week (DoW) effect in stockmarkets has been extensively studied. If returns are generated on a trade and not calendar basis, then there should be no difference in the distributions of the returns across days. This implies that a DoW efficient market or stock should have no significant differences between their seasonal distributions across trading or business days (bizdays). Analogously, significant differences between seasonal distributions across trading days indicate DoW inefficiencies.

In this paper the empirical distribution function (EDF) of the Close log-returns conditional on a particular day-of-the-week is compared to the Close log-returns conditional on the other bizdays to measure the existence of the DoW effect amongst the stocks comprising the S&P/ASX20 Index (^ATLI). Any significant deviation between the seasonal EDFs is taken as an indicator of the presence of DoW effect. The Kolmogorov-Smirnov (KS) statistic and test is used to ascertain the significance of the DoW effect. A modified KS-statistic, called the DoW-statistic, is then used to define the degree of DoW inefficiency. The lowest DoW-statistic for each stock is subsequently used to rank the 20 S&P/ASX20 stocks according to their DoW inefficiencies.

Of the 20 S&P/ASX20 stocks considered, it was found that the daily log-returns of Alumina Limited was the most DoW efficient for the period $1/1/2000$ to $1/1/2005$. The least DoW efficient was QBE Insurance Group for the same period. The DoW-statistics for S&P/ASX20 stocks range from *0.9289* to *0.8368* with higher values being more DoW efficient and lower values being more DoW inefficient.

Non-Technical Abstract

The detection of anomalies in daily returns suggests opportunities exist for profitable trading strategies. One such an anomaly is the day-of-the-week (DoW) effect. According to the DoW effect, stocks returns are significantly higher or lower on certain days of the week than on other days, with significant differences in return distributions. Detecting such a seasonal effect implies trading strategies such as buying on the low returns bizdays and selling on high returns bizdays might prove to be profitable. However, there is currently no simple statistic to enable one to rank these DoW effects on a statistical basis. In this paper we define and utilise one such a statistic, termed the DoW-statistic, to detect and rank DoW effects across stocks and markets. Practitioners will find the DoW-statistic useful in screening for DoW inefficient stocks to make trading decisions over short-horizons and for DoW efficient stocks to make investment decisions over long-horizons.

1 Introduction

The day-of-the-week (DoW) effect in stockmarkets has been extensively studied. The economic rational of these studies is that, if returns are generated on a trade and not calendar basis, there should be no difference in the distributions of the log-returns across days. This implies that a DoW efficient market should have no significant differences between their day-of-the-week distributions over trading or business days (bizdays). Analogously, significant differences between day-of-the-week distributions over bizdays days indicate DoW inefficiencies (see Cross [1973], French [1980], Gibbons and Hess [1981], Lakonishok and Levi [1982], Keim and Stambaugh [1984], Rogalski [1984a], Jaffe and Westerfield [1985], Smirlock and Starks [1986], Flannery and Protopapadakis [1988], Miller [1988], Wilson and Jones [1993], Aggarwal and Tandon [1994], Pena [1995], Dubois and Louvet [1996], Poshakwale [1996], Wang, Li, et al. [1997]), Davidson and Faff [1999], Brooks and Pesarnd [2001], Lin and Lee [2001], Steeley [2001], Bayar and Kan [2002], Kamath and Chusanachoti [2002], Kohers, Kohers, et al. [2004] and many others).

In this paper the empirical distribution function (EDF) of the Close log-returns conditional on a particular day-of-the-week is compared to the conditional Close returns of the other days to measure and detect the existence of the DoW effect in the Australian stockmarket. Any significant deviation between the conditional EDFs is an indication of the presence of the DoW effect. The Kolmogorov-Smirnov (KS) test is used to ascertain the significance of the DoW effect. A modified KS-statistic, called the DoW-statistic is then used to define the degree of DoW inefficiency.

The DoW-statistic is subsequently used to rank the 20 component stocks in the S&P/ASX20 (^ATLI[1]) index according to their DoW inefficiencies. The DoW-statistic enables the ranking of stocks and markets without making any other assumptions as regards the distributional shape of the asset returns. It is a distribution-free statistic and can be used to rank stocks within a stockmarket. It can also be used to rank stockmarkets in aggregate.

