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Price Clustering and Natural Resistance Points in the Dutch Stock Market

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Price clustering and natural resistance points in the Dutch stock market: a natural experiment

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Abstract
The main contribution of this study is the finding that round numbers can act as price barriers for individual stocks. In addition, a first step is made to explain this and the related phenomena of round number clustering by testing two competing hypotheses, using data from the Dutch stock market during 1990-2001. After January 1, 1999 stock prices were listed in euros, while guilders were still the currency of daily life until 2002. According to the aspiration level hypothesis investors will have target prices for the stocks they own. This hypothesis predicts that round number effects in guilders will only slowly disappear. The odd price hypothesis originates from cognitive psychology and marketing. Humans have to tendency to compare numbers digit by digit from left to right, and therefore consider an odd price of 19.90 as considerable less than 20.00. This hypothesis predicts an abrupt change in round number effects after January 1, 1999. The results reject the aspiration level hypothesis and are in line with the odd price hypothesis.

Keywords: behavioral finance, natural experiment, price clustering

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1. Introduction

All economic models and theories have to make assumptions about how human beings make decisions. One popular assumption has been (and still is) that all agents have stable and consistent preferences and are (unlimited) rational. Although everybody knew that these assumptions were (at least in this strict sense) unrealistic, an alternative was missing. More than four decades ago Herbert Simon made a tremendous contribution by introducing a theory of bounded rationality, in which the decision maker is not maximizing some pay off function, but is 'satisfyzing', she looks for a outcome that is good enough (better than some threshold). Although Simon's contribution was recognized in the field as being important, it did not immediately lead to a change of the behavioral assumptions in most theories and models. One of the reasons was a data problem. Only when cognitive psychologists[1] and the first experimental economists started to gather data the field of behavioral economics gained momentum.

In the development of behavioral theories the study of financial decision making and financial markets seemed to have a clear advantage above other fields: there was relatively much data available and a long tradition of empirical analyses existed. However, most of the available data was aggregated and only about prices and volumes in financial markets. Thanks to information technology data has become easier to gather and to analyze and has become less aggregated (intraday prices, but also data of individual investors is sometimes available (e.g. Odean 1998)). There are now several hundreds of behavioral finance articles published, see for an overview Hirshleifer (2001).

The standard theory that is challenged by behavioral finance is the efficient market theory. Central in this theory is that all new information that arrives is immediately reflected in the market prices and because news is unpredictable, the changes in prices are also unpredictable (random walk). The price of a stock then equals its fundamental value that is the discounted future returns. From the seventies on many 'anomalies' were found that suggested that some predictability existed (e.g. the small firm effect). Defenders of the efficient market theory have argued that some of these anomalies are caused by extra risk factors or that they are so small that they are not important. Malkiel (2003) argues that patterns or irrationality in the pricing of

[1] E.g. the prospect theory of Kahneman and Tversky 1979 was based upon much psychological

individual stocks will not persist but will be arbitraged away by rational investors who try to exploit the anomaly. However, this is refuted by De Long et al (1990) who show that arbitrage will be risky and therefore not complete. Malkiel (2003) redefinition of efficient markets as "markets that do not allow investors to earn above-average returns without above-average risks" may be good enough for a practitioner but not for a scientist who is looking for the right theory of investors behavior.

This paper focuses on the tendency of prices to cluster at round numbers (like 10, 20, 30 etc and to a lesser extend 5, 15, 25, etc) and the related effect of round number price barriers (prices pass less frequently round numbers than other numbers). These effects are small but very robust (documented in various markets, see section 2) and are against any strict definition of the efficient market theory (there is no reason that the discounted value of future returns would be relatively often a round number). Because the effect is small in absolute terms it is hard to arbitrage away profitable (this may make the effect more stable). For the investor looking for profits the effect may therefore not be very interesting, from a scientific view it is because it can give some insights in the way investors make their decisions.

There are several more or less plausible explanations for these round number phenomena (treated in section 3). The two most plausible explanations are the aspiration level hypothesis (when investors buy an asset they have already a target price in mind to sell it) and odd pricing (consumers tend to consider a odd price like 19.95 as significant lower than the close by round price of 20.00). To test these hypotheses using regular market data is hard. However, the introduction of the euro provides a unique opportunity to study the round number effect in a 'natural experiment'. What a round number is depends on the currency used: how near a stock's price (or a stock index) is near a 'psychological' important number can change drastically when the transition from local currencies to euros is made. Fortunately, the implementation of the euro was done in two steps: after fixing the exchange rates (December 1998, 2.20371 guilders is 1 euro) all stock prices were listed in euros from January 1999 onwards. Three years later (January 2002) euro coins and banknotes were introduced in daily life. This means that during the three years 1999-2001 Dutch investors had to formulate their decisions to buy or sell stocks in euros while consumption was in guilders (and all salaries were paid in guilders). This design of

research of the sixties and seventies.

the natural experiment enables us to evaluate the main hypotheses. According to the aspiration level hypothesis the round number effects in guilders will only vanish slowly after January 1, 1999 because stocks bought before this date will have a target price in guilders and the investor who sells the stock will receive guilders in her bank account (so there is no reason to change to new euro target prices). Only stocks purchased after January 1, 1999 are likely to have euro-target prices. In contrast, the odd-price hypotheses predicts that on January 1, 1999 round number effects in guilders will cease to exist and round number effects in euros will immediately arise. Based upon data from the Amsterdam Stock Exchange during the guilder years 1990-1998 and the euro years 1999-2001 we have to conclude that the aspiration level hypothesis does not very well and the odd price hypothesis is confirmed.

