Chapter 5: The beast of bias

Oliver Twisted

Please, Sir, can I have some more … frequencies?

In your SPSS output you will also see tabulated frequency distributions of each variable (below). These tables list each score and the number of times that it is found within the data set. In addition, each frequency value is expressed as a percentage of the sample. Also, the cumulative percentage is given, which tells us how many cases (as a percentage) fell below a certain score. So, for example, we can see that only 15.4% of hygiene scores were below 1 on the first day of the festival. Compare this to the table for day 2: 63.3% of scores were less than 1!

Hygiene (Day 1 of Download Festival)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0.02	1	.1	.1	.1
	0.05	1	.1	.1	.2
	0.11	2	.2	.2	.5
	0.23	2	.2	.2	.7
	0.26	1	.1	.1	.9
	0.29	1	.1	.1	1.0
	0.3	1	.1	.1	1.1
	0.32	4	.5	.5	1.6
	0.35	1	.1	.1	1.7
	0.38	3	.4	.4	2.1
	0.43	1	.1	.1	2.2
	0.44	1	.1	.1	2.3
	0.45	2	.2	.2	2.6
	0.47	3	.4	.4	3.0
	0.5	3	.4	.4	3.3
	0.51	1	.1	.1	3.5
	0.52	5	.6	.6	4.1
	0.55	4	.5	.5	4.6
	0.58	3	.4	.4	4.9
	0.59	1	.1	.1	5.1
	0.6	1	.1	.1	5.2
	0.61	5	.6	.6	5.8
	0.62	1	.1	.1	5.9
	0.64	3	.4	.4	6.3
	0.67	6	.7	.7	7.0
	0.7	3	.4	.4	7.4

	0.73	6	.7	.7	8.1
	0.76	3	.4	.4	8.5
	0.78	1	.1	.1	8.6
	0.79	1	.1	.1	8.8
	0.81	1	.1	.1	8.9
	0.82	6	.7	.7	9.6
	0.83	1	.1	.1	9.8
	0.84	2	.2	.2	10.0
	0.85	5	.6	.6	10.6
	0.88	6	.7	.7	11.4
	0.9	2	.2	.2	11.6
	0.91	2	.2	.2	11.9
	0.93	1	.1	.1	12.0
	0.94	6	.7	.7	12.7
	0.96	2	.2	.2	13.0
	0.97	7	.9	.9	13.8
	1	13	1.6	1.6	15.4
	1.02	6	.7	.7	16.2
	1.03	1	.1	.1	16.3
	1.05	5	.6	.6	16.9
	1.06	5	.6	.6	17.5
	1.08	7	.9	.9	18.4
	1.11	5	.6	.6	19.0
	1.14	12	1.5	1.5	20.5
	1.15	1	.1	.1	20.6
	1.17	5	.6	.6	21.2
	1.2	5	.6	.6	21.9
	1.21	1	.1	.1	22.0
	1.23	9	1.1	1.1	23.1
	1.24	1	.1	.1	23.2
	1.26	6	.7	.7	24.0
	1.28	2	.2	.2	24.2
	1.29	6	.7	.7	24.9
	1.31	1	.1	.1	25.1
	1.32	8	1.0	1.0	26.0
	1.33	1	.1	.1	26.2
	1.34	3	.4	.4	26.5
	1.35	9	1.1	1.1	27.7
	1.38	7	.9	.9	28.5
	1.41	11	1.4	1.4	29.9
	1.42	4	.5	.5	30.4
	1.44	11	1.4	1.4	31.7
	1.45	1	.1	.1	31.9
	1.47	17	2.1	2.1	34.0
	1.48	1	.1	.1	34.1
	1.5	14	1.7	1.7	35.8
	1.51	2	.2	.2	36.0

