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Central Limit Theorem for Empirical Process under New Dependent Coefficient

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Central Limit Theorem for Empirical Process under New Dependent Coefficient

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Introduction

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Time series and random fields are main topics in modern statistical techniques. This is because they are essential for applications where randomness plays an important role. To describe the asymptotic behavior of certain time series or random fields, many ways of modeling the weak dependence have already been worked out.

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Central Limit Theorem for Empirical Process under New Dependent Coefficient
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► One of the most popular is the notion of mixing, there exists a wide literature on limit theorems under various classical mixing conditions such as strong mixing condition (α -mixing), absolute regularity (β -mixing), or φ -mixing. Examples for such conditions to hold are investigated in Doukhan(1994) and Rio(2000). However, many commonly used models for real-world phenomena do not satisfy classical mixing conditions. Moreover, a main inconvenience of mixing assumptions is the difficulty of checking them because the calculation involves the complicated manipulation of taking the supremum over two σ -algebras.

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$\gamma_1 = \beta_0 + \beta_1 z_1 + \varepsilon_1$ \Rightarrow A reasonable question is then: how to modify the definition of the usual mixing coefficients in order to catch many more examples, without losing too much of their nice properties?

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In this paper, we propose a new dependence measure (γ -weak dependence) under the wasserstein metric for time series.

I) This definition make explicit the 'asymptotic independence' in some sense between 'past' and 'future', some examples show that this weak dependence holds in many cases of interest.

II) Our condition is much easier to compute than mixing conditions for some financial time series models, moreover, we can give the computable rate of convergence for the dependence measure.

III) We obtain central limit theorem of empirical process under γ -weak dependence following from the tightness criterion given in Theorem 2.1 of Shao and Yu(1996).

$$\text{Var}(x^2) = \frac{\left[\frac{n}{2}\right] \left(\frac{U}{\sigma^2}\right)^{\frac{n-3}{2}}}{\sqrt{n}\pi^{\frac{n}{2}}} (1 + \frac{r^2}{U})^{\frac{n-3}{2}}$$

$$f_u(t) = \frac{\left[\frac{n}{2}\right] \left(\frac{U}{\sigma^2}\right)^{\frac{n-3}{2}}}{\sqrt{n}\pi^{\frac{n}{2}}} (1 + \frac{t^2}{U})^{\frac{n-3}{2}}$$

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$$\sum_{i=1}^n \frac{(X_i - \bar{X})^2}{n-1}$$

$$\text{Var}(x^2) = \beta_0 + \beta_1 x_1 + \beta_2$$

$$f_u(t) = \frac{\Gamma\left(\frac{v+1}{2}\right)}{\sqrt{2\pi n f(\xi)}} \left(1 + \frac{t^2}{v}\right)^{\frac{-v+1}{2}}$$

$$\frac{Mn - \xi}{\sqrt{2\sqrt{n} f(\xi)}} \xrightarrow{d} N(0,1)$$

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$$\frac{Mn - \xi}{\sqrt{2\sqrt{n} f(\xi)}} \xrightarrow{d} N(0,1)$$

Wasserstein distance

Definition 1 For probability measures μ, ν on a separable metric space (U, d) , the Wasserstein distance is defined as follows:

$$\text{Var}(x^2) = \frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n-1} \quad d_W(\mu, \nu) = \inf\{E[d(X, Y)]\}, \quad (1)$$

where the inf is w.r.t. all random variables X, Y with distributions μ, ν . Kantorovich-Rubinstein theorem gives a dual representation of Wasserstein distance in terms of a Lipschitz-metric:

$$\text{Var}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^4\right)}{n} \quad P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt \quad \text{Var}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^4\right)}{n} \quad P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt \quad \text{Var}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^4\right)}{n} \quad P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

$$\sum_{i=1}^n \frac{(X_i - \bar{X})^2}{n-1} \quad d_W(\mu, \nu) = \sup | \int_{\mathbb{R}} f d(\mu - \nu) | \quad \text{Var}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^4\right)}{n} \quad P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt \quad \text{Var}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^4\right)}{n} \quad P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

