Psychological Barriers at Round Numbers in Single Stock Prices: Evidence from Three Developed Markets

Júlio Lobão[1]

João Fernandes[2]

Abstract

In this paper we examine for the first time the prices of some of the most widely traded stocks from the U.S., the U.K. and Japan for indication of psychological barriers at round numbers. The sample includes a group of 30 stocks – 10 stocks from each national market – during the period 2000-2014. We test for uniformity in the trailing digits of the stock prices and use regression and GARCH analysis to assess the differential impact of being above or below a possible barrier. Despite having rejected uniformity for all but one data series, we found no consistent psychological barriers on individual stock prices nearby round numbers. Moreover, we document that the relationship between risk and return tends to be weaker at the proximity of round numbers for about half of the stocks under study. Our results advocate special reflection about trading strategies linked to support and resistance levels on stock prices.

Keywords: psychological barriers, *M*-values, individual stocks, market psychology, round numbers
JEL Classification: G11, G12, G14, G15

[1] Júlio Lobão (corresponding author): jlobao@fep.up.pt
University of Porto – School of Economics and Management and CEPESE – Centro de Estudos de População, Economia e Sociedade - Rua Dr. Roberto Frias, 4200-464. Porto – Portugal
T: +351 22225571100; F: +351 225505050\

[2] João Fernandes: 201008507@fep.up.pt
University of Porto – School of Economics and Management - Rua Dr. Roberto Frias, 4200-464. Porto – Portugal - T: +351 22225571100; F: +351 225505050\

1 - Introduction

Market practitioners and journalists often refer to the existence of psychological barriers in stock markets. Many investors believe that round numbers serve as barriers, and that prices may resist crossing these barriers. Moreover, the use of technical analysis is based on the assertion that traders will "jump on the bandwagon" of buying (selling) once the stock price breaks up (down) through a "psychologically important" level thus suggesting that the crossing of one of these barriers may push the prices up (down) more than otherwise warranted. Frequently used phrases by the business press such as "support level" and "resistance level" imply that, until such time as an important barrier is broken, increases and decreases in the stock prices may be restrained.

The impact of such kind of psychological barriers in investors' decisions has been studied since the 1990's for a variety of asset classes, from exchange rates with De Grauwe and Decupere (1992) to stock options with Jang (2013). So far, evidence suggests some significant impacts of this phenomenon in the returns and variances of several securities.

Research on psychological barriers in stock markets has been focused mainly on stock indices from different geographies and periods. However the existing evidence about psychological barriers on single stocks prices is scant. Dorfleitner and Klein (2009) consider this gap in the literature to be 'astonishing' as real stocks can be and are traded directly on stock exchanges whereas stock indices are not immediately traded but rather by index futures and other related derivatives.

This study addresses this gap examining the existence of psychological barriers at round numbers in individual stock prices. Based on a number of different methodologies, our study is the first to our knowledge to thoroughly examine this anomaly in single stock prices from the three most important developed markets. We scrutinize a sample of stocks from the S&P 500 (U.S.), the FTSE-100 (U.K.) and the Nikkei 225 (Japan) from 2000 to 2014.

The anchoring effect, a well-known behavioural bias firstly identified by Tversky and Kahneman (1974), is the main explanation for the existence of psychological barriers in financial markets. Individuals, when performing an estimation in an ambiguous situation, tend to fixate ('to anchor') on a salient number even if that number is irrelevant for the estimation. The anchoring on round numbers is important for its great explanatory power of some of the features commonly associated to financial markets. It may help to understand, for example, the excessive price volatility [Westerhoff (2003)], the momentum effect [George and Hwang (2004)], or even the emergence of speculative bubbles [Shiller (2015)].

Of course, behavioural biases are not the only reason why barriers could exist. For example, the fact that option exercise prices also are usually round numbers may be an additional explanation for the phenomenon.

In spite of several studies about psychological barriers targeting different asset classes, it still lacks empirical evidence regarding this phenomenon in individual stock prices. Until now, only Cai *et al*. (2007) and Dorfleitner and Klein (2009) had examined individual stocks, considering Chinese stocks and German stocks, respectively.

The existence of psychological barriers contradicts the efficient market hypothesis as it points to predictability in stock prices and thus may lead to abnormal risk-adjusted returns. Hence empirical evidence for the existence of psychological barriers represents a contribution to the literature on market anomalies.

Our methodology comprises several empirical tests. We test for uniformity in the trailing digits of the stock prices and use regression and GARCH analysis to assess the differential impact of being above or below a possible barrier. Despite having rejected uniformity for all but one data series, we found no consistent psychological barriers on individual stock prices nearby round numbers. Thus, according to our results, no profitable investment strategy could have been built based on this potential anomaly. Moreover, we show that the relationship between risk and return tends to be weaker at the proximity of round numbers for about half of the stocks under study.

This paper is organized in as follows. Section 2 reviews the empirical evidence regarding psychological barriers. Section 3 presents the data and methodologies used in this paper. Section 4 presents the empirical results. Section 5 offers conclusions.

2 - Previous findings

Donaldson (1990a, 1990b) and De Grauwe and Decupere (1992) were the first to study the phenomenon of psychological barriers and showed that round numbers are indeed of special importance for investors in the stock and in the foreign exchange markets, respectively. From then on, several other studies followed, focusing not only on different geographies and periods, but also on different asset classes, such as bonds, commodities and derivatives.

However, to the best of our knowledge, only Cai *et al*. (2007) and Dorfleitner and Klein (2009) have addressed thus far the presence of psychological barriers on single stock prices.

Cai *et al*. (2007) assessed the existence of psychological barriers in a total of 1050 A-shares and 100 B-shares from both the Shanghai Stock Exchange and the Shenzhen Stock Exchange during June 2002. A range of measures for price resistance showed the digits 0 and 5 to be significant resistance points in the A-share market. A weak resistance point, digit 0, was found for the Shenzhen B-share market. No resistance point was found in the Shanghai B-share market, although digit 0 has had the highest level of resistance compared to others. These results were attributed to cultural factors. Dorfleitner and Klein (2009) analysed eight major stocks from the German DAX 30 over the period May 1996-June 2003. The prices were examined with respect to the frequency with which they lied within a certain band around the barrier and also with respect of certain characteristics and volume. In addition, they studied barrier's influence on intraday variances and the daily trading volume. The main conclusion is that the eight stocks behaved very differently around possible psychological barriers. The strongest evidence of psychological barrier's existence was found in the Commerzbank stock for both barriers that were considered. It was also detected some evidence of barriers in the Henkel stock and weak evidence in other three stocks. Overall, the authors were not able to identify a systematic and consistent pattern at barriers.

Since there are only two empirical studies about psychological barriers on individual stocks, it is difficult to extract general conclusions from the existing evidence.

Our approach is closer to the one adopted by Dorfleitner and Klein (2009) in the sense that we examine a more limited group of stocks than Cai *et al*. (2007) but consider a much longer sample period than these authors.

Other studies concerning psychological barriers in stock markets are also related to our analysis. It is the case of those articles that consider stock indices. In fact, to date, stock indices have been the target of most research concerning psychological barriers. Donaldson (1990a, 1990b) used both chi-squared tests and regression analysis to test for uniformity in the trailing digits of the Dow Jones Industrial Average (DJIA), the FTSE- 100, the TSE, and the Nikkei 225. His findings rejected uniformity for all but the Nikkei index.

Donaldson and Kim (1993) examined the DJIA for the period 1974-1990 using a Monte Carlo experiment and found evidence confirming round numbers (100-levels) as support and resistance levels. Furthermore, they concluded that once such levels were crossed through, the DJIA moved up or down more than usual in what they called a "bandwagon effect". The same was not true to the less important Wilshire 5000.

Ley and Varian (1994) also studied the DJIA considering a wider interval of time (1952-1993) and confirmed that there were in fact fewer observations around 100-levels. In 98.4% of the tested cases, uniformity in the trailing digits was rejected at the 95% significance level. Additionally, they emphasized the fact that non-uniform distribution of the final digits was not necessarily synonym of price barriers and found no evidence of stock price predictability due to these barriers.

Koedijk and Stork (1994) expanded the research to a number of indices. The authors studied the existence of psychological barriers on the Brussels Stock Index (Belgium), on the FAZ General (Germany), on the Nikkei 225 (Japan) and on the S&P 500 (U.S.) during the period January 1980 to February 1992, while the FTSE-100 (U.K.) was observed from January 1984 to February 1992. They discovered significant indications of psychological barriers' existence on the FAZ General, the FTSE-100 and the S&P 500, but weak indications on the Brussels Index, and none for the Nikkei 225. As in Ley and Varian (1994), they failed to find evidence supporting the significance of 100-levels in predicting returns. However, this may be due in part to the fact that they did not disaggregate the effects of upward and downward movements through barriers.

De Ceuster *et al*. (1998) compared the last digits of DJIA, FTSE-100, or the Nikkei 225 with the empirical distribution of a Monte Carlo simulation. They did not find any indication of the existence of psychological barriers on those three indices.

Cyree *et al*. (1999) showed that the last two digits of the DJIA, the S&P 500, the Financial Times U.K. Actuaries (London) and the DAX are not equally distributed. Prices next to barriers turn up less frequently than prices in a more distant position. The TSE 300, CAC 40, Hang Seng and Nikkei 225 exhibit some significant evidence. They also analysed the distribution of the returns with regard to expected returns and volatility in a modified GARCH model to conclude that upward movements through barriers tended to have a consistently positive impact on the conditional mean return and also that conditional variance tended to be higher in pre-crossing subperiods and lower in post-crossing subperiods.

