Performance Persistence of Spanish Pension Funds: The Best Winners and Losers Usually Repeat

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In this paper, we analyse the persistence phenomenon on the returns obtained by Spanish equity pension funds in the period 1999–2006, an unexplored topic in the Spanish financial market, one of the most emerging pension fund industries in the European Union. We provide evidence for a short-run persistence in some of the yearly periods analysed by using a contingency table approach. In this sense, we firstly apply 2×2 contingency tables to observe whether the best or worst managed funds repeat in this situation in consecutive years and to check the existence of this phenomenon for the whole investment period analysed. Then, the study improves the methodological approach by using 4×4 contingency tables, a research that leads us to interesting results confirming the findings obtained with the previous analysis and determining the pension funds that cause the persistence. On the other hand, this paper also examines the existence of long-run performance persistence obtaining worse results in general. More specifically, a minority of funds show a constant winning (losing) behaviour, presenting important (deficient) management skills.

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Introduction

In recent years, there have been many studies on performance persistence. This is an interesting topic for both professionals and academic researchers since past performance of a portfolio should be a very important information for a rational individual when it comes to making investment decisions. From the academic perspective, its interest is focussed on the implications on the efficient market hypothesis.

We can find much academic research on this phenomenon from the seminal papers of Sharpe¹ and Carlson² to the current works of Capocci and Hübner,³ Harri and Brorsen⁴ and Kosowski *et al.*,⁵ among others. In this sense, the different portfolios and time periods analysed and the existence of survivorship bias in some studies have caused assorted conclusions.

¹ Sharpe (1966).

² Carlson (1970).

³ Capocci and Hübner (2004).

⁴ Harri and Brorsen (2004).

⁵ Kosowski *et al.* (2006).

Survivorship bias is usually found in the early studies, but this bias is firstly discarded by Grinblatt and Titman⁶ and Ippolito.⁷ The incidence of this bias on determining the persistence phenomenon has been asserted by Brown *et al.*,⁸ Grinblatt and Titman⁹ and Hallahan and Faff.¹⁰

Hendricks *et al.*¹¹ and Brown and Goetzmann¹² are examples of studies that document a short-run positive correlation between abnormal returns in successive years. In these studies, the persistence phenomenon is attributed to funds sustaining poor performance. However, Grinblatt and Titman¹³ and Elton *et al.*¹⁴ provide evidence of long-term performance persistence due to the different information that management companies have and the different stock-picking abilities.

In this sense, Carhart¹⁵ argues that the short-term persistence is mostly driven by management expenses and a momentum effect discovered by Jegadeesh and Titman.¹⁶ Thus, fund managers do not really have special skills; rather they picked stocks that subsequently performed well whereas Kosowski *et al.*¹⁷ state that the performance of the best and worst funds is not solely due to luck, finding a sizable minority of managers who possess special and superior skills.

On the other hand, related with persistence literature, there are studies providing evidence for a positive relationship between performance and investment flows such as Patel *et al.*¹⁸ and Capon *et al.*¹⁹ whereas other researchers like Sirri and Tuffano²⁰ find that, although funds that perform well in a given period attract the largest investment inflows, funds that perform poorly are not penalised by proportionate equity fund outflows, indicating an asymmetric structure in the relationship between performance and fund flows and thus the existence of behavioural biases.

In general, performance persistence studies in the financial literature have focussed on investment funds, so this paper supposes an original work due to the application of this topic to Spanish Equity Pension Funds.

Related to pension funds, we can find some international relevant papers analysing performance. Ippolito and Turner²¹ and Lakonishok *et al.*²² study the U.S. market analysing over 1,500 and 700 U.S. pension funds, respectively.

⁶ Grinblatt and Titman (1989).

⁷ Ippolito (1989).

⁸ Brown *et al.* (1992).

⁹ Grinblatt and Titman (1992).

¹⁰ Hallahan and Faff (2001).

¹¹ Hendricks *et al.* (1993).

¹² Brown and Goetzmann (1995).

¹³ Grinblatt and Titman (1992).

¹⁴ Elton *et al.* (1996).

¹⁵ Carhart (1997).

¹⁶ Jegadeesh and Titman (1993).

¹⁷ Kosowski *et al.* (2006).

¹⁸ Patel *et al.* (1991).

¹⁹ Capon *et al.* (1996).

