Weight Trimming in the National Immunization Survey

Sadeq Chowdhury[1], **Meena Khare[2]**, Kirk Wolter[1]
[1]NORC at the University of Chicago, 1350 Connecticut Ave, NW, Suite 500, DC, 20036
[2]National Center for Health Statistics, CDC

Abstract

Excessively large sampling weights can unduly inflate the variances of survey estimates. The National Immunization Survey (NIS) weighting procedure involves a series of nonresponse and noncoverage adjustments that introduce a considerable variation in sampling weights, even though the sample is selected with equal probability within each estimation target area. To control such undue variance in estimates, extreme weights are trimmed. We present an analytical approach to assess the effects of weight trimming on the NIS estimates. Also, an alternative approach to trimming under the assumption of an exponential distribution of the weights is discussed and compared with the current approach.

KEY WORDS: Extreme weights, Outliers, Sampling weights

1. Introduction

In sample surveys, the final sampling weights are produced by applying various adjustments for nonresponse and noncoverage to the base sampling weights (equal to inverses of sample selection probabilities). These adjustments can introduce considerable variation in sampling weights. The design effect or precision of a survey estimate depends on the sample design and the variation in sampling weights. In some cases, the variation in sampling weights is dominated by a few extreme weights. Trimming or truncating these extreme weights can substantially reduce the overall variation in weights and can considerably improve the precision of the estimates. However, such trimming of weights may introduce some degree of bias in an estimate. If the reduction in variances is larger than the increase in bias, the result is an overall gain in terms of the mean square error (MSE) of the estimate. So, in most large-scale surveys, after doing necessary adjustments to sampling weights, the distribution of weights is routinely examined for outliers or extreme values. Potter (1990, 1988) presented an overview of procedures that can be used to trim extreme sampling weights. Pedlow *et al.* (2003, 2005), Liu *et al.* (2004), Alexander *et al.* (1997), and Little *et al.* (1997) discussed applications of weight trimming in various surveys. In this paper, we review the effectiveness of the current weight trimming procedure used in the National Immunization Survey (NIS). We develop an analytical approach to assess the impact of weight trimming on survey estimates and compare the current NIS approach with an alternative approach developed based on assuming an exponential probability distribution for the tail weights.

2. The National Immunization Survey

The NIS has been conducted quarterly since 1994, by the Centers for Disease Control and Prevention (CDC), to estimate the vaccination coverage rates among children aged 19 to 35 months in the U.S. within geographic areas (called estimation areas) consisting of 50 states, the District of Columbia and several large metropolitan areas. The NIS collects vaccination data on the following childhood vaccines: diphtheria, tetanus toxoids and pertusis vaccine (DTaP), poliovirus vaccine (polio), measles, mumps and rubella vaccine (MMR), *Haemophilus influenza* type b vaccine (HIB), hepatitis B vaccine (HepB) and varicella. The NIS uses a two-phase survey design where the first phase is a random-digit-dialing (RDD) telephone survey that identifies the households with age-eligible children and collects information on vaccinations and vaccination providers of the eligible children. In the second phase, a mail survey of providers collects detailed vaccination histories for the children for whom the RDD-phase interview was complete and consent to contact providers was received. In 2005, the NIS included 27,627 children with complete household interviews and 17,563 children with adequate provider data.

2.1 Trimming Weights in the NIS

The NIS uses a list-assisted RDD frame of telephone numbers and the sample is selected with equal probability within each estimation area. Therefore, the base sampling weights within an area are equal for all selected cases. However, for the first phase, the NIS post survey weight adjustments include a series of adjustments for nonresolution of working residential status of the sampled numbers, for incomplete age

The findings and conclusions in this paper are those of the author(s) and do not necessarily represent the views of the Centers for Disease Control and Prevention or NORC.

screening interviews of the identified working residential numbers, for incomplete household interviews of the age-eligible children, for multiple telephone lines in the household, for noncoverage of nontelephone households, and finally a poststratification and a raking adjustment for the coverage of the age-eligible children in the U.S. by socio-demographic status. In the second phase, to account for the children for whom adequate provider data could not be ascertained, another round of nonresponse and raking adjustments is done. Although the sample is drawn with an equal probability within each estimation area, after implementing all these adjustments, the variation in weights becomes large and extreme weights are observed in some areas. Figure 1 presents a box plot of RDD-phase weights in one area to show the outliers and variation in the NIS weights. The details of the sampling and estimation procedures used in the NIS can be found in Smith *et al.* (2005) and in CDC (2006).

