Chapter 1
Professor Hira Lal Koul's Contribution to Statistics

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Professor Hira Koul received his Ph.D. in Statistics from the University of California, Berkeley in 1967 under the supervision of Professor Peter Bickel. He has the unique distinction of being the first doctoral student of Professor Bickel. True to his training at Berkeley, in the initial years of his research career, he focused on developing asymptotic theory of statistical inference. He pioneered the approach of *Asymptotic Uniform Linearity* (AUL) as a theoretical tool for studying properties of the empirical process based on residuals from a semiparametric model. This approach has been widely employed by several authors in studying the asymptotic properties of tests of composite hyptheses, and has been a particularly powerful tool for deriving limit laws of goodness-of-fit tests. At around the same time, he also developed the theory of weighted empirical processes which played a fundamental role in the study of asymptotic distribution of robust estimators (e.g., Rank-based estimators and M-estimators) in linear regression models. An elegant account of the theory of weighted empirical processes for independent as well as dependent random variables is given in his monographs on the topic (Koul (1992, 2002)).

He has made significant contributions to several different areas of Statistics, including Asymptotic theory of efficient estimation, Bootstrap, Long-range dependence, Measurement Error, Robustness, Sequential Analysis, Survival Analysis, Nonlinear Time series, among others. In all his work, a common thread has been the

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use of rigorous mathematical arguments to derive useful statistical theory for estimation and testing. Here we highlight some of his major contributions to selected issues and problems to give a glimpse of the breadth and impact of his research. Building on his work on empirical processes, he developed asymptotic theory of minimum distance estimation in semi-parametric models. He also initiated the use of weighted empirical processes and repeatedly demonstrated its usefulness in studying limit distributions of classes of robust estimators, particularly the M- and R-estimators in regression models and in complex time series models. Starting in the 1980s, jointly with Professors V. Susarla and J. van Ryzin, he initiated the study of regression models in the presence of censoring and introduced the celebrated *Koul–Susarla–van Ryzin estimator* of the regression parameters in their 1980 *Annals of Statistics* paper. In contrast to its competitors, the Koul–Susarla–van Ryzin estimator is explicitly defined and easy to compute, which made it a popular choice among practitioners. Professor Koul further continued his work on censored data by establishing the Local Asymptotic Normality (LAN) property and results on asymptotic efficient estimation in semiparametric models.

Starting in the late 1980s, Professor Koul developed an interest in time series and Econometrics. He has made fundamental contributions to nonparametric and robust inference under complex temporal dependence structures, notably under long range dependence (LRD). In addition to developing asymptotic distributional theory for classes of robust estimators under LRD, jointly with Professor D. Surgailis, he derived higher order asymptotic expansions for M-estimators, which provided critical information into the structure of the successive smaller order terms. More recently, together with his long time collaborators Professors L Giraitis and D. Surgailis, he proved a Central Limit Theorem for periodogram based statistics under LRD requiring a weak Lindeberg-type condition. This is a highly effective tool for investigating asymptotic properties of such statistics, one that is bound to be used by researchers working with time series under LRD for years to come. The recent monograph, Koul, Giraitis and Surgailis (2013) gives an authoritative and detailed account of the statistical inference for time series under LRD, and contains many of Professor Koul's important results on the topic.

Many of Professor Koul's publications appeared in top-tier statistics journals. Given below is a chronological list of his publications to date.

Books:

1. *Weighted Empirical and Linear Models.* (1992). Lecture Notes-Monograph Series, 21, Institute of Mathematical Statistics, Hayward, California.
2. *Weighted Empirical Processes in Dynamic Nonlinear Models*. 2nd Edition. (2002). Lecture Notes Series in Statistics, 166, Springer, New York, N.Y., USA.
3. *Large Sample Inference For Long Memory Processes* (2013). Imperial College Press. London, UK. (with L. Giraitis and D. Surgailis).

