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Construction of Statistic Distribution Models for Nonparametric Goodness-of-Fit Tests in Testing Composite Hypotheses: The Computer Approach

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Abstract: In composite hypotheses testing, when the estimate of the scalar or vector parameter of the probabilities distribution laws is calculated by the same sample, the nonparametric goodness-of-fit Kolmogorov, Cramer-Mises-Smirnov, Anderson-Darling tests lose the free distribution property. In testing of composite hypotheses, the conditional distribution law of the statistic is affected by a number of factors: the form of the observed probabilities distribution law corresponding to the true testable hypothesis; the type of the parameter estimated and the number of parameters to be estimated; sometimes, it is a specific value of the parameter (*e.g.*, in the case of gamma-distribution and beta-distribution families); the method of parameter estimation. In this paper we present more precise results (tables of percentage points and statistic distribution models) for the nonparametric goodness-of-fit tests in testing composite hypotheses using the maximum likelihood estimate (*MSE*) for some probabilities distribution laws. Statistic distributions of the nonparametric goodness-of-fit tests are investigated by the methods of statistical simulation. Constructed empirical statistic distributions are approximated with analytical law models.

Keywords: Anderson-Darling test, composite hypotheses testing, Cramer-Mises-Smirnov test, goodness-of-fit test, Kolmogorov test.

1. Introduction

In composite hypotheses testing of the form $H_0 : F(x) \in \{F(x,\theta), \theta \in \Theta\}$, when the estimate $\hat{\theta}$ of the scalar or vector distribution parameter $F(x,\theta)$ is calculated by the same sample, the nonparametric goodness-of-fit Kolmogorov, ω^2 Cramer-Mises-Smirnov, Ω^2 Anderson-Darling tests lose the free distribution property.

The value

$$D_n = \sup_{|x|<\infty} |F_n(x) - F(x,\theta)|,$$

where $F_n(x)$ is the empirical distribution function, n is the sample size, is used in Kolmogorov test as a distance between the empirical and theoretical laws. In testing hypotheses, a statistic with Bolshev [3] correction of the form Bolshev and Smirnov [4].

$$S_K = \frac{6nD_n + 1}{6\sqrt{n}}, \tag{1}$$

where $D_n = \max(D_n^+, D_n^-)$,

$$D_n^+ = \max_{1 \le i \le n} \left\{ \frac{i}{n} - F(x_i, \theta) \right\},\ D_n^- = \max_{1 \le i \le n} \left\{ F(x_i, \theta) - \frac{i-1}{n} \right\},$$

n is the sample size, $x_1, x_2, \ldots, x_n$ are sample values in increasing order is usually used. The distribution of statistic (1) in testing simple hypotheses obeys the Kolmogorov distribution law $K(S) = \sum_{k=-\infty}^{\infty} (-1)^k e^{-2k^2 s^2}$.

In ω^2 Cramer-Mises-Smirnov test, one uses a statistic of the form

$$S_\omega = n\omega_n^2 = \frac{1}{12n} + \sum_{i=1}^{n} \left\{ F(x_i, \theta) - \frac{2i-1}{2n} \right\}^2, \tag{2}$$

and in test of Ω^2 Anderson-Darling type (Anderson and Darling [1, 2]), the statistic of the form

$$S_\Omega = -n - 2\sum_{i=1}^{n} \left\{ \frac{2i-1}{2n} \ln F(x_i, \theta) + \left(1 - \frac{2i-1}{2n}\right) \ln(1 - F(x_i, \theta)) \right\}. \tag{3}$$

In testing a simple hypothesis, statistic (2) obeys the distribution (see Bolshev and Smirnov [4]) of the form

$$a_1(S) = \frac{1}{\sqrt{2s}} \sum_{j=0}^{\infty} \frac{\Gamma\left(j+\frac{1}{2}\right)\sqrt{4j+1}}{\Gamma\left(\frac{1}{2}\right)\Gamma(j+1)} \exp\left\{ -\frac{(4j+1)^2}{16S} \right\} \times \left\{ I_{-\frac{1}{4}}\left[\frac{(4j+1)^2}{16S} \right] - I_{\frac{1}{4}}\left[\frac{(4j+1)^2}{16S} \right] \right\},$$

where $I_{-1/4}(\cdot), I_{1/4}(\cdot)$ - modified Bessel function,

$$I_\nu(z) = \sum_{k=0}^{\infty} \frac{\left(\frac{z}{2}\right)^{\nu+2k}}{\Gamma(k+1)\Gamma(k+\nu+1)},\ |z| < \infty, |\arg z| < \pi,$$

and statistic (3) obeys the distribution (Bolshev and Smirnov [4]) of the form

$$a_2(S) = \frac{\sqrt{2\pi}}{S} \sum_{j=0}^{\infty} (-1)^j \frac{\Gamma\left(j+\frac{1}{2}\right)(4j+1)}{\Gamma\left(\frac{1}{2}\right)\Gamma(j+1)} \exp\left\{ -\frac{(4j+1)^2 \pi^2}{8S} \right\} \times \int_0^{\infty} \exp\left\{ \frac{S}{8(y^2+1)} - \frac{(4j+1)^2 \pi^2 y^2}{8S} \right\} dy.$$

2. Statistic Distributions of the Tests in Testing Composite Hypotheses

In composite hypotheses testing, the conditional distribution law $G(S|H_0)$ of the statistic of the nonparametric tests when the hypothesis H_0 is valid, is affected by a number of factors: the form of the observed law $F(x, \theta)$ corresponding to the true hypothesis H_0; the type of the parameter estimated and the number of parameters to be estimated; sometimes, it is a specific value of the parameter (*e.g.*, in the case of gamma-distribution and beta-distribution families); the method of parameter estimation. The distinctions in the limiting distributions of the same statistics in testing simple and composite hypotheses are so significant that we cannot neglect them. For example, Figure 1 shows distributions of the Anderson-Darling statistic (3) while testing the composite hypotheses subject to different laws using maximum likelihood estimates (MLE) of two parameters.