To control the variation in weights due to extreme values, the weighting procedure includes detection and trimming of extreme weights, and redistribution of the trimmed portion of weights to maintain consistency with the external control totals. The procedure starts by computing the median and inter quartile range (IQR) of weights within an area and then truncates all weights greater than (median+6*IQR) to the cutoff value (median+6*IQR). The weights are readjusted after trimming to ensure the sum of weights remains the same as before within each poststratification cell. The procedure of trimming and adjusting is usually repeated several times so that no more weight remains greater than the cutoff value. As part of this investigation, we evaluate the effect of the current NIS procedure on the survey estimates and compare the effect of the slightly different trimming levels with cutoff values equal to (median+5*IQR) or (median+4*IQR). Henceforth, the current NIS trimming procedure and the two variations will be referred to as 6IQR, 5IQR, and 4IQR, respectively. We also present an alternative approach to trim extreme weights in the next section and compare it with the current NIS approach.

3. An Alternative Approach to Trim Extreme Weights

This approach is based on assuming a probability distribution of the sampling weights. Potter (1990) discussed a similar method based on weight distribution, where the sample selection probabilities are assumed to follow a Beta distribution and hence the distribution of sampling weights is shown to follow the distribution of the inverse of a Beta distribution. The trimming level is then determined by comparing the observed distribution of the sampling weights with the theoretical distribution. The parameters of the assumed distribution are estimated using the sampling weights and then a trimming level is determined based on a pre-specified level of probability using the theoretical distribution.

The alternative method that we consider is based on assuming an exponential probability distribution for the tail weights. In the NIS, since the trimming is only applied to large weights, we concentrate modeling the right tail of the weight distribution. Specifically, we model the weights that are greater than the median weight. That means, if the weight variable (W) follows an exponential distribution with the parameter, $\lambda = 1/\mu$, where μ = the mean of tail weights, then the cumulative distribution function, F, of the weights can be expressed as:

$$F(W) = 1 - \exp(-\lambda W), \quad W \ge 0; \lambda > 0$$
$$=> prob(W \ge a) = p = \exp(-\lambda a)$$
$$=> a = -\frac{\log p}{\lambda} = -\mu \log p$$

Now, the trimming level, a, can be set corresponding to a pre-specified probability, p, similar to the level of type I error specified in testing a hypothesis. The value of p can vary from survey to survey depending on the sensitivity of the estimate, in terms of variance and bias, to trimming. For the NIS, we decided to allow a 1% level of error i.e., $p = .01$. That means, the trimming level, $a = -\mu \log .01 = 4.6\mu$. However, given that weights greater than the median are included in the modeling, the trimming levels for the entire sample can be expressed as:

$a = med_W + 4.6 * \mu_Z$, where,
$Z_i = (W_i - med_W)$ with
$Z_i > 0$, med_W = median of weights, W_is, and
μ_Z = mean of Z_is.

To avoid the influence of extreme values, in computing the parameter μ_z, i.e., the mean of the distribution, the following estimator is used.

$$\hat{\mu}_Z = \frac{1}{n'-r+1}\left(\sum_{i=1}^{n'-r} Z_{(i)} + rZ_{(n'-r)}\right),$$

This estimator replaces the r largest of the $n' = n/2$ values in a stratum by the Winsorized values, where n is the total number of cases in an area. According to Fuller (1991), this is the minimum MSE estimator of the exponential mean with extreme values. For application to the NIS, we replace 1% of the weights from the tail in an area by their Winsorized values. After weights are trimmed to the desired level, these are adjusted to ensure that that the sum of the weights remains the same before and after trimming. The procedure is repeated a few times to completely remove any weight greater than the trimming level.