Before discussing the design of the present study a short overview of the relevant literature will be presented in section 2. Section 3 discusses explanations of round number phenomena. Section 4 presents the data collection and the results. Section 5 concludes.

2. Evidence for round number effects

Price clustering of individual stocks

Price clustering is the phenomenon that some prices are more frequently observed than other prices. Research into price clustering started in the 60s by Osborne (1962) and Niederhoffer (1965, 1966). The main finding was that (USA) markets prices are clustered on whole numbers, less on halves or quarters and least common are the odd eights. Many years later Harris (1991) found the price clustering at the NYSE to have persisted. Clustering was found to increase with stock's price level and volatility. Christie and Schulz (1994a) found that NASDAQ market makers avoided odd-eight quotes (and seemed to implicitly collude to keep the spread at least 25 cents), an effect that decreased drastically after media exposure of the article (Christie and Schulz 1994b). Aitken et al (1996) find price clustering on the Australian Stock Exchange and Hameed and Terry (1998) on the Stock Exchange of Singapore, in both cases price clustering increases with price level.

The studies above concentrate on the clustering at the level of whole numbers versus fractions. However, Niederhoffer (1966) suggests that there is also a tendency for limit orders to be placed at familiar whole numbers like 10, 25, 50, etc. Harris (1991) mentions that his data suggests round integer clustering at any five integers starting at 5 (Harris 1991, figure 1 and page 395) but does not analyze this phenomenon.

Price barriers in stock indices

To my knowledge no studies exist about round number barriers in individual stocks, but there is some literature about the effect in stock indices. Because this may be related I will give a short overview.

Newspapers and other mass media tend to give special attention to stock indices when they pass through some round number level (in hundreds or thousands). Passing such psychological important reference points are supposed to influence market sentiments. Markets seem to be reluctant to approach or break such level from below but when the level is passed through the same round number functions as a downward resistance level. In this sense round numbers can function as a price barrier. Note that even for a rational investor who recognizes that an index is arbitrary scaled (and that passing a round number gives no information about underlying fundamentals) it may be rational to take into account the possibility that some irrational investors trade based upon these round numbers signals. Resistance points can be self-fulfilling if enough people believe that others believe. Donaldson and Kim (1993) analyze the Dow Jones Industrial Average (DJIA) in the period 1974-1990 and find that the DJIA closes on average fewer times in index values in the neighborhood of 100-levels. These round numbers function as a support and resistance levels. When such level is passed, the DJIA moved more up or down than usual. They don't find the same results in less popular indices. Ley and Varian (1994) study the DJIA over the period 1952-1993. They find that the last two whole digits of the DJIA are not uniformly distributed (less observations around the 100 levels) and that the index seems to accelerate when in the 90s. However, these observations didn't hold in sub-samples and they conclude that there is little if any predictive value in the closing values of the DJIA. Koedijk and Stork (1994) study indices in five major stock markets (Standard and Poor Composite in USA, Brussel Stock Exchange Belgium, FAZ General Germany, Nikkei 225 in Japan and the FTSE-100 of the United Kingdom) in the period 1980-1992. They find relatively few observations near 100 levels and these levels are less often passed (the exception is the Nikkei index where no significant results are found). Koedijk et al. also look for predictability of stock returns based upon the presence of psychological barriers, but they cannot report statistically significant results.

Relation between clustering and psychological barriers

Stock indices close less often in the neighborhood of round numbers, while in contrast individual stock prices cluster on round numbers. Stock indices pass less often through round numbers and therefore these numbers seem to function as barriers or resistance points. Also in individual stocks round numbers act as price barriers (see section 5)[2]. This suggests that the price barriers in the case of individual stock have a different nature than the barriers in stock indices. In this case a clear relation may exist between clustering and barriers. If clustering of individual stock prices is caused by relatively many limit orders at round numbers, this would also cause barriers or resistance points at these numbers. For example, take a stock with a current price just below 30 euro. If relatively many owners are prepared to sell at the price of 30 euro the hump of limit orders at that price will make it more difficult to pass this point. In the present paper we study price clustering and barriers in individual stocks.

3. Explanations of the round number effects

The literature suggests several explanations for clustering, most of them focusing on the small scale price clustering (whole numbers versus fractions). We will discuss these explanations and consider the relevance for large scale (round number) clustering.

Preferences for round numbers. An obvious explanation for price clustering (but not for barriers in stock indices) is that individuals have a preference for round numbers and therefore they like to trade with round numbers prices. Against this explanation is the fact that in other situations round numbers are typically *not* preferred: the favorite numbers in lotteries are ‘lucky’ numbers like birthdays and the most popular number: ‘7’ and not the round numbers (Ziemba et al 1986, cited in Mitchell 2001)[3]. Note that numbers in lotteries are not quantities; nobody has to make calculations with their lotteries numbers. This leads to the next possible explanation.

[2] This is not just a Dutch market anomaly, but also found for the stocks in the Standard and Poor 100 (1990-2001). Data is available upon request.

[3] Interestingly, Brown, Chua and Mitchell (forthcoming) find that some Asian markets during the Chinese New Year festival fewer prices ending at a “4”, the Chinese traditional bad luck number. The effect is however small, and much smaller than the round number effect found in the same markets.

Coordination on limited price set. Harris (1991) argues that a limited discrete set of prices limits negotiation time under the assumption that new offers have to improve the standing offer (fewer possible prices limits the number of possible rounds before agreement). Traders may coordinate to restrict the price set (for example to half or whole numbers), which causes price clustering. Harris gives the example of home prices that are typically traded at round numbers. The model of Harris is persuasive in the case of small scale price clustering (see also Hameed and Terry 1998). However, clustering on the level of round whole numbers is not that extreme that it can be considered a limitation of the price set[4].