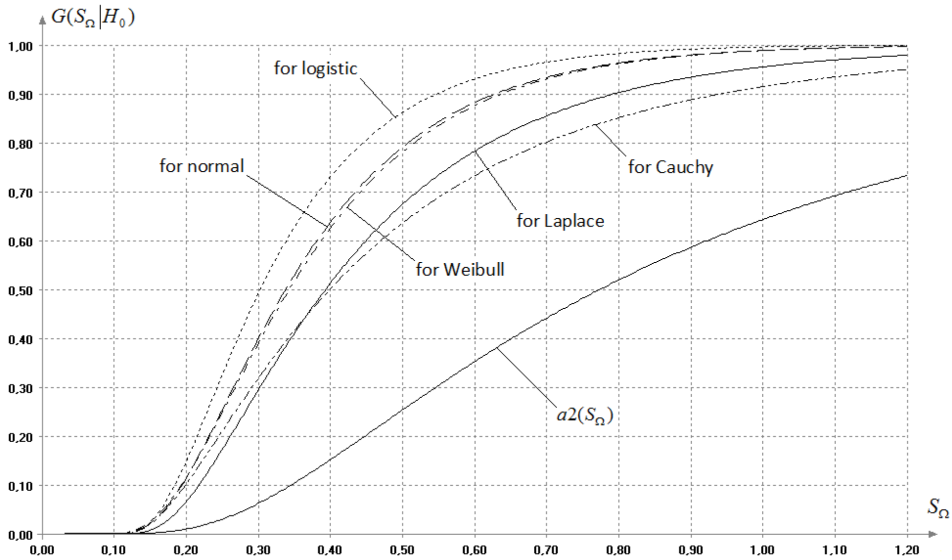

Figure 1. The Anderson-Darling statistic (3) distributions for testing composite hypotheses with calculating *MLE* of two law parameters.

Figure 2 illustrates the dependence of Kolmogorov test statistic (1) distribution upon the type and the number of estimated parameters by the example of *Su*-Jonson law.

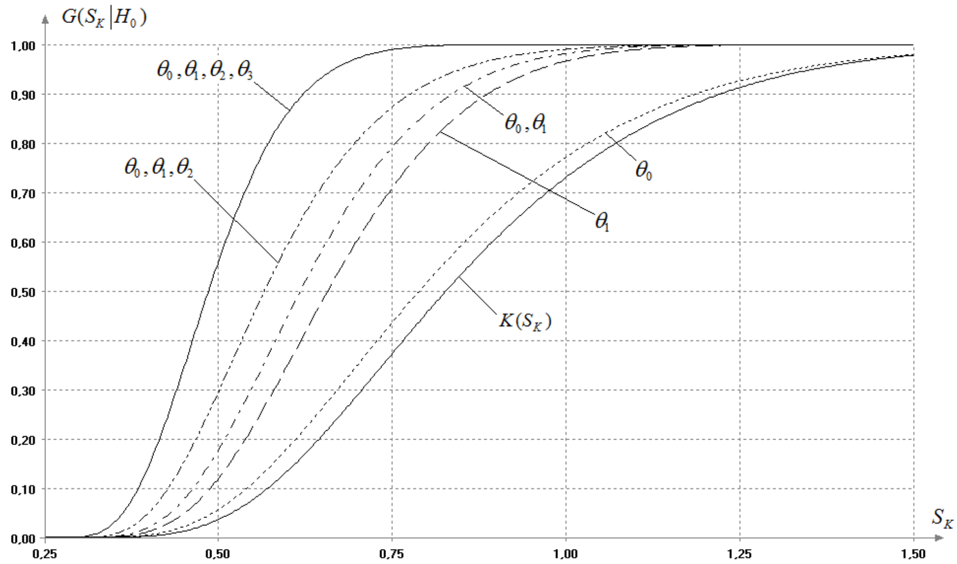

Figure 2. The Kolmogorov statistic (1) distributions for testing composite hypotheses with calculating *MLE* of Su-Jonson distribution law parameters.

The paper Kac *et al.* [14] was a pioneer in investigating statistic distributions of the nonparametric goodness-of-fit tests with composite hypotheses. Then, for the solution to this problem, various approaches where used Darling [6, 7], Durbin [8-10], Gihman [12, 13], Martinov [30], Pearson and Hartley [35], Stephens [38, 39], Chandra *et al.* [5], Tyurin [40], Tyurin and Savvushkina [41], Dzhaparidze and Nikulin [11], Nikulin [33, 34].

In our research Lemeshko and Postovalov [15-17], Lemeshko and Maklakov [18], Lemeshko *et al.* [20, 26, 28], Lemeshko and Lemeshko [23-25] statistic distributions of the nonparametric goodness-of-fit tests are investigated by the methods of statistical simulating, and for constructed empirical distributions approximate models of law are found. The results obtained were used to develop recommendations for standardization (R 50.1.037-2002 [36]).

3. Improvement of Statistic Distribution Models of the Nonparametric Goodness-of-Fit Tests

In this paper we present more precise results (tables of percentage points and statistic distribution models) for the nonparametric goodness-of-fit tests in testing composite hypotheses using the maximum likelihood estimate (MLE).

These investigations have been based on the developed software support. The software support allows of investigating probability regularities with the Monte-Carlo methods and constructing approximate analytical models for these regularities.

Table 1 contains a list of distributions relative to which we can test composite fit hypotheses using the constructed approximations of the limiting statistic distributions.

The tables of percentage points and statistic distributions models were constructed by modeled statistic samples with the size $N = 10^6$ (N is the number of runs in simulation). This number ensures the deviation of the empirical p.d.f. $G_N(S|H_0)$ from the theoretical (true) to be less than 10^{-3}. In this case, the samples of pseudorandom variables, belonging to $F(x,\theta)$, were generated with the size $n = 10^3$. For such value of n statistic p.d.f. $G(S_n|H_0)$ almost coincides with the limit p.d.f. $G(S|H_0)$.

Distributions $G(S|H_0)$ of the Kolmogorov statistic are best approximated by gamma-distributions family $\gamma(\theta_0,\theta_1,\theta_2)$ (see Table 1) or by the family of the III type beta-distributions with the density function

$$B_3(\theta_0,\theta_1,\theta_2,\theta_3,\theta_4) = \frac{\theta_2^{\theta_0}}{\theta_3 \mathrm{B}(\theta_0,\theta_1)} \frac{\left(\frac{x-\theta_4}{\theta_3}\right)^{\theta_0-1}\left(1-\frac{x-\theta_4}{\theta_3}\right)^{\theta_1-1}}{\left[1+(\theta_2-1)\frac{x-\theta_4}{\theta_3}\right]^{\theta_0+\theta_1}}.$$

And distributions of the Cramer-Mises-Smirnov and the Anderson-Darling statistics are well approximated by the family of the *Sb*-Johnson distributions $Sb(\theta_0,\theta_1,\theta_2,\theta_3)$ (see Table 1) or by the family of the III type beta-distributions $B_3(\theta_0,\theta_1,\theta_2,\theta_3,\theta_4)$.

