

## SELF-NORMALIZED LARGE DEVIATIONS

BY QI-MAN SHAO<sup>†</sup>

*University of Oregon*

Let  $\{X, X_n, n \geq 1\}$  be a sequence of independent and identically distributed random variables. The classical Cramér–Chernoff large deviation states that  $\lim_{n \rightarrow \infty} n^{-1} \ln P(\sum_{i=1}^n X_i)/n \geq x) = \ln \rho(x)$  if and only if the moment generating function of  $X$  is finite in a right neighborhood of zero. This paper uses  $n^{(p-1)/p} V_{n,p} = n^{(p-1)/p} (\sum_{i=1}^n |X_i|^p)^{1/p}$  ( $p > 1$ ) as the normalizing constant to establish a self-normalized large deviation without any moment conditions. A self-normalized moderate deviation, that is, the asymptotic probability of  $P(S_n/V_{n,p} \geq x_n)$  for  $x_n = o(n^{1/(p-1)})$ , is also found for any  $X$  in the domain of attraction of a normal or stable law. As a consequence, a precise constant in the self-normalized law of the iterated logarithm of Griffin and Kuelbs is obtained. Applications to the limit distribution of self-normalized sums, the asymptotic probability of the  $t$ -statistic as well as to the Erdős–Rényi–Shepp law of large numbers are also discussed.

1. Introduction. Throughout this paper, let  $(\Omega, \Sigma, P)$  denote a probability space, and let  $\{X, X_n, n \geq 1\}$  be a sequence of independent and identically distributed (i.i.d.) nondegenerate real-valued random variables on the probability space. Put

$$S_n = \sum_{i=1}^n X_i, \quad V_n^2 = \sum_{i=1}^n X_i^2, \quad n = 1, 2, \dots$$

The classical Cramér–Chernoff large deviation [Chernoff (1952)] states that if

$$(A) \quad E e^{t_0 X} < \infty \text{ for some } t_0 > 0,$$

then for every  $x > EX$ ,

$$\lim_{n \rightarrow \infty} n^{-1} \ln P\left(\frac{S_n}{n} \geq x\right) = \ln \rho(x),$$

or equivalently,

$$(1.1) \quad \lim_{n \rightarrow \infty} P\left(\frac{S_n}{n} \geq x\right)^{1/n} = \rho(x),$$

where  $\rho(x) = \inf_{t \geq 0} e^{-tx} E e^{tX}$ .

Roughly speaking, this type of large deviation shows that the convergence rate in the law of large numbers is exponential if the moment generating

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