More recently, Bahng (2003) applied the methodology of Donaldson and Kim (1993) to analyse seven major Asian indices including South Korea, Taiwan, Hong Kong, Thailand, Malaysia, Singapore, and Indonesia between 1990 and 1999. Their analysis showed that the Taiwanese index did possess price barrier effects and that the price level distributions of the Taiwanese, Indonesian, and Hong Kong indices were explained by quadratic functions.
Finally, Dorfleitner and Klein (2009) focused on the DAX 30, the CAC 40, the FTSE-50 and the Euro-zone-related DJ EURO STOXX 50 for different periods until 2003. They found fragile traces of psychological barriers in all indices at the 1000-level. There were also indications of barriers at the 100-level except in the CAC index.

Different studies concluded that price barriers or at least significant deviations from uniformity also exist in other asset classes such as exchange rates [De Grauwe and Decupere (1992)], bonds [Burke (2001)], commodities [Aggarwal and Lucey (2007)] and derivatives [Schwartz *et al*. (2004); Chen and Tai (2011); Jang (2013); Dowling *et al*. (2016)]. Overall, evidence of price barriers in various asset classes seems to be fairly robust.

3 - Data and methodology

3.1 Data

In this study we examine the existence of psychological barriers in the prices of a group of individual stocks belonging to each one of the three stock indices: the S&P 500 (U.S.), the FTSE-100 (U.K.) and the Nikkei 225 (Japan). These three indices have the highest weight on the MSCI World Index.

Our examination window ranges from January 3, 2000 to December 31, 2014 and covers 3913 trading days for each stock. We selected the ten stocks with the highest trading volume in their national market during the year 2000 provided i) that the stock was listed during the whole examination period and ii) that the stock did not went through any stock split during the examination period as this is a phenomenon which would severely disturb the effects of barriers at certain levels. All the data were retrieved from Thomson Reuters Datastream. Summary statistics on the stock prices are presented in Table 1 where it can be seen that the measures of skewness and kurtosis are in general inconsistent with normality.

Table 1 – Summary statistics on stock prices data series

Panel A: Companies from the U.S. (S&P500)

Company	Return series				Price series	
	Mean	SD	Skewness	Kurtosis	Minimum	Maximum
Abbott Lab.	0.00006	0.01888	-14.08140	528.284	29.63	72.13
Altria Group	0.00020	0.02521	-27.97332	1324.770	14.45	89.40
Amazon.com	0.00036	0.03539	0.45805	11.069	5.97	407.05
Amgen	0.00025	0.02097	0.26457	5.914	31.07	171.64
AT&T	-0.00010	0.01713	0.08907	6.739	19.34	58.50
Home Depot	0.00011	0.02074	-1.01077	22.355	18.00	104.97
IBM	0.00010	0.01684	-0.03887	8.659	55.07	215.80
Pfizer	-0.00001	0.01637	-0.29733	5.527	11.66	48.94
Wal Mart Stores	0.00006	0.01520	0.19741	6.014	42.27	87.54
Xilinx	-0.00001	0.02994	-0.19589	5.574	13.75	97.94

Panel B: Companies from the U.K. (FTSE-100)

Company	Return series				Price series	
	Mean	SD	Skewness	Kurtosis	Minimum	Maximum
BG Group	0.00010	0.02146	-2.37674	48.885	222.00	1564.50
BP	-0.00011	0.01714	-0.12600	5.016	302.90	712.00
BT Group	-0.00034	0.02240	-0.66655	9.411	71.40	1513.00
Diageo	0.00034	0.01428	0.18922	5.573	384.00	2136.50
HSBC Hdg.	-0.00009	0.01751	-0.67997	16.851	349.00	1092.00
ITV	-0.00027	0.03360	-13.33519	518.114	17.50	890.00
Legal & General	0.00010	0.02518	-0.27856	16.927	23.00	248.60
Lloyds BG	-0.00059	0.03197	-1.69948	41.332	21.84	817.00
Rolls-Royce Hdg.	0.00036	0.02167	-0.21044	9.957	64.25	1289.00
Tesco	0.000001	0.01606	-0.30825	7.949	156.00	492.00

Panel C: Companies from Japan (Nikkei 225)

Company	Return series				Price series	
	Mean	SD	Skewness	Kurtosis	Minimum	Maximum
Fujitsu	-0.00051	0.02462	0.15852	3.400	271.00	4730.00
Hitachi	-0.00015	0.02202	-0.27740	5.214	231.00	1690.00
Mitsubishi Electric	0.00020	0.02516	0.07805	3.923	255.00	1510.50
Mitsubishi Heavy Industries	0.00017	0.02225	0.05551	4.572	246.00	897.00
Mitsubishi Materials	0.00012	0.02609	0.25616	4.430	104.00	789.00
Nippon Steel	0.00006	0.02197	0.31843	5.297	124.00	958.00
Nissan Motor	0.00025	0.02306	0.16201	4.920	261.00	1541.00
Nomura Hdg.	-0.00025	0.02647	-0.20419	3.546	224.00	3490.00
Tokyo Gas	0.00025	0.01504	-0.13811	4.030	200.00	692.00
Toshiba	-0.00011	0.02393	-0.28325	5.115	215.00	1275.00

3.2 Methodology

3.2.1 Definition of barriers

Following Brock *et al*. (1992) and Dorfleitner and Klein (2009), we will use the so-called *band technique* and barriers will thus be defined as a certain range around the actual barrier. The main reason is that market participants will most certainly become active at a certain level before the price touches a round price level. Considering a price of €100, for instance, over-excitement is expected to begin for instance at €99 or €101, or even at €95 or €105. Barriers will thus be defined as multiples of the *l*th power of ten, with intervals with an absolute length of 2%, 5%, 10% and 25% of the corresponding power of ten as barriers. Formally, we may consider four possible barrier bands:

Barrier level l=3 (1000s)	980-20; 950-50; 900-100; 750-250
Barrier level l=2 (100s)	98-02; 95-05; 90-10; 75-25
Barrier level l=1 (10s)	9.8-0.2; 9.5-0.5; 9.0-1.0; 7.5-2.5
Barrier level l=0 (1s).	0.98-0.02; 0.95-0.05; 0.90-0.10; 0.75-0.25

For each stock, we select different barrier levels to examine for possible psychological barriers. Naturally, the tick size of each market will correspond to the lower boundary in terms of barrier levels.

3.2.2 *M*-values

M-values refer to the last digits in the integer portion of prices in the analyzed security. Initially used by Donaldson and Kim (1993), *M*-values considered potential barriers at the levels …, 300, 400, …, 3400, 3500, i.e. at:

$$k \text{ X } 100, k = 1, 2, \ldots \quad (1)$$

Later, De Ceuster *et al.* (1998) claimed that this definition was too narrow because the series was not multiplicatively regenerative, resulting, for instance, on 3400 being considered a barrier, whereas 340 would not. Additionally, the authors claimed that, as defined by Eq. (1), the gap between barriers would tend to zero as the price series increased, disrupting the intuitive appeal of a psychological barrier. Thus, one should also consider the possibility of barriers at the levels …, 10, 20, …, 100, 200, …, 1000, 2000, …, i.e. at:

$$k \text{ X } 10^l, k = 1, 2, \ldots, 9;\ l = \ldots, -1, 0, 1, \ldots; \quad (2)$$

and, on the other hand, at the levels …, 10, 11, …, 100, 110, …, 1000, 1100, …, i.e. at:

$$k \text{ X } 10^l, k = 10, 11, \ldots, 99;\ l = \ldots, -1, 0, 1, \ldots; \quad (3)$$

M-values would then be defined according to these barriers. For barriers at the levels defined in Eq. (2), *M*-values would be the pair of digits preceding the decimal point:

$$M_t^a = [P_t] \text{mod } 100, \quad (4)$$

where P_t is the integer part of P_t and mod 100 refers to the reduction modulo 100. For barriers at the levels defined by Eq. (2) and Eq. (3), the *M*-values would be defined respectively as the second and third and the third and fourth significant digits. Formally,

$$M_t^b = \left[100 \text{ X } 10^{(\log P_t) \bmod 1}\right] \bmod 100, \quad (5)$$
$$M_t^c = \left[1000 \text{ X } 10^{(\log P_t) \bmod 1}\right] \bmod 100, \quad (6)$$

where logarithms are to base 10. In practical terms, if P_t = 1234.56, then M_t^a = 34. At this level, barriers should appear when M_t^a = 00. Additionally, M_t^b = 23 and M_t^c = 12.

3.2.3 Uniformity test

Having computed the *M*-values, the next step consists of examining the uniformity of their distribution. Following Aggarwal and Lucey (2007), this will be done through a Kolmogrov-Smirnov Z-statistic test. Thus we will be testing H0: uniformity of the M-values distribution against H1: non-uniformity of the M-values distribution.

It is important to emphasize that the rejection of uniformity might suggest the existence of significant psychological barriers but it is not in itself sufficient to prove the existence of psychological barriers. Ley and Varian (1994) showed that the last digits of the Dow Jones Industrial Average were in fact not uniformly distributed and even appeared to exhibit certain patterns, but the returns conditional on the digit realization were still significantly random. Additionally, De Ceuster *et al*. (1998) noted that as a series grows without limit and the intervals between barriers become wider, the theoretical distribution of digits and the respective frequency of occurrence is no longer uniform.