²⁰ Sirri and Tufano (1998).

²¹ Ippolito and Turner (1987).

²² Lakonishok *et al.* (1992).

Figure 1. Number of investors and total assets managed by Spanish pension funds. *Total asset figures are expressed in thousand euros.

Other references on the U.K. market are Blake *et al.*²³ and Brown *et al.*²⁴ They analyse U.K. pension funds with the same single fund manager over the entire time horizon, a specification of the database that may induce some bias. Another work on the U.K. market by Thomas and Tonks²⁵ considers over 2,000 segregated pension funds from 1983 to 1997, without finding significant evidence of abnormal performance. Finally, Tonks²⁶ provides an exhaustive review on U.K. persistence research.

Nevertheless, there is still a significant lack of empirical conclusions on the performance persistence phenomenon in European pension fund industries when compared to the amount of research conducted in the U.K. and U.S. markets. In fact, no study has been carried out about performance persistence in the Spanish pension fund market.

Pension funds in Anglo-Saxon and certain European countries such as U.K., Ireland and The Netherlands have undergone a major growth, reaching a high level of maturity and representing above 45 per cent of the family saving. In contrast, the Spanish pension fund market is an emerging industry in the European Union that has been experiencing a rapid growth in recent years as can be seen in Figure 1.

The first Spanish pension plans appeared in 1988. In these early years, the assets managed by these financial instruments and the number of investors were scarce

²³ Blake *et al.* (1999).

²⁴ Brown *et al.* (1997).

²⁵ Thomas and Tonks (2001).

²⁶ Tonks (2005).

because of the novelty of the product and the broad cover provided by the Spanish Public Security System. However, this situation started to change at the end of the 20th century mainly due to the improvement in the taxation and flexibility of these financial instruments.

More recently, the doubts existing about the sustainability of the Spanish Public Security System because of the gradual ageing process, and the greater social awareness of the need to provide contingency cover for retirement, disability and widowhood among others, and to supplement public pensions in order to hold the same purchasing power, have led to a higher interest and development of the Spanish private pension funds.

It is also important to bear in mind the favourable taxation²⁷ applied on individuals investing in pension funds to explain the outstanding increase in the Spanish pension fund industry for the last years.

A total of 73,546 million euros were managed by more than 1,200 Spanish pension funds in 2005, representing more than 2 per cent of the assets of the European Union pension fund industry. More than nine million investors put their money in these portfolios, with an annual growth of over 13.8 per cent in 2005, providing evidence of the growing impact of these instruments in the Spanish society.

The preferences of the Spanish family's savings have changed over the last two decades. In 1985, pension funds represented only 0.3 per cent of all family savings whereas they represent 5.5 per cent in 2005, showing evidence of the importance of these financial instruments to promote stable and long-term savings. On the other hand, pension funds are ranked in the third position by importance after security deposits and investment funds.

The total investment in pension funds and insurance stood at 215,700 million euros in 2005, representing 26 per cent of Spanish Gross Domestic Product (GDP). This percentage is a long way from British, French and Dutch indexes but is similar to those in Finland, Norway and Austrian.

These figures show that it is worth to analyse an emerging pension fund market like the Spanish. Specifically, our objective is to provide new empirical evidence on the performance persistence phenomenon obtained by Spanish pension funds – therefore, an innovative and original study in Spain.

The paper shows a global trend towards short-term persistence by using non-parametric methodology in yearly periods. Moreover, one of the main results is the evidence of this phenomenon in the entire period analysed, 1999–2006.

On the other hand, little support of performance persistence is detected in the middle term (2–3 years). However, certain Spanish pension funds present persistence during longer periods, providing evidence for their superior (inferior) skills.

The paper is organised as follows. The following section gives details of the data used in the study. The next section describes the methodology applied to detect the persistence phenomenon. The penultimate section presents the empirical results obtained. Finally, the most relevant results and conclusions of the study are shown.

²⁷ Tax breaks are granted to individuals who invest in these financial instruments.

Working data

The study includes the monthly returns obtained by all Spanish Equity Personal Pension Funds registered in *Dirección General de Seguros y Fondos de Pensiones* (DGSFP) from January 1999 to December 2006. Thus, our database gathers the time period where the growth of the industry has been developed.

Personal funds are the most important category in the pension fund industry²⁸ representing approximately 60 per cent of the money managed by the Spanish industry and over 82 per cent of investors.

