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# The efficiency of the Warsaw Stock Exchange: the first few years 1991-1996

**Abstract.** This paper reports a test of the changing pricing efficiency of the first stage of development of the Warsaw Stock Exchange (WSE). Emerging stock markets are unlikely to be fully information-efficient, partly due to institutional rigidities which restrict information flows to the market and partly for lack of experienced market participants to rapidly impound new information into security prices. Tests for runs and autocorrelation were conducted for the 1991-1996 trading history of the WSE and also to segmented sub-periods during which different institutional arrangements applied. As the number of trading days per week increased, the general level of efficiency, although low, steadily improved (except for the "bubble" period of 1993-1994). Inefficiencies persist in some stocks, possibly explained by opportunities to conduct off-market, out-of-hours transactions in specific stocks, and the stock exchange authorities' continuing power to suspend trading.

**Keywords:** emerging stock markets, pricing efficiency, runs test.
**JEL Codes:** E44, G10, G14.

## 1. Introduction

This study examines the structure and behaviour of an emerging stock market in its first stage of development in a transitional economy. The research attempts to assess the changes in pricing efficiency of the Warsaw Stock Exchange (WSE), the second stock exchange (after Budapest) to be established in the European Emerging Market Economies (EEMEs). It is generally acknowledged (e.g., EBRD 1994, Young & Reynolds 1994) that essential ingredients in the marketisation of these formerly planned economies were privatisation of both large-scale and small-scale enterprises and the establishment of a mechanism to facilitate post-privatisation share trading. The free transfer of title to ownership of the existing securities is important in allowing securities markets to function effectively, to promote a climate likely to encourage secondary issues of securities and, ultimately to stimulate the development of a market for corporate control (Young & Reynolds 1994).

In the context of emerging economies, Dickinson and Muragu (1994) discuss the possibility of a link between the efficiency, in the information sense, of the securities markets and the economic, or allocative efficiency of the whole economy. Such a linkage might operate through the ability of the securities markets to direct capital resources in the most productive directions. In other words, an allocative-efficient securities market may enhance the likelihood of allocative efficiency in other markets. It seems doubtful, a priori, that an informational-inefficient securities market is likely to enhance efficiency at the level of the economy. It is important, therefore, to examine the extent to which securities markets in emerging economies can be regarded as information-efficient (Parkinson 1984, Kitchen 1986) and to record changes in these efficiency levels over time, in order to gauge prospects for economic progress. A common problem in emerging securities markets is that their information efficiency may be impaired by bureaucratic, rigid operating procedures that hinder the extent to which newly-released information can be impounded into the structure of share prices (Gordon & Rittenberg 1995).

Studies of "new" stock markets have been conducted in emerging economies in Africa (Parkinson 1984, 1987; Affleck-Graves & Money 1975), the Caribbean (Kitchen 1987), and Southeast Asia (D'Ambrosio 1980, Barnes 1986) as distinct from the transitional ones of the EEMEs. The contribution of this paper is to examine the pricing efficiency of the WSE, probably the most advanced stock exchange in this area, using autocorrelation procedures empirically established in testing the efficiency of other less-developed stock markets. While alternative techniques are available and have been applied to developed markets, Dickinson and Muragu (1994) provide a powerful justification for the traditional research methods used in this paper, and more fully explained below.

The WSE opened in its modern incarnation on 16 April 1991 as a joint stock company with shareholders comprised of leading banks, brokerage firms and the state treasury. Its early growth by numbers of companies listed was rather slow. By end-1991, merely 12 companies were listed, joined by only 6 more in 1992, and only nine in 1993. However, on the back of a roaring bull market, a further 33 companies went public in 1994. Despite an intervening collapse in the market in 1994-1995 and following the long-delayed mass privatisation programme (MPP), 104 companies were quoted on all three floors by the end of May 1997.

**Table 1. Key indicators for the Warsaw Stock Exchange in 1991-1996**

| | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|---|
| Market capitalisation ($m) | 144 | 222 | 2,706 | 3,057 | 4,564 | 8,390 |
| Market capitalisation (% GDP) | 0.2 | 0.3 | 3.2 | 3.5 | 3.9 | 7.9 |
| Trading value ($m) | 28 | 167 | 2,170 | 5,134 | 2,770 | 5,538 |
| Trading value (%GDP) | 0.001 | 0.2 | 2.6 | 5.5 | 2.4 | 5.2 |
| Turnover ratio (trading/market capitalisation) | 0.19 | 0.75 | 0.80 | 1.68 | 0.61 | 0.66 |
| WIG (market index at year end) | 919 | 1,040 | 12,439 | 7,473 | 7,586 | 14,343 |
| Change in WIG (%) | ... | +13 | +1,095 | -40 | +2 | +89 |
| (%) Change in WIG ($ equivalent) | … | -21 | +779 | -47 | 0 | +63 |

Source: Scholtens (1997), EBRD, Business Central Europe and the PSC.

Table 1 shows key data relating to the WSE for the period covering the launch year, 1991, through to end-1996. Over this period, despite considerable volatility during 1993-1994, the local market index grew by 431% in US$ terms, but by a factor of more than 15 in local currency terms, due to the distorting effect of persistent runaway inflation.

Movements in the overall market are recorded by the Warsaw Stock Exchange Index (the *Warszawski Indeks Giełdowy*, or WIG), a value-weighted geometric mean of price relatives, based on 1,000 as at April 1991. To augment this, the WIG20, comprising twenty companies with the greatest market capitalisation, was introduced in April 1994. It is difficult to reconcile price gyrations of the magnitude that occurred on the WSE over 1993-1994 with the notion of stock market efficiency. Yet all markets seem to suffer at some stage from herd instincts (Shiller 1989), so it could be that the events of 1993-1994 were a temporary aberration in a market gradually increasing efficiency over time, another expected characteristic of emerging capital markets (Sweeney 1996).