3.2.4 Barrier tests

Barrier tests are used to assess whether observations are less frequent near barriers than it would be expected considering a uniform distribution. The existence of a psychological barrier implies we will observe a significantly lower closing price frequency within an interval around the barrier (Donald and Kim, 1993; Ley and Varian, 1994). Therefore, the objective of the barrier tests is to investigate the influence of round numbers in the non-uniform distribution of *M*-values. We will use two types of barrier tests: the barrier proximity test and the barrier hump test.

a) Barrier proximity test

This test examines the frequency of observations, f(M), near potential barriers and will be performed according to Eq. (7).

$$f(M) = \alpha + \beta D + \varepsilon \tag{7}$$

The dummy variable will take the value of unity when the price of the stock is at the supposed barrier and zero elsewhere. As it was mentioned in section 3.2.1, this barrier will not be strictly considered as an exact number but also as a number of different specific intervals, namely with an absolute length of 2%, 5%, 10% and 25% of the corresponding power of ten as barriers. The null hypothesis of no barriers will thus imply that β equals zero, while β is expected to be negative and significant in the presence of barriers as a result of lower frequency of *M*-values at these levels.

b) Barrier hump test

The second barrier test will examine not just the tails of frequency distribution near the potential barriers, but the entire shape of the distribution. It is thus necessary to define the alternative shape that the distribution should in the presence of barriers [Donaldson and Kim (1993); Aggarwal and Lucey (2007)]. Bertola and Caballero (1992), who analysed the behaviour of exchange rates in the presence of target zones imposed by forward-looking agents, suggest that a hump-shape is an appropriate alternative for the distribution of observations.

The test to examine this possibility will follow Eq. (8), in which the frequency of observation of each *M*-value is regressed on the *M*-value itself and on its square.

$$f(M) = \alpha + \Phi M + \gamma M^2 + \eta \tag{8}$$

Under the null hypothesis of no barriers Υ is expected to be zero, whereas the presence of barriers should result in Υ being negative and significant.

3.2.5 Conditional effect tests

The rejection of uniformity on the observations of M-values is not sufficient to prove the existence of psychological barriers (Ley and Varian, 1994). Therefore, it is necessary to analyse the dynamics of the returns series around these barriers, namely regarding mean and variance in order to examine the differential effect on returns due to prices being near a barrier, and whether these barriers were being approached on an upward or on a downward movement [Cyree *et al*. (1999); Aggarwal and Lucey (2007)].

Accordingly, we will thus define four regimes around barriers: BD for the five days before prices reaching a barrier on a downward movement, AD for the five days after prices crossing a barrier on a downward movement, and BU and AU for the five days respectively before and after prices breaching a barrier on an upward movement. These dummy variables will take the value of unity for the days noted and zero otherwise. In the absence of barriers, we expect the coefficients on the indicator variables in the mean equation to be non-significantly different from zero.

$$R_t = \beta_1 + \beta_2 BD_t + \beta_3 AD_t + \beta_4 BU_t + \beta_5 AU_t + \varepsilon_t \qquad (9)$$

Following Aggarwal and Lucey (2007), we started with an OLS estimation of Eq. (9) but heteroscedasticity and autocorrelation were clearly present across our data base. Therefore, the full analysis of the effects in the proximity of barriers required us to apply the former test also to the variances. Eq. (10) represents this approach assuming autocorrelation similar to one as in Cyree *et al*. (1999) and Aggarwal and Lucey (2007). Besides the abovementioned dummy variables it includes a moving average parameter and a GARCH parameter.

$$\begin{gathered} \varepsilon_t = N(0, V_t) \\ V_t = \alpha_1 + \alpha_2 BD_t + \alpha_3 AD_t + \alpha_4 BU_t + \alpha_5 AU_t + \alpha_6 V_{t-1} \\ + \alpha_7 \varepsilon_{t-1}^2 + \eta_t \end{gathered} \qquad (10)$$

The four possible hypothesis to be tested are the following:

H1: There is no difference in the conditional mean return before and after a *downward* crossing of a barrier.
H2: There is no difference in the conditional mean return before and after an *upward* crossing of a barrier.
H3: There is no difference in conditional variance before and after a *downward* crossing of a barrier.
H4: There is no difference in the conditional variance before and after a *upward* crossing of a barrier.

4 - Empirical findings

4.1 Uniformity test

Table 2 provides the results of a uniformity test concerning the distribution of digits for the stock prices under analysis. Overall, there is strong evidence that the *M*-values do not follow a uniform distribution. Uniformity is clearly rejected for the vast majority of stocks at all significance levels. Considering a statistical significance level of 5%, uniformity is not rejected in just one situation: Xilinx at barrier level 0. Even at a statistical significance level of 1%, only three stocks – Amazon.com, AT&T and Xilinx – out of the thirty stocks of the sample do not reject uniformity at a certain barrier level. These findings are somewhat in line with the ones obtained by Dorfleitner and Klein (2009) which pointed to a rejection of uniformity for the majority of the German stocks examined, although their results were slightly more heterogeneous than ours. Nonetheless, rejecting uniformity is necessary but it is not in itself sufficient to attest the existence of psychological barriers.

Table 2 – Z test for uniformity of digits in the 30 individual stock price data series

	M0.1 (*l*=0)		**M1 (*l*=1)**		**M10 (*l*=2)**	
	Z-stat	**p-value**	**Z-stat**	**p-value**	**Z-stat**	**p-value**
S&P 500						
Abbott Lab.	1.868	0.002	3.289	0.000	-	-
Altria Group	1.852	0.002	2.463	0.000	-	-
Amazon.com	1.462	0.028	1.501	0.022	-	-
Amgen	1.878	0.002	3.245	0.000	-	-
AT&T	1.468	0.027	7.087	0.000	-	-

Home Depot	1.790	0.003	3.565	0.000	-	-
IBM	2.574	0.000	1.961	0.001	-	-
Pfizer	1.663	0.008	1.966	0.001	-	-
Wal Mart Stores	2.265	0.000	5.087	0.000	-	-
Xilinx	1.327	0.059	3.456	0.000	-	-
FTSE-100						
BG Group	-	-	-	-	3.793	0.000
BP	-	-	-	-	3.275	0.000
BT Group	-	-	-	-	5.489	0.000
Diageo	-	-	-	-	1.724	0.005
HSBC Hdg.	-	-	-	-	2.709	0.000
ITV	-	-	-	-	6.898	0.000
Legal & General	-	-	-	-	4.839	0.000
Lloyds BG	-	-	-	-	5.539	0.000
Rolls-Royce Hdg.	-	-	-	-	2.793	0.000
Tesco	-	-	-	-	4.928	0.000
Nikkei 225						
Fujitsu	-	-			1.538	0.018
Hitachi	-	-	-	-	1.918	0.001
Mitsubishi Electric	-	-	-	-	2.919	0.000
Mitsubishi Heavy Inds.	-	-	-	-	2.832	0.000
Mitsubishi Materials	-	-	-	-	2.604	0.000
Nippon Stl.	-	-	-	-	2.713	0.000
Nissan Motor	-	-	-	-	2.018	0.001
Nomura Hdg.	-	-	-	-	1.634	0.010
Tokyo Gas	-	-	-	-	1.808	0.003
Toshiba	-	-	-	-	4.040	0.000

Table 2 shows the results of a Kolmogorov-Smirnov test for uniformity. Z-stat stands for the value of the test statistic, while *p*-value gives the marginal significance of this statistic. H0: uniformity in the distribution of digits, H1: non uniformity in the distribution of digits. The null hypothesis is rejected for all stocks under consideration at 10% level, it is rejected for all but one at 5% level (Xilinx – M0.1) and is not rejected in just three cases at 1%.

4.2 Barrier tests

4.2.1 Barrier proximity test

Results for the barrier proximity tests are shown in Tables 3 to 7 for all the intervals mentioned in sections 3.2.1 and 3.2.4. As referred above, in the presence of a barrier we would expect β to be negative and significant, implying a lower frequency of *M*-values at these points. Considering a barrier in the exact zero modulo point, evidence in Table 4 shows that only IBM (US) at barrier level 0 and Mitsubishi Heavy Industries (Japan) at barrier level 2 seem to reject the no barrier hypothesis at a significance level of 5% and only the latter still rejects it at 1%. If we assume a barrier to be in the interval 98-02, conclusions are exactly the same as for the strict point barrier (see Table 4).

Table 5 shows slightly different evidence for the 95-05 interval, but no relevant conclusions can once more be deducted. IBM now rejects the no barrier hypothesis at both 1s and 10s levels for a statistical significance level of 5%, but no other stock, besides the abovementioned Mitsubishi Heavy Industries, seems to replicate this pattern.

As we keep widening the barrier interval, evidence appear to be more and more heterogeneous. Considering the 90-10 interval, Table 6 shows that the no barrier hypothesis is now rejected only for AT&T (U.S.) at the second level (statistical significance of 5%) and still for Mitsubishi Heavy Industries. All the other series are either not significant or β is not negative. Finally, Table 7 presents the results for the largest barrier interval. Besides Mitsubishi Heavy Industries, we now find negative and significant β for BG Group (U.K.), HSBC (U.K.) and Tesco (U.K.) at the highest barrier level.

Overall, evidence is clearly scattered as there is no clear pattern regardless of the interval we consider for the barrier. Besides Mitsubishi Heavy Industries, which rejects the no barrier hypothesis in all the scenarios, and IBM, which rejects it on the first three ones, all the other stocks present no consistent evidence of a barrier around round numbers for the whole sample period. R-squares are significantly low, which is in line with previous studies focused on stock indices.

