



Comparison of Dual to Ratio-Cum-Product Estimators of Population Mean

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Abstract

In this paper, some dual to ratio-cum-product estimators of population mean using known parameters of auxiliary variables are considered. These estimators are computed and compared with respect to bias and mean squared error using a simulation study from the normal population. Coefficient of skewness and coefficient of kurtosis are also computed to have an idea about the sampling distribution of dual to ratio-cum-product estimators of population mean. Dual to ratio-cum-product estimators are more efficient than that of the mean per unit, classical ratio estimator and linear regression estimators and Choudhury and Singh (2012) estimator is more efficient estimator among the dual to ratio-cum-product estimators of population mean.

Keywords: Ratio-cum-product estimator, simulation, standard error and relative bias.

Introduction

In this paper, some dual to ratio-cum-product estimators available in the literature are reviewed and their efficiencies are compared by simulation from the normal distribution with known correlation coefficient.

The estimations of the population mean is a persistent issue in sampling practice and many efforts have been made to improve the precision of the estimates. The literature on survey sampling describes a great variety of techniques for using auxiliary information by means of ratio, product and regression methods¹. Srivenkataramana first proposed dual to ratio estimator². Bandyopadhyay proposed dual to product estimator³. Singh proposed class of unbiased dual to ratio estimators⁴. Sharma and Tailor suggested a ratio-cum-dual to ratio estimator as a linear combination of classical ratio estimator and dual to ratio estimator⁵. Choudhury and Singh proposed a ratio-cum-product ratio estimator as a linear combination of classical ratio estimator and the dual to product estimator^{6, 7}. These estimators are compared with respect to standard error, relative bias, skewness and kurtosis using simulation by generating random samples from different bivariate populations with known correlation coefficients between the study and auxiliary variables.

Dual to Ratio-Cum-Product Estimators

Let (y_i, x_i) denote the values of the response variable y and an auxiliary variable x respectively in a finite population. Let \bar{y} and \bar{x} denote the sample means of study variable y and an auxiliary variable x and assuming that the population mean (\bar{X}) of auxiliary variable x is known in advance. The mean per unit estimator of population mean is given by

$$T_0 = \bar{y} = \frac{\sum_{i=1}^n y_i}{n}$$

The classical ratio estimator of population mean $\bar{Y} = \frac{\sum_{i=1}^N Y_i}{N}$ is given by $T_1 = \frac{\bar{y}}{\bar{x}} \bar{X}$

The linear regression estimator is given by $T_2 = \bar{y} - b_{yx} (\bar{x} - \bar{X})$

And the product estimator is given by $T_3 = \bar{y} \frac{\bar{x}}{\bar{X}}$

Where $\bar{y} = \frac{\sum_{i=1}^n y_i}{n}$, $\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$, $b_{yx} = \frac{s_{yx}}{s_x^2}$, $s_x^2 = \frac{1}{n-1} \sum_{i \in s} (x_i - \bar{x})^2$ and $\bar{X} = \frac{\sum_{i=1}^N X_i}{N}$.

Srivenkataramana² suggested a dual to ratio estimator using the transformation $x_i^* = \frac{N\bar{X} - nx_i}{N-n}$ or $x_i^* = (1+g)\bar{X} - gx_i$, $i=1,2, \dots, N$; where $g = \frac{n}{N-n}$. This transformation yields to new estimator $\bar{x}^* = (1+g)\bar{X} - g\bar{x}$ and which is an unbiased estimator of \bar{X} . The dual to ratio estimator due to Srivenkataramana² is given by $T_4 = \bar{y} \frac{\bar{x}^*}{\bar{X}}$

And Bandyopadhyay³ obtained dual to product estimator as $T_5 = \bar{y} \frac{\bar{X}}{\bar{x}^*}$

Sharma and Tailor⁵ suggested the following ratio-cum-dual to ratio estimator by taking the linear combination of classical ratio estimator and dual to ratio estimator.

$$T_6 = \bar{y} \left[\alpha \frac{\bar{X}}{\bar{x}} + (1-\alpha) \frac{\bar{x}^*}{\bar{X}} \right] \text{ where } \alpha = \frac{K-g}{1-g}.$$