It is also possible that this apparent irrationality is connected with the unusual structure of share ownership of Polish listed companies. The WSE has always been characterised by substantial domestic private ownership of equities, although the proportion has been falling. By 1997, 52% of market capitalisation was still in the hands of private domestic investors; foreign investors held around 30%, the state treasury held 12% and investment funds held 6%.

The remainder of the paper is organised as follows: section 2 examines the structure and operation of the WSE and considers reasons for expecting improvements in efficiency over time. We then offer a critique of previous work on the WSE (section 3), before describing the research method of the present study (section 4). After presenting findings, the final section offers a discussion and conclusions.

## 2. The *Modus Operandi* of the WSE

In the analysed period the WSE was order-driven with final settlement made on day T+3. It is a periodic call market, based on the principle of a single price auction (*par casier*). It was established along the lines of, and with the advice of experts from, the *Société de Bourses Française* and the French depository *SICOVAM*. Trading sessions were initially held at weekly intervals, but as from October 1994, daily. In a *par casier* market, investors submit offers to buy or sell a given number of shares at a given price. Specialist brokers in the WSE operated to match and adjust orders so as to balance supply and demand thus establishing one trading price for each stock at each session (WSE 1996a). In balancing the market, the authorities pursued the twofold aims of minimising price shifts while maximising turnover and volume. The market was regarded as balanced when the following orders were executed:

all "at the money" orders,

all buy orders with a price limit above the market price,

all sell orders with a price limit lower than the market price.

If there was an imbalance ratio exceeding 5:1, transactions were not executed, otherwise orders were scaled down in proportion-so-called 'reduction orders' (*redukcja kupna* or *redukcja sprzedaży*).

There are two important features in the operation of the market which, although both designed to dampen price volatility, might have ambivalent impact on efficiency. The first was the mechanism whereby the WSE placed a 10% limit on the extent to which the price of individual shares could move in a session. If this rule is persistently invoked, it suggests that some share prices may fail to fully reflect any relevant new information, thus violating market efficiency conditions. If so, we might expect a "carry-over effect" from day-to-day, following days of particularly strong pressure on prices (WSE 1996a).

The second feature might moderate any such "carry-over effect". A facility existed for trading large blocks of securities in off-session transactions. There were two types of off-session trading, both executed prior to the start of exchange trading, and distinguished according to whether the stock was already established on the market or were a new issue. In the case of newly-admitted issues, large blocks of securities were defined as those involving at least 2% of the issue. For the already-traded securities, large blocks were defined as at least the amount of securities sold during the previous three sessions (WSE 1996a). For the already traded securities, the difference between the price at which the deal was transacted and the last prior quotation might not exceed 10% of the average price over the last three sessions. Finally, if the transaction involved at least 5% of the securities issued in the company concerned, the difference might not exceed 20%.

# 3. Efficiency of the WSE

The prime consideration in devising rules such as these to govern the operation of an emerging capital market is to enable it to operate with maximum efficiency. In principle, a distinction can be made between production or operating efficiency, (how well does the market conduct its operations?) and information efficiency (how quickly and accurately is new information impounded into share prices?), although some (e.g., Ball 1994) regard these aspects as “inseparable”. There is little question that a market which is cumbersome and expensive to use is unlikely to be an efficient processor of information.

There are cogent reasons for expecting any emerging capital market to become more efficient over time. With accumulating experience and enhancement in expertise, the ability of market players to respond quickly and appropriately to new information increases. More specifically for the WSE, several other factors were significant:

(i) The increase in the number of sessions in a week.

(ii) The advent of more brokers and analysts increased competition among market players, most notably via the amount of research activity undertaken. According to a VIP of the Warsaw office of CS First Boston: “*The resulting increase in sound fundamental research is that the market is becoming more efficient. Two years ago, you couldn’t find companies which out-performed or under-performed the market. Now there are huge differences in relative performance based on fundamentals.*” (Moore 1995).

(iii) Companies increasingly appreciated the importance of financial public relations to improve their relationships with investors. More presentations and better quality company reports promoted liquidity by encouraging more confidence in company capabilities.

## Previous studies

There are very few previous studies of the efficiency of the WSE. Below we discuss those conducted by Gordon and Rittenberg (1995) and by Scholtens (1997). In this section, we outline and critique both studies, especially in relation to their selection of statistical procedures.

**Gordon and Rittenberg (1995)** documented the early development of the WSE and recorded the particular conditions likely to impede its efficient operation. Their empirical analysis, which covered only 1993-1994, was conducted in two stages. First, they cross-checked the structure and operating characteristics of the WSE against the required conditions for market efficiency to assess whether the operating rules of the WSE assisted or inhibited efficiency. They concluded that because of limited brokerage capacity, narrow information availability (although the reporting requirements of the WSE are arguably among the most transparent of the EEMEs, the threat of insider trading, investor collusion, a tax structure which encouraged speculation and the WSE's own regulations, there was little reason to expect efficient market operation in either the production or pricing sense.

Particularly problematic, in their estimation, was the 10% intervention rule. In the second strand of the study, they tested for evidence of departures from efficiency that they supposed would be due to the intervention in the market by specialist brokers. Gordon and Rittenberg postulated that such intervention would lead to a carry-over effect, arguing that posted market prices above 9.5% do not reflect the higher prices that would otherwise occur, and so there should be an enhanced price change on the day following intervention. This suggests that institutional rigidities might have been preventing share prices from adjusting instantaneously to new publicly-available information, thus contravening semi-strong efficiency. Gordon and Rittenberg separated out days following price changes above 9.5% from other days and compared the average price change for the two sets of days. The significant differences found were attributed to inefficiency due to the specialists' interventions.

