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SHARTLI BOG'LIQSIZ TASODIFIY MIQDORLAR UCHUN MARKAZIY LIMIT TEOREMA

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ANNOTATSIYA

Ushbu maqolada shartli bog’liqsiz miqdorlarni yig’indisi uchun limit teoremalar o’rganiladi va ular uchun markaziy limit teoremani o’rinli bo’lish shartlari aniqlanadi. Maqola ishining asosiy maqsadi shartli bog’liqsiz miqdorlarni yig’indisi uchun limit teoremalarni o’rganish va ular uchun markaziy limit teoremani o’rinli bo’lish shartlarini aniqlashdan iborat. **S**hartli bog’liqsiz miqdorlarni o’rganish, ularning yig’indisi uchun asimptotik qonuniyatlarni aniqlash, shartli bog’liqsiz tasodifiy miqdorlar uchun limit teoremalarni isbotlash. Shuningdek shartli bog’liqsiz miqdorlarni yig’indisi uchun limit teoremalar o’rganilgan va ular uchun markaziy limit teoremani o’rinli bo’lish shartlari ko’rilgan. Ushbu maqoladan magistratura o’qitiladigan maxsus kurslarda, hamda ilmiy tadqiqot ishlarini olib borishda foydalanish mumkin va amaliyotda bog’liq statistik ma’lumotlar bo’yicha xulosalar chiqarishda qo’llaniladi.

Kalit so’zlar: tasodifiy miqdor, shartli bog’liqsiz, sigma algebra, markaziy limit teorema

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ABSTRACT

In this article, limit theorems for the sum of conditionally independent quantities are studied and the conditions for the central limit theorem to be valid for them are determined. The main goal of the article is to study the limit theorems for the sum of conditionally independent quantities and to determine the conditions for the central limit theorem to be appropriate for them. Studying conditionally independent quantities, determining asymptotic laws for their sum, proving limit theorems for conditionally independent random quantities. Also, limit theorems for the sum of conditionally independent quantities were studied and the conditions for the central limit theorem to be appropriate for them were seen. This article can be used in special courses taught by the master's degree, as well as in conducting scientific research, and in practice it is used to draw conclusions on relevant statistical data.

Key words: random quantity, conditional independence, sigma algebra, central limit theorem

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АННОТАЦИЯ

В статье изучаются предельные теоремы для суммы условно независимых величин и определяются условия справедливости для них центральной предельной теоремы. Основная цель статьи — исследование предельных теорем для суммы условно независимых величин и определение условий применимости к ним центральной предельной теоремы. Изучение условно независимых величин, определение асимптотических законов их суммы, доказательство предельных теорем для условно независимых случайных величин. Также были изучены предельные теоремы для суммы условно независимых величин и рассмотрены условия применимости к ним центральной предельной теоремы. Эта статья может быть использована на спецкурсах, читаемых в магистратуре, а также при проведении научных исследований, а на практике используется для получения выводов по соответствующим статистическим данным.

Ключевые слова: случайная величина, условная независимость, сигма-алгебра, центральная предельная теорема.

Faraz qilaylik $\{X_{n,k}, k=1,...,k_n\}$ $n \in N$ tasodifiy miqdorlar ketma-ketligi bo‘lsin, bunda k_n - tasodifiy bo‘lmagan, $n \to \infty$ da $k_n \to \infty$ bo‘lgan ketma-ketlik bo‘lsin. Bundan keyin

$$S_n = X_{n,1} + X_{n,2} + ... + X_{n,k_n}, n \in N$$

deymiz. $A_n, n \in N$ - biror σ - algebralar ketma – ketligi bo‘lsin, $A_n \subset F, n \in N.$ Shartli bog’liqsiz tasodifiy miqdorlar uchun quyidagi Lindiberg-Feller teoremasining analogi o‘rinli.