Upper percentage points and constructed models of the limiting statistic distributions of the Kolmogorov test (when MLE are used) are presented in Table 2 [for laws: exponential, seminormal, Rayleigh, Maxwell, Laplace, normal, log-normal, Cauchy, logistic, extreme-value (maximum and minimum), Weibull].

For the same distribution laws upper percentage points and constructed models of the limiting statistic distributions of the Cramer-von Mises-Smirnov test are presented in Table 3, for Anderson-Darling test – in Table 4.

In Table 5 there are upper percentage points and models of limiting statistic distributions of nonparametric goodness-of-fit when MLE are used in the case of

Sb-Johnson distribution, in Table 6 – in the case of *Sl*-Johnson distribution, in Table 7 – in the case of *Su*-Johnson distribution.

Table 1. Random variable distribution.

Random variable distribution	Density function $f(x,\theta)$
Exponential	$\frac{1}{\theta_0} e^{-x/\theta_0}$.
Seminormal	$\frac{2}{\theta_0\sqrt{2\pi}} e^{-x^2/2\theta_0^2}$.
Rayleigh	$\frac{x}{\theta_0^2} e^{-x^2/2\theta_0^2}$.
Maxwell	$\frac{2x^2}{\theta_0^3\sqrt{2\pi}} e^{-x^2/2\theta_0^2}$.
Laplace	$\frac{1}{2\theta_0} e^{-\lvert x-\theta_1\rvert/\theta_0}$.
Normal	$\frac{1}{\theta_0\sqrt{2\pi}} e^{-\frac{(x-\theta_1)^2}{2\theta_0^2}}$.
Log-normal	$\frac{1}{x\theta_0\sqrt{2\pi}} e^{-(\ln x-\theta_1)^2/2\theta_0^2}$.
Cauchy	$\frac{\theta_0}{\pi[\theta_0^2+(x-\theta_1)^2]}$.
Logistic	$\frac{\pi}{\theta_0\sqrt{3}} \exp\left\{-\frac{\pi(x-\theta_1)}{\theta_0\sqrt{3}}\right\} \Big/ \left[1+\exp\left\{-\frac{\pi(x-\theta_1)}{\theta_0\sqrt{3}}\right\}\right]^2$.
Extreme-value (maximum)	$\frac{1}{\theta_0} \exp\left\{-\frac{x-\theta_1}{\theta_0} - \exp\left(-\frac{x-\theta_1}{\theta_0}\right)\right\}$.
Extreme-value (minimum)	$\frac{1}{\theta_0} \exp\left\{\frac{x-\theta_1}{\theta_0} - \exp\left(\frac{x-\theta_1}{\theta_0}\right)\right\}$.
Weibull	$\frac{\theta_0 x^{\theta_0-1}}{\theta_1^{\theta_0}} \exp\left\{-\left(\frac{x}{\theta_1}\right)^{\theta_0}\right\}$.
Sb-Johnson $Sb(\theta_0,\theta_1,\theta_2,\theta_3)$	$\frac{\theta_1\theta_2}{(x-\theta_3)(\theta_2+\theta_3-x)} \exp\left\{-\frac{1}{2}\left[\theta_0-\theta_1\ln\frac{x-\theta_3}{\theta_2+\theta_3-x}\right]^2\right\}$.
Sl-Johnson $Sl(\theta_0,\theta_1,\theta_2,\theta_3)$	$\frac{\theta_1}{(x-\theta_3)\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left[\theta_0+\theta_1\ln\frac{x-\theta_3}{\theta_2}\right]^2\right\}$.
Su-Johnson $Su(\theta_0,\theta_1,\theta_2,\theta_3)$	$\frac{\theta_1}{\sqrt{2\pi}\sqrt{(x-\theta_3)^2+\theta_2^2}} \exp\left\{-\frac{1}{2}\left[\theta_0+\theta_1\ln\left\{\frac{x-\theta_3}{\theta_2}+\sqrt{\left(\frac{x-\theta_3}{\theta_2}\right)^2+1}\right\}\right]^2\right\}$.
Gamma-distribution $\gamma(\theta_0,\theta_1,\theta_2)$	$\frac{1}{\theta_1^{\theta_0}\Gamma(\theta_0)}(x-\theta_2)^{\theta_0-1} e^{-(x-\theta_2)/\theta_1}$.

Distributions of the statistics of nonparametric goodness-of-fit tests if composite hypotheses are testing concerning all laws of distribution of the probabilities specified in table 1, except gamma-distribution, aren't depend on values of parameters of these laws (see Tables 2-7).

4. Improvement of Statistic Distribution Models of the Nonparametric Goodness-of-Fit Tests in the Case of Gamma-Distribution

In composite hypotheses testing subject to gamma-distribution with the density function

$$f(x,\theta)=\frac{x^{\theta_0-1}}{\theta_1^{\theta_0}\Gamma(\theta_0)}\exp\left(-\frac{x}{\theta_1}\right),$$

limiting statistics distributions of the nonparametric goodness-of-fit tests depend on values of the form parameter θ_0. For example, Figure 3 illustrates the dependence of the Kolmogorov statistic distribution upon the value θ_0 in testing a composite hypothesis only in the case of calculating *MLE* for the scale parameter of gamma-distribution.