For the 23 shares listed over this period, the mean percentage of intervention days when prices moved by more than 9.5% was 39%, suggesting that "prices may not be fully reflective of information at the close of each day of trading" Gordon and Rittenberg (1995, p. 21). Moreover, the average gain was 3.32% on days following a price increase of more than 9.5%, and for days following a price decrease of more than 9.5%, the average loss was – 1.99%. A simple t-test was used to show these gains were significantly different from corresponding data relating to price movements following other days. These results indicated that gains superior to a buy-and-hold strategy could have been achieved by acting on this information. They concluded that "although intended to encourage efficiency, certain regulations have actually had the opposite effect" Gordon and Rittenberg (1995, p. 25), and that, over this period, the WSE was driven less by investor rationality than by the "mass psychology effect" identified by Shiller (1989) in relation to the crash of 1987.

It would have been surprising had they found otherwise. The short period, 1st June 1993 to 27th July 1994, covered by Gordon and Rittenberg's study spanned the greatest volatility the WSE (or perhaps any market) has ever seen. This period:

(i) included the run-up to the peak in early March 1994, during which the market rose 700%, and the precipitous fall of 52% in March 1994;
(ii) coincided, as they note, with a wave of public education activities regarding stock exchange investment which in the prevailing bull climate served to heighten speculative inclinations;
(iii) coincided with a number of privatisations, several of which were thought to be deliberately under-priced, most notably that of Bank Slaski in early 1994. Cutler and Paszkowska (1996) claim that under-pricing of initial public offer-

ings (IPOs) by the Polish government, which also allowed payment in non-cash form and discounts to initial purchasers, promoted money illusion.

Consequently, the statement that: “the role of investor psychology on the Polish market appears more significant than the limited role conceded by efficient market proponents” (Gordon and Rittenberg, p. 25) is more of a truism than a conclusion. Although they urged that “a future study on the Polish stock exchange could seek to assess whether that market is becoming more or less efficient” (ibid. p. 25), it is questionable whether subsequent research should use similar methods to those used by Gordon and Rittenberg.

There are at least two deficiencies with the Gordon and Rittenberg (1995) study. Firstly, it seems desirable to cover a longer time period than a year and half. A notable feature of the development of the WSE has been a series of structural changes in the market especially the opening of the market to two-day, then three-day and (briefly) four-day, and finally, five-day sessions each week. Arguably, these were significant breaks, following which market efficiency was likely to increase. For example, regarding the operation of the 10% intervention rule, an increase in the number of sessions provided investors with an opportunity to ‘wait and see’ before piling in on the very next day.

Secondly, Gordon and Rittenberg did not consider the possibility of any general ‘carry-over’ effect. They assumed that specialists had intervened when posted price changes were above 9.5%. Although this may have been true they had no direct confirmation of the days when interventions occurred. In fact, specialists should intervene all the time in price-setting as a major aim is to reduce price changes in general (WSE 1996a). It is true that price changes rarely exceed 10% because of this intervention but prices often do not change at all, even if there is trading, so the intervention is clearly not restricted to particular days. Moreover, as noted above, large blocks of shares could be traded outside the official market sessions, albeit relatively rarely. These trades had to be duly reported. Presumably, the market price adjusted belatedly to those off-session transactions. A priori, it was by no means clear that the carry-over after price changed above 9.5% would be more significant than from other interventions. For example, instead of testing days following price rises above 9.5%, days following any price increases could be tested to see if they show a significantly greater price rise than other days. When this is done, examples of significant effects similar to those observed by Gordon and Rittenberg are observed. These results are not presented here because, although interesting, they do not provide an overall picture. Another problem of using an idiosyncratic test, when standard methods are available, is one of comparability with other studies. Conventional tests for inefficiency examine runs of price changes, or look for auto-correlation in time series of price relatives. Dickinson and Muragu (1994) applied this conventional approach to the Nairobi Stock Exchange, another emerging market.

**Scholtens (1997)'** perspective was broader than that of Gordon and Rittenberg (1995), being concerned to assess the attractiveness of Poland to foreign investors, one such attractor being the efficiency of the local stock exchange, both as an allocator of new capital and as a pricing mechanism. Like Gordon and Rittenberg, he exercised qualitative judgements, especially regarding economic efficiency, but went a good deal further in testing pricing efficiency by undertaking a test for auto-correlation.

Two models were developed by Scholtens. Model 1 regressed the logarithm of one session's price on the logarithm of the previous price. In principle, one would expect the regression slope coefficient of this model to be unity if a stock is efficiently priced. Also, the time series of residual errors would be expected to be uncorrelated if the logarithm of price were normally distributed. Model 2 regressed the current price return on the previous return. An efficiently priced stock should generate a regression slope coefficient that is not significantly different from zero in this case. Scholtens deflated stock prices by the consumer price index before performing these regressions, thus confounding information about stock prices with movements in consumer prices. The relationship between these could have been unstable.

The pattern of price changes was tested for only five stocks all listed on the WSE during 1991-1993, BRE, Elektrim, Mostostal Export, Wedel and Żywiec. (None of them had been floated on the opening day). The two market indices (WIG and WIG20) were also examined. Efficiency was investigated during three arbitrarily-chosen periods defined and characterised as follows:
April 16 1991-April 13 1993 – "early years, low activity",
April 20 1993-March 15 1994 – "much activity, hausse",
April 22 1994-June 27 1995 – "after the crash".