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i.e. sup over all f s.t. $|f(x) - f(y)| \leq d(x, y)$. d being the underlying metric on the space.

$$L(f) = \int_{\mathbb{R}} \frac{|f(x)|}{\theta^2} e^{-\frac{x^2}{2\theta^2}} dx$$

$$\sum_{i=1}^n \frac{|X_i - \bar{X}|}{n}$$

$$\text{Var}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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γ - weak dependence coefficient

Definition 2 The sequence $\{X_n\}_{n \in N}$ is called γ -weak dependent, if there exists a sequence $\theta = (\theta_n)_{n \in N}$ decreasing to zero at infinity such that for any u -tuple (i_1, \dots, i_u) and any v -tuple (j_1, \dots, j_v) with $i_1 \leq \dots \leq i_u < i_u + r \leq j_1 \leq \dots \leq j_v$, one has

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

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$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$dW(\mu_{uv}, v_{uv}) = \sup_{\|f\|_{L \leq 1}} \int f d(\mu_{uv} - v_{uv}) \leq (u+v)\theta_r. \quad (3)$$

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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where μ_{uv} denotes the joint distribution of $(X_{i_1}, \dots, X_{i_u}, X_{j_1}, \dots, X_{j_v})$ and $v_{uv} = v_u \times v_v$, here, v_u and v_v are the marginal distributions of $(X_{i_1}, \dots, X_{i_u})$ and $(X_{j_1}, \dots, X_{j_v})$, respectively. The Lipschitz norm is defined as follows:

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$f_x(t) = \frac{\Gamma(\frac{u+1}{2})}{\sqrt{u\pi}\Gamma(\frac{u}{2})} \left(1 + \frac{t^2}{\theta^2}\right)^{-\frac{u+1}{2}}$$

$$f_x(t) = \frac{\Gamma(\frac{u+1}{2})}{\sqrt{u\pi}\Gamma(\frac{u}{2})} \left[|f(x_1, \dots, x_u) - f(y_1, \dots, y_u)|\right]$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

$$\|f\|_L = \sup_{\substack{(x_1, \dots, x_u) \neq (y_1, \dots, y_u) \\ L(\theta) = \frac{1}{\theta^2} e^{-\frac{x^2}{2\theta^2}}}} |x_1 - y_1| + \dots + |x_u - y_u|$$

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

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$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

$$P_{2,1}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^2\right)}{n}$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

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$$\sum_{i=1}^n \frac{(X_i - \bar{X})^2}{n-1} = \frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2$$

$$f_n(t) = \frac{\Gamma\left(\frac{n+1}{2}\right)}{\left(\frac{1}{2}\right)^{\frac{n+1}{2}}} (1 + t^2)^{-\frac{n+1}{2}}$$

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$$L(\theta) = \frac{1}{\theta^{n/2}} e^{-\frac{\sum_i (X_i - \bar{X})^2}{2\theta}}$$

$$E[X_0] < \infty, \text{ then } (X_n)_{n \in \mathbb{Z}} \text{ is } \gamma\text{-weak dependent.}$$

$$\text{In fact, let } (X'_{i_1}, \dots, X'_{i_u}) \text{ is independent and identical}$$

$$\text{distributed with } (X_{i_1}, \dots, X_{i_u}), \text{ and } (X'_{i_1}, \dots, X'_{i_u}) \text{ is in-}$$

$$\text{dependent of } (\eta_n)_{n \in \mathbb{Z}}. \text{ Denote } X'_n = T(X'_{n-1}) + \eta_n, n \geq$$

$$i_u + 1, \text{ then}$$

$$\sum_{i=1}^n \frac{(X_i - \bar{X})^2}{n-1} = \frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2$$

$$y_1 = \beta_0 + \beta_1 z_1 + \varepsilon_1$$

$$y_1 = \beta_0 + \beta_1 z_1 + \varepsilon_1$$

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$$L(\theta) = \frac{1}{\theta^{n/2}} e^{-\frac{\sum_i (X_i - \bar{X})^2}{2\theta}}$$

So we can take $\theta_n = 2c^r E|X_0|$.