In Section 2 the background to empirical distribution functions (EDFs) is presented. This is followed in Section 3 with further details on the KS-statistic and KS-test. In Section 4 we define the DoW-statistic. The dataset used in this paper is described in Section 5. The hypothesis and the methodology is described and discussed in Section **Error! Reference source not found.**. In Section 7 we present the summarised results and discuss the findings and finally, in Section 8 we conclude and present areas for further investigation.

2 Empirical Distribution Functions (EDFs)

The empirical distribution function (EDF) of a sample, $F_d(x)$, is a step function defined as:

$$F_d(x) = \begin{cases} 0\ ; & x < x_{(1)} \\ i/n\ ; & x_{(i)} \le x < x_{(i+1)};\ i = 1,...,n-1 \\ 1\ ; & x_{(n)} \le x \end{cases} \tag{1.1}$$

where n is the sample size and $F_d(x)$ is the proportion of observations with a value less or equal to x, with increasing steps of $1/n$ at each observation. Figure 2-1 depicts the EDFs for the S&P/ASX20 over each of the five bizdays. In Figure 2-1, the day-of-the-week EDFs are distinct from each other. The

[1] "^ATLI" is the Yahoo.com symbol for the S&P/ASX20 Index.

challenge is to determine whether the EDFs are significantly different from each other. There are several statistical tests available for comparing $F_1(x)$ to $F_2(x)$, essentially differing in the EDF-statistic defined for comparison.

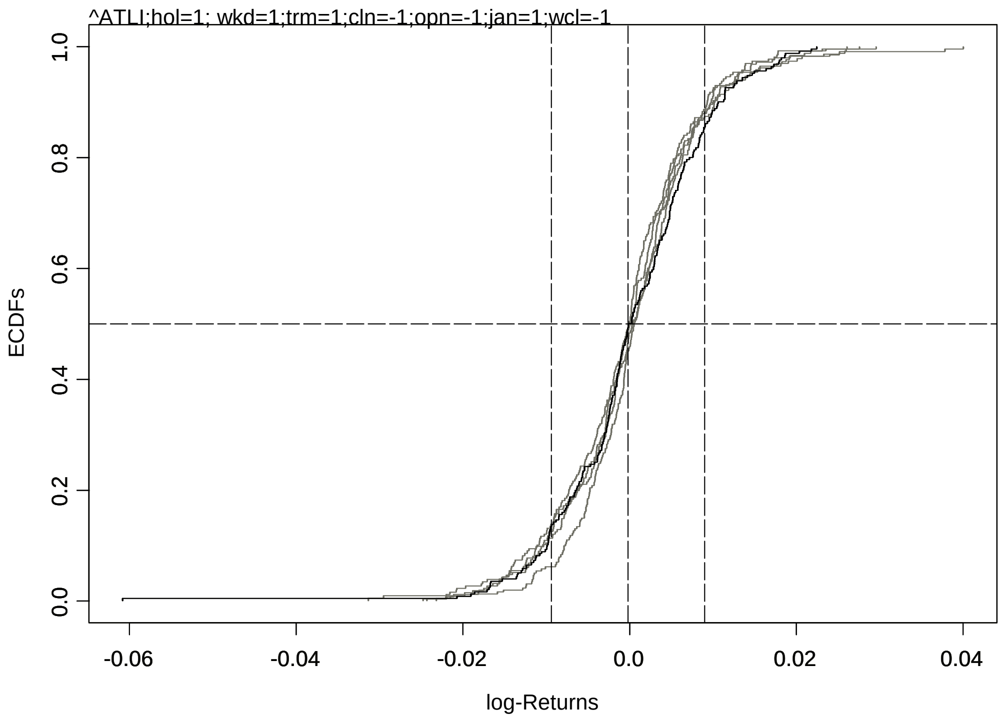

Figure 2-1 Empirical Distribution Functions (EDFs)
Notes: The black line depicts Monday log-returns. The grey lines depict all other bizdays log-returns.

The Kolmogorov-Smirnov test or the KS-test is the most commonly used of these tests, and the KS-statistic is defined as the maximum difference between the two empirical distribution functions (EDFs), $F_1(x)$ and $F_2(x)$.