Although Model 1 was stable for sub-periods it was typically not stable over the whole period analysed. Residuals showed no definite auto-correlation when the model was applied to four of the companies but did show auto-correlation when applied to the WIG index. Model 2 generated significant slope coefficients when applied over the whole time series to the Elektrim stock and the WIG index but not for the other cases. No significant coefficients were found when the model was used on the later period of the time series. The general implication of these results was that pricing was becoming more efficient. However, further tests gave a variety of results that questioned the underlying assumptions behind the models. Taking the market indices, Scholtens found the WSE not to be an efficient market over the period studied, but that its degree of efficiency appears to have substantially increased.

Although the statistical method used by Scholtens was consistent with many other studies of the efficiency of young stock markets, the study is limited by the small number of firms selected and by the arbitrariness of the sub-periods. No justification was provided as to how the sample was selected. There are clear difficulties in sample size and consistency when only five stocks (but not these five!)

have been continuous members of the WSE since its inception. Any attempt to raise sample size would have to trade off data compatibility against number of observations, given that new firms join the market at staggered intervals. Moreover, the demarcation of the overall period 1991-1995 into the three components, while having some intuitive appeal is not grounded on any theory as to why the market might be expected to become more efficient from period to period. This is rectified in the research reported below.

## 4. Research method

As will be shown below, it is possible to detect inefficient pricing behaviour in the WSE by applying two elementary tests. One test examines the runs of upward, downward or flat prices. It finds that, unlike efficiently priced stocks, WSE stock-price changes do not occur with the same probability at all times. The second test examines the auto-correlation of successive price returns. It finds that, contrary to the expectations of weak-from efficiency, the time series are auto-correlated. These tests show that measures of central tendency of WSE stock prices are dependent on their own history and the results are sufficiently convincing for the purpose of the present study. In developed markets, such as the US and the UK, such behaviour is not detected in the time series of individual stocks (Fama 1970, 1991) although some have argued this is because traditional tests are not sufficiently powerful (Shiller 1989, Summers 1986). In order to find evidence to contradict the weak-form EMH in those markets, researchers have looked for more complex behaviours in firms' size and earnings relationships (Lo & MacKinlay 1988), calendar effects (Haugen & Lakonishok 1988), long-horizon returns (Fama & French 1988, Siegel 1994) and relationships with economic indicators (Campbell et al. 1997). It is possible that WSE stocks will show long-memory dependence, calendar effects, size effects, and so on, but the historical data set is not sufficient to test these conjectures at present. There may also be interesting behaviour at the higher moments of WSE stock price distributions, such as the interdependencies of volatility known to exist in developed markets (Merton 1980). However, any study of price volatility on the WSE in its first stage of development must be treated with care because the 10% intervention rule can invalidate the underlying assumptions of the procedures. Although the methods used in this paper do not differ essentially from those employed by Fama (1965) over three decades ago, Dickinson and Muragu (1994, p. 135) provide three reasons for applying a traditional approach to emerging markets:

> *"Firstly, the findings concerning the validity of the weak-form EMH obtained from the use of traditional statistical methodologies still hold as strongly as*

*they did in the 1960s in spite of the challenge from the use of new methodologies. Secondly, given the large body of evidence on efficiency in different markets, there is a need for 'triangulation' in the research by providing evidence from developing markets ... Thirdly, there is a need to set a base for developing stock price research in emerging markets."*

### *4.1. Rationale*

Our present study monitors changes in market efficiency, particularly changes towards more efficient pricing during the full period of operation of the WSE (1991-1997). The WSE gradually increased the number of sessions in a week from one day to five days. The interesting issue is whether there has been evidence of inefficiency in the early days and, if so, whether the exchange had become more efficient. The first 36 sessions took place weekly from April to December 1991. The next 100 sessions ran from January to December 1992 and there were almost always two sessions each week. From January 1993 to June 1994 the exchange operated for 229 days and there were usually three sessions each week. During a brief period, from July to September 1994, there were 51 sessions at a rate of four each week. Finally, since October 1994, the WSE has functioned five days in most weeks. Table 2 summarises the periods of the different trading regimes in 1991-1996.

**Table 2. Periods of different regimes at the WSE in 1991-1997**

| Period | From | To | Sessions per week | Total no. of sessions |
|---|---|---|---|---|
| I | 16/04/91 | 31/12/91 | 1 | 36 |
| II | 07/01/92 | 29/12/92 | 2 | 100 |
| III | 04/01/93 | 30/06/94 | 3 | 229 |
| IV | 04/07/94 | 29/09/94 | 4 | 51 |
| V | 03/10/94 | 30/05/97 | 5 | 661 |
| All periods | 16/04/91 | 30/05/97 | - | 1078 |

Source: The WSE.

Only nine firms were listed by the end of the first calendar year of operation (Period I). A further seven firms obtained listings during 1992. This group of sixteen firms provided the focus for studying market efficiency in subsequent periods (II-V). The sample is small compared, for example, with the 30 firms used by Dickinson and Muragu (1994) in their study of the Nairobi stock exchange, but considerably larger than the five firms studied by Scholtens. However, the statistical significance of the results hinges more on a large number of observations (i.e.

the trading sessions shown in Table 2) through time rather than the number of firms. The limited sample size may influence the generalisability of the results if the sample is unrepresentative of the market. However, the 16 firms cover a range of industries, as shown in Table 3.