Data were provided by *INVERCO* (*Asociación de Instituciones de Inversión Colectiva y Fondos de Pensiones*) and following its official criteria, Spanish equity pension funds must invest over 75 per cent of their portfolios in stocks.

The inclusion of all equity pension funds guarantees the robustness of the empirical conclusions of the study because they are free of the effects of survivorship bias on determining persistence.

Methodology

Non-parametric methods are applied in order to test the persistence phenomenon on the annual performance obtained by Spanish pension funds from 1999 to 2006. A first methodology by using 2×2 contingency tables and a further approach with generalised 4×4 tables will be used in order to check performance persistence in the shortterm.

Moreover, we analyse the long-term performance persistence by examining the winner (losers) funds that remain being winners (losers) for the rest of the time horizon. Thus, this study gathers the two different temporal perspectives: the short term and the long term.

Performance persistence in the short term

2 × 2 Contingency tables

The contingency tables approach compares performance rankings in two consecutive investment periods in order to define different subsets of pension funds. In particular, applying 2×2 contingency tables, we divide the portfolios in two categories in each period, the best managed pension funds as “winners” (*W*) and the worst managed pension funds as “losers” (*L*) according to the median performance of each period.

The number of funds that are winners (or losers) in two consecutive periods are denoted by *WW* (*LL*), whereas *WL* (*LW*) represents the number of funds that were *winners* (or *losers*) in the first period, then *losers* (or *winners*) in the consecutive performance ranking.

These rankings are complemented with different tests²⁹ shown in Appendix 1 to check the statistical significance of the persistence phenomenon in our sample of Spanish pension funds.

²⁸ Depending on the constituents, the Spanish pension fund industry distinguishes between occupational and associated pension funds, which are promoted by companies or civil associations, respectively, and personal pension plans promoted by financial institutions.

²⁹ Some of these tests have been already applied in financial literature but as far as we know there is no study about performance persistence using Cochran’s method (1954). This method combines the set of 2×2 contingency tables to test the persistence phenomenon for the whole investment horizon.

Table 1 Contingency tables 2×2 and performance persistence tests

	<i>WW</i>	<i>WL</i>	<i>LW</i>	<i>LL</i>	<i>Malkiel Z-test</i>	<i>B&G Z-test</i>	<i>K&R χ^2-test</i>	<i>Cochran Y-test</i>
1999–2000	7	7	7	7	0.000	0.000	0.000	
2000–2001	12	16	16	12	−0.756	−1.0654	1.143	
2001–2002	30	15	15	30	2.236 ^a	3.100 ^b	10.000 ^b	
2002–2003	34	26	26	35	1.033	1.540	2.405	4.963 ^b
2003–2004	49	21	20	50	3.347 ^b	4.747 ^b	24.057 ^b	
2004–2005	37	32	32	37	0.602	0.851	0.725	
2005–2006	46	31	31	47	1.709	2.473 ^a	6.213 ^a	

^aPersistence statistically significant at 5 per cent.

^bPersistence statistically significant at 1 per cent.

The first column of the table shows the consecutive annual periods analysed. The next section of the table represents the 2×2 contingency tables obtained. Finally, the last two sections gathers the results of the three statistical tests already applied in financial literature to check persistence in consecutive periods whereas the last section shows the value of Cochran's test to provide evidence for this phenomenon in the whole time period.

4 × 4 Contingency tables

A more exhaustive study of the short-term performance persistence is carried out considering 4×4 contingency tables. Thus, performance rankings are compared over two consecutive investment periods establishing in this case four categories for each ranking by using quartiles.

Following this approach, we also apply several non-parametric tests on these 4×4 contingency tables that can be seen in Appendix 2.

Performance persistence in the long term

This analysis has been carried out examining the percentage of winner (loser) funds that repeat as winners (losers) in later years. Thus, we define in each year t of study the number of winner (loser)³⁰ funds according to the median criterion and then calculate the percentage of winner (loser) funds that persist in $t + 1$, subsequently determining the remaining *WW* (*LL*) funds that stay being winners (losers) in $t + 2$ and so on.

Empirical results

Performance persistence in the short term

2 × 2 Contingency tables

Table 1 provides evidence of significant 1-year performance persistence for 2001–2002, 2003–2004 and 2005–2006. On the other hand, in many comparisons, the number of repeating funds (*WW* or *LL*) is higher than the number of changing funds (*WL* or *LW*) but statistical significance is not achieved.