3 The KS-statistic and KS-test

As mentioned in Section 2, the statistic measuring the difference between $F_1(x)$ and $F_2(x)$ are called EDF statistics[2], D^+ and D^-, which are respectively the largest vertical difference when $F_1(x) > F_2(x)$ and the largest vertical difference when $F_1(x) < F_2(x)$. Formally,

$$D^+ = \sup_x \{F_1(x) - F_2(x)\} \tag{2.1}$$

$$D^- = \sup_x \{F_1(x) - F_2(x)\} \tag{2.2}$$

The more commonly used EDF statistic by however is:

$$D = \sup_x \|F_1(x) - F_2(x)\| = \max(D^+, D^-) \tag{2.3}$$

D is known as the Kolmogorov-Smirnov (KS) statistic (see Kolmogorov [1933], Chakravart, Laha, et al. [1967]).

Although this test was primarily designed for continuous distributions, it can also be applied to discrete distributions where the critical values tend to be over-conservative, i.e. a tabulated 5% critical value might in fact represent an actual 4% significance level (see Neave and Worthington [1988]). Fortunately there are modified KS-tests which are distribution free[3] (see Gibbons and Chakraborti [1992]). In this paper, the value of the KS statistic for two samples is based on the procedure given by Hollander and Wolfe [1999]. The p-value of the KS-statistic is determined using the algorithm given by Kim and

[2] Note $F_n(x)$ is used to represent the empirical distribution and $F_{n:n}(x)$ is used to represent the exact nth-order extremal distribution.

[3] The Wilcoxon ranksum test is appropriate to detect differences in location and the Siegel-Turkey test is especially appropriate to detect differences in dispersion, both of which are not of concern here.

Jennrich [1970] which corrects for the over-conservative nature of the KS-test.

4 The DoW-statistic

We introduce a Day-of-the-Week statistic (DoW-statistic) for measuring the DoW efficiency of stockmarkets. The DoW-statistic is defined as:

$$DoW = 1 - \max \begin{bmatrix} \max(D_{Mon-\overline{Mon}}), \\ \max(D_{Tue-\overline{Tue}}), \\ \max(D_{Wed-\overline{Wed}}), \\ \max(D_{Thu-\overline{Thu}}), \\ \max(D_{Fri-\overline{Fri}}) \end{bmatrix} \tag{3.1}$$

where $D_{Day-\overline{Day}} = \sup_x \left| F_{Day}(x) - F_{\overline{Day}}(x) \right|$ and $\overline{Day}$ means all other bizdays except Day, the current day. Suppose we are computing $D_{Mon-\overline{Mon}}$, then $\overline{Mon}$ ("not-Mondays") means Tuesdays, Wednesdays, Thursdays and Fridays.

This formulation ensures that the largest KS-statistic for the day in question is selected. The DoW-statistic is defined as 1 minus the maxim KS-statistic across all the bizdays. The DoW-statistic, by definition, will bounded between 0 to 1. The DoW-statistic can then be used to rank to DoW efficiency of stocks and markets, a value of 1 indicating a perfect DoW efficiency. Thus a value of 1.000 indicates perfect DoW efficiency. A DoW-statistic of say, *0.9164*, indicates 91.64% DoW efficiency.

The DoW efficiencies can subsequently be classified according to the significant level, α, of rejection of the underlying KS-statistic. If the maximum KS-statistic chosen was rejected at the 1% level, then the stock in question can be classified as DoW inefficient at the 1% level. Rejection at the 5% level indicates DoW efficiency at the 5% level. Rejection at the 10% level is DoW in efficient at the 10% level and a no rejection depicts DoW efficiency.

5 Data

The S&P/ASX 20 index is comprised of the 20 largest stocks by market capitalisation in Australia, emphasizing liquidity and "investability", and consequently is expected to be DoW efficient. For completeness, the component stocks of the S&P/ASX 20 index (^ATLI) are also investigated. The sample period is from 1/1/2000 to 1/1/2005. The Closing daily prices for the S&P/ASX20 and the 20 component stocks were downloaded from http://finance.yahoo.com/. The S&P/ASX20 is one of the most widely followed index in the world and any DoW inefficiencies, either in the index or the component stocks, should be of significance to stockmarket participants. The daily Close-to-Close log-returns were computed for all bizdays. Since we are considering only trading day or bizday anomalies, we could opt for Close-to-Open log-returns. However, for the sake of consistency we have stuck to the more traditional Close-to-Close log-returns. The results of either approaches does not significantly differ the empirical DoW classifications.