**Table 3. Profiles of companies in the sample**

| Company | First quoted | Activities |
|---|---|---|
| BIG Bank | 13-08-1992 | Banking |
| BRE Bank | 06-10-1992 | Banking |
| Elektrim | 26-03-1992 | Power plant construction and trading |
| Exbud | 16-04-1991 | Construction services |
| Irena | 30-01-1992 | Glassware manufacturer |
| Kable | 16-04-1991 | Copper cable and wiring manufacturing |
| Krosno | 16-04-1991 | Glass manufacturer |
| Mostostal Export | 28-05-1992 | Industrial and construction services |
| Okocim | 13-02-1992 | Brewing |
| Prochnik | 16-04-1991 | Clothing manufacturer |
| Swarzedz | 25-06-1991 | Furniture manufacturer |
| Tonsil | 16-04-1991 | Electronics manufacturer |
| Universal | 02-07-1992 | International trading company |
| Wedel | 26-11-1991 | Chocolate and confectionery manufacturer |
| Wolczanka | 16-07-1991 | Clothing manufacturer |
| Zywiec | 24-09-1991 | Brewing |

Source: The WSE and Polish information providers Notoria and Penetrator.

### *4.2. Statistical methods*

The argument for the weak-form EMH can be summarised as follows. If for a given security, the market price is $p_t$ on trading day $t$, and it is related to the market price on the next day,

$$p_{t+1} = p_t + e_{t+1}\,,$$

then the price change $e_{t+1}$ reflects the market's response to additional information about the security. If the market price $p_t$ reflects all available information up to day $t$, the change $e_{t+1}$ should result from new information and be independent of all previous changes, $e_t$, $e_{t-1}$, $e_{t-2}$, …, and so on. Statistical tests of weak-form informational efficiency compare the general null hypothesis that the current market-price distribution is independent of the previous information (Fama 1970) against a general alternative that the distribution is conditional on historical information. Specific tests are based upon particular models of random behaviour.

For example, any parametric test of independence makes certain assumptions about the distribution under the null. The conventional assumption is that the random values come from the same normal distribution. Now although price *changes* of securities do not follow the normal distribution, price *returns*, i.e.

$\{\ln(p_{t+1}) - \ln(p_t)\}$, are closer to normality. If $\pi_t = \ln(p_t)$, then

$\pi_{t+1} = \pi_t + \varepsilon_{t+1}$,

where now $\varepsilon_{t+1}$ is the price return for day $t+1$ .

As before, it is argued that any $\varepsilon_t$ should be independent of all other $\varepsilon_s$ (i.e., provided $t \neq s$). Moreover, normal random variables that are independent are also uncorrelated with one another so, if price returns are normally distributed and independent, their auto-correlations should be zero. Thus, for any $t$ and $l$, the null hypothesis is,

$H_0 : (\varepsilon_t, \varepsilon_t{-}1, \varepsilon_t{-}2, \ldots, \varepsilon_t{-}l\,) \sim N\,[\mathbf{0}, \sigma^2\,\mathbf{I}]$, where $VAR(\varepsilon_t) = \sigma^2$.

The alternative,

$H_1 : (\varepsilon_t, \varepsilon_t{-}1, \varepsilon_t{-}2, \ldots, \varepsilon_t{-}l\,) \sim N\,[\mathbf{0}, \mathbf{\Omega}]$,

is that some of the off-diagonal elements (i.e. terms of the form $COV(\varepsilon_{t-k}, \varepsilon_t)$) in the variance-covariance matrix, $\mathbf{\Omega}$, are not zero. The relative strength of these terms is given by the population auto-correlation, $\rho(k)$ at lag $k$, as defined as: $\rho(k) = \dfrac{COV(\varepsilon_{t-k}, \varepsilon t)}{VAR(\varepsilon_t)}$. Under the null hypothesis, $\rho(k) = 0$ for all $k > 0$. A finite series of n returns has the sample auto-correlation function: $r(k) = \dfrac{\sum_{t=1}^{n-k} (\varepsilon_{t-k} - \bar{\varepsilon})(\varepsilon_t - \bar{\varepsilon})}{\sum^{n} (\varepsilon_t - \bar{\varepsilon})^2}$,

where $\bar{\varepsilon} = \sum_{t=1}^{n} \varepsilon_t$ is the mean return.

## Testing for auto-correlation

Box and Pierce (1970) introduced a 'portmanteau' test for significant auto-correlation based on the sample auto-correlation function and later Ljung and Bax (1978) suggested the improved test statistics.

$$Q' = n(n+2) \sum_{k=1}^{l} \frac{r(k)^2}{(n-k)},$$

The statistics $Q'$ is asymptotically distributed as chi-square with $l$ degrees of freedom. It is an improvement over the original portmanteau statistics because it is suited smaller samples or situations where the time series depart from normality. It was used to assess the significance of auto-correlations out to a lag, $l$, of seven. Large values of $Q'$ indicate that the auto-correlation function is significantly different from zero and this would not be expected if price returns are independent and identically normally distributed.

In the case of the WSE, the rules governing trading and price movements mean that on a few occasions prices are allowed to move by up to 20% or so but, in general, the specialist brokers ensure that returns do not go far beyond 10%. In this study, any price return greater than 22% was treated as an outlier and excluded from the analysis. Therefore, the variance of returns was generally constant and extreme values were not allowed to influence the results unduly. However, the specialists' interventions led to a higher frequency of returns near to 10% than would be expected for a normal distribution. For large samples, the distribution of *Q* should not be sensitive to this type of departure from normality. But for modest sample sizes, even when the data are normally distributed, the sampling distribution of *Q* is known to have a much lower mean than the asymptotic chi-square. The nature of the distribution of returns on the WSE will reinforce this phenomenon.