Table 3 – Barrier proximity test: strict barrier

	M0.1 (l=0)			**M1 (l=1)**			**M10 (l=2)**		
	β	**ρ-value**	**R^2**	**β**	**ρ-value**	**R^2**	**β**	**ρ-value**	**R^2**
S&P 500									
Abbott Lab.	0.001	0.370	0.008	0.000	0.899	0.000	-	-	-
Altria Group	0.001	0.448	0.006	0.003*	0.093	0.028	-	-	-
Amazon.com	0.000	0.930	0.000		n.a.		-	-	-
Amgen	-0.001	0.272	0.012		n.a.		-	-	-
AT&T	0.000	0.923	0.000	-0.003	0.542	0.004	-	-	-
Home Depot	0.000	0.859	0.000	-0.001	0.484	0.005	-	-	-
IBM.	-0.002**	0.025	0.050	-0.001	0.512	0.004	-	-	-
Pfizer	0.001	0.429	0.006	0.001	0.584	0.003	-	-	-
Wal Mart Stores	0.001	0.527	0.004	0.001	0.710	0.001	-	-	-
Xilinx	0.002*	0.057	0.036	-0.002	0.420	0.007	-	-	-
FTSE-100									
BG Group	-	-	-	-	-	-	0.001	0.628	0.002
BP	-	-	-	-	-	-	-0.002	0.232	0.015
BT Group	-	-	-	-	-	-	0.000	0.952	0.000
Diageo	-	-	-	-	-	-	-0.001	0.260	0.013
HSBC Hdg.	-	-	-	-	-	-	0.001	0.496	0.005
ITV	-	-	-	-	-	-	-0.002	0.658	0.002
Legal & General	-	-	-	-	-	-		n.a.	
Lloyds BG	-	-	-	-	-	-	0.003	0.208	0.016

Rolls-Royce Hdg.	-	-	-	-	-	-	0.000	0.716	0.001
Tesco	-	-	-	-	-	-		n.a.	
Nikkei 225									
Fujitsu	-	-	-	-	-	-	-0.001	0.441	0.006
Hitachi	-	-	-	-	-	-	0.000	0.985	0.000
Mitsubishi Electric	-	-	-	-	-	-	0.002*	0.053	0.037
Mitsubishi Heavy Inds.	-	-	-	-	-	-	-0.004***	0.001	0.109
Mitsubishi Materials	-	-	-	-	-	-		n.a.	
Nippon Stl.	-	-	-	-	-	-		n.a.	
Nissan Motor	-	-	-	-	-	-	0.001	0.220	0.015
Nomura Hdg.	-	-	-	-	-	-	0.001	0.518	0.004
Tokyo Gas	-	-	-	-	-	-	0.001	0.468	0.005
Toshiba	-	-	-	-	-	-	-0.001	0.680	0.002

Table 3 shows the results of a regression $f(M)=\alpha+\beta D+\varepsilon$, where $f(M)$ stands for the frequency of appearance of the M-values, D is a dummy variable that takes the value of unity when M=00 and 0 otherwise. Refer to section 3.2.4 for details. “n.a.” stands for “not available” and means it was not possible to perform the test because the dummy variable had not enough observations equal to 1, being therefore close to a singular matrix. *, **, *** indicates significance at the 10%, 5% and 1% level, respectively.

Table 4 – Barrier proximity test: 98-02 barrier

	M0.1 (l=0)			M1 (l=1)			M10 (l=2)		
	β	**ρ-value**	**R^2**	**β**	**ρ-value**	**R^2**	**β**	**ρ-value**	**R^2**
S&P 500									
Abbott Lab.	0.001	0.370	0.008	0.000	0.899	0.000	-	-	-
Altria Group	0.001	0.448	0.006	0.001	0.495	0.005	-	-	-
Amazon.com	0.000	0.967	0.000	0.001	0.504	0.005	-	-	-
Amgen	-0.001	0.272	0.012	0.000	0.967	0.000	-	-	-
AT&T	0.000	0.923	0.000	-0.003	0.200	0.017	-	-	-
Home Depot	0.000	0.859	0.000	-0.001	0.171	0.019	-	-	-
IBM	-0.002**	0.025	0.050	-0.001	0.306	0.011	-	-	-
Pfizer	0.001	0.429	0.006	0.002*	0.079	0.031	-	-	-
Wal Mart Stores	0.001	0.527	0.004	0.001	0.710	0.001	-	-	-
Xilinx	0.002*	0.057	0.036	-0.001	0.343	0.009	-	-	-
FTSE-100									
BG Group	-	-	-	-	-	-	0.000	0.905	0.000
BP	-	-	-	-	-	-	0.000	0.665	0.002
BT Group	-	-	-	-	-	-	-0.002	0.117	0.025
Diageo	-	-	-	-	-	-	0.001	0.477	0.005
HSBC Hdg.	-	-	-	-	-	-	0.001	0.235	0.014
ITV	-	-	-	-	-	-	-0.002	0.192	0.017
Legal & General	-	-	-	-	-	-		n.a.	
Lloyds BG	-	-	-	-	-	-	0.001	0.408	0.007
Rolls-Royce Hdg.	-	-	-	-	-	-	-0.001	0.126	0.023

Tesco	-	-	-	-	-	-	0.002	0.316	0.010
Nikkei 225									
Fujitsu	-	-	-	-	-	-	-0.001	0.441	0.006
Hitachi	-	-	-	-	-	-	0.001	0.388	0.008
Mitsubishi Electric	-	-	-	-	-	-	0.001*	0.056	0.036
Mitsubishi Heavy Inds.	-	-	-	-	-	-	-0.002***	0.003	0.088
Mitsubishi Materials	-	-	-	-	-	-	0.002	0.422	0.007
Nippon Stl.	-	-	-	-	-	-		n.a.	
Nissan Motor	-	-	-	-	-	-	0.001	0.127	0.023
Nomura Hdg.	-	-	-	-	-	-	0.001	0.518	0.004
Tokyo Gas	-	-	-	-	-	-	0.000	0.973	0.000
Toshiba	-	-	-	-	-	-	0.001	0.346	0.009

Table 4 shows the results of a regression $f(M)=\alpha+\beta D+\varepsilon$, where $f(M)$ stands for the frequency of appearance of the *M*-values, D is a dummy variable that takes the value of unity when M=value is in the 98-02 interval and 0 otherwise. Refer to section 3.2.4 for details. "n.a." stands for "not available" and means it was not possible to perform the test because the dummy variable had not enough observations equal to 1, being therefore close to a singular matrix. *, **, *** indicates significance at the 10%, 5% and 1% level, respectively.

Table 5 – Barrier proximity test: 95-05 barrier

	M0.1 (l=0)			**M1 (l=1)**			**M10 (l=2)**		
	β	**ρ-value**	**R^2**	**β**	**ρ-value**	**R^2**	**β**	**ρ-value**	**R^2**
S&P 500									
Abbott Lab.	0.001	0.370	0.008	0.000	0.742	0.001	-	-	-
Altria Group	0.001	0.448	0.006	0.000	0.617	0.003	-	-	-
Amazon.com	0.000	0.967	0.000	0.000	0.794	0.001	-	-	-
Amgen	-0.001	0.272	0.012	0.000	0.800	0.001	-	-	-
AT&T	0.000	0.796	0.001	-0.003*	0.068	0.034	-	-	-
Home Depot	0.000	0.859	0.000	0.000	0.485	0.005	-	-	-
IBM	-0.002**	0.025	0.050	-0.001**	0.042	0.042	-	-	-
Pfizer	0.001	0.429	0.006	0.002***	0.007	0.071	-	-	-
Wal Mart Stores	0.001	0.527	0.004	0.001	0.570	0.003	-	-	-
Xilinx	0.002*	0.057	0.036	0.000	0.601	0.003	-	-	-
FTSE-100									
BG Group	-	-	-	-	-	-	0.000	0.951	0.000
BP	-	-	-	-	-	-	0.000	0.471	0.005
BT Group	-	-	-	-	-	-	0.000	0.884	0.000
Diageo	-	-	-	-	-	-	0.000	0.564	0.003
HSBC Hdg.	-	-	-	-	-	-	0.000	0.902	0.000
ITV	-	-	-	-	-	-	0.000	0.730	0.001
Legal & General	-	-	-	-	-	-		n.a.	
Lloyds BG	-	-	-	-	-	-	0.001	0.439	0.006

Rolls-Royce Hdg.	-	-	-	-	-	-	0.000	0.816	0.001
Tesco	-	-	-	-	-	-	0.001	0.438	0.006
Nikkei 225									
Fujitsu	-	-	-	-	-	-	-0.001	0.335	0.009
Hitachi	-	-	-	-	-	-	0.001*	0.087	0.029
Mitsubishi Electric	-	-	-	-	-	-	0.002**	0.023	0.051
Mitsubishi Heavy Inds.	-	-	-	-	-	-	-0.002***	0.008	0.069
Mitsubishi Materials	-	-	-	-	-	-	0.002	0.141	0.022
Nippon Stl.	-	-	-	-	-	-		n.a.	
Nissan Motor	-	-	-	-	-	-	0.000	0.766	0.001
Nomura Hdg.	-	-	-	-	-	-	0.000	0.995	0.000
Tokyo Gas	-	-	-	-	-	-	0.000	0.529	0.004
Toshiba	-	-	-	-	-	-	0.001*	0.068	0.033

Table 5 shows the results of a regression $f(M)=\alpha+\beta D+\varepsilon$, where $f(M)$ stands for the frequency of appearance of the *M*-values, D is a dummy variable that takes the value of unity when M=value is in the 95-05 interval and 0 otherwise. Refer to section 3.2.4 for details. “n.a.” stands for “not available” and means it was not possible to perform the test because the dummy variable had not enough observations equal to 1, being therefore close to a singular matrix. *, **, *** indicates significance at the 10%, 5% and 1% level, respectively.