Symbol_Description	Mean	Stdev	Skew	Kurt
AMC.AX_AMCOR	0.0003	0.0141	-0.5774	8.4286
AMP.AX_AMP	-0.0002	0.0187	-0.1758	8.1338
ANZ.AX_ANZ BANK	0.0008	0.0125	-0.3691	7.0852
AWC.AX_ALUMINA	0.0003	0.0192	-0.1636	5.6357
BHP.AX_BHP BLT	0.0005	0.0173	-0.1114	3.9093
CBA.AX_CWLTH BANK	0.0004	0.0117	-0.2587	5.1012
CML.AX_COLES MYER	0.0006	0.0133	-0.0670	6.4692
FGL.AX_FOSTERS	0.0003	0.0120	-0.5539	8.3943
NAB.AX_NAT.BANK	0.0006	0.0124	-0.0888	4.6593
NWS.AX_NEWS INC BVOTIN	-0.0003	0.0259	-0.3020	7.5553
NWSLV.AX_NEWS INC NONVOT	-0.0002	0.0262	-0.1958	6.6541
QBE.AX_QBE INSUR.	0.0012	0.0186	0.7467	10.0535
RIO.AX_RIO TINTO	0.0002	0.0168	-0.0270	4.2882
SGB.AX_ST.GEORGE	0.0008	0.0111	0.3478	7.1100
TLS.AX_TELSTRA CORPORATI	-0.0003	0.0138	-0.1621	7.9657
WBC.AX_WESTPAC	0.0007	0.0122	-0.0515	4.3563
WDC.AX_WESTFIELDG STAPLE	0.0006	0.0077	-0.0597	3.0195
WES.AX_WESFARMER	0.0012	0.0155	0.1717	6.2998
WOW.AX_WOOLWORTHS	0.0010	0.0133	-0.0260	4.9588
WPL.AX_WOODSIDE	0.0005	0.0154	0.0559	6.9260
^ATLI_S&P ASX 20	0.0002	0.0084	-0.1394	6.1785

Table 5-1 S&P/ASX20 Index Summary Statistics

Table 5-1 lists the first four moments for the 20 stocks and the S&P/ASX20 index. Many of the stocks have high skewness and kurtosis, thus making the choice of a suitable analytical distribution to depict observed returns a yet unresolved problem (see Officer [1972], Los [2003], Jeyasreedharan [2004]).

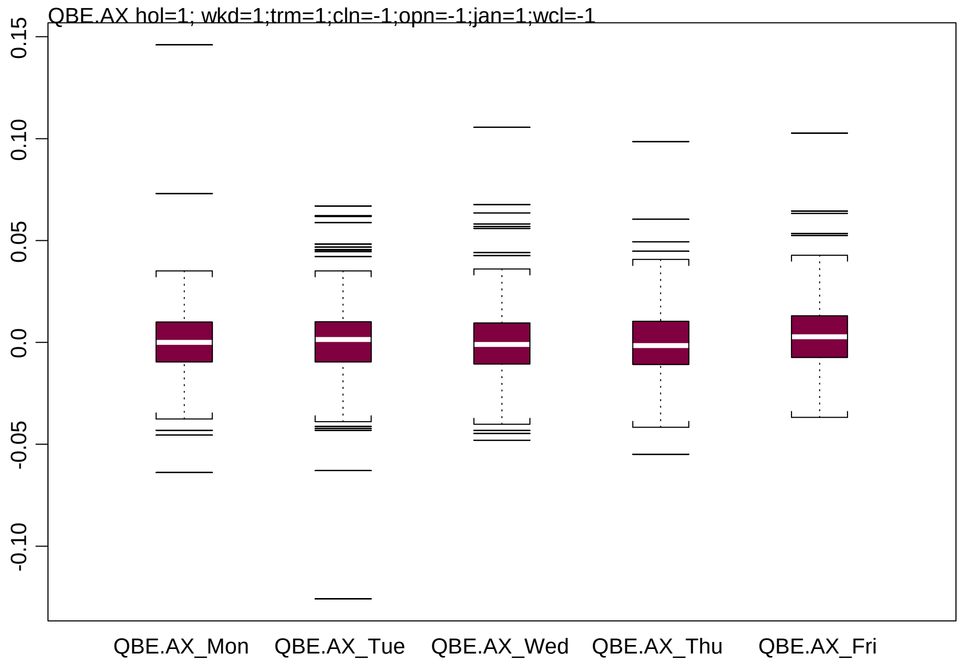

Figure 5-1 QBE log-returns Boxplot

In particular, from Table 5-1 it can be seen that QBE exhibits a very high skewness and kurtosis values. Figure 5-1 displays the boxplots for QBE log-returns for the days-of-the-week, illustrating the skewed nature of the daily log-returns. We circumvent this problem in this paper by using the empirical distribution function to depict the stock returns.