4. Measuring the Effect of Weight Trimming on Survey Estimates

The effect of weight trimming on survey estimates is usually assessed by computing estimated variance and bias before and after trimming. The drawback of this approach is that it involves intensive computation, particularly for comparing alternative trimming schemes or to find an optimal trimming level. Moreover, the bias estimated from the sample can be very unreliable. In this section, we present an analytical approach to assess the impact of trimming on variance and bias. We derive expressions for bias and relative reduction in variance when the trimming procedure involves redistributing the trimmed part of the weights within the estimation stratum as is done in the NIS. Having the explicit expressions for the effects on variance and bias makes it easy to compare the effects of different trimming levels or to identify an optimal trimming level. To present the expressions for bias and changes in variance due to trimming, let us assume the n sample cases in an estimation stratum are ordered in ascending order of weights and define,

W_i = weight of the i th case before trimming

$= \{W_1, W_2, \ldots, W_{n-m}, W_{n-m+1}, \ldots W_n\}$,

W_i^c = weight of the i th case after trimming to W^c

$= \{W_1, W_2, \ldots, W_{n-m}, W_{n-m+1}^c, \ldots, W_n^c\}$,

W_i^t = weight of the i th case after adjusting the trimmed weights i.e.,

$W_i^c = \{W_1^t, \ldots, W_{n-m}^t, W_{n-m+1}^t, \ldots, W_n^t\}$,

m = number of m largest weights that are trimmed i.e., $W_i > W^c$

X_i = a target variable, say vaccination status (1 = vaccinated, 0 = not vaccinated),

$\hat{P}_0 = \dfrac{\sum_{i=1}^{n} W_i X_i}{\sum_{i=1}^{n} W_i}$ =estimate of a proportion (vaccination rate) under the original weight,

$\hat{P}_T = \dfrac{\sum_{i=1}^{n} W_i^t X_i}{\sum_{i=1}^{n} W_i^t}$ =estimate of the proportion under the adjusted trimmed weights,

$P_0 = E(\hat{P}_0)$, $P_T = E(\hat{P}_T)$, $V_0 = Var(\hat{P}_0)$, $V_T = Var(\hat{P}_T)$.

Then, the estimated bias, $\hat{B} = \hat{P}_0 - \hat{P}_T$; bias, $B = P_0 - P_T$; $MSE_T = V_T + B^2$; and the relative reduction in MSE = $\dfrac{V_0 - MSE_T}{V_0} = 1 - \dfrac{MSE_T}{V_0}$.

A factor adjusts the trimmed weights to ensure that the sum of the weights before and after trimming remains the same (i.e., under the condition $W_i^t = AW_i^c$), such that $\sum_{i=1}^{n} W_i^t = A\sum_{i=1}^{n} W_i^c = \sum_{i=1}^{n} W_i$, can be expressed as:

$$A = \frac{\sum_{i=1}^{n} W_i}{\sum_{i=1}^{n} W_i^c} = 1 + \frac{\sum_{i=n-m+1}^{n} (W_i - W_i^c)}{\sum_{i=1}^{n} W_i - \sum_{i=n-m+1}^{n} (W_i - W_i^c)} .$$

This expression for the adjustment factor is required to derive the expressions for bias and variance.

4.1 Bias Due to Trimming

The estimated and expected bias due to trimming can be expressed as

$$B\hat{i}as = \hat{B} = \hat{P}_T - \hat{P}_0 = \hat{P}_0\,(A-1) - \frac{A\sum_{n-m+1}^{n}\left(W_i - W_i^c\right)X_i}{\sum_{i=1}^{n} W_i},$$

$$E(B\hat{i}as) = B = P_0\,(A-1) - \frac{A\sum_{n-m+1}^{n}\left(W_i - W_i^c\right)}{\sum_{i=1}^{n} W_i} P_L$$

,

where, $P_L = E(X_i), \quad i = (n-m+1)\ldots n$, i.e., the expected proportion (e.g., vaccination coverage rate) of the cases with extreme weights that are trimmed.

This implies that the bias depends on the trimming level, W^c and the difference between P_0 and P_L. If $P_0 = P_L$ then bias is zero irrespective of the trimming level.