Teorema 1 Faraz qilaylik $\{X_{n,k}, k=1,2,...,k_n, n \in N\}$ tasodifiy miqdorlar seriyalar sxemasida har bir $n \in N$ uchun $X_{n,1}, X_{n,2}, ..., X_{n,k_n}$ miqdorlar σ - algebra A_n ga nisbatan shartli bog’liqsiz, $Var^{A_n} X_{n,k} < \infty$, $k = 1,2,...k_n, n \in N$ bo‘lsin. Shu bilan birga $\left(\sigma_n^{A_n}\right)^2 := \mathrm{var}^{A_n} S_n > 0$ bo‘lsin. Bu holda quyidagi ikki munosabat

$$\max_{k=1,2,...,k_n} \frac{\mathrm{var}^{A_n} X_{n,k}}{\left(\sigma_n^{A_n}\right)^2} \xrightarrow{P} \infty, \mathrm{n} \to \infty \qquad (1)$$

va har bir $t \in R$ uchun

$$E^{A_n} \exp\left\{it \frac{S_n - E^{A_n} S_n}{\sigma_n^{A_n}}\right\} \xrightarrow{P} \exp\left\{-\frac{t^2}{2}\right\}, n \to \infty \qquad (2)$$

o‘rinli bo‘lishi uchun quyidagi A_n - shartli Lindiberg sharti: ixtiyoriy $\varepsilon > 0$ son uchun $n \to \infty$ da

$$\frac{1}{\left(\sigma_n^{A_n}\right)^2} \sum_{k=1}^{k_n} E^{A_n} \left(X_{n,k} - E^{A_n} X_{n,k}\right)^2 I\left(\left|X_{n,k} - E^{A_n} X_{n,k}\right| \geq \varepsilon \sigma_n^{A_n}\right) \to 0 \qquad (3)$$

bajarilishi zarur va yetarli.

Isboti. Faraz qilaylik (3.3.3) shart o‘rinli bo‘lsin.

$$Z_{n,k} = \frac{X_{n,k} - E^{A_n} X_{n,k}}{\sigma_n^{A_n}}, k = 1,2,...,k_n, n \in N$$

deymiz. U holda

$$T_n = \frac{S_n - E^{A_n} S_n}{\sigma_n^{A_n}} = \sum_{k=1}^{k_n} Z_{n,k}, \mathrm{n} \in \mathrm{N}.$$

Ko‘rish qiyin emaski

$$E^{A_n} Z_{n,k} = E^{A_n} \frac{X_{n,k} - E^{A_n} X_{n,k}}{\sigma_n^{A_n}} = E^{A_n}\left(\frac{X_{n,k} - E^{A_n} X_{n,k}}{\sigma_n^{A_n}}\right) == \frac{1}{E^{A_n}}\left(E^{A_n} X_{n,k} - E^{A_n} X_{n,k}\right) = 0$$

chunki $\sigma_n^{A_n}$ va $E^{A_n} X_{n,k}$ miqdorlar A_n ga nisbatan o‘lchovli.

Teorema 2 Agar X va Y tasodifiy miqdorlar $G-$bog’liqsiz bo’lib, $Z-$tasodifiy miqdor $G-$o’lchamli bo’lsa , u holda $X+Z$ va Y tasodifiy miqdorlar $G-$bog’liqsiz bo’ladi.

Teorema 3 Agar X va Y tasodifiy miqdorlar $G-$bog’liqsiz va Z tasodifiy miqdor $G-$o’lchovli bo’lsa, u holda XZ va Y tasodifiy miqdorlar $G-$bog’liqsiz bo’ladi.

. Teorema 2 va 3 ga ko‘ra $Z_{n,1}, Z_{n,2}, ..., Z_{n,k}$ tasodifiy miqdorlar A_n - shartli bog’liqsizdir. Endi (.3) shartni quyidagi

$$L_n^{A_n}(\varepsilon) = \sum_{k=1}^{n} E^{A_n}\left(Z_{n,k}^2 I\left(\left|Z_{n,k}\right| > \varepsilon\right)\right) \xrightarrow{P} 0,$$

$n \to \infty$ da ko‘rinishda yozib olamiz.

