Professor Sir Clive W.J. Granger and Cointegration

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1 First encounters

In the introduction to Chris Sims (1977), my comments on Clive Granger's paper with Paul Newbold (Granger and Newbold, 1977b) are described as 'acerbic', hardly an auspicious start to a long friendship. At issue during that 1975 conference was a disagreement over what later came to be called cointegration: its existence seemed all too obvious to me–and many others at the London School of Economics–but was essentially denied by Clive. Consequently, I missed the key point that Clive later developed into one of the foundations for modeling non-stationary time series, namely a dynamic system with a reduced-rank feedback matrix must generate integrated data, the insight for which he was awarded The Sveriges Riksbank Prize in Economic Science in Memory of Alfred Nobel in October 2003 (see Hendry, 2004). His research opened a door to powerful new ideas and methods: there are more than *11000* citations to his joint paper on cointegration with Rob Engle (Engle and Granger, 1987), who shared the 2003 Prize for his invention of the autoregressive conditional heteroskedasticity (ARCH) model. First I digress to discuss why Clive discovered what he denied, when LSE missed.

2 Background history

The story of the discovery of cointegration, like many scientific discoveries, is a fascinating tale involving false avenues, half-understood solutions, partial insights, and persistent anomalies, all finally resolved by Clive's breakthrough. The analysis of economic time series dates back to the very foundations of our discipline as a science, and has always been a fraught subject. Judy Klein (1997) notes the 1662 contribution by John of Graunt on time series of births and deaths in London, and the invention by the Bank of England in 1797 of moving averages to conceal the truly perilous state of its bullion reserves–an early example of creative accounting. In 1862, following up work by Charles Babbage–the inventor of the computer–Stanley Jevons (1884) investigated a variety of weekly financial time series over 1825–1860, including bankruptcies, currency circulation and discount rates: 'high frequency' financial econometrics is hardly new.

The real action began towards the end of the nineteenth century, in an attempt to understand why 'peculiar' correlations turned up surprisingly often, including the apocryphal infamous high correlation between the number of storks nesting in Stockholm and the number of babies born there. Hooker (1901) pioneered the first steps, but Udny Yule (1926) provided the first analytical results, showing the dangers inherent in regressions between non-stationary variables, or what he called nonsense correlations. Yule based his work on a statistical model suggested by the experiments of a biologist, Robert Brown (1828)

*Based on my Nobel Prize Talk about Clive Granger to the American Economic Association Meeting in Philadelphia.

to describe the random movements of pollen grains floating on water, now called Brownian motion (for a lovely description, see Nelson, 2001, Ch.2). This has been regularly used for equity price movements since the proposal by Louis Bachelier (1900), in the guise of a random walk, the basic integrated process. Yule showed that any two integrated series would be significantly correlated, even though their shocks and initial positions were unrelated. John Maynard Keynes (1939) referred to this 'mine Mr Yule exploded under the optimistic contraptions of economists' during his debate with Jan Tinbergen (also see Keynes, 1940), who subsequently shared the first Nobel Prize in economics with Ragnar Frisch. A remarkable precursor is Bradford Bixley Smith (1926), whose brilliant insights were almost never cited, but who foresaw much of the later literature, including the key ingredient of my comment on Granger–Newbold in Hendry (1977).[1]

And there the matter rested till the mid 1970s, when Clive with Paul Newbold drew renewed attention to the nonsense correlation problem, digital computers having allowed a proliferation of time-series regressions to be published. They showed that devices such as autocorrelation corrections did not remove the problem, although investigating only the differences of the variables did. Unfortunately that approached removed any potential role for equilibrium economic theory. In any case, the large econometric models of the time often produced less accurate forecasts than simple atheoretic time-series devices, initiating the search for an improved approach to alleviate such a headache (see e.g., Nelson, 1972). Clive set out to find a better way – and did. The story now progresses to re-introducing the role of equilibria in non-stationary time series. The saga concludes with his general formulation for the widely occurring phenomenon of cointegration in economics.

2.1 Cointegration

Clive was initially critical of a class of econometric model introduced by Denis Sargan (1964), and since called equilibrium correction, following an LSE tradition which Bill Phillips had introduced using derivative, proportional and integral control mechanisms (see Phillips, 1954, 1956). Denis's formulation added the disequilibria suggested by economics to models in first differences. For example, in his study of wages and prices, he postulated that the deviation from its mean of the log of real wages adjusted for productivity growth would influence future wage inflation (see Hendry, 2003). Clive argued that the stationarity of that combination was merely assumed, not established. More importantly, the integrated data properties were taken as given, as in Davidson, Hendry, Srba and Yeo (1978), rather than entailed by the model. In retrospect, if econometric models for the other variables were also postulated, such that the system had a long-run equilibrium, then that contradicted the fact that the data were integrated. To avoid such a debacle, the same feedbacks had to occur in several equations, so the long-run relations became trajectories. Data integration then became self-generated, not needing a separate postulate.