4.2 Effect on Variance

In this section, we express the impact on variance in terms of the design effect (*Deff*), where the design effect is defined as the ratio of the variance of an estimate under a given sample design to the variance of the same estimate under a simple random sample design. As Potter (1988) discussed, the design effect due to variation in weights can be expressed as:

$$Deff = (1 + RV_W) = n * \sum_{i=1}^{n} W_i^2 \Bigg/ \left(\sum_{i=1}^{n} W_i\right)^2,$$

where, RV_W is the relative variance of weights. Now the design effects of an estimator under the original and the trimmed weights can be expressed as

$$Deff_0 = n * \sum_{i=1}^{n} W_i^2 \Bigg/ \left(\sum_{i=1}^{n} W_i\right)^2 \text{ and}$$

$$Deff_T = n * \sum_{i=1}^{n} \left(W_i^t\right)^2 \Bigg/ \left(\sum_{i=1}^{n} W_i^t\right)^2.$$

The corresponding variances of $\hat{P}_0$ and $\hat{P}_T$ can be expressed as

$V_0 = Deff_0\, \delta\, P_0 (1 - P_0) / n,$ and

$V_T = Deff_T\, \delta\, P_T (1 - P_T) / n,$

where δ represents other components of *Deff* (e.g., due to clustering), which remains constant and can be ignored for the purpose of comparison in the case of a particular survey.

Also, the ratio of design effects after and before trimming can be expressed as

$$Deff_T / Deff_0 = A^2 \left\{ 1 - \frac{\sum_{i=n-m+1}^{n} \left(W_i^2 - (W_i^c)^2\right)}{\sum_{i=1}^{n} W_i^2} \right\} \cong \frac{V_T}{V_0}.$$

Using the expressions for variances, bias, and ratio of *Deff*s, the relative reduction in MSE due to trimming can be expressed as

$$1 - \frac{V_T + B^2}{V_0} \cong 1 - \frac{Deff_T}{Deff_0} - \frac{B^2}{V_0}.$$

5. Comparison of Alternative Trimming Procedures

In this section, we compare the effects of various trimming procedures on the NIS estimates by using the approach of computing the impact on variance and bias as discussed in the previous section. We compare the current NIS trimming procedure (6IQR) with two variations 5IQR and 4IQR as discussed in Section 2.1 and with the alternative procedure (EXP) as discussed in Section 3.

The approach used in Section 4 for measuring the relative reduction in MSE for different trimming levels requires P_0 and the difference between P_0 and P_L. Since the objective is not to estimate the MSE but to compute the relative reduction in MSE due to weight trimming, the procedure mainly relies on the distribution of weights and is not highly sensitive to the actual population values. A plausible value of P_0 and a reasonable assumption about the difference between P_0 and P_L should be sufficient to compare the alternative trimming procedures. An external source such as combined data from more than one year of the NIS can be used to obtain a plausible value of P_0 and the difference between P_0 and P_L. For this comparison, we used data from the 2005 NIS. The estimated values of P_0 by area are used as approximate values of P_0, and an idea of the difference between

P_0 and P_L is obtained from the full sample. Table 1 presents estimates of P_0 and three alternative estimates of P_L using the cases with weights greater then three trimming levels: corresponding to the 99th percentile, the 95th percentile, and the 90th percentile of the weights. The estimates are compared for two vaccination series and for an individual vaccine using the NIS provider-reported data. Differences between P_0 and P_L show that the maximum difference is about 6 percentage points. Table 2 presents a similar comparison using data from the RDD-phase household interviews. Again, the maximum difference between P_0 and P_L is about 6 percentage points. For assessing the impact of different trimming procedures, we initially assume a difference of 10 percentage points between P_0 and P_L and then we increase it to 25 percentage points considering the fact that the difference may vary considerably by areas.

Table 3 presents a comparison of cutoff values and the number of trimmed weights under different methods in areas with one or more trimmed weights. It shows that the cutoff values set by the alternative procedure (EXP) are generally between the cutoff values under 6IQR and 4IQR methods. The numbers of trimmed weights in different estimation areas also show the same pattern.

Table 4 presents percentage reduction in MSE for different trimming procedures corresponding to the assumptions of $(P_0 - P_L = .10)$ and $(P_0 - P_L = .25)$. It shows that the percentage reduction in MSE under the EXP procedure is between 6IQR and 4IQR trimming levels. It also shows that the relative reduction in MSE is mostly positive, i.e., MSE is reduced under all trimming levels. However, the relative reduction is mostly less than 4 to 5 percent of the MSE under the current procedure. This reduction in MSE is negligible compared to the low variances of NIS estimates, which are generally less than 2 percent.