Quyidagiga egamiz:

$$\frac{\mathrm{var}^{A_n} X_{n,k}}{\left(\sigma_n^{A_n}\right)^2} = E^{A_n} Z_{n.k} = E^{A_n}\left(Z_{n,k}^2 I\left(\left|Z_{n,k}\right| < \varepsilon\right)\right) + E^{A_n} I\left(Z_{n,k}^2 I\left(\left|Z_{n,k}\right| \geq \varepsilon\right)\right) \leq \varepsilon^2 + L_n^{A_n}(\varepsilon)$$

Oxirgi munosabatdan, (4) munosabatga ko‘ra (1) ni hosil qilamiz. Endi (2) ni qaraymiz. Teorema 1 ga ko’ra har bir $t \in R$ uchun quyidagi

$$\varphi_{T_n}^{A_n}(t) = \varphi_{Z_{n,1}}^{A_n}(t) \cdot ... \cdot \varphi_{Z_{n,k_n}}^{A_n}(t)$$

munosabatga egamiz. Eng avvalo

$$\max_{1 \leq k \leq k_n} \left|\varphi_{Z_{n,k}}^{A_n}(t) - 1\right| \xrightarrow{P} 0, \ n \to \infty \qquad (5)$$

ekanligini ko‘rsatamiz. Yaxshi ma’lumki har bir $u \in R$ va ixtiyoriy $p \in Z_+$ uchun quyidagi

$$\exp\{in\} = \sum_{k=0}^{p} \frac{(in)^k}{k!} + R_p(u),$$

formula o‘rinli, bunda $i^2 = -1$,

$$\left|R_p(u)\right| \leq \min\left\{2\frac{|u|^p}{p!}, \frac{|u|^{p+1}}{(p+1)!},\right\}. \qquad (6)$$

$E^{A_n} Z_{n,k} = 0$ bo‘lgani uchun

$$\varphi_{Z_{n,k}}^{A_n}(t) - 1 = E^{A_n}\left(e^{itZ_{n,k}} - 1 - itZ_{n,k}\right).$$

(6) tengsizlikda $p = 1$ deb olib quyidagini hosil qilamiz:

$$\left|\varphi_{Z_{n,k}}^{A_n}(t) - 1\right| \leq \frac{t^2}{2} E^{A_n} Z_{n,k}^2 = \frac{t^2}{2} \frac{\mathrm{var}^{A_n} X_{n,k}}{\left(\sigma_n^{A_n}\right)^2}, \qquad (7)$$

d.m., $k = 1, 2, ..., k_n$. Oxirgi tengsizlikdan va (1) dan (5) kelib chiqadi. Xususiy holda

$$P\left(\max_{1 \leq k \leq k_n} \left|\varphi_{Z_{n,k}}^{A_n}(t) - 1\right| \leq \frac{1}{2}\right) \to 1, \ n \to \infty.$$

Quyidagi

$$D_n=\left\{\max_{1\le k\le k_n}\left|\varphi_{Z_{n,k}}^{A_n}(t)-1\right|\le\frac{1}{2}\right\},\ n\in N$$

tasodifiy hodisalarni kiritamiz. Agar $|Z|\le\frac{1}{2}$ bo‘lsa

$$\left|\ln(1+z)-Z\right|\le\sum_{j=2}^{\infty}\frac{|Z|^j}{j}\le\frac{|Z|^2}{2(1-|Z|)}\le|Z|^2 \qquad (8)$$

tengsizlik o‘rinli.

Endi (8) dan $\omega\in D_n, k=1,2,...,k_n$ uchun quyidagini hosil qilamiz.

$$\ln\varphi_{Z_{n,k}}^{A_n}(t)=\ln\left(1+\left(\varphi_{Z_{n,k}}^{A_n}(t)-1\right)\right)=\varphi_{Z_{n,k}}^{A_n}(t)-1+r_{n,k}(t),$$

bunda $\left|r_{n,k}(t)\right|\le\left|\varphi_{Z_{n,k}}^{A_n}(t)-1\right|^2$.