Papers:

1. Asymptotic behavior of the Wilcoxon type condence regions for the multiple linear regression. (1969). *Ann. Math. Statist.* **40** 1950–1979.
2. A class of ADF tests for the subhypotheses in the multiple linear regression. (1970). *Ann. Math. Statist.* **41** 1273–1281.
3. Some convergence theorems for ranks and weighted empirical cumulatives. (1970). *Ann. Math. Statist.* **41** 1768–1773.
4. Asymptotic normality of random rank statistics. (1970). *Ann. Math. Statist.* **41** 2144–2149.
5. Asymptotic behavior of a class of condence regions based on ranks in regression. (1971). *Ann. Math. Statist.* **42** 466–476.
6. Some asymptotic results on random rank statistics. (1972). *Ann. Math. Statist.* **43** 842-859.
7. Asymptotic normality of signed rank statistics. (1972). *Z. Wahrscheinlichkeitstheorie, Verw. Geb.* **22** 293–300. (with R. G. Staudte, Jr.)
8. Weak convergence of weighted empirical cumulatives based on ranks. (1972). *Ann. Math. Statist.* **43** 832–841. (with R.G. Staudte, Jr.)
9. The Bahadur eciency of the Reimann-Vincze statistics. (1974). *Studia Scientiacarum Mathmaticarum Hungarica* **9** 399–403. (with M.P. Quine)
10. Asymptotic normality of H-L estimators based on dependent data. (1975). *J. Inst. Statist. Math.* **27** 429–441.
11. Power bounds for Smirnov test statistics in testing the hypothesis of symmetry. (1976). *Ann. Statist.* **4** 924–935. (Joint with R. G. Staudte, Jr.)
12. L^1 - rate of convergence for linear rank statistics. (1976). *Ann. Statist.* **4** 771–774. (with R.V. Erickson)
13. Behavior of robust estimators in the regression model with dependent errors. (1977). *Ann. Statist.* **5** 681–699.
14. A test for new better than used. (1977). *Communications: Statist. Theor. Meth.* **A6** 563–573.
15. A class of tests for new better than used. (1978). *Can. J. Statist.* **6** 249–471.
16. Testing for new is better than used in expectation. (1978). *Communications; Statist. Theory Meth.* **A7** 685–701.
17. Weighted empirical processes and the regression model. (1979). An invited paper for *J. of the Indian Statist. Assoc.* **17** 83–91.
18. Asymptotic tests of composite hypothesis for nonergodic type stochastic processes. (1979). *J. of Stoch. Proc. and Application* **9(3)** (with I.V. Basawa).
19. Some weighted empirical inferential procedures for a simple regression model. (1980). *Colloq. Math. Soc. Janos Bolyai* **32** 537–565.
20. Testing for new better than used in expectation with incomplete data. (1980). *J. Amer. Statist. Assoc.* **75** 952–956. (with V. Susarla).
21. A simulation study of some estimators of regression coefficients using censored data (1980). In *Proceedings of the annual meeting, American Statistical Association*. (with V. Susarla and J. Van Ryzin).
22. Regression analysis with randomly right censored data. (1981). *Ann. Statist.* **9** 1276–1288. (with V. Susarla and J. Van Ryzin).
23. A limit theorem for testing with randomly censored data. (1981). In *Survival Analysis, IMS Lecture Notes* **2** 189–205. (with V. Susarla).
24. Multi-step estimation of regression coecients in a linear model with censored survival data. (1981). In *Survival Analysis, IMS Lecture-Notes Monograph Series* **2** 85–100. (with V. Susarla and J. Van Ryzin).
25. Least square regression analysis with censored survival data. (1982). In *Topics in Applied Statistics* 151–165. (Eds: Chaubey, Y.P. & Dwivedi). T.D. Marcel Dekker, N.Y. (with V. Susarla and J. Van Ryzin).
26. Asymptotically minimax tests of composite hypotheses for nonergodic type processes. (1983). *J. of Stoch. Proc. & Applications* **14**. (with I.V. Basawa).