6 Methodology

The statistical methodology adopted in most of the studies mentioned above utilizes t-tests of the differences between means and F-tests of the differences between variances. The classic t-tests and F-tests are biased (see Connolly [1989]) as they assume that the underlying log-returns are normally distributed.

The methodology adopted here is a pairwise comparison of all daily EDFs as suggested by Galai and Levy [2003]. We however, do not utilize the multiple comparisons procedure (MCP), also mentioned in Galai and Levy [2003], as we do not seek the joint rejection of a particular day's distribution over all the other days. Our alternate hypothesis does not require all bizdays to be rejected, just any one of the combinations (see Connolly [1989], Alt, Fortin, et al. [2002], Galai and Levy [2003]).

In this paper the following five hypothesis are tested:

$$H_0 : \{EDF_{Mon} = EDF_{Tue} = EDF_{Wed} = EDF_{Thu} = EDF_{Fri}\} \tag{5.1}$$

$$H_{Mon} : \begin{Bmatrix} EDF_{Mon} \neq EDF_{Tue} \mid EDF_{Mon} \neq EDF_{Wed} \mid \\ EDF_{Mon} \neq EDF_{Thu} \mid EDF_{Mon} \neq EDF_{Fri} \end{Bmatrix} \tag{5.2}$$

$$H_{Tue} : \begin{Bmatrix} EDF_{Tue} \neq EDF_{Mon} \mid EDF_{Tue} \neq EDF_{Wed} \mid \\ EDF_{Tue} \neq EDF_{Thu} \mid EDF_{Tue} \neq EDF_{Fri} \end{Bmatrix} \tag{5.3}$$

$$H_{Wed} : \begin{Bmatrix} EDF_{Wed} \neq EDF_{Mon} \mid EDF_{Wed} \neq EDF_{Tues} \mid \\ EDF_{Wed} \neq EDF_{Thu} \mid EDF_{Wed} \neq EDF_{Fri} \end{Bmatrix} \tag{5.4}$$

$$H_{Thu} : \begin{Bmatrix} EDF_{Thu} \neq EDF_{Mon} \mid EDF_{Thu} \neq EDF_{Tue} \mid \\ EDF_{Thu} \neq EDF_{Wed} \mid EDF_{Thu} \neq EDF_{Fri} \end{Bmatrix} \tag{5.5}$$

$$H_{Fri} : \begin{Bmatrix} EDF_{Fri} \neq EDF_{Mon} \mid EDF_{Fri} \neq EDF_{Tue} \mid \\ EDF_{Fri} \neq EDF_{Wed} \mid EDF_{Fri} \neq EDF_{Thu} \end{Bmatrix} \tag{5.6}$$

Rejection of the null hypothesis implies that at least one of the five bizdays log-returns is not distributed equally as one of the others.

The day-of-the-week EDFs are pairwise differenced and the relevant KS-statistic and level of statistical significance determined. The largest KS-statistic or the lowest DoW-statistic across all possible combinations of bizdays is selected. For each bizday the maximum KS-statistic realized is chosen and the maximum for all bizdays is used to compute the DoW-statistic. The Dow-statistic is then the weakest pairwise combination in the sample dataset.

7 Results

We report the summarized results across each and all bizdays. For clarity we also report on the detailed Friday results for the “worst” ranking stock in the sample, the stock of the QBE Insurance Group Limited.

In Figure 7-1 one can visually observe the large discrepancy in the EDFs for the Fri-Thu pair, indicating Fri-Thu returns to be the most DoW inefficient. For the Fri-Thu combination, the null hypothesis is rejected at the 1% significance level. The Fri-Wed combination is rejected at the 5% level and all other “cross-days” rejected at the 10% significance level.

The bottom-left and bottom-right are self-comparisons (Fri-Fri, Biz-Biz) and are control plots. The top-left depict the Fri-Mon EDFs. The top-right depict Fri-Tue EDFs, the middle-left depict Fri-Wed EDFs. The middle-right depict Fri-Thu EDFs and the bottom-left depict the Fri-Fri EDFs.