Recently, Choudhury and Singh^{6,7} proposed an estimator as

$$T_7 = \bar{y} \left[\alpha \left(\frac{\bar{X}}{\bar{x}} \right) + (1-\alpha) \left(\frac{\bar{X}}{\bar{x}^*} \right) \right] \text{ where } \alpha = \frac{(K+g)}{1+g}.$$

The population quantities $K = \frac{\rho C_y}{C_x}$, $\rho = \frac{S_{yx}}{S_x S_y}$, $C_y = \frac{S_y}{\bar{Y}}$, $C_x = \frac{S_x}{\bar{X}}$, $s_x^2 = \sum_{i=1}^N (x_i - \bar{X})^2 / (N-1)$, $s_y^2 = \sum_{i=1}^N (y_i - \bar{Y})^2 / (N-1)$ and $S_{yx} = \sum_{i=1}^N (y_i - \bar{Y})(x_i - \bar{X}) / (N-1)$.

Estimates of the bias and MSE of these estimators can be obtained from their respective papers. The authors compared the efficiency of these estimators with that of the either mean per unit estimator or with the classical ratio estimators. It is very difficult to compare these estimators analytically with the remaining estimators discussed in this paper.

Comparison of Dual to Ratio-Cum-Product Estimators

In this paper, an attempt is made to compare the dual to ratio-cum-product estimators using simulation. Simulation is an alternative technique to compare the efficiency of the estimators whenever the analytical comparisons are not possible.

First we have generated the correlated samples (Y, X) of size 500 from the normal population. The correlation samples are generated using the algorithm given by Krishna Reddy et.al⁸. We have generated three populations of size N=500 as follows:

Population-I: This population consists of the two correlated variables (Y, X) with equal variances are generated using the algorithm proposed by Krishna Reddy et. al.⁸. This population will have the marginal distributions $X \sim N(10, 4)$ and $Y \sim N(10\rho + 10\sqrt{1-\rho^2}, 4)$ where ρ is the population correlation between X and Y. This bivariate population will have the variance ratio $\frac{\sigma_y^2}{\sigma_x^2} = 1$.

Population-II: This population consists of the two correlated variables (Y, X) with unequal variances are generated using the algorithm proposed by Krishna Reddy et. al.⁸. The population contains the variance of X is less than the variance of Y with the

marginal distributions $X \sim N(10, 4)$ and $Y \sim N(10\rho + 10\sqrt{1-\rho^2}, 4\rho^2 + 16(1-\rho^2))$. This bivariate population will have the variance ratio $\frac{\sigma_y^2}{\sigma_x^2} > 1$.

Population-III: This population consists of the two correlated variables (Y, X) with unequal variances are generated using the algorithm proposed by Krishna Reddy et. al.⁸. The population contains the variance of X is greater than the variance of Y with the marginal distributions $X \sim N(10, 25)$ and $Y \sim N(10\rho + 10\sqrt{1-\rho^2}, 25\rho^2 + 9(1-\rho^2))$. This bivariate population will have the variance ratio $\frac{\sigma_y^2}{\sigma_x^2} < 1$.

From each of the population, 500 simple random samples without replacement of size $n=10, 30$ and 50 are drawn and computed the above estimators in each of the sample. Let T_{ij} be the value of the estimator T_i based on the j^{th} SRSWOR for $j=1, 2, \dots, 500$ and $i=0, 1, \dots, 7$.

The estimator of population of mean using simulation is given by $\hat{Y}_i = \sum_{j=1}^{500} T_{ij}$ for $i = 0, 1, \dots, 7$. The relative bias of \hat{Y}_i is defined as

$RB(\hat{Y}_i) = \frac{|\hat{Y}_i - \bar{Y}|}{\bar{Y}}$ for $i = 0, 1, \dots, 7$. The standard error of the estimator is defined as $SE(\hat{Y}_i) = \sqrt{\frac{1}{500} \sum_{j=1}^{500} (T_{ij} - \bar{Y})^2}$ for $i = 0, 1, \dots, 7$. The

behavior of the distribution of the estimators are identified using the coefficient of skewness and coefficient of Kurtosis. For each estimator the standard error, relative bias, skewness and kurtosis are computed and presented against the sample size $n=10, 30, 50$ and correlation coefficient between the variables Y and X, $r_{yx} = 0.4, 0.6$ and 0.8 . The following tables present the results of the simulation study.