27. Minimum distance estimation in a linear regression. (1983). *Ann. Statist.* **11** 921–932. (with T. Dewet).
28. Adaptive estimation in regression. (1983). *Statistics and Decisions* **1** 379–400. (with V. Susarla).
29. Estimators of scale parameters in linear regression. (1983). *Statist. and Probab. Letters* **1** 273–277. (with V. Susarla).
30. LAN for randomly censored linear regression. (1984). *Statistics and Decision, Supplement Issue* **1** 17–30. (with W. H. Wang).
31. Test of goodness-of fit in linear regression. (1984). *Colloq. Math. Soc. Jonos. Bolyai* **45** 279–315.
32. Minimum distance estimation in multiple linear regression model. (1985). *Sankhya, Ser. A* **47** 57–74.
33. Minimum distance estimation in linear regression with unknown error distribution. (1985). *Statist. and Probab. Letters* **3** 1–8.
34. On a Kolmogorov-Smirnov type aligned test in linear regression. (1985). *Statist. & Probab. Letters* **3** 111–115. (with P.K. Sen).
35. Minimum distance estimation and goodness-of fit tests in first order autoregression. (1986). *Ann. Statist.* **14** 1194–1213.
36. An estimator of the scale parameter for the rank analysis of linear models under general score functions. (1987). *Scand. J. Statist.* **14** 131–143. (with G. Sievers and J. McKean).
37. Ecient estimation of location with censored data. (1988). *Statistics and Decisions* **4** 349–360. (with A. Schick and V. Susarla).
38. Large sample statistics based on quadratic dispersion. (1988). *Int. Statist. Rev.* **56** 199–219. (with I. V. Basawa).
39. Minimum distance estimation of scale parameter in the two sample problem: Censored and Uncensored Data. (1989). In *Recent Developments in Statistics and Their Applications* 117–134. (Eds—J. Klein and J. Lee). Freedom Press. (with S. Yang).
40. A quadraticity limit theorem useful in linear models. (1989). *Probab. Theory and Relat. Fields.* **82** 371–386.
41. Weak convergence of residual empirical process in explosive autoregression. (1989). *Ann. Statist.* **17** 1784–1794. (with S. Levental).
42. Weakly adaptive estimators in explosive autoregression. (1990). *Ann. Statist.* **18** 939–960. (with G. Pug.)
43. Weak convergence of a weighted residual empirical process in autoregression. (1991). *Statist. and Decis.* **9** 235–262. (with P. K. Sen).
44. Robustness of minimum distance estimation in linear regression against errors-in-variables model. (1991). In the *Proceedings of International Symposium on Nonparametric Statistics and Related Fields* 163–177. (Ed: A. K. Md. E. Saleh). Elsevier Science Publishers.
45. A weak convergence result useful in robust autoregression. (1991). *J. Statist. Planning and Infer.* **29** 291–308.
46. M-estimators in linear regression models with long range dependent errors. (1992). *Statist. and Probab. Letters* **14** 153–164.
47. Locally asymptotically minimax minimum distance estimators in linear regression. (1992). In the *Proceedings of the symposium on Order Statist. and Nonparmetrics in honor of A.E. Sarhan*, Alexendria, Egypt. (Eds - P.K. Sen and I.A. Salama). 405–417.
48. R-estimation of the parameters of autoregression models. (1993). *Ann. Statist.* **21** 534–551. (with A.K.Md.E. Saleh).
49. Bahadur representations for some minimum distance estimators in linear models. (1993). In *Statist. and Probab: A Raghu Raj Bahadur Festschrift*. 349–364. (Eds. J.K. Ghosh, S.K. Mitra, K.R. Parthasarathy, and B.L.S. Prakas Rao). Wiley Eastern Lmtd, Publishers. (with Z. Zhu.)
50. Asymptotics of R-, MD- and LAD-estimators in linear regression models with long range dependent errors. (1993). *Probab. Theory and Relat. Fields* **95** 535–553. (with K. Mukherjee).

