The *"Top 10"* Papers in Econometrics, 1980-2000

Les Oxley
Professor of Economics
University of Waikato

Abstract: The paper proposes a "Top 10" of contributions to econometrics for the period 1980-2000. All but one of the papers were published in *Econometrica* and none were published in the 1990s. Papers on time series econometrics dominate the Top 10 group and particularly issues relating to non-stationary (unit roots and cointegration). The second largest category relates to issues focussing on serial correlation and heteroskedasticity. These two categories of issues reflect the typical ongoing challenges facing applied economists. Some recent developments in Bayesian econometrics are raised and the continuing 'bridesmaid' status of this branch of econometrics considered.

Invited paper presented to the New Zealand Statistical Association Meeting, University of Canterbury, September, 2000

Working with a statistician is like eating a steak with a dog under the table. You eat all the good bits yourself and give the dog the grisly bits and he'll bite your leg if you don't.
G Laslett, 4th Australian Statistics Conference.

Introduction

When I was asked to present this talk I wondered 'why me', I'm not a statistician, I'm an economist!

As many of you would probably testify, economists and statisticians do not interact as often or as closely as they should. Although the *Econometrics Society,* founded by Irving Fisher and Ragnar Frisch, has been in existence since 1930, economics and statistics seem further apart than they have ever been. *It's with great pleasure, therefore that I, as an economist address you as statisticians, hoping to build some bridges.*

My original training in econometrics was via R J Nicholson (*Economic Statistics and Economic Problems 1969),* at the University of Sheffield, the son of a clergyman who passed his pulpit skills to his son! My PhD in *Modelling and Testing Macroeconomic Hypotheses*, is from CentRE at Tilburg University. Prior to moving to New Zealand, I spent 18 years in the economics department at the University of Edinburgh (a university which seems to have strong links with many New Zealand statisticians – old and new). The economics department there had little contact with statistics. It wasn't helped by being physically dislocated (they were in the James Clerk Maxwell Buildings at Kings Buildings, we were in George Square). Our only regular contact was via Peter Fisk (*Stochastically Dependent Equations: An Introductory Text for Econometricians*). The HOD at that time was Finney (their current one is Colin Aitken, a forensic-statistician, I think). When I was at Monash University economics, econometrics and statisitcs were separate departments, both competing for student EFTS. The story was a little better at ANU where the statistics department had "econometricians" on the staff.

I digress, I was asked to talk about recent developments in econometrics. Once I'd accepted, I decided I needed to know more about the *New Zealand Statistical Association*, so I acquired a copy of ***A History of Statistics in New Zealand***, edited by Stan Roberts. This made me feel much more at ease. There were so many stories I could relate too, common ground and similar experiences. The numerous references to Edinburgh and its associations with Dunedin made me feel at home. Then there were the references to Uppsala in Peter Whittle's autobiography. I was a Visiting Scholar (in Economics) there in 1982 and visited Herman Wold's house (Picture). Fraser Jackson's "Amalgamated Brick and Pipe Company" experience was different to mine (working as a student job at a brick company), but enough of a similarity to increase my comfort zone. Brian Silverstone (nephew of Harold) is a colleague and friend. Surely, these were not all random draws from nature?

Keen to use my researcher's skills, I thought I'd ask some "real" econometricians what they regarded to be the most significant developments in econometrics over the last 10 years. This question revealed something that surprised me and the people I asked (I asked 5 experts from 5 different continents[1]). All 5 replied saying, "why not 15-20 years?" The reason being was that they couldn't think of 'landmark' papers within the 10-year window, but move it to 20 and they could produce a 'Top-10'. Does this mean that there has been nothing landmark produced in the last 10 years, or does it take that long to permeate the discipline? More on this later. All

[1] I could, of course, have used citation indices. This may be something I use at a later date.

(but one[2]) of the papers were published in *Econometrica,* the journal of the Econometric Society and many have been within the domain of time series developments.