Table 6 – Barrier proximity test: 90-10 barrier

	M0.1 (l=0)			**M1 (l=1)**			**M10 (l=2)**		
	β	**ρ-value**	**R^2**	**β**	**ρ-value**	**R^2**	**β**	**ρ-value**	**R^2**
S&P 500									
Abbott Lab.	0.000	0.926	0.000	-0.001	0.233	0.015	-	-	-
Altria Group	0.001	0.413	0.007	0.000	0.664	0.002	-	-	-
Amazon.com	0.000	0.709	0.001	0.000	0.990	0.000	-	-	-
Amgen	0.000	0.595	0.003	0.000	0.350	0.009	-	-	-
AT&T	0.000	0.455	0.006	-0.003**	0.016	0.058	-	-	-
Home Depot	0.000	0.967	0.000	-0.001	0.200	0.017	-	-	-
IBM	-0.002*	0.062	0.035	0.000	0.432	0.006	-	-	-
Pfizer	0.000	0.650	0.002	0.002**	0.034	0.045	-	-	-
Wal Mart Stores	0.000	0.776	0.001	0.000	0.604	0.003	-	-	-
Xilinx	0.001	0.211	0.016	0.000	0.966	0.000	-	-	-
FTSE-100									
BG Group	-	-	-	-	-	-	-0.001	0.320	0.010
BP	-	-	-	-	-	-	0.000	0.661	0.002
BT Group	-	-	-	-	-	-	0.000	0.789	0.001
Diageo	-	-	-	-	-	-	0.000	0.440	0.006
HSBC Hdg.	-	-	-	-	-	-	0.000	0.277	0.012
ITV	-	-	-	-	-	-	-0.001	0.459	0.006
Legal & General	-	-	-	-	-	-		n.a.	
Lloyds BG	-	-	-	-	-	-	0.001	0.410	0.007
Rolls-Royce Hdg.	-	-	-	-	-	-	0.001*	0.076	0.031

Tesco	-	-	-	-	-	-	-0.001	0.179	0.018
Nikkei 225									
Fujitsu	-	-	-	-	-	-	0.000	0.889	0.000
Hitachi	-	-	-	-	-	-	0.000	0.874	0.000
Mitsubishi Electric	-	-	-	-	-	-	0.001*	0.053	0.037
Mitsubishi Heavy Inds.	-	-	-	-	-	-	-0.001**	0.011	0.063
Mitsubishi Materials	-	-	-	-	-	-	0.002*	0.060	0.035
Nippon Stl.	-	-	-	-	-	-		n.a.	
Nissan Motor	-	-	-	-	-	-	0.000	0.544	0.004
Nomura Hdg.	-	-	-	-	-	-	-0.001	0.449	0.006
Tokyo Gas	-	-	-	-	-	-	0.000	0.559	0.003
Toshiba	-	-	-	-	-	-	0.000	0.414	0.007

Table 6 shows the results of a regression $f(M)=\alpha+\beta D+\varepsilon$, where $f(M)$ stands for the frequency of appearance of the *M*-values, D is a dummy variable that takes the value of unity when M=value is in the 90-10 interval and 0 otherwise. Refer to section 3.2.4 for details. "n.a." stands for "not available" and means it was not possible to perform the test because the dummy variable had not enough observations equal to 1, being therefore close to a singular matrix. *, ** indicates significance at the 10% and 5%, respectively.

Table 7 – Barrier proximity test: 75-25 barrier

	M0.1 (l=0)			**M1 (l=1)**			**M10 (l=2)**		
	β	**ρ-value**	**R^2**	**β**	**ρ-value**	**R^2**	**β**	**ρ-value**	**R^2**
S&P 500									
Abbott Lab.	0.000	0.620	0.003	-0.001	0.097	0.028	-	-	-
Altria Group	0.000	0.603	0.003	0.001	0.392	0.007	-	-	-
Amazon.com	0.000	0.561	0.003	0.000	0.914	0.000	-	-	-
Amgen	0.000	0.905	0.000	0.000	0.476	0.005	-	-	-
AT&T	0.001	0.214	0.016	-0.001	0.144	0.022	-	-	-
Home Depot	0.000	0.638	0.002	0.000	0.788	0.001	-	-	-
IBM	-0.001	0.199	0.017	0.000	0.451	0.006	-	-	-
Pfizer	0.000	0.779	0.001	0.001*	0.079	0.031	-	-	-
Wal Mart Stores	0.001**	0.038	0.043	0.001	0.277	0.012	-	-	-
Xilinx	0.001	0.364	0.008	0.000	0.722	0.001	-	-	-
FTSE-100									
BG Group	-	-	-	-	-	-	-0.001***	0.009	0.067
BP	-	-	-	-	-	-	0.001	0.101	0.027
BT Group	-	-	-	-	-	-	0.001	0.442	0.006
Diageo	-	-	-	-	-	-	0.000	0.938	0.000
HSBC Hdg.	-	-	-	-	-	-	-0.001**	0.018	0.056
ITV	-	-	-	-	-	-	0.001	0.420	0.007
Legal & General	-	-	-	-	-	-	0.000	0.912	0.000

Lloyds BG	-	-	-	-	-	-	0.000	0.732	0.001
Rolls-Royce Hdg.	-	-	-	-	-	-	0.001	0.058	0.036
Tesco	-	-	-	-	-	-	-0.003***	0.000	0.295
Nikkei 225									
Fujitsu	-	-	-	-	-	-	0.000	0.412	0.007
Hitachi	-	-	-	-	-	-	0.000	0.842	0.000
Mitsubishi Electric	-	-	-	-	-	-	0.000	0.439	0.006
Mitsubishi Heavy Inds.	-	-	-	-	-	-	-0.002***	0.001	0.113
Mitsubishi Materials	-	-	-	-	-	-	0.000	0.616	0.003
Nippon Stl.	-	-	-	-	-	-	0.001	0.098	0.027
Nissan Motor	-	-	-	-	-	-	0.000	0.842	0.000
Nomura Hdg.	-	-	-	-	-	-	0.000	0.721	0.001
Tokyo Gas	-	-	-	-	-	-	0.000	0.831	0.000
Toshiba	-	-	-	-	-	-	0.000	0.764	0.001

Table 7 shows the results of a regression $f(M)=\alpha+\beta D+\varepsilon$, where $f(M)$ stands for the frequency of appearance of the M-values, D is a dummy variable that takes the value of unity when M=value is in the 75-25 interval and 0 otherwise. Refer to section 3.2.4 for details. *, **, *** indicates significance at the 10%, 5% and 1% level, respectively.

4.2.2 Barrier hump test

Table 8 shows the results for the barrier hump test, which is meant to test the entire shape of the distribution of *M*-values. Assuming it should follow a hump-shape distribution, we thus expected Υ to be negative and significant in the presence of barriers. However, evidence of persistent barriers is once more weak or almost inexistent. From the 30 securities under analysis, the null hypothesis of no barriers is rejected in just three situations: AT&T for the second barrier level and Tesco and Mitsubishi Heavy Industries for the highest level.

Table 8 – Barrier hump test

Panel A: Companies from the U.S.

	M0.1 (l=0)			**M1 (l=1)**		
	γ	**ρ-value**	**R^2**	**γ**	**ρ-value**	**R^2**
S&P 500						
Abbott Lab.	0.0000004	0.344	0.012	-0.0000003	0.354	0.089
Altria Group	0.0000004	0.394	0.008	0.0000002	0.673	0.003
Amazon.com	0.0000000	0.992	0.008	0.0000000	0.957	0.004
Amgen	0.0000000	0.954	0.001	0.0000000	0.875	0.002
AT&T	0.0000002	0.500	0.035	-0.0000016**	0.022	0.069
Home Depot	0.0000004	0.349	0.012	-0.0000001	0.851	0.018
IBM	-0.0000005	0.449	0.036	-0.0000003	0.219	0.016
Pfizer	0.0000002	0.619	0.003	0.0000010***	0.007	0.086
Wal Mart Stores	0.0000006	0.159	0.026	0.0000002	0.591	0.006
Xilinx	0.0000006	0.140	0.023	-0.0000001	0.769	0.005

Panel B: Companies from the U.K.