Convenience. Round numbers are more convenient. Calculations with round numbers are easy to perform. The use of round numbers limits informational load and decreases the probability of costly mistakes. Rounding to convenient numbers seems to be a human habit, for example when reading scales (Mitchell 2001). However note that in financial transactions the risk of mistakes is not very high (a limit order by telephone is always repeated by the bank employee and when internet is used a confirmation screen is common). Convenience and rounding may be an explanation for price clustering on the level of whole numbers versus fractions, but for the clustering on round whole numbers it is less plausible because there the cost of rounding would be substantial.

Odd pricing. The next explanation is from the marketing literature and cognitive psychology. Odd pricing (also called odd-ending pricing or just-below pricing) is very common in marketing of consumer goods (e.g. Holdershaw, Gendall and Garland 1997, Stiving and Winer 1997, Schindler and Kirby 1997). It means that the price is just below some round number (for example $9.99 instead of $10.00). Consumers (or at least some of them) tend to consider the odd price as significantly lower than the round numbered price. Humans may process and store numerical information in a way that the first digits, which contain more significant information than later digits, are treated as more valuable information (Brenner and Brenner 1982). To compare two numbers a left-to-right comparison (first compare the hundreds, if these are the same the tens, etc) is a very efficient procedure. The human tendency to overemphasize the first digits can also be observed in time measurement. Passing from an age of 39 to 40 is considered by many as a bigger step than for

[4] Even when stocks have very high prices and round numbers are enormously over-represented, most

example from 38 to 39 or from 40 to 41. In a financial market it would mean that a stock price of 30 would be considered (much) higher than a price of 29.9. A seller will be relatively happy to sell at 30 (and more limit sell orders will be placed at 30) while a buyer would be reluctant to pay a price that is not in the 20s but in the 30s. Note that the odd pricing hypothesis predicts that round number effects in guilders would immediately cease to exist in January 1999 and round number effects in euros would immediately show up.

Bounded rationality and aspiration levels. The next explanation is derived from bounded rationality theories (e.g. Simon 1955). Simon introduced the satisfyzing decision maker who does not try to maximize some utility function but instead looks for a 'good enough' solution. Some investors, when buying a stock, have already an idea for what price they will be able to sell the stock in the future. For example, an investor who buys a stock for 22 euro may expect the price of this stock to rise in the future to 40 euros. This target price (and the associated profit) can be considered an aspiration level in Simon's sense. Also some financial analysts use these target prices for individual stocks and these are also typically round numbers. This will lead to relatively many limit sell offers to be posted at round whole numbers. Note that stocks bought before but hold after January 1, 1999 will have target prices that are still round numbered in guilders but not so in euros. Because the consumption is still in guilders, there is no reason to change these target prices to euro-prices. So this hypothesis predicts that a round number effect in guilders will only slowly disappear after the transition to the euro. It will not disappear completely until the investors have sold all their stocks that are bought their stocks before transition.[5]

The explanations above focus on the clustering effects. What about round number price barriers? The price barriers in stock indices studies are about the (non) existence of the phenomena and don't give much attention to possible causes. One possibility is that the publicity about an index passing a round number from below (above) may coordinate the optimism (pessimism) of investors and may so become self-confirming (the effect is not found with indices which are less broadly published, Donaldson and Kim 1993). This is not a promising hypothesis for individual stocks; they receive only

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prices are not whole round numbers. See figure 1 in this study and also figure 1 in Harris 1991.

[5] Note that in the years 1999-2001 an investor who sells his stocks (listed in euros) get in fact Guilders on his bank account.

limited publicity when they pass round numbers. As pointed out above, price barriers can be caused by price clustering because a large number of limit orders at a specific round number makes it harder for the price to pass that number.

4. Data collection

Stocks that were traded at the Amsterdam stock exchange with quoted prices in guilders (euros) during the years 1990-1998 (1999-2001) were selected in Datastream. For each stock the daily, unadjusted, closing prices were obtained. These numbers were used to study price clustering. In order to calculate price barriers a small computer program was used to count the crossings.

For a specific stock the number of crossings is not independent from one day to the next (e.g. a stock that moves between 26 and 29 guilders for some weeks will have no crossings at 0 or 5 but many at 27 and 28). Therefore the data was aggregated per stock and year. Each record in the constructed data file consists of the name of the stock, the year, the number of times the stock passed through the numbers 0, 1, …9 (the 'crossings') and some variables like lowest, highest and average price in that year.

The crossings were determined as follows. Each price was compared with the previous price and if any whole number was between them that number was counted as 'crossed'. In most cases this is obvious, for example, present price is 25.1 and previous price is 23.4, crossings are at 4 and 5 (the whole numbers 24 and 25 are crossed). The situation in which a whole number is reached but not passed through, that whole number is not (yet) counted as being crossed. However, if the following price change is in the same direction, a crossing is counted at that day. For example: the present price is 33 and the previous price is 32.4 . No crossing is recorded because 33 is not yet crossed. If the following price is higher than 33, a crossing at 3 will be recorded (at that point). The program remembers the last price-change: in a price sequence of 26.6, 27, 27, 27, 27.2 a 7-crossing is counted at the last instance. A price-change of more than 10 is counted as one (but not more than one) crossing for all digits (a change from 74.2 to 87.3 counts one crossing for all 10 digits but not a double counted crossing for the 5 and 6).

Note that no effort was made to correct for stock splits or stocks going ex-dividend. The first day after a stock split *all* whole numbers are crossed (in the likely case of the original price of the stock being larger than 20) which would not influence the statistics. There is no reason to expect that stocks go ex-dividend would lead to prices to cross more or less often at specific numbers.

