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Discussion Paper

No.8905

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August 1989

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Abstract

This paper provides a non-technical discussion of some of the issues that have received attention in the econometrics literature in the last ten to fifteen years, with a special emphasis on those developments which have immediate implications for non-econometricians who undertake empirical work. Two groups of readers are especially targetted - recent graduates seeking guidance in this area; and economists whose formal training in econometrics may now be rather dated, and who wish to upgrade their empirical analysis. The discussion covers model formulation, data and computational issues, as well as developments in estimation, hypothesis testing and model-selection. The theme of the paper is that there have been important advances in all of these aspects of econometrics; that applied economists must recognise this in their work; and that as most of these developments are very easy to implement, there is no excuse for non-specialists using out-of-date techniques.

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* This paper is a shortened version of an address given to the International Postgraduate Research Conference at the Economic Research Centre, University of Western Australia, November 1988. I am most grateful to Ken Clements for the invitation to participate in that successful event, and for his encouragement to prepare the paper in this form. I would also like to thank Ray Byron, Judy Giles, Daryl Turkington and the referees for their helpful comments.

1. INTRODUCTION :

This paper is directed at economists who undertake empirical studies and use econometrics, especially those whose training in econometrics is now somewhat dated, and recent graduates seeking general guidance. It seeks to provide non-technical information about some recent developments in econometric modelling. The topics discussed are illustrative rather than definitive, and the discussion is kept quite general, focussing on broad issues rather than detail. The objective is to convince the reader that many important developments have been taking place in this field in recent times. The paper is not intended to be a comprehensive survey for specialists. An authoritative discussion of econometrics is given by Griliches and Intriligator (1983-1986)), and surveys by Pagan and Wickens (1989) and Wallis (1989) provide up to the minute material on econometric inference and forecasting, respectively, at a more technical level than is adopted here.

Increasingly, and properly, economists are using econometrics as a matter of course. Our students incorporate at least elementary econometrics in their training, and in the last fifteen years or so there has been an explosion of empirical economic studies, for several reasons. First, econometric theory itself has made enormous ground. If one takes the founding of the Econometric Society in December 1930 as the birthdate of econometrics (although see Epstein (1987) for earlier developments), then econometrics is a young subject. However, it has made a dramatic impact. Considerable intellectual progress has been made and at the same time a healthy skepticism has emerged, so our expectations of econometrics are more realistic than they were.

A second reason is the improved availability of economic data. We still don't have enough data of the right type, but we have more data, different types of data, and better quality data. While the increased reliability of published data is of obvious benefit, equally important is the reporting of associated measures of its limitations. One example is the reporting of "standard errors" associated with survey data, such as with some of the local labour force data.

Finally, there is the question of access to data. Personal computing has put economic data and its analysis at our finger tips. We can now avoid "handling" data - the software just accesses machine-readable files - and this reduces transcription errors, but there is also a cost. It is very easy to "mine" the readily available numbers. On the positive side, as official agencies take advantage of this technology, they release data with greater rapidity, and this has improved its relevance. This has led us to expect our students to estimate models of considerable complexity, using techniques that were merely described "in principle" in advanced courses in econometric theory a generation ago. And it's all done with the P.C.s on our desks or laps.

With these developments it has become increasingly difficult for applied economists to keep pace with econometric techniques and their application, and it is common to find an otherwise excellent piece of work marred by the use of dated and inappropriate econometrics. This is avoidable - that's what this paper is about.

The rest of the paper is broken into five parts, dealing with methodology, the formulation of models, data issues, estimators and tests, and computational facilities. Many important developments in time-series analysis are largely ignored; and little is said about ways in which classical hypothesis testing in econometrics has been systematised - not because these matters are unimportant, but because boundaries have to be drawn somewhere. More detail can be found in Pagan and Wickens (1989), for example. Hopefully readers will be alerted to the types of issues that have concerned econometricians in recent years, and encouraged to be more careful and skeptical in their empirical work.

2. METHODOLOGY :

Pagan (1987) provides an excellent critical appraisal of three modern econometric methodologies : those associated with David Hendry, Christopher Sims, Edward Leamer, and their colleagues. At the risk of over-simplification, the three methodologies in question can be summarised as below. In view of Pagan's paper and Aigner *et al.* (1988), a more detailed discussion would be superfluous.

Hendry's approach (Hendry (1989), Hendry and Richard (1982), Gilbert (1986)), involves working from a general model specification to a parsimonious one. The general model incorporates variables on the basis of economic theory, and simplification is achieved by testing the model's specification and predictive ability. The systematic use of diagnostic tests is one feature of Hendry's methodology, another being the "encompassing principle" - the preferred model should be capable of explaining the results produced by a competing model. In contrast to the use of structural systems in the tradition of the Cowles Commission, Hendry's analysis is in the L.S.E. tradition and emphasises dynamic single equation specifications, perhaps incorporating an "error correction" mechanism. All of this comes together in the impressive PC-GIVE computer package.