Based upon their (and my) "Top 10", I'll try to say something about *The "Top-10" Papers in Econometrics, 1980-2000.*

The developments can be categorized as follows (and this avoids ranking the papers from 1-10):

- Developments in estimating models using non-stationary data
- Developments in estimating models with 'non-standard' error properties
- Developments in estimating models using panel data
- Bayesian econometrics

Developments in estimating models using non-stationary data

David A. Dickey and Wayne A. Fuller

Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root, Econometrica, 49, 4, 1057-1072, 1981.

The publication of this paper opened-up a new way research agenda in time series econometrics, the investigation and identification of non-

[2] However, Johansen (1991) is an *Econometrica* paper.

stationary processes. In the paper they construct a likelihood ratio test of a unit root in a random walk model,

$$Y_t = a + rY_{t-1} + e_t$$

The null hypothesis that (α,ρ)=(0,1), i.e., a unit root, is investigated and the non-standard limiting distributions for the test are considered. Numerous alternative tests and extensions have been proposed including Schmidt and Phillips (1992), Phillips and Perron (1988), and with a stationary null, Kwiatkowski, *et al.* (1992). However, although the test may have both size (in the presence of serially correlated errors) and power (in the case of 'excessive' lags in its augmented form) problems, it remains the most popular test of the existence of a unit root. Note, the two quotes of Michael McAleer,

- *The power of a popular test is irrelevant*. And,
- *A test that is never used has no power*.

The DF test is routinely presented to undergraduate students of econometrics and its citations must be close to rivaling those of Durbin and Watson!

Robert Engle and Clive Granger

Co-Integration and Error Correction: Representation, Estimation and Testing, Econometrica, 55, 2, 251-276, 1987.

The Engle and Granger paper draws upon earlier work by Granger (1981) and (1983) by developing the theory presented there into practical (and simple) estimation methods.

> *If each element of a vector x_t first achieves stationarity after differencing , but a linear combination $\alpha' x_t$ is already stationary, the time series x_t are said to be co-integrated with cointegrating vector α.*

There may be several such co-integrating vectors so that α becomes a matrix. The real attraction of the result to econometricians comes from the interpretation of $\alpha' x_t = 0$ as a long-run equilibrium. Co-integration implies that deviations from equilibrium are stationary, with finite variance, even though the series themselves are nonstationary and have infinite variance. The observations (coming from Dickey and Fuller 1981) and empirical examples such as Nelson and Plosser (1982) that most macroeconomic time series appeared to be I(1) – nonstationary, could be reconciled with the

"Holy Grail" of Classical economics, one of the existence of a stable, typically unique, steady-state equilibrium. The potency of such a combination cannot be overstated. Add to this the simple estimation and test procedures based upon a two-step OLS regression that produce "super-consistent" estimates and the paper becomes a 'classic.' Testing for co-integration combines the problems of unit root tests and tests with parameters unidentified under the null. Engle and Granger proposed seven statistics including the Dickey-Fuller (DF) and Cointegrating Regression Durbin Watson (CRDW). The one that has survived the test of time is the DF.

Søren Johansen

Statistical Analysis of Cointegration Vectors, Journal of Economic Dynamics and Control, 12, 231-254, 1988.

In Engle and Granger (1987), the mere identification of a cointegrating vector $\alpha' x_t$ is not sufficient since any linear combination of the vector α would also be a cointegrating vectors. The solution in such cases was to impose a particular normalisation by say, putting one element of x on the left hand side and the other elements on the right and then apply OLS. The problem with this solution is that the results can depend (arbitrarily) on the chosen normalisation. Furthermore, if the variable one has normalised upon does not appear in the cointegrating relation, then the normalisation results in a fundamentally misspecified model.

In Johansen (1988) and (1991) the problem is resolved by using Full Information Maximum Likelihood (FIML) to estimate the linear space spanned by the cointegrating vectors. In this case the issue of choice of normalisation affecting the identification of cointegrating vectors disappears. Additionally, FIML estimation allows testing of the number of cointegrating relations 0, 1, ….., or n-1. The Engle-Granger approach based upon OLS only allowed for a test of 0 or 1 cointegrating vectors.