51. Weak convergence of randomly weighted dependent residual empiricals with applications to autoregression. (1994). *Ann. Statist.* **22** 540–562. (with M. Ossiander).
52. On bootstrapping M-estimated residual processes in multiple linear regression models. (1994). *J. Mult. Analysis.* **49** 255–265. (with S. Lahiri).
53. Regression quantiles and related processes under long range dependent errors. (1994). *J. Mult. Analysis.* **51** 318–317. (with K. Mukherjee).
54. Minimum distance estimation of the center of symmetry with randomly censored data. (1995). *Metrika* **42** 79–97. (with S. Yang).
55. Auto-regression quantiles and related rank-score processes. (1995). *Ann Statist.* **23** 670–689. (with A.K. Md. Ehsanes Saleh).
56. Bahadur-Kiefer representations for GM-estimators in auto-regression models. (1995). *J. of Stoch. Proc. and Applications* **57** 167–189. (with Z. Zhu).
57. Asymptotics normality of Regression Estimators with long memory errors. (1996). *Statist. and Probab. Letters* **29** 317–335. (with L. Giraitis and D. Surgailis).
58. Asymptotics of some estimators and sequential empiricals in non-linear time series. (1996). *Ann. Statist.* **24** 380–404.
59. Adaptive estimation in a random coefficient autoregressive model. (1996). *Ann Statist.* **24** 1025–1054. (with A. Schick).
60. Asymptotics of M-estimators in non-linear regression with long range dependent errors. (1996). In the *proceedings of the Athens Conference on Apllied Probab. & Time Series, II, honoring E.J. Hannan: Lecture Notes in Statist.* **115** 272–290. (Eds.—P. M. Robinson and M. Rosenblatt). Springer Verlag, New York.
61. Efficient estimation in non-linear time series models. (1997). *Bernoulli* **3** 247–277. (with A. Schick).
62. Note on convergence rate of semiparametric estimators of the dependence index. (1997). *Ann. Statist.* **25** 1725–1739. (with Peter Hall and Berwin Turlach).
63. Testing for the equality of two nonparametric regression curves. (1997) *J. Statist. Planning & Inference* **65** 293–314. (with Anton Schick).
64. Asymptotic expansion of M-estimators with long memory errors. (1997). *Ann. Statist.* **25** 818–850. (with D. Surgailis).
65. Estimation of the dependence parameter in linear regression with long-range dependent errors. (1997). *J. Stoch. Proces. and Appl.* **71** 207–224. (with L. Giraitis).
66. Lack-of fit tests in regression with non-random design. (1998). In *Applied Statist. Science III; Nonparametric statistics & related fields: a volume honoring A.K.Md.E. Saleh.*. pp 53–70. (Eds: S. Ahmad, M. Ahsanullah & B. Sinha). Nova Sci. Publishers, Inc. (with W. Stute).
67. Regression model tting with long memory errors. (1998). *J. Statist. Planning & Inference* **71** 35–56. (with W. Stute).
68. Nonparametric model checks in time series. (1999). *Ann. Statist.* **27** 204–237. (with W. Stute).
69. Inference about the ratio of scale parameters in a two sample setting with current status data. (1999). *Statist. & Probab. Letters* **45** 359–370. (with A. Schick.)
70. Estimation of the dependence parameter in non-linear regression with random design and long memory errors. (2000). In *Perspectives in Statistical Sciences* (Eds - D. Basu, J.K. Ghosh, P.K. Sen & B.K. Sinha) pp. 191–208, Oxford University Press.
71. Asymptotic normality of the Whittle estimator in linear regression models with long memory errors. (2000). *Statist. Inference for Stochast. Processes* **3** 129–147. (with D. Surgailis).
72. Second order behaviour of M-estimators in linear regression with long memory param- eter. (2000). *J. Statist. Planning & Inference* **91** 399–412. (with D. Surgailis).
73. Asymptotics of empirical processes of long memory moving averages with innite vari- ance. (2001). *J. Stochastic Procsses & App.* **91** 309–336. (with D. Surgailis).
74. Asymptotics of maximum likelihood estimator in a two-phase linear regression model. February 2001. (2002). *J. Statist. Planning & Inference* **108** 99–119. (with L. Qian).