Table-1
Comparison of estimators of population mean from Population-I with r=0.4

r	n	Estimator	Estimate	SE	RB	Skewness	Kurtosis
0.40	10	T_0	13.304	0.400	0.003	0.018	2.671
		T_1	13.329	0.760	0.004	0.315	3.370
		T_2	13.227	0.371	0.003	0.035	2.912
		T_3	13.337	1.637	0.005	0.066	2.843
		T_4	13.303	0.391	0.003	0.015	2.685
		T_5	13.304	0.410	0.003	0.021	2.659
		T_6	13.313	0.341	0.003	0.000	2.889
		T_7	13.311	0.340	0.003	0.000	2.892
	30	T_0	13.273	0.134	0.000	0.014	2.773
		T_1	13.287	0.202	0.001	0.110	3.281
		T_2	13.244	0.102	0.002	0.000	3.359
		T_3	13.277	0.594	0.001	0.095	2.514
		T_4	13.272	0.123	0.000	0.007	2.863
		T_5	13.273	0.148	0.000	0.024	2.697
		T_6	13.278	0.099	0.001	-0.001	3.243
	50	T_7	13.276	0.099	0.001	-0.001	3.249
		T_0	13.275	0.084	0.000	0.027	2.354
		T_1	13.279	0.123	0.001	0.210	3.184
		T_2	13.257	0.063	0.001	0.013	3.272
		T_3	13.282	0.345	0.001	0.155	2.630
		T_4	13.274	0.073	0.000	0.011	2.509
		T_5	13.276	0.098	0.000	0.052	2.295
		T_6	13.277	0.064	0.001	0.004	3.007
		T_7	13.275	0.064	0.000	0.004	3.024

Table-2
Comparison of estimators of population mean from Population-I with r=0.6

r	n	Estimator	Estimate	SE	RB	Skewness	Kurtosis
0.60	10	T ₀	14.002	0.458	0.000	-0.004	2.989
		T ₁	13.998	0.440	0.000	0.003	2.971
		T ₂	13.912	0.302	0.006	-0.124	3.337
		T ₃	14.066	2.159	0.005	0.002	2.746
		T ₄	14.000	0.441	0.000	-0.005	3.000
		T ₅	14.003	0.476	0.000	-0.003	2.978
		T ₆	14.001	0.238	0.000	-0.042	3.190
		T ₇	13.999	0.238	0.000	-0.042	3.190
	30	T ₀	14.025	0.168	0.002	-0.276	3.244
		T ₁	14.017	0.166	0.001	0.110	3.389
		T ₂	13.980	0.095	0.001	-0.522	3.663
		T ₃	14.057	0.842	0.004	-0.063	2.538
		T ₄	14.023	0.147	0.002	-0.320	3.354
		T ₅	14.027	0.191	0.002	-0.237	3.139
		T ₆	14.022	0.082	0.002	-0.279	3.438
		T ₇	14.020	0.082	0.002	-0.282	3.432
	50	T ₀	14.008	0.090	0.001	-0.032	2.629
		T ₁	14.006	0.090	0.001	0.076	3.789
		T ₂	13.985	0.045	0.001	-0.272	3.252
		T ₃	14.022	0.456	0.002	-0.011	2.439
		T ₄	14.006	0.072	0.001	-0.060	2.806
		T ₅	14.009	0.113	0.001	-0.019	2.510
		T ₆	14.008	0.044	0.001	-0.232	3.379
		T ₇	14.006	0.044	0.001	-0.234	3.369