Shunday qilib, $\omega\in D_n$, uchun

$$\ln\varphi_{T_n}^{A_n}(t)=\ln\prod_{k=1}^{k_n}\varphi_{Z_{n,k}}^{A_n}(t)=\sum_{k=1}^{k_n}\ln\varphi_{Z_{n,k}}^{A_n}(t)+2\pi N_n(t), \qquad (9)$$

bunda $N_n(t)$ musbat butun qiymatlar qabul qiladi, qoldiq had $r_n(t)=\sum_{k=1}^{k_n}r_{n,k}(t)$.

Shunung ω ning ko‘rsatilgan qiymatlari uchun

$$\left|r_n(t)\right|\le\sum_{k=1}^{k_n}\left|\varphi_{Z_{n,k}}^{A_n}(t)-1\right|^2\le\max_{1\le k\le k_n}\left|\varphi_{Z_{n,k}}^{A_n}(t)-1\right|\sum_{k=1}^{k_n}\left|\varphi_{Z_{n,k}}^{A_n}(t)-1\right| \qquad (10)$$

bo‘ladi. (7) ga ko‘ra

$$\sum_{k=0}^{k_n}\left|\varphi_{Z_{n,k}}^{A_n}(t)-1\right|\le\frac{t^2}{2}\sum_{k=1}^{k_n}E^{A_n}Z_{n,k}=\frac{t^2}{2} \qquad (11)$$

Endi $\omega\in D_n$ uchun $r_n(t)=0$ deylik. U holda (5), (10) va (11) ga ko‘ra har bir $t\in R$ uchun

$$r_n(t)\xrightarrow{p}0, n\to\infty. \qquad (12)$$

Belgilaymiz:

$$\sigma_n^{A_n}(t)=\sum_{k=1}^{k_n}\left|\varphi_{Z_{n,k}}^{A_n}(t)-1\right|+\frac{t^2}{2}, \quad \text{va} \quad g_t(x)=e^{itx}-1-itx-\frac{(itx)^2}{2},\ x\in R.$$

Endi

$$\sum_{k=1}^{k_n}E^{A_n}Z_{n,k}^2=1$$

ekanligini hisobga olib ixtiyoriy $\varepsilon>0$ son uchun quyidagiga egamiz:

$$G_n^{A_n}(t)=\sum_{k=1}^{k_n}E^{A_n}g_t\left(Z_{n,k}\right)=\sum_{k=1}^{k_n}E^{A_n}g_t\left(Z_{n,k}\right)I\left(\left|Z_{n,k}\right|<\varepsilon\right)+\sum_{k=1}^{k_n}E^{A_n}g_t\left(Z_{n,k}\right)I\left(\left|Z_{n,k}\right|>\varepsilon\right).$$

(3.3.6) bahoni qo‘llab, quyidagini hosil qilamiz:

$$\left|G_n^{A_n}(t)\right|\le\frac{|t|^3}{3!}\sum_{k=1}^{k_n}E^{A_n}\left(\left|Z_{n,k}\right|^3I\left(\left|Z_{n,k}\right|<\varepsilon\right)\right)+t^2\sum_{k=1}^{k_n}E^{A_n}\left(\left|Z_{n,k}\right|^2I\left(\left|Z_{n,k}\right|\ge\varepsilon\right)\right)\le\frac{|t|^3\varepsilon}{6}+t^2L_n^{A_n}(\varepsilon)$$