5. Results

First we will look at price clustering (section 5.1) and resistance points (section 5.2) in the guilder years (1990-1998). Section 5.3 studies price clustering during the euro-years (1999-2001), measured in euros (the currency of the stock market) and converted to guilders (the currency of everyday life during these years). Section 5.4 examines round number resistance points at both currencies. A closer look is taken at the months around the introduction of the euro in the stock market (January 1999) in section 5.5.

5.1 Clustering in the guilders years 1990-1998

Figure 1 shows the price clustering in the guilders years. First notice that the data exhibits price clustering on the small scale comparable with the findings on USA, Australian and Singapore markets (e.g. Harris 1991, Aitken et al 1996, Hameed and Terry 1998): whole numbers are more common than half numbers and half numbers are more common than other fractions. On the larger scale we find that 6.5% of all prices are multiples of exactly 10 guilders, while a uniform distribution of prices would predict 1%! The next highest peak is at 5 (15, 25, etc) guilders.

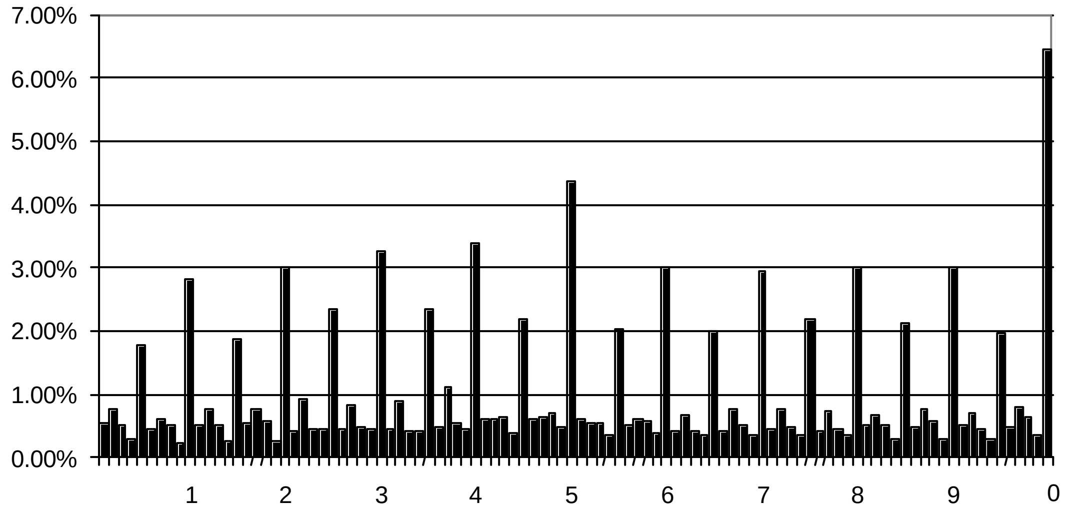

Figure 1: On the horizontal axis are the last two digits (last number before decimal point and the number after decimal point) of prices of stocks in 1990-1998 in guilders. On the vertical axis is the occurrence in percentage of all prices. The minimal tick size was 10-cents in the guilders years.

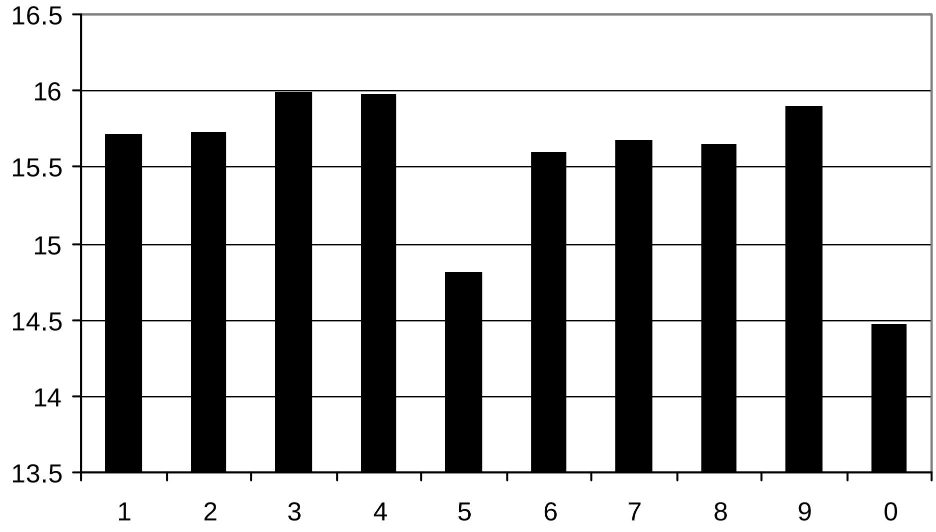

Figure 2: The average number of times a stock passed through a whole number 1, 2, etc, per year, in Dutch guilders, in the years 1990-1998.

5.2 Round number resistance points in the guilder years

Figure 2 displays the average number of times a stock passed through a whole number 1, 2, etc, per year, in Dutch guilders, in the years 1990-1998. We find fewer crossings at 0 and 5 than crossings at other whole numbers. This result is very robust and persistent over the years, as table 1 shows. Comparing the crossings of a round 0 price with crossings of the eight non-round numbers (1, 2, 3, 4, 6, 7, 8, 9) in each of the 9 guilder-years of the data set counts up to 72 comparisons, all of them in the expected direction! However, some of these differences are small and not statistically significant (49 out of 72 are significant, 2-sided Wilcoxon test). Repeating this analysis for the crossings of 5-prices, we find 70 out of 72 comparisons in the expected directions, of which 44 are statistically significant (2-sided Wilcoxon test).