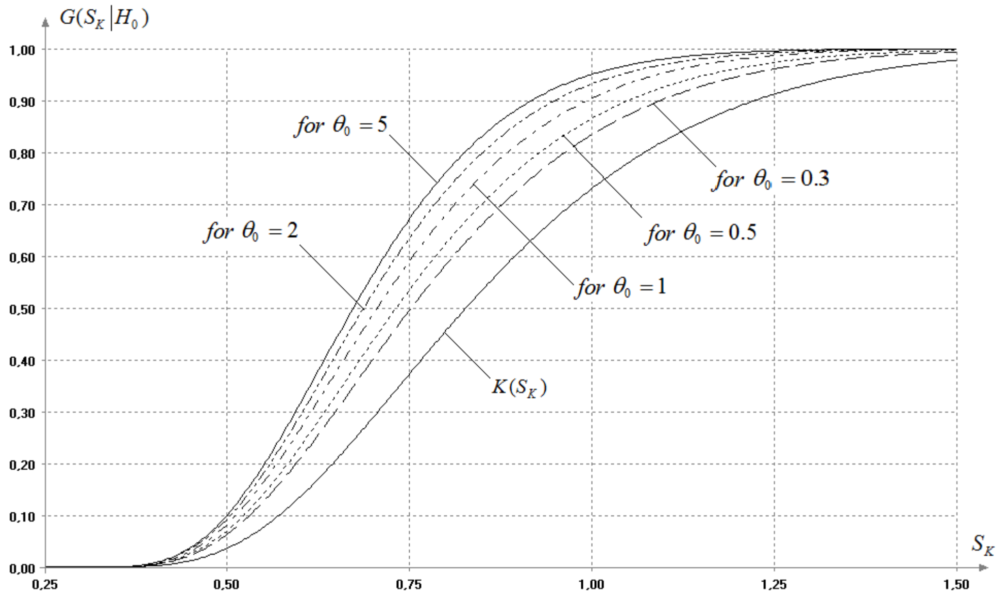

Figure 3. The Kolmogorov statistic (1) distributions for testing composite hypotheses with calculating *MLE* of scale parameter depend on the form parameter value of gamma-distribution.

Upper percentage points constructed as a result of statistical modeling and constructed models of limiting statistic distributions of the Kolmogorov test when *MLE* are used in the case of gamma-distribution are given in Table 8, for Cramer-von Mises-Smirnov test – in Table 9, for Anderson-Darling test – in Table 10. In this case the statistic distributions are well approximated by the family of the III type beta-distributions $B_3(\theta_0,\theta_1,\theta_2,\theta_3,\theta_4)$.

The upper percentage points and the models of statistic distributions, presented in Tables 8-10, improve the results given in recommendations (R 50.1.037–2002 [36]).

Table 2. Upper percentage points and models of limiting statistic distributions of the Kolmogorov's test when *MLE* are used.

Random variable distribution	Parameter estimated	Percentage points			Model
		0.1	0.05	0.01	
Exponential & Rayleigh	Scale	0.995	1.094	1.292	γ(5.1092; 0.0861; 0.2950)
Seminormal	Scale	1.051	1.160	1.381	γ(4.5462; 0.1001; 0.3100)
Maxwell	Scale	0.969	1.062	1.251	γ(5.4566; 0.0794; 0.2870)
Laplace	Scale	1.177	1.313	1.586	γ(3.3950; 0.1426; 0.3405)
	Shift	0.957	1.044	1.223	γ(5.1092; 0.0861; 0.2950)
	2 parameters	0.863	0.940	1.096	γ(6.2949; 0.0624; 0.2613)
Normal & Log-normal	Scale	1.191	1.327	1.600	γ(3.5609; 0.1401; 0.3375)
	Shift	0.888	0.963	1.114	γ(7.5304; 0.0580; 0.2400)
	2 parameters	0.835	0.909	1.057	γ(6.4721; 0.0580; 0.2620)
Cauchy	Scale	1.137	1.275	1.550	γ(3.0987; 0.1463; 0.3350)
	Shift	0.975	1.070	1.260	γ(5.9860; 0.0780; 0.2528)
	2 parameters	0.815	0.893	1.048	γ(5.3642; 0.0654; 0.2600)
Logistic	Scale	1.180	1.316	1.589	γ(3.4954; 0.1411; 0.3325)
	Shift	0.837	0.907	1.046	γ(7.6325; 0.0531; 0.2368)
	2 parameters	0.747	0.805	0.923	γ(7.5402; 0.0451; 0.2422)
Extreme-value & Weibull	Scale 1)	1.182	1.316	1.583	γ(3.6805; 0.1355; 0.3350) 1)
	Shift 2)	0.995	1.093	1.292	γ(5.2194; 0.0848; 0.2920) 2)
	2 parameters	0.824	0.895	1.037	γ(6.6012; 0.0563; 0.2598)

Note. 1) - we estimated the Weibull distribution form parameter, 2) - the Weibull distribution scale parameter.

Table 3. Upper percentage points and models of limiting statistic distributions of the Cramer-Mises-Smirnov's test when *MLE* are used.

Random variable distribution	Parameter estimated	Percentage points			Model
		0.1	0.05	0.01	
Exponential & Rayleigh	Scale	0.174	0.221	0.337	*Sb*(3.3738; 1.2145; 1.0792; 0.011)
Seminormal	Scale	0.205	0.266	0.415	*Sb*(3.527; 1.1515; 1.5527; 0.012)
Maxwell	Scale	0.162	0.204	0.306	*Sb*(3.353; 1.220; 0.9786; 0.0118)
Laplace	Scale	0.323	0.438	0.719	*Sb*(3.2262; 0.9416; 2.703; 0.015)
	Shift	0.151	0.187	0.267	*Sb*(2.9669; 1.2534; 0.6936; 0.01)
	2 parameters	0.115	0.144	0.214	*Sb*(3.768; 1.2865; 0.8336; 0.0113)
Normal & Log-normal	Scale	0.327	0.443	0.727	*Sb*(3.153; 0.9448; 2.5477; 0.016)
	Shift	0.134	0.165	0.238	*Sb*(3.243; 1.315; 0.6826; 0.0095)
	2 parameters	0.103	0.126	0.178	*Sb*(4.3950; 1.4428; 0.915; 0.009)
Cauchy	Scale	0.316	0.430	0.711	*Sb*(3.1895; 0.9134; 2.690; 0.013)
	Shift	0.172	0.216	0.319	*Sb*(2.359; 1.0732; 0.595; 0.0129)
	2 parameters	0.129	0.170	0.271	*Sb*(3.4364; 1.0678; 1.000; 0.011)
Logistic	Scale	0.323	0.438	0.719	*Sb*(3.264; 0.9581; 2.7046; 0.014)
	Shift	0.119	0.148	0.216	*Sb*(4.0026; 1.2853; 1.00; 0.0122)
	2 parameters	0.081	0.098	0.135	*Sb*(3.2137; 1.3612; 0.36; 0.0105)
Extreme-value & Weibull	Scale 1)	0.320	0.431	0.704	*Sb*(3.343; 0.9817; 2.753; 0.015) 1)
	Shift 2)	0.174	0.221	0.336	*Sb*(3.498; 1.2236; 1.1632; 0.01) 2)
	2 parameters	0.102	0.124	0.174	*Sb*(3.3854; 1.4453; 0.4986; 0.007)

Note. 1) - we estimated the Weibull distribution form parameter, 2) - the Weibull distribution scale parameter.