Bundan, ε ni ixtiyoriyligidan, $G_n^{A_n}(t)\xrightarrow{p}0,\ n\to\infty$ ekanligi kelib chiqadi. (9) ga ko‘ra $\omega\in D_n$ lar uchun

$$\varphi_{T_n}^{A_n}(t)=\exp\left\{-\frac{t^2}{2}+G_n^{A_n}(t)+r_n(t)\right\}$$

ekanligi kelib chiqadi. U holda $\omega\in\Omega$ uchun

$$\varphi_{T_n}^{A_n}(t)=\exp\left\{-\frac{t^2}{2}+G_n^{A_n}(t)+r_n(t)\right\}I(D_n)+\varphi_{T_n}^{A_n}(t)I(D_n)$$

Oxirgi munosabatdan, Lebegning mojarirlangan yaqinlashish haqidagi teoremasiga ko‘ra (2) kelib chiqadi.

Endi (1) va (2) bajarilsin. U holda (3) ham bajarilishini ko‘rsatamiz. Biz (1) dan (5) kelib chiqishini ko‘rdik. Demak, (9) va (12) munosabatlar o‘rinli. (9) ga ko‘ra $\omega\in D_n$ uchun har bir $t\in R$ da

$$\operatorname{Re}\ln\varphi_{T_n}^{A_n}(t)=\sum_{k=1}^{k_n}\left(\operatorname{Re}\varphi_{Z_{n,k}}^{A_n}(t)-1\right)+\operatorname{Re}r_n(t)$$

o‘rinli, ya’ni $\ln\left|\varphi_{T_n}^{A_n}(t)\right|=\sum_{k=1}^{k_n}\left(E^{A_n}\cos\left(tZ_{n,k}\right)-1\right)+\operatorname{Re}r_n(t).$

(2) munosabatdan $\left|\varphi_{T_n}^{A_n}(t)\right|\xrightarrow{p}e^{-\frac{t^2}{2}},\ n\to\infty$ ekanligi kelib chiqadi.

Shunday qilib, $\omega\in D_n$ uchun $\ln\left|\varphi_{T_n}^{A_n}(t)\right|=-\frac{t^2}{2}+q_n(t),$ bunda $q_n(t)\xrightarrow{p}0,\ n\to\infty.$

Demak, $\omega\in D_n$ da $\sum_{k=1}^{k_n}E^{A_n}\left(\cos\left(tZ_{n,k}\right)-1\right)=-\frac{t^2}{2}+\alpha_n(t),$

bunda $\alpha_n(t):=q_n(t)-\operatorname{Re}\tau_n(t)\xrightarrow{p}0,\ n\to\infty.$

Ixtiyoriy $\varepsilon>0$ va $\omega\in D_n$ uchun quyidagiga egamiz:

$$\frac{t^2}{2}-\sum_{k=1}^{k_n}E^{A_n}\left(1-\cos\left(tZ_{n,k}\right)\right)I\left(\left|Z_n\right|<\varepsilon\right)=\sum_{k=1}^{k_n}E^{A_n}\left(1-\cos\left(tZ_{n,k}\right)\right)I\left(\left|Z_n\right|\geq\varepsilon\right)+\alpha_n(t).$$

Endi $1-\cos(\alpha)\leq\frac{\alpha^2}{2},\ \alpha\in R$ tengsizlikni hisobga olib, quyidagi tengsizlikni hosil qilamiz:

$$\sum_{k=1}^{k_n}E^{A_n}\left(1-\cos\left(tZ_{n,k}\right)\right)I\left(\left|Z_n\right|<\varepsilon\right)\leq\frac{t^2}{2}\sum_{k=1}^{k_n}E^{A_n}(Z_{n,k}^2I\left(\left|Z_n\right|<\varepsilon\right)=\frac{t^2}{2}\left(1-L_n^{A_n}(\varepsilon)\right).$$

Demak, $\frac{t^2}{2}-\sum_{k=1}^{k_n}E^{A_n}\left(1-\cos\left(tZ_{n,k}\right)\right)I\left(\left|Z_n\right|<\varepsilon\right)\geq\frac{t^2}{2}\alpha_n^{A_n}(\varepsilon).$