Sims's methodology, much of which is summarised in his 1980 *Econometrica* article, discards structural models as being underidentified, and concentrates on reduced form specifications. There is a heavy emphasis on Vector Autoregressive Representations (VAR models), which explain a vector of variables in terms of lagged values of this vector (plus, perhaps, some totally exogenous variables). The lags are restricted to simplify the model and to take account of causal directions and the limitations of degrees of freedom. This methodology frequently blends Bayesian and frequentist ideas, as in the work of Litterman (1986a, 1986b), and the RATS computer package is specifically designed to implement this methodology.

The third methodology which Pagan discusses in detail is that of Leamer (see Leamer (1978,1983a,1983b,1985) and Leamer and Leonard (1983)). This methodology is essentially Bayesian, but with some novel and controversial twists. The twists that distinguish Leamer's approach from "textbook Bayesian analysis" include, for example, the use of "Extreme Bounds Analysis". This essentially involves considering the extreme values that the point estimate of a parameter of interest can take (say, under least squares estimation) as all possible linear combinations of the "doubtful" regressors in the model are included in regressions with the set of "non-doubtful" variables. The idea is to get a measure of specification uncertainty - narrow bounds are desirable as they suggest that the point estimate of interest is insensitive to changes in the model's specification. Leamer's methodology emphasises various types of sensitivity analysis, and can implemented with the aid of his SEARCH computer package.

Although the Bayesian view has not converted econometricians en masse, or become the cornerstone of our applied research, it has had an important influence on our approach to econometrics. Arnold Zellner's name is the one we associate with Bayesian econometrics, and Zellner (1971) covers a lot of his earlier work. A good recent reference is Zellner (1988), in a special issue of the Journal of Econometrics devoted to "Competing Statistical Paradigms in Econometrics". The appearance of such volumes, and the panel discussions being scheduled at professional conferences (see Pagan (1987) and Aigner et al. (1988)), reflect a recognition that methodology matters.

3. NEW TYPES OF MODELS :

Most of us learn our econometrics in terms of "structural" models. Relationships are postulated on the basis of economic theory, which also suggests restrictions on functional form and parameter values. This section discusses some important developments with such models and some alternative model types.

3.1 VAR Modelling :

VAR modelling is really time-series modelling, rather than structural modelling - a set of variables is explained in terms of just the lagged values of those variables (plus, perhaps, some exogenous variables such as to allow for trend and seasonality). Using formal testing, zero restrictions are imposed on the lags, reducing the otherwise excessive depletion of degrees of freedom and introducing elements of causality into the system. Although developments in the theory of causality are beyond the scope of this paper, the contributions of Granger (1969) and Sims (1972) might be noted.

A VAR model is a dynamic "Seemingly Unrelated Regressions Model" (Zellner (1962), Srivastava and Giles (1987)). It allows for non-zero cross-equation error covariances with potential for improved estimation efficiency. VAR models are best suited for prediction rather than policy analysis, and there is evidence that they can generally out-forecast univariate time-series models (see Kinal and Ratner (1982), Hoehn *et al.* (1984), and Wan (1988)). Litterman (1986a,1986b) also provides compelling evidence in favour of VAR models and McNees (1986) demonstrates how well they forecast relative to the main U.S. structural super-models. On the other hand, Runkle (1987) offers some cautionary comments as far as *unrestricted* VAR's (as opposed to *Bayesian* VAR's) are concerned.

The usual argument in favour of structural models for forecasting is that they incorporate prior information, so they should have greater predictive efficiency than unrestricted reduced form models. This ignores the results of Dhrymes (1973): while a structural model incorporates more prior information than a reduced form model, it also incorporates *less* sample information, so relative predictive efficiencies are an empirical issue. (See, also, McCarthy (1972).) Further, in Litterman's Bayesian VAR modelling prior information of a type *is* introduced, and his forecasting record is excellent. One area where VAR models have been useful is in regional economics, where we often have data on some regional variables, but lack data on all of the other variables needed *at the regional level* to estimate a structural econometric model. A VAR model requires only past data on the variables to be predicted.