Table 4. Upper percentage points and models of limiting statistic distributions of the Anderson-Darling's test when *MLE* are used.

Random variable distribution	Parameter estimated	Percentage points			Model
		0.1	0.05	0.01	
Exponential & Rayleigh	Scale	1.060	1.319	1.954	*Sb*(3.8386; 1.3429; 7.500; 0.090)
Seminormal	Scale	1.188	1.499	2.267	*Sb*(4.2019; 1.2918; 11.500; 0.100)
Maxwell	Scale	1.010	1.247	1.832	*Sb*(3.9591; 1.3296; 7.800; 0.1010)
Laplace	Scale	1.726	2.286	3.684	*Sb*(4.3260; 1.0982; 27.00; 0.110)
	Shift	1.070	1.301	1.832	*Sb*(3.1506; 1.3352; 4.9573; 0.096)
	2 parameters	0.797	0.982	1.440	*Sb*(3,8071; 1,3531; 5,1809; 0,10)
Normal & Log-normal	Scale	1.745	2.309	3.706	*Sb*(4.3271; 1.0895; 28.000; 0.120)
	Shift	0.892	1.087	1.551	*Sb*(3.3085; 1.4043; 4.2537; 0.080)
	2 parameters	0.629	0.750	1.030	*Sb*(3.5601; 1.4846; 3.0987; 0.08)
Cauchy	Scale	1.716	2.277	3.673	*Sb*(3.7830; 1.0678; 18.0; 0.11)
	Shift	1.215	1.512	2.211	*Sb*(3.4814; 1.2375; 7.810; 0.1)
	2 parameters	0.948	1.226	1.913	*Sb*(3.290; 1.129; 5.837; 0.099)
Logistic	Scale	1.724	2.285	3.682	*Sb*(3.516;1.054; 14.748; 0.117)
	Shift	0.856	1.043	1.495	*Sb*(5.1316; 1.5681; 10.0; 0.065)
	2 parameters	0.562	0.665	0.903	*Sb*(3.409; 1.434; 2.448; 0.095)
Extreme-value & Weibull	Scale [1)]	1.723	2.273	3.634	*Sb*(3.512;1.064;14.496;0.125) [1)]
	Shift [2)]	1.059	1.318	1.952	*Sb*(4.799; 1.402; 13.0; 0.085) [2)]
	2 parameters	0.634	0.755	1.040	*Sb*(3.4830; 1.5138; 3.00; 0.07)

Note. [1)] - we estimated the Weibull distribution form parameter, [2)] - the Weibull distribution scale parameter.

Table 5. Upper percentage points and models of limiting statistic distributions of nonparametric goodness-of-fit when *MLE* are used in the case of *Sb*-Johnson distribution.

Parameter estimated	Percentage points			Model
	0.9	0.95	0.99	
for Kolmogorov's test				
θ_0	0.888	0.963	1.115	B_3(6.3484, 7.4913, 2.3663, 1.4790, 0.27)
θ_1	1.189	1.326	1.600	B_3(6.8242, 4.7737, 5.2621, 2.3878, 0.27)
θ_0, θ_1	0.836	0.909	1.058	B_3(6.6559, 8.1766, 2.9405, 1.6143, 0.27)
for Cramer-Mises-Smirnov's test				
θ_0	0.134	0.165	0.238	B_3(4.2304, 3.8058, 13.1934, 0.6908, 0.0086)
θ_1	0.327	0.442	0.724	B_3(2.9153, 2.0048, 33.4135, 2.07821, 0.0114)
θ_0, θ_1	0.104	0.126	0.179	B_3(4.3897, 4.0574, 12.1009, 0.5119, 0.0086)
for Anderson-Darling's test				
θ_0	0.893	1.087	1.553	B_3(4.2657, 4.3788, 11.4946, 4.6551, 0.084)
θ_1	1.741	2.309	3.702	B_3(4.1703, 2.3363, 42.0833, 12.6019, 0.088)
θ_0, θ_1	0.631	0.751	1.034	B_3(4.0891, 5.9708, 9.6497, 4.0000, 0.082)

Table 6. Upper percentage points and models of limiting statistic distributions of nonparametric goodness-of-fit when *MLE* are used in the case of *Sl*-Johnson distribution.