75. Robust estimators in regression models with long memory errors. In *Theory and Applications of Long Range Dependence*. 339–354. (Eds—G. Oppenheim, P. Doukhan and M. S. Taqqu). Birkhauser (2002). (with D. Surgailis).
76. Fitting a two phase linear regression model. (2000). *J. Indian Statist. Assoc.* **38** 331–353.
77. Asymptotics of M-estimators in two phase linear regression models. (2003). *J. Stochastic Processes & Applications* **103** 123–154. (with L. Qian & D. Surgailis).
78. Testing for superiority among two regression curves. (2003). *J. Statist. Planning & Inference* **117** 15–33. (with Anton Schick).
79. Asymptotic expansion of the empirical process of long memory moving averages. (2002). An invited review article for the book *Empirical Process Techniques for Dependent Data.* (Eds–Dehling, H.G., Mikosch, T. and Sorensen M.). Birkhauser pp. 213–239. (with D. Surgailis).
80. On weighted and sequential residual empiricals in ARCH models with some applications. (with Kanchan Mukherjee). Included in the monograph Weighted empirical processes in dynamic nonlinear models, second edition. (2002). Springer Lecture Notes, 166.
81. Asymptotic distributions of some scale estimators in nonlinear models. (2002). *Metrika* **55** 75–90.
82. Asymptotics of M-estimators in non-linear regression with long memory design. (2003). *Statist. & Probab. Letters* **61** 237–252. (with Baillie, R.T.)
83. Minimum distance estimation in a unit root autoregressive model. (2004). *J. Indian Statistical Assoc.* **41** 285–307. (with U. Naik-Nimbalkar).
84. Uniform reduction principle and some implications. (2004). (Invited paper) *J. Indian Statist. Assoc.* **21** 309–338. (with D. Surgailis).
85. Minimum distance regression model checking. (2004). *J. Statist. Planning & Inference* **119** 109–142. (with Pingping Ni).
86. Regression model checking with a long memory covariate process. (2004). *Econometric Theory* **20** 485–512. (with R.T. Baillie and D. Surgailis).
87. Martingale transforms goodness-of fit tests in regression models. (2004). *Ann. Statist.* **32** 995–1034. (with E. Khmaladze).
88. Model diagnosis for SETAR time series. (2005). *Statistica Sinica* **15** 795–817. (with W. Stute and Li, F.)
89. Testing for superiority among two time series. (2005). *Statist. Inference for Stochast. Processes* **6** (with Fang Li).
90. Goodness-of-fit testing in regression: A finite sample comparison of bootstrap methodology and Khmaladze transformation. (2005) *Statist. & Probab. Letters* **74** 290–302. (with Lyudmila Sakhanenko).
91. Fitting an error distribution in some heteroscedastic time series models. (2006). *Ann. Statist.* **34** 994–1012. (with Shiqing Ling).
92. Goodness-of-fit testing in interval censoring case 1. (2006). *Statist. & Probab. Letters* **76** 709–718. (with Tingting Yi).
93. Regression model fitting for the interval censored 1 responses. (2006). *Austrian J. Statist.* **35** 143–156. (with Tingting Yi).
94. Model Checks of Higher Order Time Series. (2006). *Statist. & Probab. Letters* **76** 1385–1396. (with W. Stute, M. Presedo Quindimil, and W. Gonzalez Manteiga).
95. Model Diagnostics via Martingale Transforms: A Brief Review. In *Frontiers in Statistics.* (2006), pp 183–206. Imperial College Press, London, UK. (Eds—J. Fan and H. L. Koul).
96. Nonparametric regression with heteroscedastic long memory errors. (2007). —it J. Statist. Planning & Inference **137** 379–404. (with H. Guo).
97. Serial auto-regression and regression rank scores statistics. (with Marc Hallin and Jana Jurechkova). An invited paper in *Advances in Statistical Modeling and Inference* (2007), 335–362. World Scientific, Singapore. (Editor: V. Nair).
98. Regression model checking with Berkson measurement errors. (2008). *J. Statist. Plan- ning & Inference* **138** 1615–1628. (with Weixing Song).