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Example 2 For non-strong mixing Markov chain

$$f_n(t) = \frac{\Gamma\left(\frac{n+1}{2}\right)}{\sqrt{\pi n!}} \left(1 + \frac{t^2}{\nu}\right)^{-\frac{n+1}{2}}$$

$$\frac{Mn - \xi}{\sqrt{2}\sqrt{n} f(\xi)} \xrightarrow{t \rightarrow N(0,1)}$$

$$X_n = \frac{(X_{n-1} + \eta_n)/2}{\sqrt{\nu n!}} \sim N(0,1)$$

$$f_n(t) = \frac{\Gamma\left(\frac{n+1}{2}\right)}{\sqrt{\pi n!}} \left(1 + \frac{t^2}{\nu}\right)^{-\frac{n+1}{2}}$$

$$\frac{Mn - \xi}{\sqrt{2}\sqrt{n} f(\xi)} \xrightarrow{t \rightarrow N(0,1)}$$

where $(\eta_n)_{n \geq 0}$ is i.i.d., $P(\eta_0 = 0) = P(\eta_0 = 1) = 1/2$.

If $E|X_0| < \infty$, then $(X_n)_{n \in N}$ is γ -weak dependent, here

$$\theta_r = 2E|X_0| \frac{1}{2r} \int_{-\infty}^{\infty} \frac{t}{\theta^2} e^{-\frac{|t|}{\theta^2}} dt$$

Example 3 Consider random coefficient autoregressive model:

$$f_n(t) = \frac{\Gamma\left(\frac{n+1}{2}\right)}{\sqrt{\pi n!}} \left(1 + \frac{t^2}{\nu}\right)^{-\frac{n+1}{2}}$$

$$\frac{Mn - \xi}{\sqrt{2}\sqrt{n} f(\xi)} \xrightarrow{t \rightarrow N(0,1)}$$

$$X_t = c(\eta_{t-1}) X_{t-1} + g(\eta_{t-1}) \sim N(0,1)$$

$$f_n(t) = \frac{\Gamma\left(\frac{n+1}{2}\right)}{\sqrt{\pi n!}} \left(1 + \frac{t^2}{\nu}\right)^{-\frac{n+1}{2}}$$

$$\frac{Mn - \xi}{\sqrt{2}\sqrt{n} f(\xi)} \xrightarrow{t \rightarrow N(0,1)}$$

where $\{\eta_t\}_{t \geq 1}$ is i.i.d. r.v.s. and independent of X_0 . If $\{X_t\}$ initialized from stationary distribution, $\rho = E|c(\eta_t)| <$

$1, E|X_0| < \infty$, then $\{X_t\}_{t \geq 1}$ is γ -weak dependent, where

$$\theta_n = 2E|X_0|\rho^n.$$

Example 4 Let $(\varepsilon_i)_{i \in N}$ be a sequence independent random variables, F is a measurable function, $(X_i)_{i \in N}$ is a Markov chain and defined as follows:

$$L(\theta) = \prod_{i=1}^{n-1} \frac{s_i}{\theta^{1/2}} e^{-\frac{s_i^2}{2\theta^2}}$$

$$X_{n+1} = F(X_n, \varepsilon_{n+1}), \quad (4)$$

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t}{\theta^2}} dt$$

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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Suppose the initial distribution X_0 is independent of $(\varepsilon_i)_{i \in N}$, and F satisfy for some $a \geq 1, 0 < \alpha < 1$,

$$E|F(0, \varepsilon_1)|^a < \infty, E|F(x, \varepsilon_1) - F(y, \varepsilon_1)|^a \leq \alpha^a |x-y|^a. \quad (5)$$

$$f_n(t) = \frac{1}{\sqrt{n\pi t}} \left(\frac{t}{\theta} \right)^{\frac{n-3}{2}} e^{-\frac{t^2}{2\theta^2}}$$

$$f_n(t) = \frac{1}{\sqrt{2\sqrt{n} f(\xi)}} \left(\frac{t}{\theta} \right)^{\frac{n-3}{2}} e^{-\frac{(t-\xi)^2}{2\theta^2}}$$