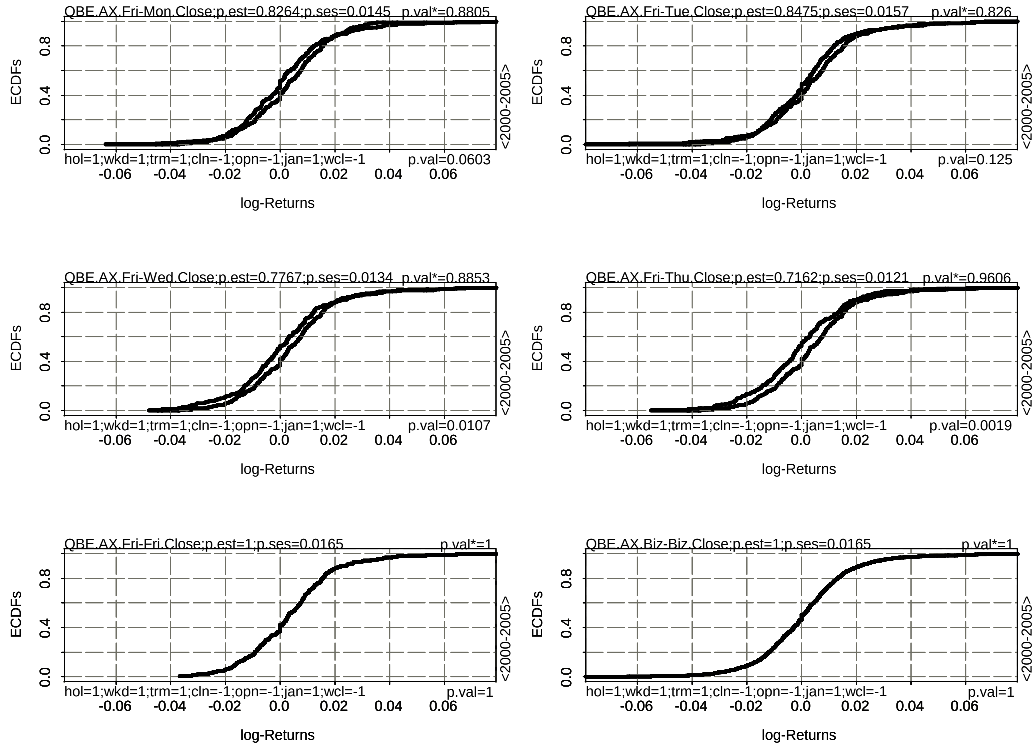

Figure 7-1 Friday EDFs for QBE Insurance Group Limited (QBE.AX)
Note: The bottom-left and bottom-right are self-comparisons (Fri-Fri, Biz-Biz) and are control plots. The top-left depict the Fri-Mon EDFs. The top-right depict Fri-Tue EDFs, the middle-left depict Fri-Wed EDFs. The middle-right depict Fri-Thu EDFs and the bottom-left depict the Fri-Fri EDFs.

The maximum KS-statistic is obtained for the Friday anomaly is from the Fri-Thu combination. The summarized results are listed in Table 7-1. In addition the stocks that are ranked from 1 to 9 do not exhibit DoW effects. Stocks ranked from 10 to 15 exhibit DoW effects at the 10% significance level. Stocks ranked from 16 to 20 exhibit DoW effects at the 5% significance level and only one stock, QBE, ranked 21 exhibit DoW effects at the 1% significance level.

The most DoW efficient S&P/ASX20 stock is Alumina Limited and the most DoW inefficient S&P/ASX20 stock is QBE Insurance Group Limited for the period considered. The S&P/ASX20 index does not exhibit any significant DoW effects and is ranked 11 or is in the top third of the table. Consequently, when we use market indices to test for DoW effects, we should not quote market-based DoW efficiency measures to make inferences regarding the

DoW efficiencies of the component stocks. Individually the component stocks might, as is the case here, exhibit varying degrees of DoW anomalies.