Table-3
Comparison of estimators of population mean from Population-I with r=0.8

r	n	Estimator	Estimate	SE	RB	Skewness	Kurtosis
0.80	10	T ₀	13.879	0.375	0.000	0.047	2.851
		T ₁	13.877	0.258	0.000	0.100	2.975
		T ₂	13.839	0.162	0.003	0.029	2.950
		T ₃	13.931	1.906	0.004	0.153	3.217
		T ₄	13.878	0.359	0.000	0.043	2.834
		T ₅	13.880	0.392	0.000	0.051	2.869
		T ₆	13.878	0.139	0.000	0.003	3.145
		T ₇	13.877	0.139	0.000	0.003	3.146
	30	T ₀	13.875	0.124	0.000	-0.032	2.563
		T ₁	13.856	0.082	0.002	0.011	2.489
		T ₂	13.850	0.049	0.002	-0.015	2.963
		T ₃	13.911	0.611	0.002	0.003	2.395
		T ₄	13.873	0.108	0.000	-0.041	2.615
		T ₅	13.878	0.141	0.000	-0.023	2.522
		T ₆	13.864	0.046	0.001	-0.003	2.820
		T ₇	13.863	0.046	0.001	-0.002	2.819
	50	T ₀	13.863	0.068	0.001	-0.001	2.690
		T ₁	13.868	0.046	0.001	0.003	2.360
		T ₂	13.859	0.027	0.001	-0.050	2.561
		T ₃	13.867	0.329	0.001	0.000	2.364
		T ₄	13.863	0.054	0.001	-0.003	2.815
		T ₅	13.864	0.086	0.001	0.000	2.591
		T ₆	13.867	0.026	0.001	-0.040	2.401
		T ₇	13.866	0.026	0.001	-0.040	2.405

Table-4
Comparison of estimators of population mean from Population-II with r=0.4

r	n	Estimator	Estimate	SE	RB	Skewness	Kurtosis
0.40	10	T ₀	13.397	1.398	0.005	0.004	2.798
		T ₁	13.424	1.810	0.007	0.097	3.101
		T ₂	13.249	1.484	0.006	0.035	2.912
		T ₃	13.430	2.669	0.007	0.116	2.680
		T ₄	13.396	1.389	0.005	0.003	2.806
		T ₅	13.398	1.408	0.005	0.004	2.789
		T ₆	13.407	1.352	0.006	0.000	2.901
		T ₇	13.406	1.351	0.005	0.000	2.903
	30	T ₀	13.341	0.443	0.001	0.002	3.005
		T ₁	13.354	0.477	0.002	0.029	3.354
		T ₂	13.282	0.407	0.004	0.000	3.359
		T ₃	13.347	0.949	0.001	0.094	2.548
		T ₄	13.340	0.429	0.001	0.000	3.057
		T ₅	13.341	0.459	0.001	0.004	2.954
		T ₆	13.346	0.394	0.001	-0.001	3.251
		T ₇	13.345	0.394	0.001	-0.001	3.254
	50	T ₀	13.343	0.282	0.001	0.008	2.589
		T ₁	13.347	0.303	0.001	0.096	3.422
		T ₂	13.308	0.250	0.002	0.013	3.272
		T ₃	13.351	0.569	0.001	0.128	2.375
		T ₄	13.343	0.269	0.001	0.005	2.721
		T ₅	13.344	0.299	0.001	0.014	2.480
		T ₆	13.345	0.255	0.001	0.004	3.023
		T ₇	13.344	0.254	0.001	0.005	3.031

Table-5
Comparison of estimators of population mean from Population-II with r=0.6

r	n	Estimator	Estimate	SE	RB	Skewness	Kurtosis
0.60	10	T ₀	14.000	1.250	0.000	-0.007	3.123
		T ₁	13.991	1.085	0.001	-0.016	3.034
		T ₂	13.835	1.209	0.012	-0.124	3.337
		T ₃	14.068	3.099	0.005	0.010	2.888
		T ₄	13.998	1.230	0.000	-0.008	3.128
		T ₅	14.001	1.271	0.000	-0.006	3.117
		T ₆	13.995	0.951	0.001	-0.043	3.182
		T ₇	13.994	0.951	0.001	-0.043	3.182
	30	T ₀	14.052	0.440	0.003	-0.390	3.563
		T ₁	14.041	0.389	0.003	-0.002	3.218
		T ₂	13.970	0.382	0.002	-0.522	3.663
		T ₃	14.086	1.166	0.006	-0.104	2.827
		T ₄	14.049	0.416	0.003	-0.411	3.595
		T ₅	14.054	0.466	0.004	-0.364	3.521
		T ₆	14.047	0.328	0.003	-0.287	3.431
		T ₇	14.045	0.328	0.003	-0.289	3.428
	50	T ₀	14.022	0.236	0.001	-0.097	3.018
		T ₁	14.019	0.208	0.001	-0.027	3.444
		T ₂	13.981	0.182	0.002	-0.272	3.252
		T ₃	14.038	0.632	0.003	-0.005	2.423
		T ₄	14.020	0.214	0.001	-0.135	3.130
		T ₅	14.024	0.262	0.002	-0.067	2.904
		T ₆	14.021	0.175	0.001	-0.235	3.367
		T ₇	14.020	0.174	0.001	-0.236	3.363