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$$L(\theta) = \frac{1}{\theta^{2n}} e^{-\frac{\sum x_i}{\theta^2}}$$

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Duflo show that under the condition (5) Markov chain $(X_i)_{i \in N}$ have stationary law with finite moment of order α . Suppose Markov chain $(X_i)_{i \in N}$ initialized from stationary law, if $E|X_0|^a < \infty$, then $\{X_t\}_{t \geq 1}$ is γ -weak dependent, here $\theta_n = 2(\alpha^a)^n E|X_0|^a$.

Example 5 A simple bilinear process with recurrence equation

$$X_t = aX_{t-1} + bX_{t-1}\eta_{t-1} + \eta_t.$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

$$L(\theta) = \frac{1}{\theta^{2n}} e^{-\frac{\sum x_i}{\theta^2}}$$

If $\{X_t\}$ initialized from stationary law X_0 , and satisfy $|c| = E|a+b\eta_0| < 1, E|X_0|^{a+1} < \infty$, then $\{X_t\}_{t \geq 1}$ is γ -weak dependent, here $\theta_n = 2c^n E|X_0|$.

$$L(\theta) = \frac{1}{\theta^{2n}} e^{-\frac{\sum x_i}{\theta^2}}$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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An Empirical Process CLT

$$f_n(t) = \frac{\Gamma\left(\frac{n+1}{2}\right)}{\sqrt{\pi}} \left(1 + \frac{t^2}{\theta^2} - \frac{\sigma^2}{2}\right)^{-\frac{n+1}{2}}$$

$$\frac{Mn - \xi}{\sqrt{2\sqrt{n} f(\xi)}} \xrightarrow{D} N(0, 1)$$

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$$\frac{Mn - \xi}{\sqrt{2\sqrt{n} f(\xi)}} \xrightarrow{D} N(0, 1)$$

Let $\{Y_t\}_{t \in \mathbb{Z}}$ be a real-valued stationary process. The empirical process of the sequence $\{Y_t\}_{t \in \mathbb{Z}}$ at time n is defined as $\frac{1}{\sqrt{n}}E_n(x)$, where

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

$$E_n(x) = \sum_{k=1}^n (\mathbf{1}_{(Y_k \leq x)} \xrightarrow{\frac{d}{dt}} P(Y_k \leq x)).$$

$$\beta_0 + \beta_1 z_1 + \beta_2$$

$$\frac{\sum_{k=1}^n (X_k - \bar{X})^2}{n-1}$$

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We consider the following convergence result in the Skorohod space $D([0, 1])$ when the sample size n tends to infinity:

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

$$\frac{1}{\sqrt{n}} E_n(x) \xrightarrow{d} \bar{B}(x), \quad \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}}$$

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

Here $\bar{B}(x)$ denotes a centered Gaussian process with covariance given by

$$\frac{\Gamma\left(\frac{n+1}{2}\right)}{\sqrt{n}\pi\Gamma\left(\frac{n}{2}\right)}$$

$$\frac{\Gamma\left(\frac{n+1}{2}\right)}{\sqrt{n}\pi\Gamma\left(\frac{n}{2}\right)}$$

$$\frac{Mn - \xi}{\sqrt{2\sqrt{n} f(\xi)}} \xrightarrow{D} N(0, 1)$$

$$\frac{\Gamma\left(\frac{n+1}{2}\right)}{\sqrt{n}\pi\Gamma\left(\frac{n}{2}\right)}$$

$$\frac{Mn - \xi}{\sqrt{2\sqrt{n} f(\xi)}} \xrightarrow{D} N(0, 1)$$

$$E\bar{B}(x)\bar{B}(y) = \sum_{k=-\infty}^{\infty} (P(Y_0 \leq x, Y_k \leq y) \xrightarrow{\frac{1}{\theta^2} \frac{z_k}{n}} P(Y_0 \leq x)P(Y_k \leq y)).$$

$$\frac{\sum_{k=1}^n z_k}{n-1}$$

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$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$P(X \leq x) = \int_0^x \frac{t}{\theta^2} e^{-\frac{t}{\theta^2}} dt$$