Symbol	Monday	Tuesday	Wednesday	Thursday	Friday	KS.max	DoW	Rank
AWC.AX_ALUMINA	0.0635	0.0684	0.0711	0.0609	0.0711	0.0711	0.9289	1
AMC.AX_AMCOR	0.0792	0.0687	0.0792	0.0787	0.0771	0.0792	0.9208	2
CBA.AX_CWLTH BANK	0.0826	0.0677	0.0844	0.0844	0.0767	0.0844	0.9156	3
BHP.AX_BHP BLT	0.0819	0.0846	0.0846	0.0767	0.0797	0.0846	0.9154	4
AMP.AX_AMP	0.0594	0.0906	0.0906	0.0629	0.0631	0.0906	0.9094	5
TLS.AX_TELSTRA CORPORATI	0.0944	0.0673	0.0896	0.0944	0.0636	0.0944	0.9056	6
^ATLI_S&P ASX 20	0.0916	0.0988	0.0988	0.0936	0.0916	0.0988	0.9012	7
SGB.AX_ST.GEORGE	0.0882	0.1007	0.1007	0.0904	0.0887	0.1007	0.8993	8
WOW.AX_WOOLWORTHS	0.0864	0.101	0.101	0.0994	0.0876	0.101	0.899	9
WPL.AX_WOODSIDE	0.0676	0.0797	0.0867	0.1079*	0.1079*	0.1079*	0.8921	10
FGL.AX_FOSTERS	0.1081*	0.0919	0.0902	0.1081*	0.0818	0.1081*	0.8919	11
CML.AX_COLES MYER	0.1003	0.1089*	0.1089*	0.0986	0.0881	0.1089*	0.8911	12
RIO.AX_RIO TINTO	0.1116*	0.1058	0.1116*	0.1102*	0.0927	0.1116*	0.8884	13
WDC.AX_WESTFIELDG STAPLE	0.1155*	0.09	0.1155*	0.0773	0.0951	0.1155*	0.8845	14
WBC.AX_WESTPAC	0.1164*	0.0916	0.1164*	0.0803	0.0975	0.1164*	0.8836	15
ANZ.AX_ANZ BANK	0.0945	0.1195**	0.0781	0.1066*	0.1195**	0.1195**	0.8805	16
WES.AX_WESFARMER	0.0835	0.1155*	0.1107*	0.1206**	0.1206**	0.1206**	0.8794	17
NWS.AX_NEWS INC BVOTIN	0.1265**	0.1265**	0.1235**	0.1147*	0.0915	0.1265**	0.8735	18
NWSLV.AX_NEWS INC NONVOT	0.1346**	0.1346**	0.1185*	0.094	0.0882	0.1346**	0.8654	19
NAB.AX_NAT.BANK	0.1099*	0.1275**	0.1368**	0.1002	0.1368**	0.1368**	0.8632	20
QBE.AX_QBE INSUR.	0.1164*	0.1024	0.1414**	0.1632***	0.1632***	0.1632***	0.8368	21

Table 7-1 KS- and DoW-statistics for S&P/ASX20 stocks
Note: “*” depicts 10% (low) significance; “**” depicts 5% (medium) significance; “***” depicts 1% (high) significance.

More than half of the S&P/ASX20 stocks are DoW inefficient at the 10% level. About a quarter of the S&P/ASX20 stocks are Dow inefficient at the 5% level and only one of the stocks are DoW inefficient at the 1% level.

As illustrated in Figure 7-2 there is high degree of variation in the DoW-statistics across stocks and across bizdays indicates some degree of variation in the DoW anomalies across stocks and bizdays. On average, the S&P/ASX20 Index is most DoW-efficient on Fridays and least DoW-efficient on Wednesdays.