	M10 (l=2)		
	γ	**ρ-value**	**R^2**
FTSE-100			
BG Group	-0.0000005	0.131	0.039
BP	0.0000002	0.391	0.017
BT Group	0.0000002	0.637	0.019
Diageo	-0.0000001	0.759	0.001
HSBC Hdg.	-0.0000002	0.449	0.090
ITV	-0.0000001	0.868	0.015
Legal & General	0.0000009	0.683	0.002
Lloyds BG	0.0000005	0.421	0.007
Rolls-Royce Hdg.	0.0000005	0.110	0.027
Tesco	-0.0000014***	0.001	0.213

Panel C: Companies from Japan

	M10 (l=2)		
	γ	**ρ-value**	**R^2**
Nikkei 225			
Fujitsu	0.0000001	0.730	0.003
Hitachi	0.0000001	0.724	0.002
Mitsubishi Electric	0.0000004	0.155	0.057
Mitsubishi Heavy Inds.	-0.0000009***	0.002	0.120
Mitsubishi Materials	0.0000003	0.477	0.017
Nippon Stl.	0.0000002	0.855	0.101
Nissan Motor	-0.0000001	0.813	0.017
Nomura Hdg.	-0.0000006	0.392	0.032
Tokyo Gas	0.0000019**	0.017	0.064

Toshiba	0.0000003	0.299	0.014

Table 8 shows the results of a regression $f(M)=\alpha+\phi M+\Upsilon M^2+\eta$, where f(M), the frequency of appearance of each M-values, is regressed on M, the *M*-value itself, and M^2, its square. **, *** indicates significance at the 5% and 1% level, respectively.

4.2.3 Conditional effects test

Assuming the existence of psychological barriers, we expected the dynamics of individual return series to be different around these points. However, results in Table 9 provide no clear evidence of mean effects around barriers, as there is no clear pattern for effects on individual stock returns before and after crossing a possible barrier. We note however that in general the sum of the coefficients around upward movements is greater than of downward movements in Japan whereas in the U.K. the opposite happens. In the case of U.S. stocks there is no evidence of a different reaction depending on whether one is moving through a barrier from below or above.

Table 9 – GARCH analysis: mean equation

		β_1	β_2	β_3	β_4	β_5
S&P 500						
Abbott Lab.	*Coef.*	0.00022	-0.00373	0.00059	0.00256	0.00308
	ρ-value	0.408	0.163	0.721	0.314	0.158
Altria Group	*Coef.*	-0.00049	0.00247	0.00078	0.00090	0.00545*
	ρ-value	0.752	0.437	0.820	0.746	0.064
Amazon.com	*Coef.*	0.00070	0.00236	0.00049	-0.00100	0.00286
	ρ-value	0.150	0.321	0.849	0.711	0.275
Amgen	*Coef.*	0.00030	0.00157	0.00321	-0.00097	-0.00325**
	ρ-value	0.238	0.309	0.173	0.576	0.030
AT&T	*Coef.*	0.00011	-0.00135	0.00015	0.00418**	0.00140
	ρ-value	0.562	0.455	0.918	0.018	0.361
Home Depot	*Coef.*	0.00082***	-0.00081	0.00082	-0.00187*	-0.00039
	ρ-value	0.001	0.542	0.593	0.076	0.703
IBM	*Coef.*	0.00035**	0.00023	0.00088	0.00010	0.00191**
	ρ-value	0.065	0.867	0.522	0.918	0.040
Pfizer	*Coef.*	0.00004	0.00278*	0.00116	-0.00227*	0.00024
	ρ-value	0.837	0.074	0.462	0.085	0.861
Wal Mart Stores	*Coef.*	0.00015	0.00218	-0.00186	0.00183	0.00038
	ρ-value	0.406	0.248	0.191	0.127	0.773
Xilinx	*Coef.*	0.00028	-0.00089	0.00335	-0.00307	0.00128

	ρ-value	0.437	0.829	0.281	0.262	0.633
FTSE-100						
BG Group	*Coef.*	0.00111***	-0.00250	0.00056	-0.00062	0.00043
	ρ-value	0.001	0.283	0.818	0.697	0.826
BP	*Coef.*	0.00027	-0.00134***	0.00152	-0.00113	0.00003
	ρ-value	0.264	0.000	0.180	0.515	0.984
BT Group	*Coef.*	0.00061**	-0.00143	-0.00018	-0.00057	-0.00269
	ρ-value	0.023	0.427	0.932	0.744	0.120
Diageo	*Coef.*	0.00058***	0.00007	0.00033	-0.00046	-0.00080
	ρ-value	0.001	0.951	0.765	0.613	0.457
HSBC Hdg.	*Coef.*	0.00025	-0.00274**	0.00083	-0.00128	0.00080
	ρ-value	0.170	0.023	0.531	0.459	0.589
ITV	*Coef.*	-0.00017	-0.00192	0.00287	-0.00287	-0.00130
	ρ-value	0.929	0.847	0.747	0.771	0.875
Legal & General	*Coef.*	0.00045	0.00553	-0.00299	-0.00305	-0.00284
	ρ-value	0.629	0.147	0.377	0.339	0.345
Lloyds BG	*Coef.*	0.00024	-0.00270	0.00341	-0.00007	-0.00224
	ρ-value	0.348	0.206	0.147	0.975	0.400
Rolls-Royce Hdg.	*Coef.*	0.00103***	-0.00040	0.00091	-0.00463*	0.00053
	ρ-value	0.000	0.875	0.623	0.056	0.802
Tesco	*Coef.*	0.00044**	0.00197*	-0.00049	-0.00163	-0.00097
	ρ-value	0.046	0.100	0.711	0.169	0.507
Nikkei 225						
Fujitsu	*Coef.*	-0.00008	-0.00119	0.00020	0.00081	0.00018
	ρ-value	0.837	0.564	0.914	0.689	0.925
Hitachi	*Coef.*	0.00054*	0.00041	0.00274	-0.00495**	-0.00529*
	ρ-value	0.083	0.830	0.190	0.037	0.093
Mitsubishi Electric	*Coef.*	0.00068**	-0.00254	0.00260	0.00154	-0.00032
	ρ-value	0.046	0.312	0.345	0.439	0.874
Mitsubishi Heavy Inds.	*Coef.*	0.00051*	-0.00358	-0.00242	0.00201	0.00049
	ρ-value	0.094	0.170	0.398	0.356	0.814
Mitsubishi Materials	*Coef.*	0.00060	-0.00111	-0.00063	-0.00205	0.00056
	ρ-value	0.117	0.731	0.842	0.493	0.881
Nippon Stl.	*Coef.*	0.00037	0.00050	-0.00129	-0.00215	-0.00154
	ρ-value	0.244	0.815	0.578	0.434	0.601
Nissan Motor	*Coef.*	0.00039	0.00003	0.00001	0.00154	0.00301***
	ρ-value	0.169	0.983	0.995	0.307	0.006
Nomura Hdg.	*Coef.*	0.00003	0.00088	0.00115	-0.00274*	0.00158
	ρ-value	0.940	0.558	0.523	0.087	0.344
Tokyo Gas	*Coef.*	0.00047**	-0.00181	0.00079	0.00151	-0.00042
	ρ-value	0.022	0.126	0.449	0.259	0.733

Toshiba	*Coef.*	0.00040	-0.00076	0.00015	-0.00003	0.00196
	ρ-value	0.236	0.737	0.949	0.987	0.273

Table 9 shows the results of the mean equation of a GARCH estimation of the form $R_t=\beta_1+ \beta_2BD+ \beta_3AD+ \beta_4BU+ \beta_5AU+\varepsilon_t$; $\varepsilon_t \sim N(0,V_t)$; $V_t= \alpha_1+ \alpha_2BD+ \alpha_3AD+ \alpha_4BU+ \alpha_5AU+\alpha_6V_{t-1}+\alpha_7\varepsilon^2_{t-1}+\eta_t$. BD, AD, BU and AU are dummy variables. BD takes the value 1 in the 5 days before crossing a barrier on a downward movement and zero otherwise, whereas AD is for the 5 days after the same event. BU is for the 5 days before crossing a barrier from below, while AU is 1 in the 5 days after the same upward crossing. V_{t-1} refers to the moving average parameter and ε^2_{t-1} stands for the GARCH parameter. Barriers at *l*=1 are tested in the case of U.S. stocks barriers at *l*=2 are tested in the case of the stocks from the U.K. and Japan. *, **, *** indicates significance at the 10%, 5% and 1% level, respectively.

Table 10 contains results for the conditional variance equation. In this case, evidence is substantially stronger, although there is still no clear pattern among all stocks. The constant is positive and significant for all indices. The GARCH term in the conditional variance is positive and significant, indicating significant GARCH effects around barriers. The coefficients of the lagged squared residuals are all significant at the 1% level. The variance effects are particularly evident after an upward movement through a barrier: the coefficient of AU in the variance equation is negative and statistically significant in ten out of the thirty stocks. This indicates that these stock prices tend to calm after having risen through a barrier. However, these effects are not uniform across the series tested. In fact, BG Group and Hitachi show significant increases in variance after crossing a barrier as part of an upward move.

The results in the pre-crossing period are also somewhat heterogeneous. Altria Group, BG Group, ITV, Legal & General, Tesco and Nomura Hdg. all show significant decreases in variance effects before a barrier is crossed as part of an upward move while Amgen, BP and Rolls-Royce Hdg. exhibits significant increases in variance in the same circumstances.

It is also noteworthy that the variance tends to be higher in most stocks in pre-crossing periods than in post-crossing periods which is consistent with the possibility of increased technical trading in the pre-crossing period.

Table 10 – GARCH analysis: variance equation
Panel A: Companies from the U.S.