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Theorem Let $(Y_i)_{i \in \mathbb{Z}}$ be a stationary γ -weak dependent sequence, if there exists constant $C > 0, a > 5$ such that

$$f_n(t) = \frac{1}{\sqrt{n}} \left(\sum_{i=1}^n Y_i^2 \right)^{\frac{1}{2}} \xrightarrow{d} N(0, 1)$$

$$f_n(t) \xrightarrow{d} \frac{1}{\sqrt{n}} \left(\sum_{i=1}^n E(Y_i^2) \right)^{\frac{1}{2}} \xrightarrow{d} N(0, 1)$$

$$f_n(t) \xrightarrow{d} \frac{1}{\sqrt{n}} \left(\sum_{i=1}^n \left(\mu_2 + \frac{(Y_i - \bar{Y})^2}{n-1} \right) \right)^{\frac{1}{2}} \xrightarrow{d} N(0, 1)$$

$$f_n(t) \xrightarrow{d} \frac{1}{\sqrt{n}} \left(\sum_{i=1}^n \left(\mu_2 + \frac{(Y_i - \bar{Y})^2}{n-1} \right) \right)^{\frac{1}{2}} \xrightarrow{d} N(0, 1)$$

Then the following empirical functional convergence holds true in the Skorohod space of real-valued càdlàg functions on the unit interval, $D([0, 1])$:

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$P(X \leq x) = \int_0^x \frac{t}{\theta^2} e^{-\frac{t}{\theta^2}} dt$$

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$$y_1 = \beta_0 + \beta_1 z_1 + \varepsilon_1$$

$$\sum_{i=1}^n (X_i - \bar{X})^2$$

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$$y_1 = \beta_0 + \beta_1 z_1 + \varepsilon_1$$

$$f_n(t) = \frac{\Gamma\left(\frac{v+1}{2}\right)}{\sqrt{v\pi}\Gamma\left(\frac{v}{2}\right)} \left(1 + \frac{t^2}{v}\right)^{-\frac{v+1}{2}}$$

$$\frac{Mn - \xi}{\sqrt{2}\sqrt{n}f(\xi)} \xrightarrow{d} N(0, 1)$$

$$f_n(t) = \frac{\Gamma\left(\frac{v+1}{2}\right)}{\sqrt{v\pi}\Gamma\left(\frac{v}{2}\right)} \left(1 + \frac{t^2}{v}\right)^{-\frac{v+1}{2}}$$

$$L(\theta) = \frac{\prod_{i=1}^n z_i}{\theta^{2k}} e^{-\frac{\sum_{i=1}^n Y_i^2}{2\theta^2}}$$

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

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Several Key Lemmas

$$\sum_{i=1}^n \frac{x_i}{\beta_0 + \beta_1 x_i} \stackrel{\text{Law}}{\rightarrow} \text{Uniform}[0, 1]$$

$$f_n(t) = \frac{\Gamma\left(\frac{n+1}{2}\right)}{\sqrt{\pi/2}} \frac{1}{(1+t^2/\theta^2)^{(n+1)/2}}$$

$$\frac{Mn - \xi}{\sqrt{2\int_0^\infty f(\xi)}} \xrightarrow{D} N(0, 1)$$

$$f_n(t) = \frac{\Gamma\left(\frac{n+1}{2}\right)}{\sqrt{\pi/2}} \frac{1}{(1+t^2/\theta^2)^{(n+1)/2}}$$

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$$\frac{Mn - \xi}{\sqrt{2\int_0^\infty f(\xi)}} \xrightarrow{D} N(0, 1)$$

We use a quantile transform to obtain that the marginal distribution of this sequence is the uniform law on $[0, 1]$.