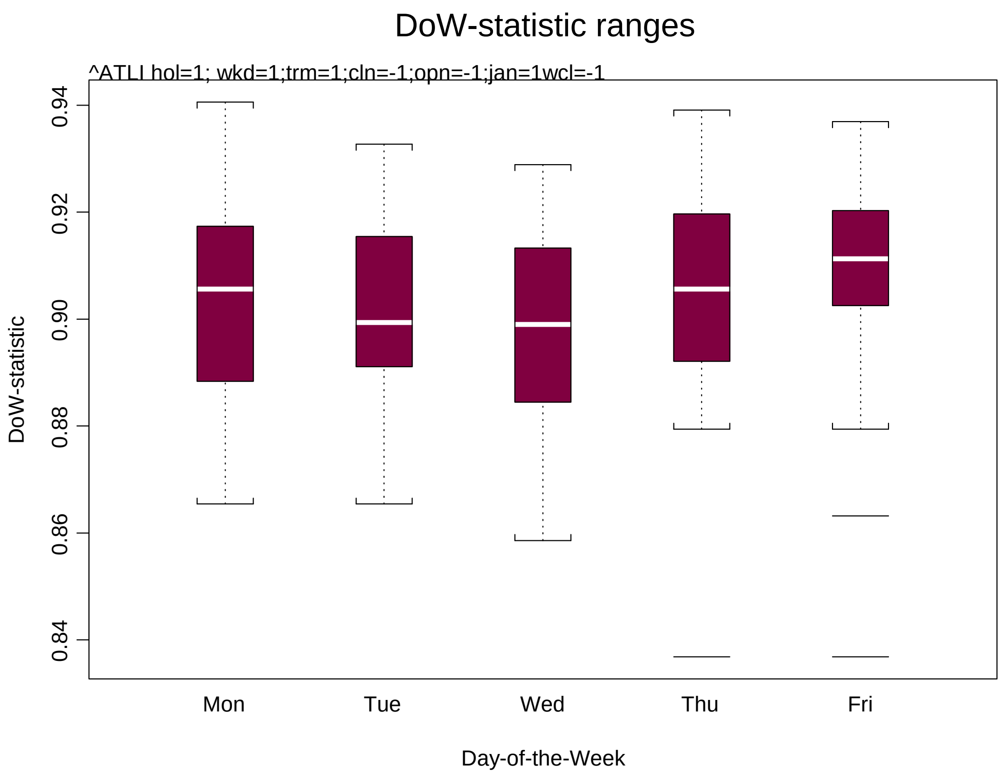

Figure 7-2 Range of DoW-statistics

In summary, there is a wide range of variations of the DoW-statistics over the 20 S&P/ASX20 stocks investigated indicating a high possibility of significant DoW inefficiencies being detected for the lower DoW-scores. This is confirmed by the number of asterisks displayed under the “KS.max” column of Table 7-1.

8 Conclusions

The DoW-statistic is shown to be a convenient measure of DoW efficiency. It is a relative measure based on the day-of-the-week EDFs of sample log-returns and is thus unit and scale invariant. We are able to classify the DoW inefficiencies using the level of significant rejections of 10%, 5% and 1%, being Class I, Class II and Class III DoW inefficiencies respectively. A DoW inefficient stock is one in which the null hypothesis is rejected at the 10% or less significant level. Analogously, a DoW efficient stock is one that cannot be rejected at the 1% level.

Although we used the S&P/ASX20 Index (^ATLI) stocks to illustrate the DoW-statistic, the DoW-statistic can be applied to any other aggregate market or stock. Of the 20 S&P/ASX20 stocks tested, it was found that the stock of Alumina Limited was the most DoW efficient for the period $1/1/2000$ to $1/1/2005$. The least DoW efficient was the QBE Insurance Group Limited. The DoW-statistics range from *0.9289* to *0.8368* with higher values being more DoW efficient and lower values being more DoW inefficient. Of the 20 stocks tested, only one was found to be DoW inefficient at the 1% significant level. It must be stressed at this juncture that DoW efficiency/inefficiency is only one aspect of stockmarket efficiency/ inefficiency. A DoW efficient/ inefficient market might be inefficient/efficient is a different sense, i.e. there might be a dependency structure in the timeseries of log-returns (see Bessembinder and Hertzel [1993]) or stock prices mirror true values.

All we can say, using the DoW-statistic cum test, is whether or not a market or stock is DoW efficient. In doing so, we rank the stocks and markets accordingly and obtain a DoW-ordered list for potential investment and trading decisions. The presence of a significant DoW inefficiency is evidence against the random walk and efficient market hypothesis for the affected stocks. One might be seen to be prudent investing in a DoW efficient market but also might be seen to be equally prudent trading in a DoW inefficient market.

We do not attempt here to explain why these DoW anomalies or effects occur as there are already a number of competing hypotheses offering conflicting explanations (see Rogalski [1984b], Condoyanni, O'Hanlon, et al. [1987], Edward [1988], Damodaran [1989], Ziemba [1993], Kohers and Kohers [1995] and many others). In addition, the question of whether abnormal gains can be realized by trading in DoW inefficient stocks or whether transaction costs and time varying risk-premium will prevent these gains from being realized is also not investigated (see Hsiao and Solt [2004], Kohers, Kohers, et al. [2004]). Both the theoretical explanations and practical applications are left for further investigation and discussion.

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