	1.52	11	1.4	1.4	37.4
	1.53	1	.1	.1	37.5
	1.54	1	.1	.1	37.7
	1.55	7	.9	.9	38.5
	1.56	2	.2	.2	38.8
	1.57	2	.2	.2	39.0
	1.58	15	1.9	1.9	40.9
	1.59	1	.1	.1	41.0
	1.6	3	.4	.4	41.4
	1.61	7	.9	.9	42.2
	1.64	13	1.6	1.6	43.8
	1.66	4	.5	.5	44.3
	1.67	11	1.4	1.4	45.7
	1.68	1	.1	.1	45.8
	1.69	1	.1	.1	45.9
	1.7	7	.9	.9	46.8
	1.71	1	.1	.1	46.9
	1.73	11	1.4	1.4	48.3
	1.75	1	.1	.1	48.4
	1.76	5	.6	.6	49.0
	1.77	1	.1	.1	49.1
	1.78	2	.2	.2	49.4
	1.79	10	1.2	1.2	50.6
	1.81	2	.2	.2	50.9
	1.82	12	1.5	1.5	52.3
	1.84	2	.2	.2	52.6
	1.85	14	1.7	1.7	54.3
	1.87	2	.2	.2	54.6
	1.88	5	.6	.6	55.2
	1.9	3	.4	.4	55.6
	1.91	11	1.4	1.4	56.9
	1.93	4	.5	.5	57.4
	1.94	14	1.7	1.7	59.1
	1.96	1	.1	.1	59.3
	1.97	6	.7	.7	60.0
	2	19	2.3	2.3	62.3
	2.02	16	2.0	2.0	64.3
	2.03	1	.1	.1	64.4
	2.05	14	1.7	1.7	66.2
	2.06	1	.1	.1	66.3
	2.08	10	1.2	1.2	67.5
	2.09	2	.2	.2	67.8
	2.11	4	.5	.5	68.3
	2.12	2	.2	.2	68.5
	2.14	8	1.0	1.0	69.5
	2.16	1	.1	.1	69.6
	2.17	15	1.9	1.9	71.5

	2.18	3	.4	.4	71.9
	2.2	10	1.2	1.2	73.1
	2.21	2	.2	.2	73.3
	2.22	1	.1	.1	73.5
	2.23	14	1.7	1.7	75.2
	2.24	1	.1	.1	75.3
	2.26	6	.7	.7	76.0
	2.27	1	.1	.1	76.2
	2.28	1	.1	.1	76.3
	2.29	12	1.5	1.5	77.8
	2.3	3	.4	.4	78.1
	2.31	1	.1	.1	78.3
	2.32	10	1.2	1.2	79.5
	2.33	1	.1	.1	79.6
	2.34	1	.1	.1	79.8
	2.35	5	.6	.6	80.4
	2.36	2	.2	.2	80.6
	2.38	2	.2	.2	80.9
	2.39	2	.2	.2	81.1
	2.41	3	.4	.4	81.5
	2.42	1	.1	.1	81.6
	2.44	8	1.0	1.0	82.6
	2.45	2	.2	.2	82.8
	2.46	2	.2	.2	83.1
	2.47	4	.5	.5	83.6
	2.48	1	.1	.1	83.7
	2.5	10	1.2	1.2	84.9
	2.51	2	.2	.2	85.2
	2.52	9	1.1	1.1	86.3
	2.53	1	.1	.1	86.4
	2.55	4	.5	.5	86.9
	2.56	2	.2	.2	87.2
	2.57	2	.2	.2	87.4
	2.58	6	.7	.7	88.1
	2.61	3	.4	.4	88.5
	2.62	1	.1	.1	88.6
	2.63	3	.4	.4	89.0
	2.64	5	.6	.6	89.6
	2.66	1	.1	.1	89.8
	2.67	5	.6	.6	90.4
	2.7	4	.5	.5	90.9
	2.71	1	.1	.1	91.0
	2.73	5	.6	.6	91.6
	2.75	1	.1	.1	91.7
	2.76	4	.5	.5	92.2
	2.78	1	.1	.1	92.3
	2.79	2	.2	.2	92.6