The Johansen approach is a form of reduced-rank regression. He develops two tests for the existence of cointegrating vectors, the maximal eigenvalue and trace test. Both tests are now routinely included in econometric software and the Johansen approach is probably the most common applied to the estimation and testing of cointegrating relations. In part, this is because of it's ability to impose and test for the validity of various restrictions on the cointegrating space. This is particularly useful in the literature on exchange rate models which imply Purchasing Power Parity, or models of growth which imply 'convergence' of growth rates. However, the inclusion of nuisance parameters can dramatically affect the distributions of the test statistics (which are typically calculated via response function-type methods). The trace and eigenvalue test statistics have been calculated for models that include either restricted or unrestricted intercepts and trends in the model and both their absences. However, including ad hoc., intervention dummies can seriously affect these calculated values and in principle requires individual calculation for each case.

However, the popularity of the Johansen approach is extremely high. Used and abused, it is now part of the time series toolkit of all modern-trained econometricians.

Peter Phillips

Time Series Regression with a Unit Root, Econometrica, 55, 2, 277-301, 1987.

The distributional theory used in the seminal work of Dickey and Fuller (1981) and the others that immediately followed, concentrated on the case where the innovations in the model were independent with a common variance. Frequently the assumptions were iid(0, σ^2) or iid N(0, σ^2).

Phillips points out that such assumptions are particularly strong when it comes to applied econometrics and that it is important to develop tests that do not depend upon such restrictive assumptions.

Phillips (1987) provides an asymptotic theory for the least squares regression estimator and the associated regression *t* statistic that allows for quite general weakly dependent and heterogeneously distributed innovations. One of the useful outcomes of the work is that the new test statistics he proposes are, in their limiting distributions, identical to those found in Dickey and Fuller. Hence, the assumption of iid errors remains relevant for a much wider class of models.

Developments in estimating models with non-standard error properties

Lars Peter Hansen

Large Sample Properties of Generalized Method of Moments Estimators, Econometrica, 50, 4, 1029-1049, 1982.

One very common way to approach the estimation of an unknown vector of parameters is to use ML – the estimate that would most likely have been observed. A drawback of the approach, however, is that the form of the likelihood function needs to be specified.

Hansen (1982) popularised an alternative approach to the problem of estimating an unknown vector of parameters using a class of generalized method of moments (GMM) estimators. GMM was not new, but Hansen (1982) certainly brought it widespread coverage.

The basic advantage of GMM is that it requires only the specification of certain moment conditions and not the full density as in ML. Furthermore, as Hansen demonstrates, the GMM estimators encompass many standard econometric estimators for example, the nonlinear instrumental variable estimators of Amemiya (1974, 1977), Jorgenson and Laffont (1974) and Gallant (1977); the two-step estmators of Cumby, Huizinga and Obstfeld (1981) and the generalized instrumental variable estimators from nonlinear stochastic Euler equations developed by Hansen and Singleton (1982). However, the main impact of the GMM approach was to allow economists to test many theoretical restrictions directly within the estimation process by simply embedding them in as orthogonality conditions.

They could simply write-down the relevant first-order conditions for their particular problem and estimate via GMM.

A further important property of Hansen's GMM estimator is that it permits both serially correlated and heteroskedastic disturbance terms. Although the resultant estimators are not asymptotically efficient Hansen suggests that:

> *Researchers may be willing to sacrifice asymptotic efficiency for not having to specify completely the nature of the serial correlation and/or heteroskedasticity or in exchange for computationally simpler estimation strategies.*

This was something of a breakthrough for the types of macroeconomic model that were being developed, particularly in the testing of market efficiency, linear rational expectations models and exchange rate models. In these cases the disturbance terms are typically serially correlated, but orthogonal to current and past values of a subset of variables that are not strictly exogenous.