Endi $1-\cos(x)\leq 2$ ekanligini hisobga olib,

$$\sum_{k=1}^{k_n}E^{A_n}\left(\left(1-\cos\left(tZ_{n,k}\right)\right)I\left\{\left|Z_n\right|\geq\varepsilon\right\}\right)\leq 2\sum_{k=1}^{k_n}E^{A_n}I\left\{\left|Z_n\right|\geq\varepsilon\right\}\leq\frac{2}{\varepsilon^2}\sum_{k=1}^{k_n}E^{A_n}\left(Z_{n,k}^2I\left\{\left|Z_n\right|\geq\varepsilon\right\}\right)\leq\frac{2}{\varepsilon^2}.$$

Shuning uchun $\omega\in D_n$ lar uchun

$$0\leq L_n^{A_n}(\varepsilon)\leq\frac{2}{t^2}\left(\frac{2}{\varepsilon}+\alpha_n(t)\right)$$

Quyidagiga egamiz: $L_n^{A_n}(\varepsilon)=I(D_n)L_n^{A_n}(\varepsilon)+I\left(\overline{D}\right)L_n^{A_n}(\varepsilon).$

Tushunarliki, $I\left(\overline{D}\right)L_n^{A_n}(\varepsilon)\xrightarrow{p}0,\ n\to\infty.$

Ko‘rish qiyin emaski, $I(D_n)L_n^{A_n}(\varepsilon)\leq\frac{2}{t^2}\left(\frac{2}{\varepsilon^2}+\alpha_n(t)\right).$

Ixtiyoriy $\delta>0$ son uchun t_0 ni $u\big/\left(t_0^2\varepsilon^2\right)=\delta\big/2$

munosabatni qanoatlantiradigan qilib tanlaymiz. U holda

$$P\left(I\left(D_n\right)L_n^{A_n}\left(\varepsilon\right)>\delta\right)\le P\left(\alpha_n\left(t_0\right)>\frac{\delta t_0^2}{4}\right)\to 0,\ n\to\infty.$$

Biz (4) ni bajarilishiga, ya’ni (3) ni bajarilishiga ishonch hosil qildik. Teorema isbot bo‘ldi.

Biror sigma algebraga nisbatan aniqlangan shartli xarakteristik funksiya bir ehtimollik bilan xarakteristik funksiyaning barcha asosiy xossalariga ega ekan. Tasodifiy miqdorlarning xarakteristik funksiyalarini bir xilligidan ularning shartli shartli xarakteristik funksiyalari bir xilligi kelib chiqmas ekan. Ikkita tasodifiy miqdorning shartli xarakteristik funksiyalarini ustma-ust tushishidan ularning xarakteristik funksiyalari bir xil ekanligi kelib chiqadi. Shartli xarakteristik funksiyalar yaqinlashishidan mos xarakteristik funksiyalar yaqinlashishi kelib chiqadi, lekin aksi to'g'ri bo'lmasligi mumkin. Shartli bog'liqsiz va shartli bir xil taqsimlangan tasodifiy miqdorlarning yig'indisi uchun markaziy limit teorema o'rinli bo'lishi uchun bu miqdorlarning shartli dispersiyasi bir ehtimollik bilan mavjud va musbat bo'lishi yetarli ekan.

Ma’lumki ehtimollar nazariyasi va matematik statistikaning ko’pgina
masalalari shartli bog’liqsiz miqdorlarni o’rganishga keltiriladi. Shu sababdan shartli bog’liqsiz miqdorlarni o’rganish, ularning yig’indisi uchun asimptotik qonuniyatlarni aniqlash muhim masaladir. Xususan, shartli bog’liqsiz tasodifiy miqdorlar uchun limit teoremalar kerak bo’ladi. Ushbu maqolada shartli bog’liqsiz miqdorlar yig’indisi uchun markaziy limit teoremalar shartli variantlari o’rganilgan, teorema isbotlangan.

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