	2.81	4	.5	.5	93.1
	2.82	2	.2	.2	93.3
	2.84	2	.2	.2	93.6
	2.85	1	.1	.1	93.7
	2.87	1	.1	.1	93.8
	2.88	8	1.0	1.0	94.8
	2.9	1	.1	.1	94.9
	2.91	3	.4	.4	95.3
	2.92	1	.1	.1	95.4
	2.94	3	.4	.4	95.8
	2.97	3	.4	.4	96.2
	3	2	.2	.2	96.4
	3.02	2	.2	.2	96.7
	3.03	1	.1	.1	96.8
	3.08	1	.1	.1	96.9
	3.09	1	.1	.1	97.0
	3.11	1	.1	.1	97.2
	3.12	1	.1	.1	97.3
	3.14	1	.1	.1	97.4
	3.15	2	.2	.2	97.7
	3.17	1	.1	.1	97.8
	3.2	2	.2	.2	98.0
	3.21	3	.4	.4	98.4
	3.23	1	.1	.1	98.5
	3.26	1	.1	.1	98.6
	3.29	2	.2	.2	98.9
	3.32	3	.4	.4	99.3
	3.38	2	.2	.2	99.5
	3.41	1	.1	.1	99.6
	3.44	1	.1	.1	99.8
	3.58	1	.1	.1	99.9
	3.69	1	.1	.1	100.0
	Total	810	100.0	100.0	

Hygiene (Day 2 of Download Festival)					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	.1	.4	.4
	0.02	2	.2	.8	1.1
	0.05	1	.1	.4	1.5
	0.06	1	.1	.4	1.9
	0.08	2	.2	.8	2.7
	0.11	3	.4	1.1	3.8
	0.14	8	1.0	3.0	6.8
	0.17	6	.7	2.3	9.1
	0.2	8	1.0	3.0	12.1

	0.23	10	1.2	3.8	15.9
	0.26	5	.6	1.9	17.8
	0.28	1	.1	.4	18.2
	0.29	2	.2	.8	18.9
	0.32	5	.6	1.9	20.8
	0.35	4	.5	1.5	22.3
	0.38	6	.7	2.3	24.6
	0.41	4	.5	1.5	26.1
	0.44	5	.6	1.9	28.0
	0.45	1	.1	.4	28.4
	0.47	4	.5	1.5	29.9
	0.48	1	.1	.4	30.3
	0.5	2	.2	.8	31.1
	0.52	5	.6	1.9	33.0
	0.55	5	.6	1.9	34.8
	0.56	1	.1	.4	35.2
	0.58	7	.9	2.7	37.9
	0.64	4	.5	1.5	39.4
	0.67	3	.4	1.1	40.5
	0.7	7	.9	2.7	43.2
	0.73	2	.2	.8	43.9
	0.76	9	1.1	3.4	47.3
	0.78	1	.1	.4	47.7
	0.79	7	.9	2.7	50.4
	0.82	4	.5	1.5	51.9
	0.84	2	.2	.8	52.7
	0.85	8	1.0	3.0	55.7
	0.88	1	.1	.4	56.1
	0.9	1	.1	.4	56.4
	0.91	6	.7	2.3	58.7
	0.94	6	.7	2.3	61.0
	0.97	1	.1	.4	61.4
	1	5	.6	1.9	63.3
	1.02	4	.5	1.5	64.8
	1.05	1	.1	.4	65.2
	1.06	1	.1	.4	65.5
	1.08	2	.2	.8	66.3
	1.11	5	.6	1.9	68.2
	1.13	1	.1	.4	68.6
	1.14	5	.6	1.9	70.5
	1.17	3	.4	1.1	71.6
	1.18	1	.1	.4	72.0
	1.2	2	.2	.8	72.7
	1.21	1	.1	.4	73.1
	1.23	1	.1	.4	73.5
	1.29	1	.1	.4	73.9
	1.32	2	.2	.8	74.6

	1.35	4	.5	1.5	76.1
	1.38	3	.4	1.1	77.3
	1.41	2	.2	.8	78.0
	1.44	3	.4	1.1	79.2
	1.45	1	.1	.4	79.5
	1.5	1	.1	.4	79.9
	1.52	2	.2	.8	80.7
	1.54	1	.1	.4	81.1
	1.55	1	.1	.4	81.4
	1.58	3	.4	1.1	82.6
	1.64	2	.2	.8	83.3
	1.7	4	.5	1.5	84.8
	1.73	1	.1	.4	85.2
	1.75	1	.1	.4	85.6
	1.76	1	.1	.4	86.0
	1.78	1	.1	.4	86.4
	1.79	1	.1	.4	86.7
	1.82	1	.1	.4	87.1
	1.87	1	.1	.4	87.5
	1.88	1	.1	.4	87.9
	1.9	1	.1	.4	88.3
	1.94	2	.2	.8	89.0
	1.97	2	.2	.8	89.8
	2.05	2	.2	.8	90.5
	2.08	2	.2	.8	91.3
	2.12	1	.1	.4	91.7
	2.2	1	.1	.4	92.0
	2.23	1	.1	.4	92.4
	2.29	1	.1	.4	92.8
	2.32	1	.1	.4	93.2
	2.38	1	.1	.4	93.6
	2.41	1	.1	.4	93.9
	2.42	1	.1	.4	94.3
	2.44	2	.2	.8	95.1
	2.5	2	.2	.8	95.8
	2.53	1	.1	.4	96.2
	2.55	1	.1	.4	96.6
	2.61	1	.1	.4	97.0
	2.7	1	.1	.4	97.3
	2.72	1	.1	.4	97.7
	2.85	1	.1	.4	98.1
	2.91	1	.1	.4	98.5
	3	1	.1	.4	98.9
	3.21	1	.1	.4	99.2
	3.35	1	.1	.4	99.6
	3.44	1	.1	.4	100.0
	Total	264	32.6	100.0	