Halbert White

A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity, Econometrica, 48, 4, 817-838, 1980.

"Whitewashing", has become a common occurrence in applied econometrics, i.e., report heteroskedastic-consistent estimates by applying the covariance matrix corrections from White. The approach has been extended by Newey-West (1987) to give heteroskedasticity- and autocorrelation-consistent standard errors for the OLS estimator. However, the original White (1980) approach considered cases where the errors were serially uncorrelated, but with a general form of heteroskedasticity.

When the disturbances in a model exhibit heteroskedasticity it is well known that the estimates obtained, though consistent, are inefficient, but the covariance matrix is inconsistent. As a consequence, inferences will be 'faulty' and hypothesis testing non-robust. If the form of the hetero- is 'known' these problems can be eliminated by (say) application of GLS or imposing appropriate linear transformations on the data. However, the circumstances under which the form of hetero- is known are rare, and inappropriate transformation may exacerbate the problem or lead to other problems. The transformation may remove some of the inefficiencies in estimation of the parameters of interest (and be guided by their values), the same cannot easily be said for inference.

The White (1980) solution is to develop a covariance matrix estimator that is consistent in the presence of heteroskedasticity, but does not rely on the possibly incorrect specific formal model of the structure of the heteroskedasticity. Even when the heteroskedasticity cannot be eliminated, valid inferences can be made.

In addition, White developed a simple test of the existence of heteroskedasticity based upon a comparison of his consistent estimator to the usual covariance matrix estimator. In the absence of hetero- both should be the same. The White test was extended to time series regressions by Nicholls and Pagan (1983) and Breusch and Pagan (1980) as an LM test of the simple TR^2 applied to the auxiliary testing equation.

White-correction, Newey-West-correction and Breusch-Pagan tests of heteroskedasticity are all weapons in the time-series economist's arsenal.

Robert Engle

Autoregressive Conditional Heteroskedasticity with Estimates of the Variance of United Kingdom Inflation. Econometrica, 50, 4, 987-1007, 1982.

I think this is the development that has created the most acronyms of any 'recent' development in econometrics. AutoRegressive Conditional Heteroskedasticity (ARCH) has led to GARCH, EGARCH IGARCH, ARCH-M, NARCH, AARCH, PNP ARCH, QARCH, QTARCH, TARCH, (then I stopped looking!).

The origins or ARCH go back to Bachelier (1900) who was the first to produce a rigorous study of speculative prices. Mandelbrot (1963, 1967) revived interest in the time series properties of asset prices with his theory that "random variables with an infinite population variance are indispensable for a workable description of price changes". His observations such as, "that unconditional distributions have thick tails, variances change over time and large (small) changes tend to be followed by large (small) changes of either sign" are the stylised facts of financial variables.

Engle took these stylised facts and produced the ARCH stochastic process. Such a process, which can apply to a variety of contexts, but often applied to the error term, can be expressed as:

$$y_t = x_t' x_t + e_t \qquad t = 1, \ldots., T$$

The ARCH model characterises the distribution of the stochastic error term, $\mathbf{e_t}$, conditional on the realised set of the variables:

$$\Psi_{t-1} = \{ y_{t-1}, x_{t-1}, y_{t-2}, x_{t-2}, \ldots. \}$$

Specifically,

$$e_t | \Psi_{t-1} \sim N(0, h_t)$$

where,

$$h_t = a_0 + a_1 e_{t-1}^2 + \ldots.. + a_q e_{t-q}^2$$

The conditional variance h_t is a function of the conditioning set $\mathbf{Y}_{t-1}$, but also importantly notice that the chosen functional form means that the variance of the current error $\mathbf{e_t}$, conditional on the value of the lagged errors, is an increasing function of the magnitude of the lagged errors, irrespective of their signs. Large (small) errors of either sign tend to be followed by large (small) errors of either sign.