Lemma 1 Assume that $(Y_i)_{i \in \mathbb{Z}}$ is a stationary sequence and the density of Y_i are bounded by C_Y . For $s < t, s, t \in [0, 1]$, denote $g_{t,s}(x) = \mathbf{1}\{x \leq t\} - \mathbf{1}\{x \leq s\}$. Let $\mathbf{i} = (i_1, \dots, i_u) \in \mathbb{Z}^u, \mathbf{j} = (j_1, \dots, j_v) \in \mathbb{Z}^v$, and $i_1 \leq \dots \leq i_u < i_u + r \leq j_1 \leq \dots \leq j_v$. Let G and H be two bounded Lipschitz functions on \mathbb{R}^u and \mathbb{R}^v respectively. Denote $\mathbf{Y}_{\mathbf{i}} = (Y_{i_1}, \dots, Y_{i_u})$. If $(Y_i)_{i \in \mathbb{Z}}$ is γ -weak dependent, then

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$|Cov(G(g_{t,s}(\mathbf{Y}_{\mathbf{i}})), H(g_{t,s}(\mathbf{Y}_{\mathbf{j}})))| \leq \frac{\int_{-\infty}^t \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt}{\frac{\sqrt{(X_1 - \bar{X})^2}}{\sqrt{n-1}}} \frac{\int_s^t \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt}{\frac{\sqrt{(X_1 - \bar{X})^2}}{\sqrt{n-1}}}$$

$$y_1 = \beta_0 + \beta_1 x_1 + \epsilon_1$$

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$$y_1 = \beta_0 + \beta_1 x_1 + \epsilon_1$$

$$f_n(t) = \frac{\Gamma\left(\frac{u+1}{2}\right)}{\sqrt{u\pi/2}} \frac{1}{(1+t^2/\theta^2)^{(u+1)/2}}$$

$$|Cov(G(g_{t,s}(\mathbf{Y}_{\mathbf{i}})), H(g_{t,s}(\mathbf{Y}_{\mathbf{j}})))| \leq 2\sqrt{2C_Y(u+v)}(\|H\|_\infty Lip(G) + \|G\|_\infty Lip(H))\theta_r^{\frac{u}{2}}$$

$$f_n(t) = \frac{\Gamma\left(\frac{u+1}{2}\right)}{\sqrt{u\pi/2}} \frac{1}{(1+t^2/\theta^2)^{(u+1)/2}}$$

$$f_n(t) = \frac{\Gamma\left(\frac{v+1}{2}\right)}{\sqrt{v\pi/2}} \frac{1}{(1+t^2/\theta^2)^{(v+1)/2}}$$

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$\frac{\sqrt{(X_1 - \bar{X})^2}}{\sqrt{n-1}} \frac{\sqrt{(X_1 - \bar{X})^2}}{\sqrt{n-1}}$$

$$L(\theta) = \prod_{i=1}^n \frac{x_i}{\beta_0 + \beta_1 x_i} e^{-\frac{\sum x_i}{\theta}}$$

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$$\text{Var}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

Lemma 2 If $(X_n)_{n \in N_{\beta_0}}$ is a sequence of centred r.v.s., then

$$f_x(t) = \frac{\Gamma(\frac{v+1}{2})}{\sqrt{v\pi}\Gamma(\frac{v}{2})} (1 + \frac{t^2}{v})^{-\frac{v+1}{2}}$$

$$\frac{Mn - \xi}{\sqrt{2}\sqrt{n}f(x)} \xrightarrow{D} N(0,1)$$

$$ES_n^4 \leq 4! \left\{ \left(n \sum_{r=0}^{n-1} C_{r,2} \right) + n \sum_{r=0}^{n-1} (r+1)^2 C_{r,4} \right\}.$$