Parameter estimated	Percentage points			Model
	0.9	0.95	0.99	
for Kolmogorov's test				
θ_0	0.888	0.963	1.115	B_3(6.3484, 7.4913, 2.3663, 1.4790, 0.27)
θ_1	1.189	1.326	1.600	B_3(6.8242, 4.7737, 5.2621, 2.3878, 0.27)
θ_2	0.888	0.963	1.115	B_3(6.3484, 7.4913, 2.3663, 1.4790, 0.27)
θ_0, θ_1	0.836	0.909	1.058	B_3(6.6559, 8.1766, 2.9405, 1.6143, 0.27)
θ_0, θ_2	0.888	0.963	1.115	B_3(6.3484, 7.4913, 2.3663, 1.4790, 0.27)
θ_1, θ_2	0.836	0.909	1.058	B_3(6.6559, 8.1766, 2.9405, 1.6143, 0.27)
$\theta_0, \theta_1, \theta_2$	0.836	0.909	1.058	B_3(6.6559, 8.1766, 2.9405, 1.6143, 0.27)
for Cramer-Mises-Smirnov's test				
θ_0	0.134	0.165	0.238	B_3(4.2304, 3.8058, 13.1934, 0.6908, 0.0086)
θ_1	0.327	0.442	0.724	B_3(2.9153, 2.0048, 33.4135, 2.07821, 0.0114)
θ_2	0.134	0.165	0.238	B_3(4.2304, 3.8058, 13.1934, 0.6908, 0.0086)
θ_0, θ_1	0.104	0.126	0.179	B_3(4.3897, 4.0574, 12.1009, 0.5119, 0.0086)
θ_0, θ_2	0.134	0.165	0.238	B_3(4.2304, 3.8058, 13.1934, 0.6908, 0.0086)
θ_1, θ_2	0.104	0.126	0.179	B_3(4.3897, 4.0574, 12.1009, 0.5119, 0.0086)
$\theta_0, \theta_1, \theta_2$	0.104	0.126	0.179	B_3(4.3897, 4.0574, 12.1009, 0.5119, 0.0086)
for Anderson-Darling's test				
θ_0	0.893	1.087	1.553	B_3(4.2657, 4.3788, 11.4946, 4.6551, 0.084)
θ_1	1.741	2.309	3.702	B_3(4.1703, 2.3363, 42.0833, 12.6019, 0.088)
θ_2	0.893	1.087	1.553	B_3(4.2657, 4.3788, 11.4946, 4.6551, 0.084)
θ_0, θ_1	0.631	0.751	1.034	B_3(4.0891, 5.9708, 9.6497, 4.0000, 0.082)
θ_0, θ_2	0.893	1.087	1.553	B_3(4.2657, 4.3788, 11.4946, 4.6551, 0.084)
θ_1, θ_2	0.631	0.751	1.034	B_3(4.0891, 5.9708, 9.6497, 4.0000, 0.082)
$\theta_0, \theta_1, \theta_2$	0.631	0.751	1.034	B_3(4.0891, 5.9708, 9.6497, 4.0000, 0.082)

5. Conclusions

In this paper we present more precise models of statistic distributions of the nonparametric goodness-of-fit tests in testing composite hypotheses subject to some laws considered in recommendations for standardization R 50.1.037-2002 [36]. The models of statistic distributions of the nonparametric goodness-of-fit tests for testing composite hypotheses of the Exponential family (Lemeshko and Maklakov [18]) were made more precise earlier and haven't been improved now.

In the case of the I, II, III type beta-distribution families' statistic distributions depend on a specific value of two form parameter of these distributions. Statistic distributions models and tables of percentage points for various combinations of values of two form parameters (more than 1500 models) were constructed in the thesis of Lemeshko S. B. [29] and partly were published in the paper Lemeshko and Lemeshko [23].

Testing composite hypotheses, nonparametric goodness-of-fit tests of the Anderson-Darling and Kramer-Mises-Smirnov are more powerful, than Pearson χ^2 test or the modified χ^2 type Nikulin-Rao-Robson test (Nikulin [33, 34], Rao and Robson [37]). The results of comparative analysis of goodness-of-fit tests power (nonparametric and χ^2 type) subject to some sufficiently close pair of alternative are presented in Lemeshko *et al*. [19, 21, 22]. The results of application of the computer approach to research statistics distributions of the various tests checking hypotheses are considered in Lemeshko *et al*. [27].

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Table 7. Upper percentage points and models of limiting statistic distributions of nonparametric goodness-of-fit when *MLE* are used in the case of Su-Johnson distribution.

Parameter estimated	Percentage points			Model
	0.9	0.95	0.99	
for Kolmogorov's test				
θ_0	0.888	0.963	1.115	B_3(6.3484, 7.4913, 2.3663, 1.4790, 0.27)
θ_1	1.189	1.326	1.600	B_3(6.8242, 4.7737, 5.2621, 2.3878, 0.27)
θ_2	1.161	1.300	1.576	B_3(5.3417, 4.6440, 4.7448, 2.3802, 0.29)
θ_3	0.880	0.960	1.122	B_3(6.6252, 7.4025, 3.0590, 1.6516, 0.27)
θ_0, θ_1	0.836	0.909	1.058	B_3(6.4792, 7.0243, 2.8437, 1.4260, 0.27)
θ_0, θ_2	0.798	0.872	1.024	B_3(6.4496, 6.7714, 3.3119, 1.4226, 0.27)
θ_0, θ_3	0.802	0.875	1.023	B_3(6.3069, 6.1065, 3.2916, 1.3317, 0.27)
θ_1, θ_2	1.142	1.282	1.561	B_3(5.9751, 4.4559, 5.6810, 2.4123, 0.27)
θ_1, θ_3	0.792	0.858	0.994	B_3(6.4839, 7.0152, 2.7376, 1.2838, 0.27)
θ_2, θ_3	0.733	0.791	0.910	B_3((6.2438, 6.9161, 2.5011, 1.0904, 0.27)
$\theta_0, \theta_1, \theta_2$	0.776	0.851	1.007	B_3(6.2414, 6.4027, 3.7458, 1.4361, 0.27)
$\theta_0, \theta_1, \theta_3$	0.720	0.780	0.901	B_3(6.4262, 6.9732, 2.7325, 1.1317, 0.26)
$\theta_0, \theta_2, \theta_3$	0.658	0.706	0.806	B_3(6.1239, 7.9516, 2.24033, 0.9839, 0.26)
$\theta_1, \theta_2, \theta_3$	0.704	0.760	0.878	B_3(7.1354, 8.0363, 2.7466, 1.1766, 0.25)
$\theta_0, \theta_1, \theta_2, \theta_3$	0.622	0.666	0.755	B_3(6.6889, 8.1712, 2.3857, 0.9291, 0.25)

Table 7. (*continued*)