Missing	System	546	67.4
Total		810	100.0

Hygiene (Day 3 of Download Festival)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0.02	2	.2	1.6	1.6
	0.08	1	.1	.8	2.4
	0.11	1	.1	.8	3.3
	0.14	2	.2	1.6	4.9
	0.17	3	.4	2.4	7.3
	0.2	3	.4	2.4	9.8
	0.26	1	.1	.8	10.6
	0.29	3	.4	2.4	13.0
	0.32	1	.1	.8	13.8
	0.33	2	.2	1.6	15.4
	0.35	2	.2	1.6	17.1
	0.38	5	.6	4.1	21.1
	0.39	1	.1	.8	22.0
	0.41	1	.1	.8	22.8
	0.44	6	.7	4.9	27.6
	0.45	1	.1	.8	28.5
	0.47	5	.6	4.1	32.5
	0.5	1	.1	.8	33.3
	0.52	4	.5	3.3	36.6
	0.53	1	.1	.8	37.4
	0.55	3	.4	2.4	39.8
	0.58	2	.2	1.6	41.5
	0.61	1	.1	.8	42.3
	0.67	1	.1	.8	43.1
	0.7	3	.4	2.4	45.5
	0.72	1	.1	.8	46.3
	0.73	1	.1	.8	47.2
	0.76	6	.7	4.9	52.0
	0.81	1	.1	.8	52.8
	0.82	1	.1	.8	53.7
	0.85	1	.1	.8	54.5
	0.88	1	.1	.8	55.3
	0.91	5	.6	4.1	59.3
	0.94	2	.2	1.6	61.0
	0.96	1	.1	.8	61.8
	1.02	4	.5	3.3	65.0
	1.17	1	.1	.8	65.9
	1.18	1	.1	.8	66.7
	1.19	1	.1	.8	67.5
	1.2	2	.2	1.6	69.1

	1.26	1	.1	.8	69.9
	1.29	1	.1	.8	70.7
	1.32	1	.1	.8	71.5
	1.38	1	.1	.8	72.4
	1.44	1	.1	.8	73.2
	1.5	2	.2	1.6	74.8
	1.55	1	.1	.8	75.6
	1.58	2	.2	1.6	77.2
	1.61	1	.1	.8	78.0
	1.66	1	.1	.8	78.9
	1.67	3	.4	2.4	81.3
	1.7	3	.4	2.4	83.7
	1.73	2	.2	1.6	85.4
	1.76	2	.2	1.6	87.0
	1.85	1	.1	.8	87.8
	1.88	2	.2	1.6	89.4
	1.91	3	.4	2.4	91.9
	2	1	.1	.8	92.7
	2.11	2	.2	1.6	94.3
	2.15	1	.1	.8	95.1
	2.29	1	.1	.8	95.9
	2.55	1	.1	.8	96.7
	2.7	1	.1	.8	97.6
	3.02	2	.2	1.6	99.2
	3.41	1	.1	.8	100.0
	Total	123	15.2	100.0	
Missing	System	687	84.8		
Total		810	100.0		

Please, Sir, can I have some more … normality tests?