3.2 Functional Forms :

Historically, for computational ease, much econometric work involved linear relationships. With modern computing technology, such limitations are unnecessary, and we can take account of *appropriate* functional forms for our models. If the functional form is dictated by economic theory, there is little at issue; but what if a choice is to be made? In answering this question there has been a lot of emphasis in the past fifteen years or so on the use of "flexible functional forms" in applied econometrics, especially since the introduction of the generalised Leontief function by Diewert (1971), the Transcendental Logarithmic (Translog) model of Christensen et al. (1973), and the general contributions of Diewert (1973,1974). These flexible forms are linear in the parameters but give a second-order approximation to any arbitrary function. They are non-linear in the variables, incorporating second-order terms in the regressors, and have been applied widely in empirical production, cost and demand studies.

A useful survey is given by Lau (1984). He isolates five criteria for the choice of functional form : theoretical consistency; domain of applicability; flexibility; computational facility; and factual conformity. He stresses that we should not expect to find one function which meets all of these criteria - trade-offs may be needed. Here Lau makes some specific suggestions, including one that we should try to avoid sacrificing linearity.

There are two sides to this suggestion. It is true that our statistical results in econometrics are better developed for linear models than non-linear ones, but it is not clear that the relevant results are that much better developed. For example, while we have strong finite-sample results for the estimation of the linear regression model with fixed regressors, these have limited applicability. Models with stochastic regressors are more relevant, and here our results are fewer and weaker. This is comparable to our state of knowledge when it comes to non-linear models, so why should we discount the latter on these grounds? On the other hand, large non-linear systems raise some practical computational issues that shouldn't be discounted. Although we have the algorithms and the computational power to estimate such models, obtaining results which are numerically stable is often difficult and many reported results are quite sensitive to the choice of initial values for the algorithms used (or indeed the choice of algorithm itself). Applied researchers should be encouraged to check the sensitivity of their results to such choices.

3.3 Limited Dependent Variables Models :

It is not always appropriate to formulate regression models so that the dependent variable can take any real value. This assumption is implicit when we assume Normal disturbances. In many applications the dependent variable can take only discrete values, or is constrained in sign. There are also so-called "censored regression models", in which the dependent variable are limited in its range by an underlying stochastic choice mechanism. An example of the first situation is where the dependent variable is qualitative, such as if we "explain" individuals' decisions to take a degree course using a model with a binary "dummy" dependent variable. An example of the second situation arises when measuring expenditures; and an example of the third occurs in the measurement of the demand for durables, where many of the households surveyed report zero expenditures because the item is purchased only infrequently. There is some threshold level of expenditure which stochastically determines if a purchase is made.

What are the consequences? Least squares estimates of the parameters are biased, and least squares is no longer maximum likelihood, so the estimation and testing strategy has to be re-thought. Fortunately, there is a substantial literature on this topic, with useful references including Dhrymes (1986), Maddala (1983), and a special 1987 issue of The Journal of Econometrics. Computer packages (e.g., LIMDEP) which allow for the appropriate estimation of these models are readily available, so there is no excuse for ignoring the important issues associated with these situations. However, there are traps. For example, Jarque (1987) extends the Linear Expenditure System to allow for limited dependent variables, but in his approach the estimates do not satisfy Engel aggregation.

As with many econometric results, especially those based on maximum likelihood estimation and the associated tests, the procedures which have been developed for these models rely on the validity of the underlying assumptions. If these are violated, the estimators are generally inconsistent, so diagnostic testing is essential. In this regard see Hausman and McFadden (1984), Gourieroux et al. (1987), Chesher and Irish (1987), Smith (1987), and Newey (1987).

3.4 "Switching" Models :

Testing and allowing for "structural change" has a long tradition in econometrics. The Chow (1960) Test, subsequently recognised to be just a Wald test of linear restrictions, is familiar enough, as are the CUSUM and CUSUMSQ tests (Brown et al. (1975)), and now recognised to be of the Lagrange Multiplier type. These tests are limited by their underlying assumptions too, and it is common to see them wrongly applied to dynamic models or simultaneous systems. This is unnecessary, as Giles (1981a,1981b), Tsurumi (1982), Dufour (1982), Erlat (1983), and Kramer et al. (1988) show.

Recently there has been interest in modelling with an explicit allowance for structural change. Much of this work has a Bayesian basis (e.g., Broemeling and Tsurumi (1986)). As well as emphasising structural change in simultaneous systems, this literature also emphasises robustness to departures from the usual error term assumptions. Important recent contributions include Hsu (1982)) and Erlat (1984). This emphasis on robustness is now common in econometrics and the results are especially relevant to applied researchers. Only in this way can we assess the likely costs of mis-applying standard results.