## Runs test

The runs test is non-parametric and so makes no assumptions about the magnitude of share-price changes. In a sequence of $n$+1 prices, there will be $n_+$, $n_0$ and $n_-$ upward, null or downward changes, where $n = (n_+ + n_0 + n_-)$. An upward run of $j$ price-changes occurs if the sequence of prices $\{p_t < p_{t+1} <\ldots < p_{t+j}\}$ is terminated by $p_{t-1} \geq p_t$ and $p_{t+j} \geq p_{t+j+1}$ . Similarly, we can define a flat run, where prices do not change, and a downward run of decreasing prices. Similarly, there will be $R_+$, $R_0$ and $R_-$ runs that are correspondingly upward, flat or downward. The total number of runs is therefore, $R = (R_+ + R_0 + R_-)$. The observed series of runs can be thought of as one realisation of the possible runs that could have been generated by the $n_+$, $n_0$ and $n_-$ share-price changes. In other words, the runs observed are a sample from this population of possible runs. If price changes are independent, the expected number of runs, m,

$$\text{M=E}\left(R \mid n_+, n_0, n_-\right) = \frac{(n+1) - \nu^2}{n}, \text{ where } \nu^2 = n_+^2 + n_0^2 + n_-^2.$$

Null versus alternative hypotheses can now be tested. These are, respectively, that the mean number of runs is or is not equal to $m$. The sampling distribution of the observed number of runs, $R$, tends to the normal for large n with variance,

$$\sigma_m^2 = \frac{\left\{\nu^2\left[\nu^2 + n(n+1)\right] - 2n\nu^2\right\} - n^2}{\left\{n^2(n-1)\right\}}.$$

**Table 4. The results of the portmanteau test for autocorrelation and the runs test, by period**

| | Period | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | | | II | | | III | | | IV | | | V | | | VI | | |
| Security | ACF | Runs | Pattern | ACF | Runs | Pattern | ACF | Runs | Pattern | ACF | Runs | Pattern | ACF | Runs | Pattern | ACF | Runs | Pattern |
| BIG | … | n.a. | ... | | | Short | ** | | Long | | | Long | *** | | Long | *** | * | Long |
| BRE | … | n.a. | ... | | | Long | *** | * | Long | | | Long | * | | Long | *** | ** | Long |
| Elektrim | … | n.a. | ... | * | | Long | * | * | Long | | | Long | | | Long | *** | ** | Long |
| Exbud | | | Long | * | * | Long | *** | | Long | * | | Short | | * | Long | *** | ** | Long |
| Irena | ... | n.a. | ... | | | Long | ** | | Long | | | Long | *** | * | Long | *** | ** | Long |
| Kable | | | Long | * | | Long | *** | * | Long | | | Long | * | | Long | *** | ** | Long |
| Krosno | * | | Long | * | | Long | *** | | Long | | | Short | | | Long | *** | * | Long |
| Mostostal Ex. | … | n.a. | … | * | | Long | ** | | Long | | | Short | | | Long | ** | * | Long |
| Okocim | ... | n.a. | … | | | Long | * | * | Long | | | Long | | | Long | ** | ** | Long |
| Próchnik | * | | Long | ** | | Long | *** | | Long | | | Short | | | Short | *** | | Long |
| Swarzędz | * | | Long | *** | * | Long | *** | * | Long | | | Long | | | Long | *** | ** | Long |
| Tonsil | * | | Long | *** | * | Long | *** | * | Long | | | Long | * | | Long | *** | ** | Long |
| Universal | ... | n.a. | ... | | | Long | *** | ** | Long | | | Long | ** | | Long | *** | ** | Long |
| Wedel | ... | n.a. | ... | | | Long | | | Long | | | Long | ** | | Long | | * | Long |
| Wólczanka | * | | Long | | | Long | ** | * | Long | | | Long | | | Short | ** | | Long |
| Żywiec | ... | n.a. | ... | | | Long | | | Long | | | Short | *** | | Short | | | Long |

Key: ACF: Result of Q' test on autocorrelation function,

Runs: Result of runs test.

Pattern: Indicates sign of runs test statistics.

Level of significance of result: *p<5%, **p<1%, ***p<0.1%.

Thus the test statistic, $Z = \dfrac{\left[R-(m+0.5)\right]}{\sigma_m}$, is approximately distributed as a standard normal variable. This was used to test for significant departures from the expected number of runs.

### *4.3. Findings*

As explained above, the 16 firms listed since the second year of the WSE were chosen for analysis. Firstly, the price returns series of all 16 firms using all the data from April 1991 to May 1997 were tested. Next, in order to test if more frequent price setting had impacted on day-to-day pricing behaviour, data were analysed separately in each of the periods, I-V. The results for the *Q'* statistic and the runs test (Z statistic) are summarised in Table 4. Table 4 also shows the performance of a naïve, equal-weighted portfolio made up of each of the 16 companies.

#### Auto-correlation in the full data series

Table 4 shows that, when all the WSE sessions are considered, there is evidence to reject the hypothesis that the auto-correlation function is zero for 14 of the 16 securities. Returns from the naïve portfolio also show significant auto-correlation. Their auto-correlation function, $r(l)$, is different from zero at the first lag, $l = 1$, and essentially zero at other lags. A negative value of $r(1)$ would indicate that successive price returns had opposite signs, so that a price increase would tend to follow a decrease and vice versa. A positive value is observed for $r(1)$ indicating that successive price returns tend to have the same sign, so that a positive return tends to be followed by a positive return in the next session, and a negative return is followed by another fall in price. The detailed results for individual companies show that most of the securities do show positive auto-correlation and this indicates that trends in price returns persist.

#### Analyses of series by period

The data were separated into each of the periods, I-V, and tested for serial dependence. Splitting the data in this way was reasonable for this purpose but needs some explanation. The session-to-session price changes within each period relate to similar calendar time intervals (i.e. the intervals between sessions) and are comparable with one another on that basis. However, the sensitivity of the statistical tests (see Table 2) increases in proportion to $\sqrt{,n}$, where $(n + 1)$ is the number of sessions in each period. So although like was compared with within each of the periods, I-V, the power of the tests to detect inefficiency was different in each period.