Table-6
Comparison of estimators of population mean from Population-II with r=0.8

r	n	Estimator	Estimate	SE	RB	Skewness	Kurtosis
0.80	10	T ₀	13.805	0.798	0.001	0.015	2.728
		T ₁	13.802	0.664	0.001	0.051	3.175
		T ₂	13.738	0.650	0.005	0.029	2.950
		T ₃	13.857	2.350	0.003	0.160	3.117
		T ₄	13.803	0.782	0.001	0.014	2.728
		T ₅	13.806	0.816	0.000	0.017	2.730
		T ₆	13.803	0.553	0.001	0.004	3.154
		T ₇	13.802	0.552	0.001	0.004	3.154
	30	T ₀	13.795	0.266	0.001	-0.051	2.844
		T ₁	13.775	0.215	0.003	0.011	2.536
		T ₂	13.758	0.196	0.004	-0.015	2.963
		T ₃	13.830	0.756	0.001	-0.003	2.450
		T ₄	13.792	0.250	0.001	-0.051	2.880
		T ₅	13.797	0.284	0.001	-0.049	2.806
		T ₆	13.783	0.183	0.002	-0.002	2.821
		T ₇	13.782	0.183	0.002	-0.002	2.821
	50	T ₀	13.787	0.150	0.002	-0.008	2.976
		T ₁	13.791	0.122	0.002	-0.009	2.081
		T ₂	13.777	0.106	0.003	-0.050	2.561
		T ₃	13.791	0.414	0.002	0.001	2.514
		T ₄	13.786	0.135	0.002	-0.014	2.988
		T ₅	13.787	0.168	0.002	-0.004	2.933
		T ₆	13.790	0.105	0.002	-0.040	2.408
		T ₇	13.789	0.105	0.002	-0.040	2.410

Table-7
Comparison of estimators of population mean from Population-III with r=0.4

r	n	Estimator	Estimate	SE	RB	Skewness	Kurtosis
0.40	10	T ₀	13.418	1.176	0.004	0.040	2.590
		T ₁	13.657	4.247	0.022	2.042	6.185
		T ₂	13.298	0.835	0.005	0.035	2.912
		T ₃	13.564	8.926	0.015	0.089	3.039
		T ₄	13.415	1.118	0.004	0.034	2.591
		T ₅	13.421	1.237	0.004	0.046	2.593
		T ₆	13.500	0.858	0.010	0.013	2.932
		T ₇	13.489	0.843	0.010	0.010	2.910
	30	T ₀	13.365	0.416	0.000	0.041	2.573
		T ₁	13.451	0.974	0.007	0.475	3.999
		T ₂	13.323	0.229	0.003	0.000	3.359
		T ₃	13.401	3.180	0.003	0.113	2.599
		T ₄	13.363	0.350	0.000	0.022	2.653
		T ₅	13.368	0.495	0.001	0.060	2.529
		T ₆	13.398	0.231	0.003	-0.001	3.209
		T ₇	13.387	0.227	0.002	-0.001	3.228
	50	T ₀	13.370	0.253	0.001	0.069	2.286
		T ₁	13.408	0.556	0.003	0.399	3.313
		T ₂	13.342	0.141	0.001	0.013	3.272
		T ₃	13.401	1.826	0.003	0.164	2.819
		T ₄	13.367	0.193	0.000	0.026	2.331
		T ₅	13.375	0.336	0.001	0.117	2.372
		T ₆	13.387	0.149	0.002	0.003	2.934
		T ₇	13.377	0.145	0.001	0.005	3.000