There are similarities between the modelling of structural change and the modelling of systems which are out of equilibrium. The traditional analysis of equilibrium models is unnecessarily restrictive. Whether a market is in equilibrium is a testable hypothesis, so it makes sense to model in ways which allow for disequilibrium, with equilibrium as a special case (e.g. Bowden (1978)). Quandt (1982) gives an excellent survey of applications in this field, but this topic is easily overlooked in applied studies, even though equilibrium assumptions are often unduly restrictive. Similar comments apply to markets which are only in temporary equilibrium. The empirical analysis of such models is the subject of a special 1986 issue of the Journal of Econometrics, applications of this type being relevant to the modelling of both production and consumption behaviour, especially where regulatory-induced distortions are present. Again, static equilibrium can be modelled as a special testable case (e.g, Schankerman and Nadiri (1986)). Econometric models of disequilibrium and temporary equilibrium typify situations where empirical modelling has kept pace with developments in economic theory, and deserve wider application.

"Self-selection models", in which the dependent variable is observed in only one of two possible regimes, are a further type of switching model. Here the relevant distribution is truncated by the agents' behaviour (such as a decision to work or not), so these are also limited dependent variables models. Various types of switching models are categorised and surveyed by Maddala (1986). Also related are simultaneous systems which allow for switching between endogeneity and exogeneity. Such situations arise if a government has discretion over its choice of policy instruments, with important implications for estimation and hypothesis testing (see Richard (1980) and Hillier and Giles (1984)).

3.5 Rational Expectations Models :

As the reader will know, Muth's (1961) definition of "rational expectations" as the "... prediction of the relevant economic theory" has had a profound effect on dynamic macroeconomic modelling and associated econometric applications (e.g., Lucas and Sargent (1981)). Empirically, rational expectations are the predictions obtained as the solution of a complete structural econometric model. That is, they are conditional on the model that is specified, and one question that has to be posed is "in what sense is any econometric model the right model?"

Both the Instrumental Variables and Maximum Likelihood principles, discussed in section 5.1 below, are used in the estimation of rational expectations models, and a good survey is given by Pesaran (1987). The literature on single equation rational expectations models, emphasises the so-called "errors in variables" method and uses Instrumental Variables estimation. This approach holds some traps for the unwary reader - there were several "false starts" before appropriate formulations of the estimators were devised. Also of importance is the distinction between expectations formed in the past about the current value of a variable, and expectations formed now about the future value of the variable. This distinction involves more than a trivial temporal shift, and has important implications for both the estimation and solution of rational expectations models. Neither is the the question of the identifiability of such models simple - it is not just a matter of applying the usual rules relating to linear structural systems (Wallis (1980)).

Full systems estimation of rational expectations models is considered by Wickens (1982), for example, and he distinguishes between two distinct estimation strategies that have since become standard for such models - the "substitution method" and the "errors in variables" method. The latter is a straightforward generalisation of its single-equation counterpart, and often has advantages over the substitution method. For example, no non-linearities are added to the estimation problem; conventional Full Information Maximum Likelihood and Three Stage Least Squares estimation can often be applied quite directly to get efficient estimates; future expectations are easily handled; and the estimator is relatively robust to gaps in the expectations information set. The sustitution method, in contrast, lacks these advantages.

The empirical application of models incorporating rational expectations has been of considerable importance in the last decade. As with many of the other model developments discussed, care must be taken that the peculiar characteristics of such models are taken into account properly - the standard textbook econometric results need to be modified.

4. DATA ISSUES :

Much econometric modelling has been based on time-series data, especially when macroeconometrics received more attention than did microeconometrics. Many early econometric studies were based on slender data sets - official data were gathered only annually. For example, Klein's (1950) "Model I" of the U.S. economy comprised eight structural equations in which twelve coefficients were estimated from twenty one annual observations. Over time, data have become more plentiful for two reasons. The first is obvious, and the second is that data have been gathered more frequently: now we expect to have quarterly or monthly data. In a sense it is ironic that at the same time the emphasis in econometric theory has gone from asymptotic results to exact finite-sample analysis.

In the case of cross-section data the developments have been less dramatic, and often such data are published only in a form in which much of their richness is masked. For example, household expenditure data may be published only as averages for income groups. There are grounds for confidentiality, but this seriously limits the usefulness of such data. An additional irony is that while such limitations are common in developed Western countries, they are less prevalent in developing economies, a point was made recently by Deaton (1987,1988). The release of some of the unit records of the Australian Household Expenditure Survey is an encouraging step, though of course this information tends to be dated and much of its usefulness is reduced accordingly.

Apart from developments in the availability of time-series and cross-section data, new types of data have emerged (e.g., see Griliches (1986)), with implications for econometric analysis.