Table 4 shows the results of testing for significant auto-correlation in each period. A positive or negative symbol is used to indicate the sign of the auto-correlation function, $r(1)$, at the first lag. Given that there was a loss of power in some tests, due to smaller sample sizes, the analyses of price returns by each period still reveal significant results. In period I, despite the limited nature of the sample, auto-correlation was detected in five out of seven, or over 70%, of the securities. In period II, auto-correlation was detected in 50% of the securities. The analysis in period III shows a dramatic increase in significant results. The tests in this period were more powerful and many results are highly significant. Almost 90%, or 14 of 16 securities, had detectable auto-correlation. The size of sample in period IV was comparable to that for period I but now only one security had detectable auto-correlation at the 5% level of significance. This result could have occurred by chance, given the number of securities tested, since one in twenty such tests should generate a false signal. In period V, positive auto-correlation was detected in 6 of the 16 securities and two showed significant negative auto-correlation. However, the tests were based on a large sample and were substantially more sensitive than tests for earlier periods. In order to gain further understanding of the timing of the inefficient behaviour, period V was divided into three equal sub-periods, V-A, V-B and V-C. These were comparable in sample size to period III, where a substantial number of significant results had been found. When the results from these sub-periods are compared to period III, one cannot fail to be impressed by the evidence of inefficiency in WSE prices during 1993 and early 1994 (cf. Scholtens 1997).

The detailed results in Table 4 reveal a variety of price-setting behaviours. As explained above, a shorter time series implies a less sensitive test, so weak but persistent auto-correlation may be detected in a long time series but may not be detected in its sub-periods. Moreover, if auto-correlated behaviour does not persist it may be detected in a sub-period but its effect may be swamped by other behaviour when the longer time series is analysed. Both phenomena are evident, as are more obvious results.

The results for BIG, BRE, Irena, Kable and Tonsil are significant overall and are straightforward to explain. There was significant auto-correlation in periods III and V, and significant auto-correlation was detected in a sub-period of V. Auto-correlation has persisted in the returns on these securities and there is some evidence that it was stronger in those periods shown in Table 4. Price returns for Elektrim, Exbud, Mostostal Export, Próchnik and Okocim had significant auto-correlation in periods II or III and a persistent degree of auto-correlation could be detected overall. It was not detected in period V so it may be concluded that the positive auto-correlation observed initially was not masked by different behaviour in the later periods. Returns for Krosno, Swarzędz and Wólczanka behaved similarly but also showed significant results in a sub-period of period V. Surprisingly, they had no significant results for period V as a whole, so these securities have had a persistent low level of auto-correlation in recent years that has occasionally become more prominent. Finally, the returns for Wedel and Żywiec had no detectable auto-correlation overall but did show significant negative auto-correlation in period V. The erratic pricing of these securities that was detectable in the last period was masked by a low level of positive auto-correlation overall.

## Results of runs analyses

The runs test is less powerful than the test for auto-correlation, so fewer significant results were expected. Table 4 shows that the hypothesis of independence of price returns could not be rejected for the securities tested in period I. For period II, dependence was detected in three out of 16 securities, while in period III, this number increased to 8 or 50% of those tested. In period IV, no dependence was detected. In period V, the hypothesis of independence could only be rejected for two securities. However, in addition to these individual results, patterns of long runs were almost always observed.

The sign of the test statistic, *Z*, was used to classify the pattern of runs as either relatively short or long. If runs had occurred randomly, patterns of runs would be classified as short or long in equal proportion. Table 4 shows that price returns tended to have long runs. Predominance of long runs cannot be attributed to chance and, in fact, this non-random behaviour was detected in the results of the runs test for the whole data set. Strong evidence for dependence of price returns was found when all sessions of the WSE were analysed. The null hypothesis, that the number of runs was consistent with independent changes in price for 13 of the 16 securities, was rejected.

The general conclusion drawn from the runs tests is that the price changes in individual securities were dependent on the previous price changes. The exception is the significant pattern of long runs in the returns for Wedel. This should be associated with positive auto-correlation and yet no significant overall auto-correlation was detected. Previously it was noted that, for this security, the negative auto-correlation in period V was masked by a persistent but weak positive auto-correlation overall. It is this weak but persistent pattern that is detected by the runs test. A similar explanation was proposed for the lack of a significant overall auto-correlation in the returns of Żywiec but in this case, although the runs were long overall, the runs test did not yield a significant result.

## 5. Conclusion

It appears that the WSE began with inefficient pricing behaviour when sessions were limited to one or two days weekly. The period of three sessions of trading each week coincided with dramatic changes in the country's economic climate. Prices did not respond efficiently and immediately to available information during this period and investors could have secured predictable returns from the individual securities or from a naïve, equal-weighted portfolio. Later, the number of sessions increased to four and then five days each week and the general level of inefficiency was lower, although still detectable in certain securities. Overall, runs analyses show that longer runs have predominated. Presumably, this phenomenon has been due to the action of the specialist traders who were fulfilling their role in minimizing the day-to-day changes in market prices. But it is too simple just to represent the first stage of the WSE development as an inefficient market where consecutive price returns are correlated. As we have shown, the detailed results paint a more complex picture that shows a variety of price-setting behaviours.

### *References*


Affleck-Graves J.P., Money A.H. (1975), *A Note on the Random Walk and South African Share Prices*, "South African Journal of Economics" Vol. 43, pp. 382-388.

Ball R. (1994), *The Development, Accomplishments and Limitations of the Theory of Stock Market Efficiency*, "Managerial Finance" Vol. 20, No. 2/3, pp. 3-48.