Table-8
Comparison of estimators of population mean from Population-III with r=0.6

r	n	Estimator	Estimate	SE	RB	Skewness	Kurtosis
0.60	10	T ₀	14.006	1.736	0.002	-0.005	2.870
		T ₁	14.134	2.334	0.011	0.706	4.400
		T ₂	13.858	0.680	0.009	-0.124	3.337
		T ₃	14.269	2.113	0.020	0.039	2.715
		T ₄	14.001	1.636	0.001	-0.007	2.883
		T ₅	14.012	1.841	0.002	-0.003	2.858
		T ₆	14.070	0.567	0.006	-0.029	3.177
	30	T ₇	14.061	0.562	0.006	-0.033	3.169
		T ₀	14.036	0.658	0.004	-0.176	2.875
		T ₁	14.068	0.861	0.006	0.700	4.362
		T ₂	13.960	0.215	0.002	-0.522	3.663
		T ₃	14.158	4.736	0.012	-0.019	2.450
		T ₄	14.028	0.540	0.003	-0.229	3.002
		T ₅	14.044	0.793	0.004	-0.135	2.776
	50	T ₆	14.056	0.196	0.005	-0.186	3.662
		T ₇	14.045	0.193	0.004	-0.218	3.600
		T ₀	14.005	0.354	0.001	-0.017	2.414
		T ₁	14.029	0.455	0.003	0.672	4.773
		T ₂	13.968	0.102	0.001	-0.272	3.252
		T ₃	14.064	2.572	0.006	-0.005	2.526
		T ₄	13.998	0.248	0.001	-0.032	2.512

Table-9
Comparison of estimators of population mean from Population-III with r=0.8.

r	n	Estimator	Estimate	SE	RB	Skewness	Kurtosis
0.80	10	T ₀	13.773	1.766	0.001	0.062	3.025
		T ₁	13.854	1.242	0.007	0.835	4.760
		T ₂	13.700	0.365	0.004	0.029	2.950
		T ₃	14.013	1.620	0.019	0.334	3.430
		T ₄	13.768	1.662	0.001	0.053	3.005
		T ₅	13.778	1.873	0.002	0.071	3.045
		T ₆	13.823	0.351	0.005	0.019	3.317
	30	T ₇	13.817	0.347	0.004	0.017	3.297
		T ₀	13.769	0.577	0.001	-0.007	2.423
		T ₁	13.745	0.341	0.001	0.064	2.618
		T ₂	13.715	0.110	0.003	-0.015	2.963
		T ₃	13.893	1.645	0.010	0.035	2.437
		T ₄	13.761	0.479	0.000	-0.016	2.448
		T ₅	13.777	0.688	0.002	-0.002	2.409
	50	T ₆	13.757	0.103	0.000	-0.010	2.872
		T ₇	13.752	0.103	0.000	-0.008	2.877
		T ₀	13.735	0.315	0.001	-0.001	2.452
		T ₁	13.761	0.194	0.000	0.109	2.848
		T ₂	13.729	0.060	0.002	-0.050	2.561
		T ₃	13.764	1.934	0.001	0.003	2.367
		T ₄	13.732	0.227	0.002	-0.003	2.542

Conclusion

From the above tables, it is observed that i. The estimators considered in this paper are almost unbiased in all the three populations. ii. It is also observed that the estimators are asymptotically normally distributed, since the skewness values are near to zero and kurtosis values are near to 3 in all the considered populations. iii. The standard error of the estimators decreases when the correlation and sample size increases in the populations-I, II and III. iv. From the standard errors of the estimators it is observed that the estimators proposed by Choudhury and Singh^{6,7} (T_7) and Sharma and Tailor⁵ (T_6) are almost equally efficient estimators and these two estimators showing the standard error almost equal to the standard error of the linear regression estimator (T_2). These three estimators (T_7 , T_6 and T_2) are more efficient estimators than that of the mean per unit estimator (T_0) and classical ratio estimator (T_1). v. The standard error of the product estimator (T_3) is very high compared to the standard errors of the remaining estimators. vi. The dual to ratio estimator (T_4) and dual to product estimator (T_5) are efficient than that of the mean per unit estimator (T_0) and ratio estimator (T_1). vii. The dual to ratio estimator (T_4) is efficient than that of the dual to product estimator (T_5). viii. From the above study, it is clearly observed that the dual to ratio-cum-product estimators are more efficient than that of the mean per unit estimator, classical ratio estimator and linear regression estimators. Specially, Choudhury and Singh^{6,7} and Sharma and Tailor⁵ estimators are more efficient estimators as compared to the other dual to ratio-cum-product estimators.

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