Thus, in order to clarify these findings and to determine whether it can be stated that Spanish pension funds present short-term performance persistence, Cochran's test

³⁰ Thus, a winner (loser) pension fund is defined as in the 2×2 contingency table analysis as any pension fund that obtains an annual return above (below) the median return of the ranking.

is applied. The result provided by this test highlights the evidence of 1-year performance persistence for the whole time period 1999–2006, as shown in the last column of Table 1 with a very high significance level.

Table 2 Contingency tables 4×4 and performance persistence tests

<i>2001–2002</i>	<i>Q1</i>	<i>Q2</i>	<i>Q3</i>	<i>Q4</i>	χ^2
Q1	15 (5,054) ^a	6 (0,212)	2 (–2,037) ^b	0 (–3,257) ^a	22,394 ^a
Q2	4 (–0,912)	5 (–0,216)	6 (0,355)	7 (0,775)	0,904
Q3	3 (–1,475)	9 (2,067) ^b	3 (–1,357)	7 (0,775)	5,052
Q4	1 (–2,703) ^b	2 (–2,037) ^b	11 (3,024) ^a	9 (1,730)	13,184 ^a 41,534 ^a
<i>2002–2003</i>	<i>Q1</i>	<i>Q2</i>	<i>Q3</i>	<i>Q4</i>	χ^2
Q1	13 (2,712) ^a	7 (–0,214)	4 (–1,676)	6 (–0,813)	6,144
Q2	10 (1,249)	4 (–1,676)	11 (1,737)	5 (–1,295)	5,116
Q3	1 (–3,139) ^a	9 (0,762)	8 (0,274)	12 (2,081) ^b	8,364 ^b
Q4	6 (–0,813)	10 (1,116)	7 (–0,331)	8 (0,028)	1,128 20,752 ^b
<i>2003–2004</i>	<i>Q1</i>	<i>Q2</i>	<i>Q3</i>	<i>Q4</i>	χ^2
Q1	20 (5,071) ^a	6 (–1,240)	3 (–2,592) ^a	6 (–1,240)	19,971 ^a
Q2	8 (–0,338)	16 (3,268) ^a	10 (0,563)	1 (–3,493) ^a	13,114 ^a
Q3	5 (–1,690)	5 (–1,690)	16 (3,268) ^a	9 (0,113)	9,228 ^b
Q4	2 (–3,043) ^a	8 (–0,338)	6 (–1,240)	19 (4,620) ^a	18,142 ^a 60,457 ^a
<i>2004–2005</i>	<i>Q1</i>	<i>Q2</i>	<i>Q3</i>	<i>Q4</i>	χ^2
Q1	7 (–0,844)	8 (–0,283)	12 (1,533)	8 (–0,394)	1,851
Q2	9 (0,171)	13 (2,120) ^b	8 (–0,173)	4 (–2,099) ^b	5,064
Q3	9 (0,171)	8 (–0,173)	8 (–0,173)	9 (0,171)	0,067
Q4	10 (0,505)	5 (–1,645)	6 (–1,191)	14 (2,304) ^b	5,419 12,401
<i>2005–2006</i>	<i>Q1</i>	<i>Q2</i>	<i>Q3</i>	<i>Q4</i>	χ^2
Q1	9 (–0,347)	9 (–0,242)	8 (–0,773)	13 (1,359)	1,470
Q2	11 (0,619)	17 (3,335) ^a	6 (–1,532)	4 (–2,393) ^b	11,115 ^b
Q3	13 (1,359)	8 (–0,672)	14 (1,786)	4 (–2,480) ^b	6,520
Q4	6 (–1,626)	4 (–2,393) ^b	11 (0,506)	18 (3,492) ^a	11,691 ^a 30,796 ^a

^aPersistence statistically significant at 1 per cent.

^bPersistence statistically significant at 5 per cent.

The first column of this table indicates the consecutive annual periods analysed and the different quartiles (*Q1*, ..., *Q4*). Columns 2–5 contain the 4×4 contingency tables obtained when comparing the performance rankings. Each cell also contains the results of the analysis of residuals, shown in brackets. These figures identify the categories responsible for a significant Chi-square value; this statistic is presented in the last column of the table.