Table 2 displays the effect for different stock sizes. In the category of cheapest stocks the effect is (unsurprisingly) strong: very cheap stocks cannot cross the zero-boundary because prices are positive, and the nearest 0-crossing at 10 is often too high. Fortunately there are only very few stocks in this category (1.5%). In all price categories except one (mean price between 75 and 85) we find less 0-crossings than not-round-number crossings. Fewer 5-crossings than not-round-number crossings are found in all but two categories (mean price in interval 0-5 and 85-95). However, the effect seems to be bigger for the expensive stocks. This is in line with the literature on price clustering mentioned in section 2.

We conclude that during the guilder years round numbers behaved like a resistance points: prices with round numbers (10, 20, 30, etc) are less often crossed as other whole numbers. To a slightly lesser extend this also holds for round numbers ending on 5.

	Average number of crossings (Dutch guilders)										
Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*0*	*N*
1990	**15.26**	**15.16**	**15.40**	**15.19**	13.92	**14.75**	**14.85**	**14.93**	**15.08**	13.45	226
1991	**12.98**	**13.15**	**13.38**	**12.88**	11.65	12.57	12.38	**12.88**	**12.86**	11.73	207
1992	**11.74**	**11.78**	**12.17**	**12.35**	**11.42**	**12.01**	**11.76**	**11.14**	**11.37**	10.30	192
1993	12.64	12.83	12.70	12.86	11.64	12.25	12.41	**12.92**	**13.12**	11.82	189
1994	12.32	12.74	**13.68**	**13.51**	12.24	**13.54**	**13.66**	**13.14**	**13.32**	11.79	180
1995	**10.93**	**11.14**	**11.35**	**11.33**	10.56	11.15	**11.85**	**11.54**	**11.55**	10.03	183
1996	**16.86**	16.60	16.42	16.57	15.12	16.04	16.03	16.37	16.89	15.34	187
1997	**22.27**	**22.17**	22.20	21.92	21.14	22.10	22.30	22.17	**23.35**	21.22	199
1998	**24.73**	**24.42**	**25.02**	**25.57**	24.02	**24.52**	**24.39**	**24.26**	**24.07**	23.05	219

Table 1: Bold printed numbers differ statistically significant from the average number of 0-crossings (Wilcoxon tests, two sided on 5%), underlined numbers differ from 5-crossings.

Mean Price	*Average number of not-round-number crossings (1,2,3,4,6,7,8,9)*	*Average number of crossings 5*	*Average number of crossings 0*	*Number of observations*
0-5	1.14	2.50	0.08	26
5-15	2.70	2.34	2.48	99
15-25	4.72	4.34	4.56	140
25-35	6.40	6.17	6.24	164
35-45	8.12	7.92	7.93	175
45-55	9.39	9.13	8.84	190
55-65	11.66	10.98	11.09	124
65-75	13.52	13.15	13.27	108
75-85	13.19	12.61	13.29	110
85-95	16.34	16.53	14.96	85
95-105	19.41	17.82	18.19	67
105-115	20.83	19.52	18.86	50
115-125	20.93	19.88	20.06	48
125-135	21.94	20.50	21.42	36
135-145	25.97	24.24	23.95	42
145-155	24.09	22.91	20.78	23
155-165	28.43	25.68	25.21	19
165-175	22.29	18.82	20.29	17
175-185	28.04	25.33	23.67	9
185-195	36.55	34.64	33.59	22
195-205	33.32	32.76	31.14	21
=205	42.02	38.06	35.99	207
Total	15.78	14.80	14.47	1782

Table 2: Average number of integer guilder crossings differentiated by the mean price of the stock in that year. Years 1990-1998.

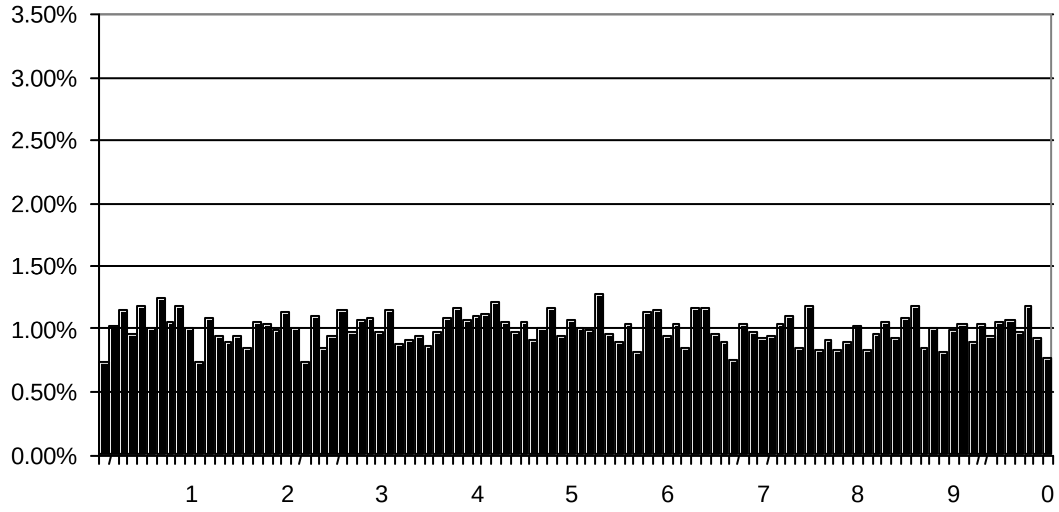

Figure 3: On the horizontal axis are the last two digits (last number before decimal point and the number after decimal point) of prices of stocks in 1999-2001 converted from euros to guilders. On the vertical axis is the occurrence in percentage of all prices.