4.1 Longitudinal Data :

Longitudinal data are a time-series of cross-sections, and can be used to enhance the precision of econometric estimators and reduce the collinearity among regressors. Recently (Heckman and Singh (1986)) the emphasis has been on developing techniques to exploit their features in different ways. For example, it may be possible to estimate dynamic economic processes, at the micro level, of a type that cannot be identified in a single cross-section. Longitudinal data also allow us to test various assumptions that have to be imposed if working with time-series or cross-section data. However, some new estimation issues arise, partly through the need to allow for different error components and partly because the time-series component of longitudinal data typically is rather short, so asymptotic properties are approached by (hypothetically) enlarging the data set in the cross-sectional direction. Such matters are discussed by Chamberlain (1982), Anderson and Hsiao (1982), and MaCurdy (1982), for example.

The term "Panel Data" refers more specifically to observations on a fixed set of individuals (say) over time (see Chamberlain (1984) and Hsiao (1986)). Although panels of economic data are not that common in Australasia, the recently released Australian labour market data set is an welcome exception. There are some are some important examples of such data internationally, again often relating to labour markets. These are documented by Borus (1981) and by Ashenfelter and Solon (1982).

The emergence of longitudinal data has provided a new type of information. It also brings a responsibility - the need to learn about the econometric tools which are relevant for the analysis of such data. In some cases, given the imperfections of the longitudinal data sets that are available locally, a great deal of ingenuity is needed, a good example being the work of Perkins (1984).

4.2 Experimental Data :

Traditionally, economics is regarded as non-experimental. This conflicts with the one of the assumptions on which the classical regression model is based - that the regressors are "fixed in repeated samples". Econometric theory is concerned with what happens when such assumptions are violated, either through our choice of data, or because of the model's characteristics. Social experimentation is expensive and raises legal and ethical questions. Despite these impediments, some noteworthy experimental data have been generated in connection with issues of public policy in recent years, and these data have facilitated some novel econometric studies. Among such data sets in the U.S. are ones dealing with income maintenance, health insurance, housing, and time-of-day electricity pricing. One of the distinguishing features of these data sets is that for cost reasons, unlike classical ANOVA experimental designs, they exhibit unequal numbers of observations per "treatment". When modelling with such data, the problem is that the optimal choice of sample size per treatment depends on the unknown functional relationships. Here is another example where imposing false restrictions on the model (under-parameterising it) induces greater penalties in terms of sampling properties than does the converse error.

Such data sets raise important issues for applied economists (e.g., Hausman and Wise (1977)), and the reader is referred to special issues of The Journal of Econometrics in 1979 and 1984 for further details. Already, more experimental data are becoming available (e.g., see Peter Phillips' comments in Aigner et al. (1988, 346). This is an exciting prospect for economists and, as Dennis Aigner remarked recently, a real privilege for the few people who become involved in their generation.

4.3 Duration Data :

Another type of data which has attracted recent attention is that associated with the duration of particular events, such as labour strikes or job search. Again, here are data with special characteristics, necessitating the use of special modelling techniques (see Kiefer (1985)). These include hazard functions, Markov and semi-Markov processes, and (Olsen and Wolpin (1983)) "waiting time regression". The usual steps of econometric modelling have to be re-considered, underscoring one of the main messages of this paper: when faced with a particular type of economic model or data, we must be careful in applying the "textbook" tools of econometrics. In all likelihood they will be inappropriate.

4.4 Integrated Data :

The use of time-series data in econometric analysis raises the potential for several problems, many of which have been recognised for several years, but some of which have only recently been fully appreciated. The treatment of seasonal time-series is one such example, but here the discussion focusses on the trend component. Many economic time series are non-stationary, which flies in the face of the assumptions underlying much econometric theory, with serious implications for our inferences. A stationary series is said to be "integrated of order zero", while a series whose D'th differences form a stationary series is "integrated of order D". When D is unity we have the random walk model. (Engle and Granger (1987).) The use of integrated series in regression analysis can lead to "spurious correlations", so that the model appears to explain the data better than is reallu the case. It also distorts the sampling distributions of our estimators, and hence the conclusions we may draw from tests of hypotheses, etc. A growing number of tests of whether a time-series is integrated (especially of order one) are available, the best known being that of Dickey and Fuller (1976,1981).

One simple way in which some of the implications of modelling with integrated data may be seen, is to note that if integrated variables are omitted from the model (a very likely situation in practice), then the error term will itself be integrated. This is just a generalisation of an old idea, familiar to all who fit least squares regressions - an omitted variable is likely to be reflected in a systematic residual pattern, and perhaps be detected through the value of the Durbin-Watson test statistic. As we know, non-independent regression errors distort the usual least squares results. There is now an extensive literature on the estimation of models with integrated time-series data. Much of the emphasis is on formulating the model in such a way that an "error correction" term is introduced. This idea was noted earlier in connection with David Hendry's methodology.