99. Asymptotic inference for some regression models under heteroscedasticity and long memory design and errors. (2008). *Ann. Statist.* **36** 458–487. (with H. Guo).
100. Minimum distance inference in unilateral autoregressive lattice processes. (2008). *Statistica Sinica* **18** 617–631. (with Marc Genton).
101. Testing of a sub-hypothesis in linear regression models with long memory covariates and errors. (2008). *Applications of Mathematics* **53** 235–248. (with Donatas Surgailis).
102. Minimum empirical distance goodness-of-fit tests for current status data. (2008). *J. Indian Statistical Association* **46** 79–124. (with D. Aggarwal).
103. Minimum distance regression model checking with Berkson measurement errors. (2009). *Ann. Statist.* **37** 132–156. (with Weixing Song).
104. Testing of a sub-hypothesis in linear regression models with long memory errors and deterministic design. (2009). *J. Statistical Planning & Inference* **139** 2715–2730. (with D. Surgailis).
105. Testing the tail index in autoregressive models. (2009). *Annals of Institute of Statistical Mathematics* **61** 579–598. (with J. Jurechkova and J. Picek).
106. Goodness-of-fit problem for errors in non-parametric regression: distribution free approach. (2009). *Ann. Statist.* **37** 3165–3185. (with E.V. Khmaladze).
107. Model checking in partial linear regression models with Berkson measurement errors. (2010). *Statistica Sinica* **20** 1551–1579. (with Weixing Song).
108. A class of minimum distance estimators in AR(p) models with infinite error variance. (2010). In *Nonparametrics and Robustness in Modern Statistical Inference and Time Series Analysis: A Festschrift in honor of Professor Jana Jureckov. IMS Collections* **7** 143–152. (Eds.—Antoch, J., Huskova, M. & Sen, P.K.) (with Xiaoyu Li).
109. Goodness of fit testing under long memory. (2010). *J. Statist. Planning & Inference* **140** 3742–3753. (with D. Surgailis).
110. Conditional variance model checking. (2010). *J. Statist. Planning & Inference* **140** 1056–1072. (with Weixing Song).
111. Khmaladze transformation. In *International Encyclopedia of Statistical Science*. Springer Verlag, Berlin, (*DOI 10.1007/978-3642-04898-2*). (2010).
112. Minimum distance lack-of-fit tests in fixed design. (2011). *J. Statist. Planning & Inference* **141** 65–79.
113. A goodness-of-fit test for GARCH innovation density. (2012). *Metrika* **75** 127–149. (with Nao Mimoto).
114. Lack-of-fit testing of the conditional mean function in a class of Markov duration models. (2012). *Econometric Theory* **28** 1283–1312. (with Indeewara Perera and Meryvn Silvaphulle). (*DOI: http://dx.doi.org/10.1017/ S0266466612000102*).
115. A class of goodness of fit tests in a linear errors-in-variables model. (2012). *J. French Statist. Soc.* **153** 52–70. (with Weixing Song).
116. Complete Case Analysis Revisited. (2012). *Ann. Statist.* **40** 3031–3049. (with U. Mueller-Harknett and Anton Schick).
117. Goodness-of-fit tests for long memory moving average marginal density. (2013). *Metrika* **76** 205–224. (Joint with N. Mimoto & D. Surgailis).
118. On asymptotic distributions of weighted sums of periodograms. (2013). *Bernoulli* (To appear). (with L. Giraitis).
119. Asymptotic normality for weighted sums of linear processes. (Submitted) (with K.M. Abadir, W. Distaso, L. Giraitis).
120. Automatic studentization in nonparametric regression. (Submitted) (with V. Dalla and L. Giraitis).
121. Large sample results for varying kernel regression estimates. (Submitted) (with Weixing Song).
122. Model checking in Tobit regression via nonparametric smoothing. (Submitted). (with Weixing Song and Shan Liu).
123. Minimum distance lack-of-fit tests under long memory errors. (Submitted). (with D. Surgailis).