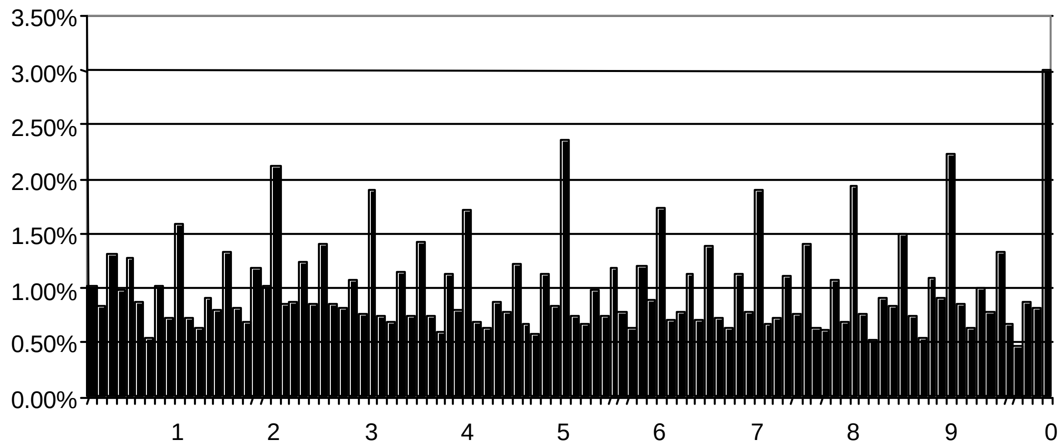

Figure 4: On the horizontal axis are the last two digits (last number before decimal point and the number after decimal point) of prices of stocks in 1999-2001 in euros. On the vertical axis is the occurrence in percentage of all prices.

5.3 Price clustering in the euro years 1999-2001

In the years 1999-2001 the euro was the currency on the stock markets while the guilder was still the currency for everyday life. Figure 3 shows the distribution of stock prices, converted from euros to guilders (rounded to 10 guilder cents). The distribution looks uniform, in sharp contrast to figure 1. Figure 4 displays the distribution in the original euro prices. The tick size is 1 eurocent, but for display reasons the prices are rounded to 10 cents. The highest peaks are at 0 and 5 euro prices. Table 3 shows that the smaller tick size (one eurocent is only 22% of 10 guilder cents) is really used. However, the distribution is far from uniform. Prices in whole euros are much too common, and round numbers are much more common than non-round numbers. We can conclude that clustering is at round euro prices, but not at the converted round guilder prices.

Prices ending on:			*Expected*	*Found*	*Factor*
*.*1, *.*2, *.*3, *.*4, *.*6, *.*7, *.*8, *.*9,			80%	36.88%	0.46
*.*5			10%	18.70%	1.87
*.*0			10%	44.41%	4.44
Of which:	*.10,*.20,*.30,*.40,*.60,*.70,*.80,*.90		8%	18.45%	2.31
	*.50 (0.50, 1.50, 2.50 etc)		1%	9.88%	9.88
	*.00 (whole euros)		1%	16.08%	16.1
	Of which:	*1, *2, *3,*4,*6,*7,*8,*9	0.8%	11.56%	14.5
		*5 euro (5, 15, 25 etc)	0.1%	1.97%	19.7
		*0 euro (10, 20, etc)	0.1%	2.55%	25.5

Table 3: Price clustering in 1999-2001 (euro). Tick size is 1 cent. In the first column * is used as a wildcard (any digit). The second column shows the percentages if prices would be distributed uniformly. The third column shows the percentages found in the data. The last column divides the found percentages (column 3) by the expected (column 2).

5.4 Round number resistance points in the euro years

To study the existence of resistance points in the euro years we look again at the crossings of whole numbers. The top panel of table 4 shows the average numbers of crossings with the (euro) prices converted to guilders. No clear round number effect can be observed: of the 24 comparisons only 15 in the case of 0-crossings and 8 in the case of 5-crossings are in the direction that round numbers all less often crossed. In none of these cases the difference was significant. However, at first sight there may be still an (small) effect for the 0-crossings in 1999 (7 out of 8 comparison in the expected direction). We will have a closer look at the transition period in section 6.

The lower panel of table 4 shows the crossings in whole euros. Comparing the crossings of a round 0 price with crossings of the eight non-round numbers (1, 2, 3, 4, 6, 7, 8, 9) in each of the 3 euro-years of the data set counts up to 24 comparisons, 22 of them in the expected direction! However, only 14 differences are statistically significant (2-sided Wilcoxon test). Repeating this analyses for the crossings of 5-

prices, we find 21 out of 24 comparisons in the expected directions, but none statistically significant (2-sided Wilcoxon test)[6].

We conclude that during the euro years (1999-2001), with the original prices *converted to guilders,* the round number disappeared. In the original euro prices, we observe price barriers at multiples of 10 euros and at a lesser extend at 5-prices.

	*Average number of crossings (**guilders**)*										
Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*0*	*N*
1999	19.18	19.10	19.29	19.93	19.88	19.71	19.98	19.46	19.17	19.15	234
2000	23.65	23.25	23.33	24.02	23.93	23.99	23.35	23.96	24.11	23.93	214
2001	15.83	15.62	15.77	16.03	16.05	15.61	14.65	15.11	16.09	15.79	183
	*Average number of crossings (**euros**)*										
Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*0*	*N*
1999	**8.27**	**8.42**	8.25	8.26	7.97	**8.55**	**8.56**	**8.46**	**8.06**	7.45	234
2000	**9.67**	**10.30**	**10.34**	9.73	9.57	**10.04**	**10.12**	**10.00**	**9.74**	8.92	214
2001	**6.19**	6.03	6.24	6.31	5.80	5.66	5.76	5.13	6.16	5.67	183

Table 4 Bold printed numbers differ statistically significant from the average number of 0-crossings (Wilcoxon tests, two sided on 5%), underlined numbers differ from 5-crossings.