Parameter estimated	Percentage points			Model
	0.9	0.95	0.99	
for Cramer-Mises-Smirnov's test				
θ_0	0.134	0.165	0.238	B_3(3.6736, 3.9355, 11.2146, 0.6908, 0.01)
θ_1	0.327	0.442	0.724	B_3(2.9153, 2.0048,33.4135,2.07821, 0.0114)
θ_2	0.318	0.433	0.716	B_3(2.2077, 1.7250, 28.4959, 1.75, 0.015)
θ_3	0.125	0.154	0.225	B_3(3.6990, 3.8775, 11.9942, 0.6601, 0.01)
θ_0, θ_1	0.104	0.126	0.179	B_3(4.3897, 4.0574, 12.1009, 0.5119, 0.0086)
θ_0, θ_2	0.090	0.110	0.161	B_3(5.2030, 3.9325, 15.6968, 0.4659, 0.0075)
θ_0, θ_3	0.104	0.133	0.203	B_3(5.9540, 3.1023, 30.6943, 0.6380, 0.0071)
θ_1, θ_2	0.314	0.428	0.711	B_3(2.4905, 1.6985, 45.9674, 2.3084, 0.012)
θ_1, θ_3	0.094	0.113	0.158	B_3(4.6011, 5.7370, 19.1580, 1.0, 0.0075)
θ_2, θ_3	0.080	0.096	0.137	B_3(4.7686, 4.6085, 11.1421, 0.3929, 0.0075)
$\theta_0, \theta_1, \theta_2$	0.083	0.104	0.155	B_3(5.2574, 3.6440, 19.9213, 0.4707, 0.0075)
$\theta_0, \theta_1, \theta_3$	0.071	0.086	0.122	B_3(5.7750, 4.7935, 18.1182, 0.4777, 0.0065)
$\theta_0, \theta_2, \theta_3$	0.056	0.066	0.089	B_3(7.3500, 5.4726, 13.7452, 0.2883, 0.0052)
$\theta_1, \theta_2, \theta_3$	0.073	0.089	0.130	B_3(5.6379, 4.0985, 18.5518, 0.42100, 0.007)
$\theta_0, \theta_1, \theta_2, \theta_3$	0.048	0.056	0.075	B_3(6.9739, 6.6406, 13.7433, 0.3151, 0.0052)
for Anderson-Darling's test				
θ_0	0.893	1.087	1.553	B_3(4.2329, 4.5369, 10.8807, 4.6551, 0.082)
θ_1	1.741	2.309	3.702	B_3(4.1703, 2.3363,42.0833, 12.6019, 0.088)
θ_2	1.707	2.275	3.667	B_3(2.6348, 1.9774, 21.3842, 7.75, 0.125)
θ_3	0.952	1.161	1.649	B_3(3.5597, 4.9656, 11.4180, 6.5202, 0.092)
θ_0, θ_1	0.631	0.751	1.034	B_3(4.0891, 5.9708, 9.6497, 4.0000 , 0.082)
θ_0, θ_2	0.577	0.689	0.961	B_3(5.5368, 4.9114, 13.1278, 3.0625, 0.07)
θ_0, θ_3	0.737	0.920	1.386	B_3(5.6629, 3.4912, 25.1600, 4.5052, 0.07)
θ_1, θ_2	1.666	2.232	3.627	B_3(3.8896, 1.6253, 31.1820, 5.80, 0.09)
θ_1, θ_3	0.694	0.842	1.200	B_3(4.6199, 5.2874, 19.2708, 6.5610, 0.074)
θ_2, θ_3	0.642	0.935	1.140	B_3(4.4276, 4.30288, 14.6688, 3.7865, 0.08)
$\theta_0, \theta_1, \theta_2$	0.518	0.627	0.898	B_3(5.5158, 4.3512, 14.7750, 2.6199, 0.067)
$\theta_0, \theta_1, \theta_3$	0.454	0.536	0.733	B_3(5.3306, 5.8858, 10.7581, 2.5087, 0.065)
$\theta_0, \theta_2, \theta_3$	0.396	0.459	0.606	B_3(5.7098, 6.8325, 7.9837, 1.8803, 0.06)
$\theta_1, \theta_2, \theta_3$	0.585	0.729	1.087	B_3(5.1840, 3.2993, 19.3614, 2.7865, 0.073)
$\theta_0, \theta_1, \theta_2, \theta_3$	0.329	0.378	0.489	B_3(7.1015, 5.8708, 7.1323, 1.0517, 0.05)

Table 8. Upper percentage points and models of limiting statistic distributions of the Kolmogorov's test when *MLE* are used in the case of gamma-distribution.

Value of the form parameter	Parameter estimated	Percentage points			Model
		0.1	0.05	0.01	
0.3	Scale	1.096	1.211	1.444	B_3(6.6871; 4.8368; 4.4047; 1.9440; 0.281)
	form	0.976	1.070	1.262	B_3(6.4536; 5.7519; 3.3099; 1.6503; 0.280)
	2 parameters	0.905	0.990	1.162	B_3(6.9705; 5.6777; 3.6297; 1.5070; 0.270)
0.5	Scale	1.051	1.160	1.379	B_3(6.9356; 5.0081; 4.3582; 1.8470; 0.280)
	form	0.961	1.052	1.236	B_3(6.3860; 5.9685; 3.1228; 1.6154; 0.280)
	2 parameters	0.884	0.965	1.131	B_3(6.4083; 5.9339; 3.2063; 1.4483; 0.2774)
1.0	Scale	0.994	1.095	1.299	B_3(6.7187; 5.3740; 3.7755; 1.6875; 0.282)
	form	0.936	1.022	1.191	B_3(6.1176; 6.4704; 2.6933; 1.5501; 0.280)
	2 parameters	0.862	0.940	1.097	B_3(5.6031; 6.1293; 2.7065; 1.3607; 0.2903)
2.0	Scale	0.952	1.044	1.228	B_3(5.8359; 22.6032; 2.1921; 4.00; 0.282)
	form	0.915	0.995	1.155	B_3(6.1387; 6.5644; 2.6021; 1.4840; 0.280)
	2 parameters	0.849	0.924	1.077	B_3(5.8324; 6.1446; 2.7546; 1.3280; 0.2862)
3.0	Scale	0.933	1.020	1.200	B_3(5.9055; 24.4312; 2.0996; 4.00; 0.282)
	form	0.906	0.985	1.140	B_3(6.1221; 6.6131; 2.5536; 1.4590; 0.280)
	2 parameters	0.845	0.919	1.070	B_3(6.0393; 6.1276; 2.8312; 1.3203; 0.2827)
4.0	Scale	0.923	1.008	1.181	B_3(5.9419; 27.1264; 1.9151; 4.00; 0.282)
	form	0.901	0.980	1.132	B_3(6.0827; 6.7095; 2.4956; 1.4494; 0.280)
	2 parameters	0.843	0.916	1.066	B_3(6.1584; 6.1187; 2.8748; 1.3170; 0.2807)
5.0	Scale	0.917	1.000	1.170	B_3(5.8774; 30.0692; 1.7199; 4.00; 0.282)
	form	0.899	0.977	1.127	B_3(6.0887; 6.7265; 2.4894; 1.4432; 0.280)
	2 parameters	0.842	0.915	1.063	B_3(6.1957; 6.1114; 2.8894; 1.3140; 0.2801)

Table 9. Upper percentage points and models of limiting statistic distributions of the Cramer-Mises-Smirnov's test when *MLE* are used in the case of gamma-distribution.