4.5 Measurement Errors and Missing Observations :

A recognition that measurement errors matter, and the development of appropriate inferential tools, lie at the foundations of econometrics. Measurement errors have attracted renewed attention as more microeconometric applications have been undertaken. The standard "errors in variables" model and related matters are surveyed by Griliches (1986), for example. The application of the "Instrumental Variables" (I.V.) family of estimators is intimately associated with data measurement errors - in the classical linear model, such errors imply random regressors which are correlated with the disturbance term, just as in a structural equation from a simultaneous system. As our models become increasingly non-linear, there are traps to be avoided. For example, in such models, unless we modify the I.V. estimator it is inconsistent, reinstating the problem we are trying to avoid with this choice of estimator! (For example, see Hausman (1988).) Again, it is important to understand the econometric tools if they are to be applied properly.

An extreme example of measurement error arises when certain data are simply unavailable (Kmenta (1986) Giles (1986a)). In specific situations missing data may have serious implications, such as with the use of "proxy" variables (Wickens (1972)), and in household expenditure surveys where zero expenditures may be recorded for infrequently purchased items. Least squares is biased and inconsistent if applied to such data, though this is often forgotten. Intuitively, an I.V. approach seems likely to be helpful here, and in fact this is so (Keen (1986)). Other procedures, such as the Durbin-Watson test, also have to be modified in the context of missing observations (Savin and White (1978)) so we need to be on our guard.

Much of the official data we use are flawed. For example, national accounts generally include a "residual" balancing item and the idea of "balancing" national accounts data without such a term was considered by Stone et al. (1942), but received practical recognition only recently (Stone(1975, 1984, 1987) and Byron(1978)). Similarly, a general discussion of issues arising with the adjustment of survey data to allow for missing observations is given by Little (1988).

Time-series data are frequently released in "provisional" form and subsequently revised (often several times), and there is a long-standing literature on the effects of data revisions on the conclusions drawn from econometric models (e.g. Denton and Kuiper (1965), Giles (1975), and Trivellato and Rettore (1986)). More recently, attention has focussed on the informational content of preliminary data releases and the extent to which they are "rational" predictors of the final numbers (e.g., de Jong (1987), Maravall and Pierce (1983), Mork (1987), Milbourne and Smith (1988) and Browning (1988)). However, some important issues remain. The fact that many data are just estimates based on surveys is sometimes correctly highlighted with the reporting of "standard errors" to reflect the precision of the figures. These standard errors contain important information which, if used, should improve the precision of our regression estimates. This idea appears not to have been properly explored.

There is no doubt that the quality of our data is fundamentally important. New types of data have emerged and there have been improvements in quantity and quality. However, we must always question the accuracy and relevance of our data, consider the implications for our inferences, and decide if refinements to our procedures are needed. This seems obvious, but it is often overlooked. As users of data we must be vigilant in pressing for improvements in their quality - in terms of accuracy, timeliness, relevance, and internal consistency.

5. MATTERS OF INFERENCE :

5.1 General Principles :

Although not reflected in most texts, in teaching econometric theory it is preferable to emphasise principles rather than specific results. There are good reasons for this. First, formal coursework cannot cater for all eventualities and there is a tendency to panic when faced with a problem not discussed in class. If general principles are stressed, the student later has a conceptual framework for dealing with new situations. Secondly, much of the econometrics literature can be unified along systematic lines. This was not fully appreciated when some of the foundations of econometrics were laid. Where it was recognised it could not always be exploited in practice, given computational constraints, and it is often overlooked in applied work today. One example is in the area of simultaneous equations models, where all of the standard structural form estimators can be expressed as I.V. estimators (see Hendry (1976) and Bowden and Turkington (1984)), a result which immediately discloses their asymptotic properties, and suggests how to formulate hypothesis tests.

There are three unifying frameworks which can be noted here. These are the Bayesian approach; the Likelihood approach; and the principle of Instrumental Variables. There are important connections between these approaches, so really they should not be regarded as separate, and other unifying themes can also be developed. The first two of raise philosophical issues which will not be discussed and (with apologies to Arnold!) as the emphasis here is on applied econometrics, neither will Bayesian inference. This leaves two principles which are directly relevant to empirical economic analysis.

Maximum Likelihood estimation and the associated Likelihood Ratio, Wald and Lagrange Multiplier tests provide the basis for most econometric theory (e.g., see Engle (1984), Cramer(1986)). Unfortunately, most introductory and intermediate courses don't highlight this, and economists who use this training as the basis for their applied research overlook this unity of econometrics. It is important to appreciate the assumptions underlying these procedures to understand their strengths and weaknesses.