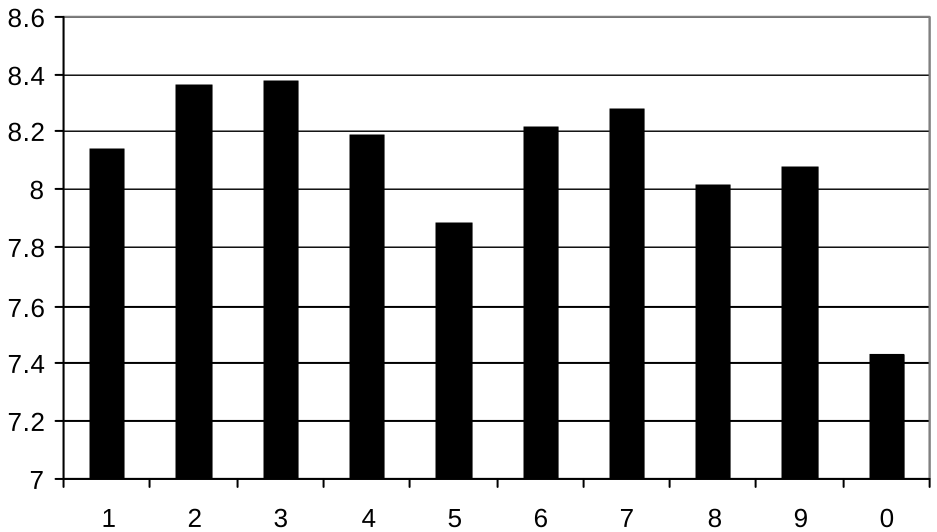

Figure 5: The average number of times a stock passed through a whole number 1, 2, etc, per year, in euros, in the years 1999-2001.

5.5 The transition period from guilders to euro

Section 5.3 and 5.4 showed the existence of round number effects in guilders before 1999 and in euros after 1999. No round numbers effects were found in guilders during the years 1999-2001. This section takes a closer look at the transition period: how fast

[6] Note that because a euro is 2.20 guilders worth, fewer crossings are observed overall. This causes a lower power of the statistical test.

did the round number effects in guilders vanish after the introduction data January 1, 1999?

Figure 6 shows the price clustering during the transition period. Clustering in round guilder prices seems to disappear overnight and price clustering in round euro prices arises immediately (although less strong in January than in later months).

Figure 7 displays the round number price barriers. In each month the number of 0-crossings is divided by the number of all round number crossings. The change in January 1999 is very clear, although less drastic than the price clustering in figure 6. At first sight the figure suggests that round number resistance at round euro prices already starts in November and December 1998, but this is very unlikely because the exchange rate was only fixed at the end of December 1998; it has to be chance.

The very fast change of round number effects in guilders to round number effects in euros discredits the aspiration level hypothesis and is in line with the odd pricing hypothesis.

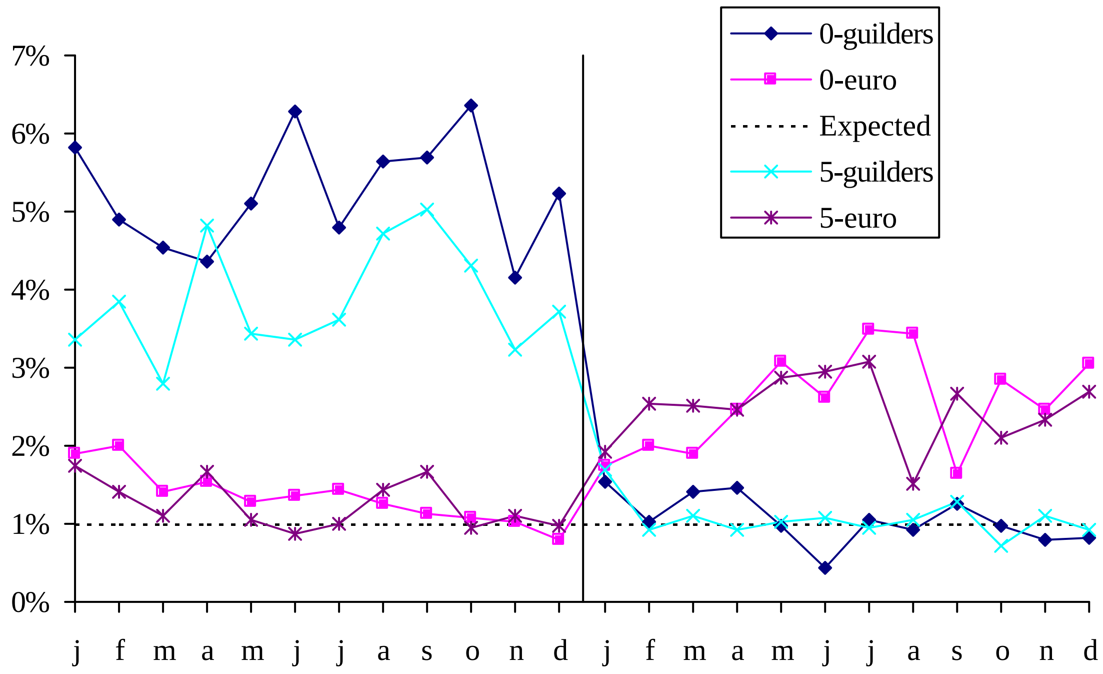

Figure 6: Price-clustering in 1998-1999, percentage of prices at round numbers multiples of 10 or 5. The 1999 euro-prices are rounded on the nearest 10 guilder-cents (that is the minimal tick size before 1999).