		α_1	α_2	α_3	α_4	α_5	α_6	α_7
S&P 500								
Abbott Lab.	*Coef.*	0.00000***	0.00000	-0.00002***	0.00001*	-0.00003***	1.00068***	-0.00108***
	ρ-value	0.000	0.973	0.001	0.079	0.000	0.000	0.000
Altria Group	*Coef.*	0.00063***	-0.00020***	-0.00020**	-0.00039***	-0.00025***	0.59664***	-0.00083*
	ρ-value	0.001	0.000	0.018	0.000	0.004	0.000	0.096
Amazon.com	*Coef.t*	0.00000***	0.00000	0.00000	-0.00001	-0.00001	0.98886***	0.00764***
	ρ-value	0.000	0.745	0.402	0.345	0.610	0.000	0.000
Amgen	*Coef.*	0.00000***	-0.00001	0.00003***	0.00001**	-0.00002***	0.93332***	0.05598***
	ρ-value	0.000	0.152	0.000	0.025	0.001	0.000	0.000
AT&T	*Coef.*	0.00000***	0.00001	0.00000	0.00000	-0.00001	0.94329***	0.05102***
	ρ-value	0.000	0.335	0.461	0.690	0.185	0.000	0.000
Home Depot	*Coef.*	0.00000***	0.00000	0.00000	0.00000	0.00000	0.93556***	0.06288***
	ρ-value	0.000	0.867	0.815	0.743	0.398	0.000	0.000
IBM	*Coef.*	0.00001***	0.00002***	-0.00001***	0.00000	0.00000	0.87835***	0.10220***
	ρ-value	0.000	0.000	0.000	0.184	0.490	0.000	0.000
Pfizer	*Coef.*	0.00000***	0.00001*	0.00000	0.00000	0.00000	0.93380***	0.05566***
	ρ-value	0.000	0.086	0.677	0.681	0.867	0.000	0.000
Wal Mart Stores	*Coef.*	0.00000***	0.00003***	-0.00003***	0.00000	0.00000	0.95981***	0.03568***
	ρ-value	0.000	0.000	0.000	0.826	0.861	0.000	0.000
Xilinx	*Coef.*	0.00000***	0.00002	-0.00004*	0.00000	0.00001	0.97729***	0.01814***
	ρ-value	0.000	0.267	0.074	0.928	0.515	0.000	0.000

Panel B: Companies from the U.K.

		α_1	α_2	α_3	α_4	α_5	α_6	α_7
FTSE-100								
BG Group	*Coef.*	0.00002***	0.00002	-0.00001	-0.00004***	0.00004***	0.90129***	0.07104***
	ρ-value	0.000	0.120	0.318	0.000	0.000	0.000	0.000
BP	*Coef.*	0.00002***	-0.00004***	0.00001**	0.00006***	-0.00003***	0.76014***	0.15936***
	ρ-value	0.000	0.000	0.011	0.000	0.000	0.000	0.000
BT Group	*Coef.*	0.00000***	0.00000	0.00001	0.00000	0.00000	0.94830***	0.04665***
	ρ-value	0.000	0.904	0.212	0.753	0.524	0.000	0.000
Diageo	*Coef.*	0.00000***	0.00001**	0.00000	0.00000	0.00000	0.93933***	0.05186***
	ρ-value	0.000	0.016	0.342	0.502	0.469	0.000	0.000
HSBC Hdg.	*Coef.*	0.00000***	0.00001	0.00001**	0.00001*	-0.00001***	0.91623***	0.08204***
	ρ-value	0.000	0.229	0.019	0.083	0.008	0.000	0.000
ITV	*Coef.*	0.00112***	-0.00043*	-0.00043*	-0.00046**	-0.00054**	0.59637***	0.10863***
	ρ-value	0.000	0.065	0.061	0.034	0.035	0.000	0.003
Legal & General	*Coef.*	0.00048***	-0.00003	-0.00011	-0.00022***	-0.00019***	0.55186***	0.14579***
	ρ-value	0.000	0.611	0.137	0.000	0.003	0.000	0.000
Lloyds BG	*Coef.*	0.00000***	0.00001	-0.00001*	0.00001	0.00001	0.91941***	0.08570***
	ρ-value	0.000	0.221	0.096	0.627	0.473	0.000	0.000
Rolls-Royce Hdg.	*Coef.*	0.00001***	0.00005***	-0.00001	0.00010***	-0.00007***	0.89112***	0.09045***
	ρ-value	0.000	0.000	0.111	0.000	0.000	0.000	0.000
Tesco	*Coef.*	0.00001***	-0.00001***	0.00001**	-0.00001***	0.00001	0.89164***	0.09013***
	ρ-value	0.000	0.001	0.041	0.000	0.313	0.000	0.000

Panel C: Companies from Japan

		α_1	α_2	α_3	α_4	α_5	α_6	α_7
Nikkei 225								
Fujitsu	*Coef.*	0.00001***	-0.00001	0.00000	0.00001	-0.00001	0.92947***	0.05769***
	ρ-value	0.000	0.394	0.850	0.378	0.621	0.000	0.000
Hitachi	*Coef.*	0.00001***	0.00001	-0.00001*	0.00001	0.00003***	0.93041***	0.05552***
	ρ-value	0.000	0.268	0.072	0.326	0.000	0.000	0.000
Mitsubishi Electric	*Coef.*	0.00001***	0.00002	0.00000	0.00001	0.00000	0.89777***	0.08780***
	ρ-value	0.000	0.177	0.997	0.316	0.762	0.000	0.000
Mitsubishi Heavy Inds.	*Coef.*	0.00001***	0.00000	0.00004***	0.00000	-0.00001	0.91381***	0.07467***
	ρ-value	0.000	0.826	0.007	0.765	0.399	0.000	0.000
Mitsubishi Materials	*Coef.*	0.00001***	-0.00018**	0.00010***	-0.00004*	-0.00006***	0.91073***	0.06472***
	ρ-value	0.000	0.012	0.000	0.086	0.001	0.000	0.000
Nippon Stl.	*Coef.*	0.00002***	0.00000	-0.00002*	0.00001	0.00002	0.87910***	0.08885***
	ρ-value	0.000	0.954	0.065	0.647	0.307	0.000	0.000
Nissan Motor	*Coef.*	0.00000***	0.00001	-0.00001**	0.00000	-0.00001***	0.91644***	0.07801***
	ρ-value	0.000	0.167	0.029	0.632	0.007	0.000	0.000
Nomura Hdg.	*Coef.*	0.00001***	0.00000	0.00003***	-0.00002**	0.00001	0.92758***	0.06211***
	ρ-value	0.000	0.954	0.000	0.028	0.202	0.000	0.000
Tokyo Gas	*Coef.*	0.00001***	0.00000	0.00000	0.00000	-0.00001	0.88470***	0.09327***
	ρ-value	0.000	0.395	0.632	0.427	0.222	0.000	0.000
Toshiba	*Coef.*	0.00001***	0.00003***	-0.00004***	-0.00001	0.00000	0.92679***	0.06682***
	ρ-value	0.000	0.010	0.001	0.170	0.593	0.000	0.000

Table 10 shows the results of the variance equation of a GARCH estimation of the form $R_t=\beta_1+ \beta_2BD+ \beta_3AD+ \beta_4BU+ \beta_5AU+\varepsilon_t$; $\varepsilon_t \sim N(0,V_t)$; $V_t= \alpha_1+ \alpha_2BD+ \alpha_3AD+ \alpha_4BU+ \alpha_5AU+\alpha_6V_{t-1}+\alpha_7\varepsilon^2_{t-1}+\eta_t$. BD, AD, BU and AU are dummy variables. BD takes the value 1 in the 5 days before crossing a barrier on a downward movement and zero otherwise, whereas AD is for the 5 days after the same event. BU is for the 5 days before crossing a barrier from below, while AU is 1 in the 5 days after the same upward crossing. V_{t-1} refers to the moving average parameter and ε^2_{t-1} stands for the GARCH parameter. Barriers at *l*=1 are tested in the U.S. and barriers at *l*=2 are tested in the U.K. and Japan. *, **, *** indicates significance at the 10%, 5% and 1% level, respectively.

Table 11 shows the test results of the four barrier hypothesis mentioned in section 3.2.5. If some kind of barrier indeed existed, we would expect that the restraints in terms of mean and variance would be relaxed after the price crossed that barrier. In line with our previous analysis, evidence is once more weak regarding conditional mean returns associated with prices breaching a barrier. In fact, with the exception of BP, there is no significant change in the conditional mean returns in those circumstances.