For example, which of the three testing procedures mentioned above is the more useful in practice depends to some extent on the relative ease with which the restricted and unrestricted maximum likelihood estimators can be computed. Also,it is easy to overlook the fact that the Full Information Maximum Likelihood (F.I.M.L.) algorithms in standard econometric computer packages assume independently, identically Normally distributed data, and (because it is the concentrated log-likelihood function that is usually coded) that there are no restrictions on the elements of the disturbances' covariance matrix. In practice such conditions are often violated, such as when estimating rational expectations models (Wickens (1982)), so care must be taken. Particularly with the advent of personal computing, too much empirical economic research is undertaken in a "black box" fashion.

Instrumental Variables estimation provides an equally important unifying principle, both algebraically and statistically. Bowden and Turkington (1984) present an excellent coverage of this material, and provide an exception to the rule that books on econometric theory fail to stress a thematic approach. In practice, ordinary least squares estimation (and most of the standard diagnostic tests) are frequently used out of context. For example, even the simplest regression problem usually involves relationships which are really part of a simultaneous structure, so that least squares is inconsistent and biased, and the usual confidence intervals and tests are invalid. If the model is dynamic, we again have problems with least squares, as is well known, but how many us still report "t" and "F" tests in this case? These tests are also invalid in dynamic models (e.g., Evans and Savin (1982)). The procedures suggested by Hausman (1978) and others can be used to test the independence of the regressors and the error term, to see if least squares estimation is justified. What too many economists overlook is that these problems can be resolved by the application of I.V. estimation and the associated tests, and that with modern econometrics packages the effort involved is literally no greater than if using least squares. Why do we see so much nonsensical use of least squares then? Partly it reflects a failure to keep abreast of recent developments (though the I.V. principle is as old as most practising economists), and the failure of econometrics courses to emphasise unifying themes which are of great practical importance.

There is really no excuse. It is not true that to estimate a single structural equation consistently one needs to know the specification of the complete system. Equally, there are some simple "tricks" to help us estimate incomplete models relatively efficiently. For example, if we have a partially complete simultaneous system but are left with certain endogenous regressors for which we are unable to specify relationships, I.V. estimation can be applied, equation by equation. If there are cross-equation restrictions on the parameters we can "close off" the sub-system, and use a F.I.M.L. algorithm to obtain Limited Information Maximum Likelihood (L.I.M.L.) estimates (Godfrey and Wickens (1983)). Cross-equation restrictions can be imposed, and the estimator is (asymptotically) more efficient than any other I.V. estimator.

In fact, I.V. estimators (and in some cases M.L. estimators) are special cases of an even broader family - the "Generalised Method of Moments" estimators (e.g., Hansen (1982), Cumby *et al.* (1983)). This estimator family has gained special prominence in the estimation of rational expectations models, where the notion of rationality itself (in the sense of Muth (1961)) provides the means of formulating consistent and asymptotically efficient estimators.

5.2 Finite - Sample Results :

Historically, most of the strong econometric results have been only asymptotically valid, and this limits their practical appeal. One of the most important recent growth areas has been the development of exact finite-sample theory, especially in the context of simultaneous systems and dynamic models. This is a daunting field, but useful overviews are given by Anderson (1982), Phillips (1982 ,1983), Rothenberg (1984), and Savin (1984). For the applied researcher the difficulty is to extract practical lessons from the highly technical results that are now available.

However, by way of illustration, there are several exact analytic results in simultaneous equations estimation that are of direct relevance to applied econometricians. We know that the L.I.M.L. estimator has no finite moments, so in finite samples it is infinitely biased and imprecise; and that integer moments for the Two Stage Least Squares (T.S.L.S.) estimator exist up to the degree of overidentification of the equation. In the case of arbitrary I.V. estimators, increasing the number of endogenous regressors reduces the precision of the estimator (just as for least squares), and reduces the rate at which the sampling distribution concentrates as the sample size grows. The bias of this estimator grows with the number of instruments, but its precision increases so there is a mean squared error trade-off. We know that under certain conditions the F.I.M.L. Estimator for structural coefficients has no finite integral moments; and we know the conditions under which its reduced form counterpart possesses finite moments (see Sargan (1976)).

There are a few similar results on associated tests, but not many to help the applied econometrician with a limited data set, and there is much to be done in this field. One of the challenges is to generate computational procedures which allow evaluations of the emerging results in forms that can be understood by non-specialists.