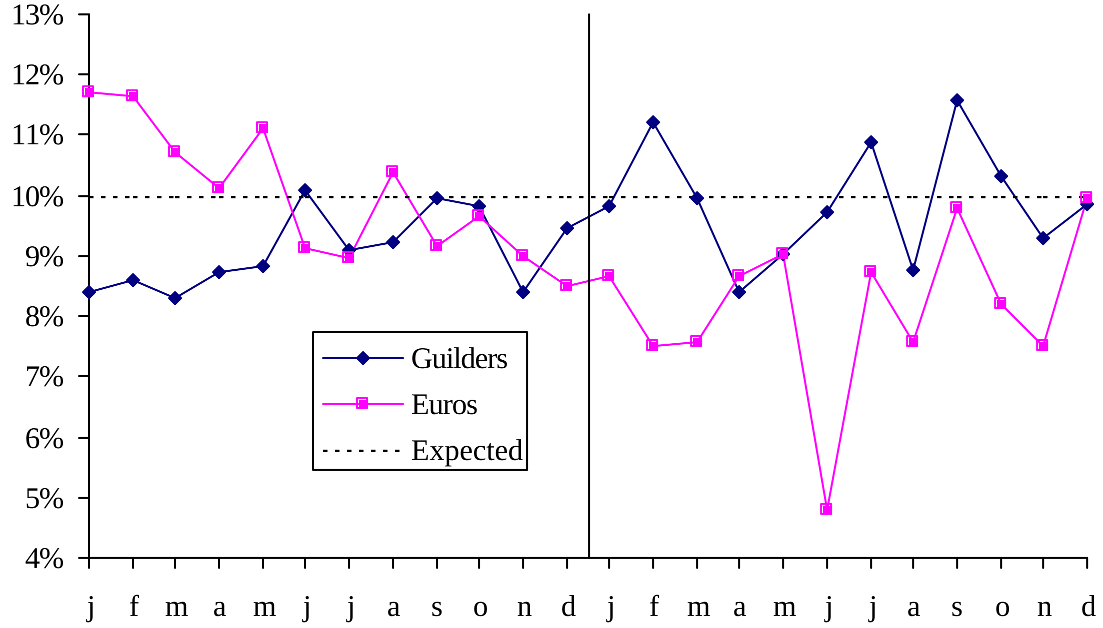

Figure 7 Round number resistance points in the year before (1998) and after (1999) the introduction of the euro in the stock market. The percentages on the vertical axis are the number of 0-crossings divided by the number of all round number crossings.

6 Discussion

Previous studies about price clustering focus on fractions versus whole numbers. Niederhoffer (1966) and Harris (1991) show that price clustering also exist on the level of round numbers (multiples of 5). This finding is replicated for the Dutch stock market during 1990-1998 (prices in guilders) and 1999-2001 (prices in euros).

There is no previous literature about price barriers at round numbers for individual stocks, only for stock indices. However, the nature of these barriers seems to be different, because the individual stock clusters on the round number barriers while stock indices have less often values at the round numbers barriers. The most common explanation of prices barriers in stock indices is the publicity around the passing of a round number coordinates the optimism (or pessimism) of the investors and is self confirming. Individual stocks receive less publicity. Relatively many limit prices in round numbers can cause both the clustering of prices and the barriers at these numbers (if many investors are willing to sell at 40 euro, the many limit orders at that price will cause a barrier). Unfortunately, the order book history is not available to examine this[7].

[7] Interestingly, a recent paper by Cooney, van Ness and van Ness (2003) uses New York Stock

Several hypotheses regarding round number effects were discussed in section 3. One of them is the aspiration level hypothesis from the bounded rationality literature. When buying a stock investors have already a target price for which they hope to sell the stock in the future. Also analysts often provide target prices, often round numbers. This would lead to relatively many sell limit orders at round numbers, causing both the clustering and the barriers. The odd price hypothesis is from the marketing literature. Prices just below a round number (e.g. 19.99) are by many consumers considered to be significant lower than the round number (e.g. 20). If decision-making is costly this tendency to compare numbers from left to right can be efficient because the first digit contain more valuable information.

The implementation of the euro in the stock markets, 3 years before the euro was introduced in daily life constitutes a unique opportunity. In this natural experiment we can confront the aspiration level hypothesis with the odd price hypothesis. An investor who bought a stock before 1999 will have a target price in guilders. There is no reason to change this target price to a round number in euros, because when the stock is sold guilders will be received (and consumed), during the years 1999-2001. According to the aspiration level hypothesis round number effects in guilders should therefore continue into the euro years until the fraction of stocks purchased before 1999 diminishes. In contrast, the odd price hypothesis predicts that round number effects in guilders will vanish immediately after January 1, 1999 because all transactions will be in euros, and effects in euros will also arise immediately.

The results show that the change after January 1, 1999 is drastic. This is evidence against the aspiration level hypothesis[8], and in favor of the odd price hypothesis[9]. Apparently, not only for a consumer 19.90 looks much less than 20.00, it also looks that way for an investor.

Exchange limit orders in 1990-1991 to study small scale price clustering. They find more even-eight than odd-eight limit prices.

[8] That is, our target-price interpretation of the aspiration level hypothesis is refuted. In other institutions behavior of many decision makers can be characterized as 'satisfyzing', see for example Sonnemans (1998).

[9] Of course, it is also in line with the coordination, convenience, and preference hypotheses introduced in section 3. But these hypothesis are unlikely on other grounds (e.g. the clustering is not that strong that there is coordination), see section 3.

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