The ARCH process and its generalisation to the empirically popular GARCH

$$h_t = a_0 + a_1 e_{t-1}^2 + ... + a_q e_{t-q}^2 + b_1 h_{t-1} + ... + b_p h_{t-p}$$

has proved to be *incredibly* popular and successful way of explaining and forecasting time series financial data.

On testing for ARCH – this has become a standard diagnostic test in software packages based upon a LM (TR**2**)-type test of for example,

$$H_0 = \alpha_q = \alpha_2 = \ldots .. \alpha_1 = 0.$$

Whitney Newey

Maximum Likelihood Specification Testing and Conditional Moment Tests, Econometrica, 53, 5, 1985.

Much of the day-to-day work of econometrics involves obtaining "good' estimates of population parameters, where minimally one would expect the estimators to be consistent. However, model misspecification can lead to inconsistent estimates and hence *specification tests* have become a central feature of modern econometrics. With the increased use of maximum likelihood estimation in for example, limited dependent variable models, the consistency of the estimators can be sensitive to the validity of the assumed distributional properties of the model.

Hausman (1978) presented a general scheme for forming specification tests based on the differences of two estimators of the vector of parameters of interest. This test used the information matrix equality and a test based upon the likelihood ratio score. Each of these tests can be seen as tests of specific population moment conditions.

In Newey (1985) a moment testing framework is proposed which includes each of the two testing frameworks noted above and additionally a Lagrange multiplier alternative. The paper focuses on the power properties of the tests for local misspecification providing insights into the power of the alternative test forms for particular local misspecification. When exogenous variables are present, the expectation of the score vector of an observation, conditioned on the exogenous variables, is zero, so that functions of exogenous variables should be uncorrelated with elements of the score vector. As such, moment conditions tests can be based on sample covariances of functions of exogenous variables and the score function evaluated at the ML estimator.

Moment conditions tests can also be based upon other functions that have conditional expectation zero. This is what Newey calls *conditional moments restrictions* or *CM tests*. These CM tests can be used for misspecification tests including heteroskedasticity, non-normality, simultaneity, and omitted variables. Here, as with Breusch-Pagan (1980), the tests do not depend upon the particular form of hetero-. Under particular conditions, the CM test is the LM test for heteroskedasticity. Likewise, under certain conditions the CM test is the information matrix test for probit. Finally, the test for simultaneity can, under certain general conditions, become an LM test.

However, like many/most tests of misspecification it is difficult to distinguish certain forms of misspecification see also McAleer (1995). In particular, the "test for nonnormality has a vector of moment functions which are linear combinations of the moment functions for the optimal test for hetero- which depends on the distinct nonconstant cross-product of the probit regression variables x_1." (Newey, p.1064).

Developments in estimating models using panel data

Jerry Hausman and William Taylor

Panel Data and Unobservable Individual Effects, Econometrica, 49, 6, 1377-1398, 1981.

The use of panel data, i.e., combined time-series and cross-section data has become an increasingly popular approach in econometrics in part because of the increased availability of such data. One important purpose in such combinations is to control for individual-specific unobservable effects that might be correlated with other explanatory variables. Hausman and Taylor derive a test for the presence of such effects, necessary and sufficient conditions for identification and an asymptotically efficient instrumental variable estimator.

In contrast, using OLS or GLS in such cases leads to biased and inconsistent estimates. The resolution to this problem typically involved transforming the data into deviations from individual means. However, the

OLS estimates from the transformed data, the fixed effects estimator, has two important deficiencies. Firstly, all time-invariant variables are eliminated and secondly, under certain conditions the within-group or fixed-effects estimator is not fully efficient. The first problem can be particularly annoying when the main reason for the estimation is to measure the unknown coefficients of the time invariant variables.