If you want to test whether a model is a good fit of your data you can use a goodness-of-fit test (you can read about these in the chapter on categorical data analysis in the book), which has a chi-square test statistic (with the associated distribution). One problem with this test is that it needs a certain sample size to be accurate. The Kolmogorov–Smirnov (K-S) test was developed as a test of whether a distribution of scores matches a hypothesized distribution (Massey, 1951). One good thing about the test is that the distribution of the K-S test statistic does not depend on the hypothesized distribution (in other words, the hypothesized distribution doesn't have to be a particular distribution). It is also what is known as an exact test, which means that it can be used on small samples. It also appears to have more power to detect deviations from the hypothesized distribution than the chi-square test (Lilliefors, 1967). However, one major limitation of the K-S test is that if location (i.e. the mean) and shape parameters (i.e. the standard deviation) are estimated from the data then the K-S test is very conservative, which means it fails to detect deviations from the distribution of interest (i.e. normal). What Lilliefors did was to adjust the critical values for significance for the K-S test to make it less conservative (Lilliefors, 1967) using Monte Carlo simulations (these new values were about two-thirds the size of the standard values). He also reported that this test was more powerful than a standard chi-square test (and obviously the standard K-S test).

Another test you'll use to test normality is the Shapiro–Wilk test (Shapiro & Wilk, 1965) which was developed specifically to test whether a distribution is normal (whereas the K-S test can be used to test against distributions other than normal). They concluded that their test was 'comparatively quite sensitive to a wide range of non-normality, even with samples as small as n = 20. It seems to be especially sensitive to asymmetry, long-tailedness and to some degree to short-tailedness' (p. 608). To test the power of these tests they applied them to several samples (n = 20) from various non-normal distributions. In each case they took 500 samples which allowed them to see how many times (in 500) the test correctly identified a deviation from normality (this is the power of the test). They show in these simulations (see Table 7 in their paper) that the Shapiro–Wilk test is considerably more powerful to detect deviations from normality than the K-S test. They verified this general conclusion in a much more extensive set of simulations as well (Shapiro, Wilk, & Chen, 1968).

References

Lilliefors, H. W. (1967). On the Kolmogorov-Smirnov test for normality with mean and variance unknown. *Journal of the American Statistical Association*, *62*(318), 399–402.

Massey, F. J. (1951). The Kolmogorov-Smirnov test for goodness of fit. *Journal of the American Statistical Association*, *4*6(253), 68–78.

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, *52*(3/4), 591–611.

Shapiro, S. S., Wilk, M. B., & Chen, H. J. (1968). A comparative study of various tests for normality. *Journal of the American Statistical Association*, *63*(324), 1343–1372.

Please, Sir, can I have some more … Hartley's F_{max}?

Critical values for Hartley's test (α = .05).

(*n* – 1) per group	Number of Variances Compared										
	2	3	4	5	6	7	8	9	10	11	12
2	39.00	87.50	142.00	202.00	266.00	333.00	403.00	475.00	550.00	626.00	704.00
3	15.40	27.80	39.20	50.70	62.00	72.90	83.50	93.90	104.00	114.00	124.00
4	9.60	15.50	20.60	25.20	29.50	33.60	37.50	41.40	44.60	48.00	51.40
5	7.15	10.80	13.70	16.30	18.70	20.80	22.90	24.70	26.50	28.20	29.90
6	5.82	8.38	10.40	12.10	13.70	15.00	16.30	17.50	18.60	19.70	20.70
7	4.99	6.94	8.44	9.70	10.80	11.80	12.70	13.50	14.30	15.10	15.80
8	4.43	6.00	7.18	8.12	9.03	9.80	10.50	11.10	11.70	12.20	12.70
9	4.03	5.34	6.31	7.11	7.80	8.41	8.95	9.45	9.91	10.30	10.70
10	3.72	4.85	5.67	6.34	6.92	7.42	7.87	8.28	8.66	9.01	9.34
12	3.28	4.16	4.79	5.30	5.72	6.09	6.42	6.72	7.00	7.25	7.48
15	2.86	3.54	4.01	4.37	4.68	4.95	5.19	5.40	5.59	5.77	5.93
20	2.46	2.95	3.29	3.54	3.76	3.94	4.10	4.24	4.37	4.49	4.59
30	2.07	2.40	2.61	2.78	2.91	3.02	3.12	3.21	3.29	3.36	3.39
60	1.67	1.85	1.96	2.04	2.11	2.17	2.22	2.26	2.30	2.33	2.36
∞	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00