As he records in his *Econometric Theory Interview* Phillips (1997), Clive set out to prove that such linear combinations of integrated variables would in fact remain integrated, so equilibrium correction was not a viable model class. In the process, he instead established the conditions under which 'cointegration' could occur, so some linear combinations were of a lower order of integration than the original variables. The Granger representation theorem is the main result, and is the centerpiece of modern econometric analyses of integrated processes. The condition that there are fewer levels feedbacks than variables generates a reduced-rank in the long-run matrix of the dynamics and leads to the multivariate cointegration approach developed by Søren Johansen (1988, 1995). To complete the discovery, Clive and Rob Engle proposed a way of estimating equations containing potentially cointegrated relationships, and their two-step estimation technique opened the gates to a flood of new theory and applications. Because the original levels series are integrated, but some combinations are not, cointegration must cancel any 'common trends' that drive all the related variables in the long-run.

[1]Brought to my attention by Mills (2009).

Cointegration is basically a linear concept, and the classical assumption in empirical work has been that drift towards the equilibrium, postulated by models with cointegrated variables, is symmetric: the strength of attraction is a linear function of the distance of the system from the equilibrium. Clive has also pioneered non-linear cointegration, loosening the symmetry assumption, as is sometimes necessary in macroeconomics.

3 Other contributions

We now turn, perforce briefly, to consider some of the many other contributions Clive has made to theoretical and empirical econometrics. His first major research concerned causal relationships between economic variables, since regularly referred to as Granger causality (Granger, 1969). Clive gave a central role in his definition to the 'arrow of time'. Most economic relations are inexact, so stochastic formulations seem inevitable, leading to his idea of evaluating causality in terms of changes to the joint distributions of the observables. His concept was operational, and thus testable: 'Granger-causality' provided macroeconomics with empirical tests of economic theories which imply time-related causal relationships between economic variables. A vast literature followed this path-breaking work and his 1969 article is one of the most influential papers in econometrics, having been cited more than 4000 times.

Clive also advanced the theory of economic forecasting in a series of major publications, including showing that pooled forecasts might dominate the best of a set of separate forecasts, as well as forecasting white noise (see Bates and Granger, 1969, Granger and Newbold, 1977a, and Granger, 1983). The role of forecasting in evaluating econometric models has been one of the recurring themes in his research, despite the dangers we all know are inherent in any forecasting enterprise. Finally, Clive has made important contributions to financial econometrics, one of the most rapidly growing fields in economics, initially on spectral analysis with Michio Hatanaka (Granger, 1964), then in his work on commodities, with Walter Labys, his first doctoral student at Nottingham University (see Labys and Granger, 1970), as well as aggregation and stock market behavior. He also developed long memory models with Roselyne Joyeux, where the autocorrelation function decays at a much slower rate than that of a linear autoregressive-moving average (Granger and Joyeux, 1980). With the increased availability of long financial time series, the importance of long-memory models in econometrics has grown, and been applied to modeling conditional variances – which manifest considerable persistence – consistent with long memory in volatility. Clive was one of the first econometricians to study non-linear time-series models, specifically bi-linear models (Granger and Andersen, 1978), and later worked with Timo Teräsvirta (Granger and Teräsvirta, 1993). That work may have helped Rob Engle in the formulation of ARCH (Engle, 1982).

4 Conclusion

The hallmark of Clive's research was creative new ideas in quantitative economics. His basic attitude is well expressed by my countryman, David Hume (1758), paraphrased from its origin to suit the present context:

> "Take in hand any volume of economics; let us ask, 'Does it contain any abstract reasoning concerning quantity or number?' No. 'Does it contain any experimental reasoning concerning matter of fact and existence'. No. Commit it then to the flames: for it can contain nothing but sophistry and illusion."

Clive's contributions have combined to implement his long-term research agenda of improving the quality of econometric model building by a better match with empirical evidence. His research has shaped the agenda of many econometricians, and given rise to a large number of applications, from sun-spot activity and land use in the Brazilian Amazon, through Gold, Silver and Stock Market Prices, and Eighteenth Century wheat prices, to electricity demand, exchange rates, volatility clustering, and yield curves. His unraveling of cointegration and common trends and their properties was a major development, buttressed by many later important insights. He was a major generator of new ideas, yet always in context of solving a real problem, not just for its own sake: the wealth of further advances and applications of his ideas bear witness to his fecundity. Sir Clive Granger's was one of the most successful research programmes in the history of econometrics as his total citations of more than 45000 corroborates, and will be a lasting contribution to our discipline.

The personal conclusion: we agreed completely about cointegration, and shared the same basic objective of improving the quality of empirical economics, albeit by different routes–so became close friends.

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