Table 5 presents the bias as a percentage of standard error (SE) for different trimming levels. Since bias is not accounted for in measuring the precision of an estimate, a large bias compare to the SE can distort the confidence intervals for the population parameters. Hence, it is desirable to keep the bias component less than 10% of SE irrespective of the reduction in MSE (Cochran, 1975). Table 5 shows that the ratio of the bias and SE is less than 10 percent for most of the trimming levels when the difference between P_0 and P_L is small. However, when the difference between P_0 and P_L is large, the ratio is larger than 10 percent in some areas when trimming levels are low under the EXP or the 4IQR methods. This indicates that additional trimming of weights in the NIS, even with a further reduction in MSE, can be risky in terms of the ratio of bias and SE.

6. Conclusion

The alternative weight trimming procedure considered in this paper for the NIS, based on the assumption of an exponential distribution of the tail of the weight distribution, suggests a larger extent of weight trimming than the current NIS trimming level. However, it seems that further reduction in MSE is likely to be insignificant for reducing the trimming cutoff level any further. Moreover, the risk of a larger bias compared to SE may be higher when target characteristics for the cases with trimmed weights are very different than those characteristics for the remaining cases whose weights are not trimmed. This can affect the reliability of the confidence intervals for the population parameters. So, even if the alternative trimming procedure can perform slightly better than the current procedure, the gain is not large enough to justify changing the current NIS trimming procedure.

The procedure derived and used in this paper for assessing the impact of weight trimming on variance and bias can be used in other surveys. The explicit expressions derived for measuring the impact of trimming on variance and bias are useful in comparing different trimming levels. Using some basic summary statistics (such as the sum and the sum of squares) of weights and having some idea of the expected difference between the cases with extreme weights and the remaining cases in terms of target characteristics, effects of various trimming levels can be assessed by avoiding repeated computation of estimates and their SEs. Unlike most commonly used methods, which are based on the distribution of weights only, this offers an option to easily consider both weight distribution and influence on the bias and variance of an estimate in deriving an optimal trimming level.

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Figure 1. Box-Plot Distribution of Sampling Weights in a selected Stratum, National Immunization Survey, 2005.

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                                    Estimation Area=002

                                 Histogram                          #               Boxplot
            1650+*                                                  2                  *
                .
                .
                .*                                                  2                  *
                .*                                                  1                  *
                .*                                                  1                  *
                .
                .
             850+*                                                  1                  0
                .*                                                  3                  |
                .                                                                      |
                .**********                                        38                  |
                .*****************                                 66               +-----+
                .***                                               12               |  +  |
                .******************************************       166               *-----*
                .**********                                        39                  |
              50+*****                                             18                  |
                 ----+----+----+----+----+----+----+----+--
                 * may represent up to 4 counts
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Table 1. Comparison of $\hat{P}_0$ and $\hat{P}_L$ for Different Vaccines and Vaccine Series from the Provider Reported Data, National Immunization Survey, 2005.

Sample	P43133*	P431**	PPOL***
Full Sample ($\hat{P}_0$)	80.75	83.10	91.70
W_i >99th percentile ($\hat{P}_L$)	86.87	87.69	93.48
W_i >95th percentile ($\hat{P}_L$)	76.53	78.23	88.44
W_i >90th percentile ($\hat{P}_L$)	76.23	79.48	89.60

**P431= 4+ DTaP, 3 + Polio, 1 + MMR
**P43133= P431, 3 + HIB, 3 +HEPB; ***PPOL=3+Polio

Table 2. Comparison of $\hat{P}_0$ and $\hat{P}_L$ for H_431* from the Household Reported (includes both Shot Card and Parental Report) Data, National Immunization Survey, 2005.

	H_431		
Sample	Yes	No	Unknown
Full Sample ($\hat{P}_0$)	38.65	28.94	32.41
W_i >99th percentile ($\hat{P}_L$)	32.28	32.77	34.95
W_i >95th percentile ($\hat{P}_L$)	35.24	31.24	33.52
W_i >90th percentile ($\hat{P}_L$)	35.77	31.08	33.15

*H_431= 4+ DTaP, 3 + Polio, 1 + MMR

Table 3. Comparison of Cutoff Values and Number of Weights Trimmed under Different Schemes, National Immunization Survey, 2005.