The Hausman-Taylor approach is to assume certain variables are uncorrelated with the latent individual effect allowing consistent and efficient estimation of the coefficients attached to the time-varying and time-invariant observable variables. The time-varying observable variables that are uncorrelated with the latent individual effects serve two purposes. Firstly, using deviations from individual means they provide unbiased estimates of the parameters attached to the time-varying variables. Secondly, using the individual means, they provide valid instruments for the columns of time-invariant variables that are correlated with the latent individual effects.

Of course, the choice of time-varying variables that are assumed to be uncorrelated to the latent individual effects can be important. However, Hausman and Taylor show that under certain conditions their approach allows the non-correlation assumptions to be tested, hence reducing the problem of invalid choices.

Bayesian econometrics

Arnold Zellner

Bayesian Econometrics, Econometrica, 53, 2, 1985.

The previous nine articles have had a distinct *classical* perspective. The final paper considers Bayesian arguments for incorporating prior information in econometric estimation, testing and prediction.

Zellner argues that what he calls the traditional approach[3] of VAR and ARMA time series models in econometrics led to vastly over-parameterised models. In contrast the incorporation of prior information can lead to greater *simplicity.* Interestingly, Zellner sees Bayesian econometricians as interacting "a good deal" with statisticians – perhaps an exception to the rule!

[3] This is a traditional US approach where in the 1980s the VAR had been popularized by for example Sims (1980). Some of my collaborators placed this article as #11 in the Top 10.

What is the message and contribution of Zellner? He asks the question, "why are we interested in the Bayesian approach?" His answer is that many aspects of econometrics include prior information informally, so why not use the formal methods of the Bayesian approach, i.e., 'do it systematically'? Using a range of examples Zellner demonstrates that

> *.....many, if not all, non-Bayesian results can be produced by Bayesian methods under special assumptions. For example, with a large sample assumption, it was mentioned earlier that a posterior mean that is optimal relative to a quadratic loss is approximately equal to the ML estimate. Also many non-Bayesian estimates such as SUR regression coefficient estimates, 2SLS and 3SLS, Cochrane-Orcutt estimates etc., have been shown to be means of conditional pdfs, based upon diffuse priors.*

Question/Comment: So why haven't Bayesian methods made a serious impact on traditional econometrics? There are some exceptions including Bayesian influences on unit root testing. The development of the Gibbs sampler, see

Koop (1994) and recently the embedding of Metroplis-Hastings within a Markov chain Monte Carlo (MCMC) environment. Undoubtedly increased computing power has helped, but probably the largest impediments to the adoption of Bayesian econometrics are the 'sunk costs' from the classical camp and the lack of training in Bayesian econometrics for young econometricians. The Zellner paper helped to up the anti, but in the year of the Olympics, the torch needs to be carried further and wider.

Epilogue

Were the 1990s a drought?

None of the 10 papers discussed above were published during the 1990s. Does this mean that nothing happened then or does it take time for the seminal work to find its way to the populace? To answer this will probably require a 'proper' survey of the discipline or analysis of the relevant citation indices.

Why so little Bayesian econometrics?

The *Journal of Econometrics* has a number of Bayesian econometricians on its Board and publishes a significant number of Bayesian papers. However, many are from the same group including a large contingent of Continental European authors. So why so relatively few Bayesians? Perhaps part of the answer lies with undergraduate and graduate education that focuses upon Classical statistics and econometrics. Perhaps it's the computer intensive nature of much of the applied Bayesian econometrics, although computing power has increased enormously. In fact, Bayesian econometrics is increasing its profile in part because of advances in computing power allowing Markov chain Monte Carlo (MCMC) methods to be 'routinely' applied. However, the future of Bayesian econometrics probably lies with the training of future generations of economists/statisticians.

Time series econometrics was given an enormous boost and energy with the non-stationarity issues 'discovered' is macroeconomic data. The financial econometrics area was driven in, apart, by the search for 'profitable' uses of the research. Micro-econometrics was given a boost by the availability of large (unit record) data sets. For Bayesians their popularity might depend on a uniquely Bayesian solution to a relevant economic issue or the ability to make money from Bayes.

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