Value of the form parameter	Parameter estimated	Percentage points			Model
		0.1	0.05	0.01	
0.3	Scale	0.233	0.305	0.482	B_3(3.2722; 1.9595; 16.1768; 0.750; 0.013)
	form	0.166	0.209	0.316	B_3(3.0247; 3.2256; 11.113; 0.7755; 0.0125)
	2 parameters	0.127	0.158	0.233	B_3(2.3607; 4.0840; 7.0606; 0.6189; 0.0145)
0.5	Scale	0.205	0.264	0.413	B_3(3.2296; 2.1984; 14.3153; 0.700; 0.013)
	form	0.159	0.199	0.298	B_3(3.0143; 3.3504; 10.095; 0.7214; 0.0125)
	2 parameters	0.119	0.146	0.212	B_3(2.7216; 3.9844; 7.4993; 0.5372; 0.013)
1.0	Scale	0.175	0.220	0.336	B_3(3.1201; 2.5460; 11.1200; 0.600; 0.013)
	form	0.149	0.186	0.273	B_3(2.9928; 3.4716; 8.8275; 0.6346; 0.0125)
	2 parameters	0.111	0.136	0.194	B_3(3.0000; 3.8959; 7.3247; 0.4508; 0.012)
2.0	Scale	0.155	0.193	0.288	B_3(2.9463; 3.1124; 9.1160; 0.600; 0.013)
	form	0.142	0.176	0.256	B_3(2.9909; 3.5333; 8.2010; 0.5786; 0.0125)
	2 parameters	0.107	0.131	0.185	B_3(3.0533; 3.9402; 7.1173; 0.4246; 0.0118)
3.0	Scale	0.148	0.184	0.272	B_3(2.8840; 3.3796; 8.4342; 0.600; 0.013)
	form	0.139	0.172	0.251	B_3(2.9737; 3.5528; 7.8843; 0.5549; 0.0125)
	2 parameters	0.106	0.129	0.182	B_3(3.0703; 3.9618; 7.034; 0.4163; 0.0117)
4.0	Scale	0.145	0.179	0.264	B_3(2.8522; 3.5285; 8.1044; 0.600; 0.013)
	form	0.138	0.171	0.248	B_3(2.9677; 3.5426; 7.7632; 0.5418; 0.0125)
	2 parameters	0.105	0.128	0.180	B_3(3.0967; 3.9539; 7.064; 0.4122; 0.0116)
5.0	Scale	0.142	0.176	0.259	B_3(2.8249; 3.6280; 7.8756; 0.6000; 0.013)
	form	0.137	0.169	0.246	B_3(2.9638; 3.5465; 7.6558; 0.5334; 0.0125)
	2 parameters	0.105	0.128	0.179	B_3(4.4332; 3.6256; 10.552; 0.4098; 0.0084)

Table 10. Upper percentage points and models of limiting statistic distributions of the Anderson-Darling's test when *MLE* are used in the case of gamma-distribution.

Value of the form parameter	Parameter estimated	Percentage points			Model
		0.1	0.05	0.01	
0.3	Scale	1.300	1.655	2.543	B_3(3.3848; 2.8829; 14.684; 6.0416; 0.1088)
	form	1.021	1.258	1.865	B_3(3.1073; 3.7039; 8.6717; 4.3439; 0.1120)
	2 parameters	0.718	0.870	1.233	B_3(4.5322; 4.060; 10.0718; 2.9212; 0.078)
0.5	Scale	1.183	1.490	2.260	B_3(5.0045; 2.9358; 18.8524; 5.2436; 0.077)
	form	0.993	1.221	1.791	B_3(3.1104; 3.7292; 8.0678; 4.0132; 0.1120)
	2 parameters	0.684	0.824	1.145	B_3(5.0079; 4.056; 10.0292; 2.5872; 0.073)
1.0	Scale	1.058	1.313	1.955	B_3(5.0314; 3.1848; 15.4626; 4.3804; 0.077)
	form	0.952	1.166	1.696	B_3(3.1149; 3.7919; 7.4813; 3.6770; 0.1120)
	2 parameters	0.657	0.785	1.084	B_3(5.0034; 4.1093; 9.1610; 2.3427; 0.073)
2.0	Scale	0.980	1.203	1.771	B_3(4.9479; 3.3747; 13.0426; 3.8304; 0.077)
	form	0.922	1.125	1.625	B_3(3.0434; 4.1620; 7.1516; 3.8500; 0.1120)
	2 parameters	0.643	0.766	1.051	B_3(4.9237; 4.2091; 8.6643; 2.2754; 0.073)
3.0	Scale	0.952	1.163	1.702	B_3(5.0367; 3.4129; 12.9013; 3.6867; 0.077)
	form	0.912	1.110	1.601	B_3(3.0565; 3.9092; 6.7844; 3.3972; 0.1120)
	2 parameters	0.639	0.761	1.043	B_3(4.9475; 4.2070; 8.6686; 2.2512; 0.073)
4.0	Scale	0.937	1.141	1.662	B_3(4.9432; 3.5038; 12.2240; 3.6302; 0.077)
	form	0.906	1.103	1.590	B_3(3.0531; 3.9437; 6.7619; 3.3993; 0.1120)
	2 parameters	0.637	0.758	1.039	B_3(4.9274; 4.2279; 8.5573; 2.2390; 0.073)
5.0	Scale	0.927	1.130	1.640	B_3(4.8810; 3.5762; 11.7894; 3.6051; 0.077)
	form	0.902	1.099	1.586	B_3(3.0502; 3.9640; 6.7510; 3.4024; 0.1120)
	2 parameters	0.636	0.757	1.037	B_3(4.9207; 4.2432; 8.4881; 2.2314; 0.073)

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