Barnes P. (1986), *Thin Trading and Stock Market Efficiency: The Case of the Kuala Lumpur Stock Exchange*, "Journal of Business Finance & Accounting" Vol. 13, No. 4, pp. 609-617.

Box G.E.P., Pierce D.A. (1970), *Distribution of Residual Autocorrelations in Autoregressive-Integrated Moving Average Time Series Models*, "Journal of the American Statistical Association" Vol. 65, pp. 1509-1526.

Campbell J.A., Lo A., MacKinlay A.C. (1997), *The Econometrics of Financial Markets*, Princeton University Press, Princeton, NJ.

Cooper J.C.B. (1982), *World Stock Markets: Some Random Walk Tests*, "Applied Economics" Vol. 14, pp. 515-531.

Cooper J.C.B. (1983), *The Korea Stock Exchange: A Qualitative and Quantitative Assessment*, "The Investment Analyst" No. 70, pp. 5-12.

Cutler M.M., Paszkowska G. (1996), *The Warsaw Stock Market: Bear or Bull? Lessons for New Exchanges*, "Managerial Finance" Vol. 22, No 10, pp. 55-62.

Dickinson J.P., Muragu K. (1994), *Market Efficiency in Developing Countries: A Case Study of the Nairobi Stock Exchange*, "Journal of Business Finance & Accounting" Vol. 21, No. 1, pp. 133-150.

Fama E. (1965), *The Behaviour of Stock Market Prices*, "Journal of Business" Vol. 38, pp. 34-105.

Fama E. (1970), *Efficient Capital Markets: A Review of Theory and Empirical Work*, “Journal of Finance” Vol. 25, No. 2, pp. 383-417.
Fama E. (1991), *Efficient Capital Markets II*, “Journal of Finance” Vol. 46, pp. 1575-1674.
Fama E., French K.R. (1988), *Permanent and Temporary Components of Stock Prices*, “Journal of Political Economy” Vol. 96, No. 1, pp. 246-273.
Gandi D.K., Saunders A., Woodward R.S. (1980), *Thin Capital Markets: A Case Study of the Kuwait Stock Market*, “Applied Economics” Vol. 12 (1980), pp. 341-349.
Gordon B., Rittenberg L. (1995), *The Warsaw Stock Exchange: A Test of Market Efficiency. Comparative*, “Economic Studies” Vol. 37, No. 2, pp. 1-27.
Haugen R., Lakonishok J. (1988), *The Incredible January Effect*, Dow-Jones Irwin, Homewood, IL.
Kitchen R.L. (1986), *Finance for the Developing Countries*, John Wiley & Sons, Chichester.
Kitchen R.L. (1987), *The Role of the Jamaica Stock Exchange in The Capital Market: An Historical Analysis*, “Savings and Development” Vol. 11, No. 3, pp. 249-273.
Ljung G.M., Box G.E.P. (1978), *On a Measure of Lack of Fit in Time Series Models*, “Biometrika” Vol. 66, pp. 265-270.
Lo A.W., MacKinlay A.C. (1988), *Stock Markets Prices Do Not Follow Random Walks: Evidence From a Simple Specification Test*, “The Review of Financial Studies” Vol. 1, No. 1, pp. 41-66.
Merton R.C. (1980), *On Estimating the Expected Return on the Market: An Exploratory Investigation*, “Journal of Financial Economics” Vol. 8, No. 4, pp. 323-361.
Moore P. (1995), *The Privatisation Game in Poland*, “Euromoney” September 1995, pp. 185-187.
Parkinson J.M. (1984), *The Nairobi Stock Exchange in the Context of Development of Kenya*, “Savings and Development” Vol. 8, No. 4, pp. 363-370.
Parkinson J.M. (1987), *The EMH and the CAPM on the Nairobi Stock Exchange*, “East Africa Economic Review” Vol. 3, No. 2, pp. 105-110.
*Polish Securities Commission*, Annual Report (1995),
Ross S.A., Westerfield I. (1988), *Corporate Finance*, Times Mirror/Mosby College Publishers.
Samuels J.M. (1981), *Inefficient Capital Markets and Their Implications*, in: *Risk Capital Costs and Project Financing Decision*, (eds.) F.G.J. Derkinderen, R.L. Crum, Martinus Nijhell, Boston/The Hague/London, 1981, pp. 129-148.
Scholtens B. (1997), *The Attractiveness of Poland to Foreign Investors: Stock Market Efficiency and Country Risk*, pp. 165-194, in: *Financial Reform in Emerging Market Economies*, (ed.) T. Kowalski, Wydawnictwo AE w Poznaniu, Poznań.
Shiller R.J. (1989), *Market Volatility*, MIT Press, Cambridge, MA.
Siegel J. (1994), *Stocks for the Long Run*, Irwin, Homewood, IL.
Summers L.H. (1986), *Does the Stock Market Rationally Reflect Fundamental Values?* “Journal of Finance” Vol. 41, pp. 591-601.
Sweeney R.J. (1996), *Nowe rynki papierów wartościowych a lekcje z historii*, “Ruch Prawniczy, Ekonomiczny i Socjologiczny” Vol. 58, No. 4, pp. 151-165.
Wong K.A., Mak K.K. (1983), *Relative Strength Testing of Hong-Kong Stock Prices*, “The

Investment Analyst" No. 70, pp. 13-17.
WSE (1996a), *The Warsaw Stock Exchange in the 1996 Guide to Poland*, "Euromoney" December 1996, pp. 7-10.
WSE (1996b), *Rules and Regulations of the Warsaw Stock Exchange*, Warsaw Stock Exchange, Warsaw.