Here,

$$\text{Var}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

$$\gamma_1 = \beta_0 + \beta_1 z_1 + z_1$$

$$\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n(n-1)}$$

$$f_x(t) = \frac{\Gamma(\frac{v+1}{2})}{\sqrt{v\pi}\Gamma(\frac{v}{2})} (1 + \frac{t^2}{v})^{-\frac{v+1}{2}}$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\theta^2} e^{-\frac{t^2}{2\theta^2}} dt$$

$$C_{r,q} = \sup \left| \text{Cov}(X_{t_1} \cdots X_{t_m}, X_{t_{m+1}} \cdots X_{t_q}) \right|,$$

$$\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n(n-1)}$$

$$f_x(t) = \frac{\Gamma(\frac{v+1}{2})}{\sqrt{v\pi}\Gamma(\frac{v}{2})} (1 + \frac{t^2}{v})^{-\frac{v+1}{2}}$$

$$\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n(n-1)}$$

$$\text{Var}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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$$\text{Var}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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$$\bar{Z}(\sigma^2) = \left(\frac{\mu_k - \frac{n-3}{n-1}\sigma^2}{\sigma} \right)$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\sigma^2} e^{-\frac{t^2}{2\sigma^2}} dt$$

$$\bar{Z}_{2R}(\sigma^2) = \left(\frac{\mu_k - \frac{n-3}{n-1}\sigma^2}{\sigma} \right)$$

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$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\sigma^2} e^{-\frac{t^2}{2\sigma^2}} dt$$

Denote

$$\sum_{i=1}^n \frac{(X_i - \bar{X})^2}{n-1}$$

$$S_n = n^{-\frac{1}{2}} \sum_{j \in \{0, \dots, n\}} \alpha_j X_j.$$

$$\sum_{i=1}^n \frac{(X_i - \bar{X})^2}{n-1}$$

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Let $p(n)$ and $q(n)$ be sequences of integers such that $p(n) = o(n), q(n) = o(p(n))$. Assume that $k = [n/(p+q)]$, $r = n - k(p+q)$, for $i = 1, \dots, k$ we define the interval $P_i = \{(p+q)(i-1) + 1, \dots, (p+q)i - q\}$, if $r \neq 0$, $P_{k+1} = \{(p+q)k + 1, \dots, (p+q)k + r \vee p\}$. Q the set of indices that are not in one of the P_i . Note that the cardinal of Q is less than kq . Denote $K = \{1, 2, \dots, k+1\}$. For each block $P_i (1 \leq i \leq k+1)$ and Q , we define the partial sums:

$$\bar{Z}(\sigma^2) = \left(\frac{\mu_k - \frac{n-3}{n-1}\sigma^2}{\sigma} \right)$$

$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\sigma^2} e^{-\frac{t^2}{2\sigma^2}} dt$$

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$$P(X \leq x) = \int_{-\infty}^x \frac{t}{\sigma^2} e^{-\frac{t^2}{2\sigma^2}} dt$$

$$u_i = \frac{1}{\sqrt{n}} \sum_{j \in P_i} \alpha_j X_j,$$

$$v = \frac{1}{\sqrt{n}} \sum_{j \in Q} \alpha_j X_j.$$

$$\bar{Z}(\sigma^2) = \left(\frac{\mu_k - \frac{n-3}{n-1}\sigma^2}{\sigma} \right)$$

$$\sum_{i=1}^n \frac{(X_i - \bar{X})^2}{n-1}$$

$$f_u(t) = \frac{\Gamma(\frac{v+1}{2})}{\sqrt{v\pi t}} \left(1 + \frac{t^2}{v} \right)^{-\frac{v+1}{2}}$$

$$\frac{Mn - \xi}{\sqrt{2n} f(\xi)} \rightarrow N(0, 1)$$

$$f_v(t) = \frac{\Gamma(\frac{v+1}{2})}{\sqrt{v\pi t}} \left(1 + \frac{t^2}{v} \right)^{-\frac{v+1}{2}}$$