The analysis of 4×4 contingency tables has not been applied in the first years of the time horizon because of the little number of pension funds in existence. Everitt (1992) mentions the problem arising when expected frequencies are lower than 5, the fact that occurred in the first years of our database.

4 × 4 Contingency tables

As we have mentioned previously, 4 × 4 tables are worked out to obtain more exhaustive results about the short-term persistence phenomenon. Thus, pension funds are classified in quartiles (*Q1*, *Q2*, *Q3* or *Q4*) in each annual performance ranking.

Table 2 shows a significant value for the Chi-square test in all the annual periods analysed except for 2004–2005. This fact reinforces the existence of short-term persistence in the Spanish equity pension funds. Thus, the next step is to identify the quartiles responsible for these results by examining the adjusted residuals.

This analysis yields some appealing results. In the majority of the comparisons carried out, both first and fourth quartiles present statistical significance, indicating that the best and worst managed plans persist over consecutive periods.

On the other hand, it is also worth highlighting the result obtained in 2003–2004, where the main diagonal presents positive and significant values, which means that it is highly probable that a pension fund remains in the same category. Moreover, negative and significant values are found when two extremely different categories are compared, indicating that it is unlikely that a pension fund changes to a very different category. Hence, all the analyses conducted point to the existence of performance persistence in the short term.

Performance persistence in the long term

In general, the analysis of long-term performance persistence yields worse results than short-term analysis. In this sense, Table 3 displays that the percentages of winner

Table 3 Long-term performance persistence

<i>Panel A</i>	<i>t + 1 (%)</i>	<i>t + 2 (%)</i>	<i>t + 3 (%)</i>	<i>t + 4 (%)</i>	<i>t + 5 (%)</i>	<i>t + 6 (%)</i>	<i>t + 7 (%)</i>
1999	(7) 50.0	(4) 57.1	(1) 25.0	(1) 100.0	(1) 100.0	(1) 100.0	(1) 100.0
2000	(12) 42.9	(8) 66.7	(4) 50.0	(3) 75.0	(2) 66.67	(2) 100.0	—
2001	(30) 66.7	(11) 36.7	(6) 54.5	(2) 33.3	(2) 100.0	—	—
2002	(34) 56.7	(24) 70.6	(7) 29.2	(7) 100.0	—	—	—
2003	(49) 70.0	(24) 49.0	(22) 91.7	—	—	—	—
2004	(37) 53.9	(28) 75.7	—	—	—	—	—
2005	(46) 59.7	—	—	—	—	—	—
<i>Panel B</i>	<i>t + 1 (%)</i>	<i>t + 2 (%)</i>	<i>t + 3 (%)</i>	<i>t + 4 (%)</i>	<i>t + 5 (%)</i>	<i>t + 6 (%)</i>	<i>t + 7 (%)</i>
1999	(7) 50.0	(3) 42.9	(2) 66.7	(1) 50.0	(0) 0.0	^a	^a
2000	(12) 42.9	(9) 75.0	(3) 33.3	(2) 66.7	(1) 50.0	(1) 100	—
2001	(30) 66.7	(10) 33.3	(6) 60.0	(2) 33.3	(2) 100.0	—	—
2002	(35) 57.4	(21) 60.0	(10) 47.6	(9) 90.0	—	—	—
2003	(50) 71.4	(25) 50.0	(19) 76.0	—	—	—	—
2004	(37) 53.6	(27) 73.0	—	—	—	—	—
2005	(47) 60.3	—	—	—	—	—	—

^aThese figures cannot be determined because no pension funds are losers for such a long period.

This table contains two panels, A and B, showing the persistent winners and losers, respectively. The first column of the table indicates the annual periods analysed whereas the following columns gather the percentage of winning or losing pension funds that repeat as winner or loser in the next years of the time horizon (*t + 1*, *t + 2*, ...). Additionally, each cell also contains in brackets the number of persistent winner or loser pension funds in each time period.

(loser) funds that repeat in these categories in the subsequent 2 or 3 years are approximately 50 per cent, indicating a certain independence of the results and therefore a lack of performance persistence, except in 2003 and 2004, where the percentages are more relevant.

The results also show meaningful values when we extend the persistence analysis to more than 3 years although it is quite clear that the number of pension funds repeating as winners (losers) for longer periods (4, 5, 6 or 7 years) is very scarce. Thus, it can be concluded that a little number of Spanish pension funds show superior skills whereas certain pension funds present deficient management skills.