Estimation Area	Cutoff Values				Number of Weights Trimmed			
	6*IQR	5*IQR	4*IQR	Exp	6*IQR	5*IQR	4*IQR	Exp
001	775	674	574	604	2	4	8	8
002	1601	1382	1163	1148	2	3	6	6
005	146	131	115	156	9	9	12	7
006	133	118	103	121	4	5	16	5
008	1862	1606	1349	1455	2	3	7	5
010	1553	1376	1198	1370	2	4	5	4
016	1934	1682	1431	1549	2	3	5	4
018	1224	1067	909	1193	3	12	14	3
035	525	459	393	475	8	9	13	9
036	1516	1317	1119	1212	1	3	5	4
043	300	263	226	234	1	1	2	2
044	783	692	600	700	5	5	8	5
045	246	214	182	241	7	8	9	7
053	248	214	180	186	1	1	1	1
058	844	735	626	677	1	3	9	5
059	428	375	321	286	1	3	5	7
061	202	175	148	148	1	2	3	3

Table 4. Comparison of MSE under Different Weight Trimming Schemes, National Immunization Survey, 2005.

Estimation Area	% Reduction in MSE (assuming $P_0 - P_L$=.10)				% Reduction in MSE (assuming $P_0 - P_L$=.25)			
	6*IQR	5*IQR	4*IQR	EXP	6*IQR	5*IQR	4*IQR	EXP
001	0.78	2.29	5.10	4.47	0.730	2.00	3.16	3.32
002	0.73	2.18	4.98	4.96	0.730	2.07	4.12	3.98
005	8.46	8.92	9.57	7.31	2.720	0.73	-3.69	3.38
006	0.85	1.62	3.01	1.64	0.670	1.07	0.69	1.20
008	0.00	1.36	3.97	2.69	-0.010	1.24	2.94	2.22
010	0.00	0.85	1.64	0.85	0.000	0.75	1.13	0.74
016	2.37	3.1	4.55	3.85	2.220	2.73	3.45	3.22
018	0.00	2.14	5.21	0.74	0.000	1.64	1.22	0.73
035	2.17	4.84	6.47	4.19	1.830	3.24	1.86	3.01
036	1.51	2.25	3.67	2.97	1.490	2.14	3.03	2.65
043	4.8	5.53	6.29	5.5	4.320	4.94	5.46	4.75
044	1.59	3.05	4.4	3.07	1.300	2.14	2.13	2.23
045	6.73	8.75	11.2	6.47	4.860	4.32	1.69	4.48
053	0.79	1.58	1.57	1.57	0.790	1.55	1.48	1.50
058	0.00	0.79	3.07	1.56	0.000	0.76	2.53	1.43
059	16.97	17.43	18.51	19.52	14.670	14.79	14.33	13.39
061	0.79	1.57	3.12	3.12	0.790	1.51	2.81	2.81

Table 5. Comparison of Bias/SE under Different Weight Trimming Schemes, National Immunization Survey, 2005.

Estimation Area	Bias as Percent of SE (assuming $P_0 - P_L$=.10)				Bias as Percent of SE (assuming $P_0 - P_L$=.25			
	6*IQR	5*IQR	4*IQR	EXP	6*IQR	5*IQR	4*IQR	EXP
001	0.51	2.38	6.25	4.8	2.37	5.96	15.63	11.99
002	0.21	1.48	4.16	4.43	0.63	3.71	10.40	11.07
005	6.73	13.20	16.95	9.03	25.97	33.01	42.38	22.57
006	0.85	3.27	6.76	2.92	4.40	8.17	16.91	7.29
008	0.25	1.57	4.52	3.02	1.00	3.93	11.30	7.54
010	0.17	1.39	3.14	1.43	0.64	3.47	7.86	3.57
016	1.21	2.70	4.69	3.53	4.02	6.76	11.73	8.83
018	0.15	3.12	8.99	0.45	0.54	7.81	22.48	1.13
035	1.89	5.68	9.74	4.84	6.24	14.2	24.36	12.09
036	0.52	1.49	3.54	2.49	1.63	3.73	8.85	6.23
043	1.95	3.45	4.12	3.9	7.35	8.61	10.30	9.74
044	1.59	4.24	6.75	4.06	5.66	10.6	16.88	10.14
045	3.57	9.66	14.44	6.38	14.62	24.14	36.08	15.94
053	0.19	0.75	1.32	1.22	0.47	1.88	3.30	3.05
058	0.09	0.69	3.27	1.6	0.24	1.72	8.17	3.99
059	5.71	7.82	9.93	12.13	17.64	19.55	24.84	30.33
061	0.03	1.13	2.46	2.44	0.09	2.82	6.16	6.10