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$$L(\theta) = \frac{\prod_{i=1}^n \frac{X_i}{\theta} \frac{\sum_{j=1}^n X_j}{\theta^{n-1}}}{\theta^n} e^{-\frac{\sum_{j=1}^n X_j}{\theta}}$$

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Lemma 3 Let $S_n = n^{-\frac{1}{2}} \sum_{j \in \{0, \dots, n\}} \alpha_j X_j$ be a sum of centred stationary r.v.s.. Set $\sigma_n^2 = \text{Var} S_n$. Suppose that:

(i)

$$\mathbb{E}[g(\frac{x_1 - \bar{X}_n}{\theta})] = \frac{1}{\theta^{2k}} \int_{-\infty}^x g(\frac{x_1 - \bar{X}_n}{\theta}) \frac{dx}{e^{-\frac{(x-\bar{X}_n)^2}{2\theta^2}}}$$

$$\mathbb{E}[g(\frac{x_1 - \bar{X}_n}{\theta})] = \frac{1}{\theta^{2k}} \int_{-\infty}^x g(\frac{x_1 - \bar{X}_n}{\theta}) \frac{dx}{e^{-\frac{(x-\bar{X}_n)^2}{2\theta^2}}}$$

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(ii) For any $t \in R$,

$$\sum_{j \in K} \left| \text{Cov} \left(g \left(\frac{x_1 - \bar{X}_n}{\sigma_n} \sum_{i \in K, i < j} u_i \right), h \left(\frac{x_1 - \bar{X}_n}{\sigma_n} u_j \right) \right) \right| \rightarrow 0. \quad (7)$$

$$\sum_{j \in K} \left| \text{Cov} \left(g \left(\frac{x_1 - \bar{X}_n}{\sigma_n} \sum_{i \in K, i < j} u_i \right), h \left(\frac{x_1 - \bar{X}_n}{\sigma_n} u_j \right) \right) \right| \rightarrow 0. \quad (7)$$

$$\sum_{j \in K} \left| \text{Cov} \left(g \left(\frac{x_1 - \bar{X}_n}{\sigma_n} \sum_{i \in K, i < j} u_i \right), h \left(\frac{x_1 - \bar{X}_n}{\sigma_n} u_j \right) \right) \right| \rightarrow 0. \quad (7)$$

where h and g be one of the trigonometric functions $x \rightarrow \cos x, x \rightarrow \sin x$.

$$\text{Var}(x^2) = \frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

(iii) For any $\varepsilon > 0$,

$$\frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n} \left(1 + \frac{\varepsilon^2}{\theta^2}\right)^{-\frac{n-1}{2}} \rightarrow N(0, 1)$$

$$\frac{\left(\mu_4 - \frac{n-3}{n-1}\sigma^4\right)}{n} \left(1 + \frac{\varepsilon^2}{\theta^2}\right)^{-\frac{n-1}{2}} \rightarrow N(0, 1)$$

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$$\lim_{n \rightarrow \infty} \frac{1}{\sigma_n^2} \sum_{i \in K} E |u_i|^2 I\{|u_i| \geq \varepsilon \sigma_n\} = 0 \quad (8)$$

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(iv)

$$\sum_{i=1}^n \frac{(X_i - \bar{X})^2}{n-1}$$

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$$(9) \quad \frac{Mn - \xi}{\sqrt{2n} f(\xi)} \xrightarrow{D} N(0, 1)$$

$$L(\theta) = \prod_{i=1}^n \frac{z_i}{\theta^{1/k}} e^{-\frac{S_i^k}{2\theta^k}}$$

Then $\frac{S_n}{\sigma_n}$ converges in distribution to a Gaussian

$\text{Var}(x^2) = N(0, 1)$ —distribution.

$$\text{Var}(x^2) = \frac{\left(\mu_k - \frac{n-3}{n-1}\sigma^4\right)}{n}$$

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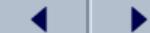
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Central Limit Theorem
for Empirical Process
under New Dependent
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by Huang Xudong
July, 2008



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