Conclusions

This paper involves an in-depth analysis of performance persistence in Spanish equity pension funds during the period of growth of this industry. In this sense, we have analysed this phenomenon considering both the short term and the long term.

The findings point out a global trend towards short-term persistence in the period 1999–2006 by using non-parametric methodology. Specifically, the persistence is statistically significant in some years using 2×2 contingency tables and also in the analysis of 4×4 tables. However, one of the main results is the evidence of short-term performance persistence in the entire period analysed by using Cochran's test.

On the other hand, there is little evidence of performance persistence in middle term (2 or 3 years) although some Spanish pension funds present persistence during longer periods such as 4, 5, 6 or 7 years, providing evidence for their superior (inferior) management skills.

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Appendix 1

Statistical tests applied in 2×2 contingency tables

*The Z-test applied by Malkiel*³¹

$$Z = \frac{(Y - np)}{\sqrt{np(1-p)}} \quad Z \approx N(0, 1) \quad (1)$$

where Y is the number of winner funds in two consecutive periods (WW), n is the number of winners in the first period ($WW + WL$), p is the probability of a winner fund to repeat as a winner in the following period (0.5).

The Odds Ratio (OR) applied by Brown and Goetzmann (1995)

$$OR = \frac{WW * LL}{WL * LW} \quad (2)$$

³¹ Malkiel (1995).

A *Z*-statistic is calculated on the basis of this odds ratio.

$$Z = \frac{\ln(OR)}{\sigma_{\log(OR)}} \quad Z \approx N(0, 1) \quad (3)$$

where

$$\sigma_{\log(OR)} = \sqrt{\frac{1}{WW} + \frac{1}{WL} + \frac{1}{LW} + \frac{1}{LL}} \quad (4)$$

The χ^2 -statistic applied by Kahn and Rudd (1995)

$$\chi^2 = \sum_{i=1}^n \sum_{j=1}^n \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \quad \chi^2 \approx \chi_1^2 \quad (5)$$

where O_{ij} is the actual frequency in the i th row and the j th column in the contingency table and E_{ij} is the expected frequency in the i th row and the j th column in the contingency table.

The Cochran method (1954)

$$Y = \frac{\sum_{i=1}^g w_i d_i}{\left(\sum_{i=1}^g w_i P_i Q_i \right)^{1/2}} \quad Y \approx N(0, 1) \quad (6)$$

where

$$P_i = \frac{n_{i1}p_{i1} + n_{i2}p_{i2}}{(n_{i1} + n_{i2})} \quad (7)$$

$$Q_i = (1 - P_i) \quad (8)$$

$$d_i = (p_{i1} - p_{i2}) \quad (9)$$

$$w_i = \frac{n_{i1}n_{i2}}{(n_{i1} + n_{i2})} \quad (10)$$

n_{i1} (n_{i2}) is $WW + WL$ ($LL + LW$) in each contingency table,
 p_{i1} (p_{i2}) is the relationship between WW (LW) and n_{i1} (n_{i2}),
 g is the number of 2×2 tables analysed.

Appendix 2

Statistical tests applied in 4×4 contingency tables

Chi-squared test

This method consists merely in the comparison of expected and observed frequencies, as in 2×2 contingency table case.

*The analysis of residuals by Haberman*³²

This procedure identifies the categories responsible for a significant Chi-square value. Therefore, it is necessary the examination of the standardised residuals, e_{ij} :

$$e_{ij} = \frac{n_{ij} - E_{ij}}{(\sqrt{E_{ij}})} \quad (11)$$

where E_{ij} (n_{ij}) is the expected (observed) frequency in the i th row and the j th column of the contingency table.

An estimate of the variance of e_{ij} is given by the following expression:

$$v_{ij} = \left(1 - \frac{n_i}{N}\right) \left(1 - \frac{n_j}{N}\right) \quad (12)$$

where n_i (n_j) is the total number of observations in the i th (j th) category of the row (column) variable.

Thus for each cell in the contingency table we may compute an adjusted residual d_{ij} , where

$$d_{ij} = \frac{e_{ij}}{\sqrt{v_{ij}}} \quad d_{ij} \approx N(0, 1) \quad (13)$$

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³² Haberman (1973).