Table 11 – Barrier hypothesis tests

		H1	**H2**	**H3**	**H4**
S&P 500					
Abbott Lab.	χ^2	1.8713	0.0221	2.5927	6.8788***
	ρ-value	0.171	0.882	0.107	0.009
Altria Group	χ^2	0.0918	1.1832	0.0000	4.4445**
	ρ-value	0.762	0.277	0.999	0.035
Amazon.com	χ^2	0.2845	0.9245	0.3420	0.0521
	ρ-value	0.594	0.336	0.559	0.819
Amgen	χ^2	0.3457	1.0154	12.9349***	8.6795***
	ρ-value	0.557	0.314	0.000	0.003
AT&T	χ^2	0.4055	1.4203	0.7699	0.8302
	ρ-value	0.524	0.233	0.380***	0.362
Home Depot	χ^2	0.6636	1.0450	0.0016	0.3478
	ρ-value	0.415	0.307	0.968	0.555
IBM	χ^2	0.1070	1.8487	32.7172***	1.2085
	ρ-value	0.744	0.174	0.000	0.272
Pfizer	χ^2	0.5554	1.6459	1.3178	0.0954
	ρ-value	0.456	0.200	0.251	0.757
Wal Mart Stores	χ^2	2.9903*	2.9903*	18.1844***	0.0412
	ρ-value	0.084	0.084	0.000	0.839
Xilinx	χ^2	0.6550	1.1643	2.1214	0.0810
	ρ-value	0.418	0.281	0.145	0.776
FTSE-100					
BG Group	χ^2	0.7829	0.1538	1.9119	67.3568***
	ρ-value	0.376	0.695	0.167	0.000
BP	χ^2	6.0105**	0.2588	76.8395***	22.7072***
	ρ-value	0.014	0.611	0.000	0.000
BT Group	χ^2	0.2202	0.7074	0.4457	0.2306
	ρ-value	0.639	0.400	0.504	0.631
Diageo	χ^2	0.0304	0.0535	3.3530*	0.5672

	ρ-value	0.861	0.817	0.067	0.451
HSBC Hdg.	χ^2	3.8376*	0.6556	0.3493	5.1757**
	ρ-value	0.050	0.418	0.555	0.023
ITV	χ^2	0.1086	0.0107	0.0000	0.0815
	ρ-value	0.742	0.918	0.996	0.775
Legal & General	χ^2	2.5972	0.0020	0.4255	0.1041
	ρ-value	0.107	0.965	0.514	0.747
Lloyds BG	χ^2	3.8019*	0.3853	2.2577	0.0003
	ρ-value	0.051	0.535	0.133	0.987
Rolls-Royce Hdg.	χ^2	0.1721	2.5748	19.2434***	83.6461***
	ρ-value	0.678	0.109	0.000	0.000
Tesco	χ^2	1.7642	0.1119	8.3505***	6.1306**
	ρ-value	0.184	0.738	0.004	0.013
Nikkei 225					
Fujitsu	χ^2	0.2154	0.0513	0.2905	0.5452
	ρ-value	0.643	0.821	0.590	0.460
Hitachi	χ^2	0.6183	0.0072	2.4319	0.8296
	ρ-value	0.432	0.932	0.119	0.362
Mitsubishi Electric	χ^2	1.9695	0.4475	0.5868	0.5214
	ρ-value	0.161	0.504	0.444	0.470
Mitsubishi Heavy Inds.	χ^2	0.0893	0.2047	1.8108	0.0377
	ρ-value	0.765	0.651	0.178	0.846
Mitsubishi Materials	χ^2	0.0108	0.2968	13.8003***	0.4382
	ρ-value	0.917	0.586	0.000	0.508
Nippon Stl.	χ^2	0.3269	0.0225	0.9340	0.0808
	ρ-value	0.568	0.881	0.334	0.776
Nissan Motor	χ^2	0.0001	0.6500	3.6819**	2.0821
	ρ-value	0.992	0.420	0.055	0.149
Nomura Hdg.	χ^2	0.0127	3.4670*	2.6067	3.3361*
	ρ-value	0.910	0.063	0.106	0.068
Tokyo Gas	χ^2	2.4746	1.0703	0.5383	1.1729
	ρ-value	0.116	0.301	0.463	0.279
Toshiba	χ^2	0.0816	0.5824	9.2365***	1.0514
	ρ-value	0.775	0.445	0.002	0.305

Table 11 shows the results for a χ^2 test of four different null hypothesis. H1: There is no difference in the conditional mean return before and after a downward crossing of a barrier; H2: There is no difference in the conditional mean return before and after an upward crossing of a barrier. H3: There is no difference in conditional variance before and after a downward crossing of a barrier; H4: There is no difference in the conditional variance before and after an upward crossing of a barrier. *, **, *** indicates significance at the 10%, 5% and 1% level, respectively.

The first hypothesis, which tested differences in conditional mean returns before and after a downwards crossing of a barrier, is only rejected at a 10% level for four stocks overall, whereas the second one, which focus on the upward movement, is rejected only once.

Following again our previous findings, evidence is slightly more consistent regarding the conditional volatility of stock prices, although it is still somewhat scattered. Regarding the third parameter restriction, which tested the difference in the conditional variance before and after a downwards crossing of a barrier, we now find that this difference is statistically significant at a 10% level for ten out of the thirty stocks of the sample. Regarding the dynamics of volatility on upwards movements across barriers, evidence is not as strong as for a downward path, but we can still reject the inexistence of difference in conditional variance before and after an upwards breaching of a barrier for eight out of the stocks which comprise the sample.

Overall, evidence suggests that, although there are no significant effects in terms of returns in stock prices around barrier points, volatility is in fact affected in nearly half of the stocks under scrutiny.

A similar result was obtained by Cyree *et al*. (1999) for several indices representing developed stock markets. The authors noticed that their result – a simultaneous increase in conditional return and a decrease in conditional variance – appeared to represent an “aberration” in the equilibrium risk–return relationship. As pointed out also by Aggarwal and Lucey (2007), such findings pose some relevant implications for the positive risk-return relationship postulated by the standard financial models. As variance is normally used as a proxy for risk, changes in this parameter should be linked to changes in expected returns. However, our findings suggest that this relationship may be biased in the case of individual stock prices near round numbers.

5 - Conclusion

Psychological barriers have been found to impact financial markets in different geographies and asset classes. Due to several behavioural biases and the consequent inability to take fully rational decisions, the average market practitioner is often affected, directly or indirectly, by such phenomenon. After evidence presented by previous studies had shown that stock indices were indeed affected by psychological barriers, our study focused on individual stocks as they usually are the securities which investors actually trade in stock exchanges.

Following the most widely used methodologies for studying psychological barriers, we provide new evidence regarding psychological barriers in single stock prices for the three most important developed markets. Considering a sample period of 14 years (2000-2014), we examined the existence of such phenomenon in some of the major stocks trading in the U.S., the U.K. and Japan.

In summary, the effects of psychological barriers on individual stocks are significantly dissimilar across stocks and definitely much less consistent that what previous studies found regarding stock indices. Evidence is mostly scattered and only slightly significant. No relevant global pattern was found in our tests.

Although a uniform distribution is rejected for the prices of every single stock under analysis, barrier tests show no consistent evidence of psychological barriers around round numbers for all barrier levels. Nonetheless, our test for conditional effects showed that in fact nearly half of the stocks suffered some impacts in terms of volatility around barriers. More specifically, evidence suggests that these stocks tended to be significantly more volatile before breaching through a barrier on an upward movement and then registered significant calmness after such point was crossed. Considering downward movements, impacts on the dynamics of volatility were not as significant.

All in all, our major result is thus that there are no consistent barriers in single stock prices, in spite of the documented effects on volatility. Our findings are thus in line with the ones of Dorfleitner and Klein (2009), who focused only on German stocks, and also with the results of Cai *et al*. (2007) for price resistance in Chinese stocks.

Round numbers do not appear to be of special importance at least for investors considering single stocks. However, the implications of these results for the debate about the market efficiency are, in our view, ambiguous. It is true that the absence of psychological barriers is consistent with an highly informationally efficient market. But what is often disregarded is that the absence of psychological barriers would also be what one would expect to observe in a financial market dominated by noise traders and where prices were dictated by complex patterns of shifting fads and moods.

The implications of the results presented here are somewhat problematic for standard risk-return equilibrium models which predict a positive relationship between these two variables. The findings regarding the barrier hypothesis tests presented in Table 11 above, show that in about half of the stocks under analysis there were statistically significant changes in the volatility of prices between the pre-crossing and the post-crossing periods. Changes in variance, as a proxy for risk, \should of course be associated with changes in expected returns. However, only in the case of one stock (BP), there was a contemporaneous statistical significant change in the observed returns between those two periods. This lead us to conclude that the relationship between risk and return became weaker around the psychological barrier for an important number of stocks of the sample.

The fragility in the relationship between risk and return, both in cross-sectional and in temporal frameworks, has been highlighted by several authors over the last decades. For example, Fama and French (1998, 2004) have shown that, after controlling the data for factors such as the book-to-market and the stock capitalization, the relationship between the observed returns and the beta risk parameter becomes statistically non-significant, if not negative. And more recently, Savor and Wilson (2014) have shown that beta is positively related to average stock returns only on days when macroeconomics news regarding employment, inflation, and interest rate are scheduled to be announced. On the remaining days, beta is unrelated or even negatively related to average returns. The results of our study suggest an additional circumstance where the relationship between risk and return tends to be weaker: in the proximity of psychological barriers (in our case, round numbers).

The significance of our results for those investors who use trading strategies based on round numbers as support and resistance levels is evident. The empirical evidence presented here does not support the possibility of obtaining abnormal positive returns with such strategies.

At last, there is the issue of reconciling the results obtained in the study of single stocks with the existing empirical evidence suggesting that there are significant psychological barriers in stock indices. In fact, how is it possible that several studies have found significant barriers in stock market indices [e.g. Donaldson and Kim (1993); Koedijk and Stork (1994); Cyree *et al*. (1999); Bahng (2003)] when the evidence on barriers in individual stocks is so fragile? There are, in our opinion, at least two non-mutually exclusive possible explanations. First, psychological barriers are not a statistically significant phenomenon nowadays because investors, by exploiting this anomaly, eventually eliminated it [e.g. Schwert (2003); Marquering *et al*. (2006)]. The second explanation has to do with a problem that Dorfleitner and Klein (2009) referred to as a “publication bias”. According to these authors, studies with significant results are more likely to be published whereas studies without such results are often not published. The lack of published studies with non-significant results would then lead to a biased perception that psychological barriers are a common phenomenon in financial markets.

We hope to have contributed with this article to tackle the problem identified by Dorfleitner and Klein (2009).

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