5.3 <u>Model Selection</u> :

The discussion so far presumes, implicitly, that the model specification is known to the researcher. This differs markedly from the situation in practice. The problem of "selecting" an appropriate model specification has received considerable attention in the past decade. Usually in economics there are several competing theories, so there are ambiguities as to which variables are to be used, what functional forms should be adopted, and how the dynamic structure of the relationships should be specified. It is helpful to distinguish between so-called "nested" models and those which are "non-nested" or "separate" (though, as Pagan (1987) points out, both nested and non-nested model-selection can be interpreted as special cases of the "encompassing principle" associated with David Hendry's methodology). With the first type, one model can be obtained from (nested within) another by the imposition of parameter restrictions. Models of the second type cannot be written in this form. Selecting between nested models can be undertaken by means of the Likelihood Ratio, Wald, and Lagrange Multiplier tests, for example (see Engle (1984)).

Choosing between non-nested models is more challenging. An excellent survey of this field is given by McAleer (1987). Hendry <u>et al.</u> (1984) is a useful reference for the case of dynamic models, and important collections of papers appear in special issues of the <u>Journal of Econometrics</u> in 1981 and 1983. A distinction should be drawn between "discrimination criteria", such as Akaike's (1973,1974) Information Criterion and related measures; and specification <u>tests</u>. The former rank competing models according to predictive ability, with an allowance for parsimony. As McAleer (1987, p.147) points out, a problem with such criteria is that they always lead to the selection of one of the competing models, whether or not this model can predict the performance of the alternative ones significantly well.

Many of the procedures that have been developed for <u>testing</u> are based on the approach of Cox (1961, 1962), which essentially involves the use of a modified likelihood ratio. Various extensions of this idea have been proposed, useful references being Pesaran (1974) and Pesaran and Deaton (1978). The other strand of testing procedures is based on the principle of Atkinson (1970), which involves nesting the separate models within a more general model. The results of Davidson and MacKinnon (1981) and others fall into this category. These references are merely illustrative, and scarcely do justice to the recent progress that has been made in this field.

5.4 Diagnostic Testing :

Diagnostic testing of regression models is closely allied to model selection. Beggs (1988) and Godfrey (1988) provide comprehensive discussions, and further important material is given by Pagan and Wickens (1989). Diagnostic testing amounts to the application of a "battery" of tests, some informal and some (apparently) formal, in an attempt to see if an estimated model can "survive" the interrogation. The tests typically address the error term assumptions (serial independence, homoscedastisity, normality); functional form; exogeneity of regressors; and structural stability. In a sense, there is nothing new about any of this - testing of this type has always been standard fare in econometric applications. It is the intensity of the testing, and the explosion of available tests of each of the assumptions, that characterises this new wave of enthusiasm for diagnostic testing. Also of relevance are the forms of the tests employed. Many can be characterised as Lagrange Multiplier tests; others fall into the "variable addition" category; and some new classes of test have also been devised (e.g., King (1988)).

I have commented elsewhere (Giles(1989)) on this topic, but briefly I have some reservations which hinge on the contention that much diagnostic testing is inappropriately applied, and that basic ideas (such as using good graphical analysis) can be just as helpful without the misleading shroud of "scientific repsectability". (In this respect, David Hendry's PC-GIVE package offers a welcome balance.) Certainly, in applied studies it is common to see diagnostic tests being used in situations where the assumptions behind their validity are patently not satisfied. This is especially disturbing when more appropriate tests are available. To reiterate, it is important to understand the tools we use if we are to avoid misapplying them.

5.5 Preliminary-Test Strategies :

Statisticians have known for many years that the properties of an estimator depend on how the choice of estimator is arrived at. In econometrics "preliminary-test" estimation (and testing) is commonplace. We invariably use pre-test estimators whenever we estimate any simple economic model, and much diagnostic testing involves extensive use of pre-test strategies.

For example, we may fit a regression by O.L.S., test the significance of one of the regressors with a t-test, and then retain the original model and O.L.S. estimates, or delete the regressor and re-estimate the model by O.L.S.. Which O.L.S. estimator we use is randomised according to the outcome of the t-test. In this example, the pre-test estimator is consistent but biased and inefficient, even if the model satisfies all of the conditions of the Gauss-Markov Theorem. It is also "inadmissible" - it is always possible to find another estimator with uniformly smaller mean squared error than the pre-test estimator. So is the standard O.L.S. estimator for models with more than two regressors in this example, but pre-test estimators are always inadmissible. Pre-testing also distorts the usual properties of confidence intervals and tests - going through this procedure we step beyond the textbook situation and the standard results are invalidated. This may be very serious for the applied researcher: an estimator which is believed to be unbiased may be biased, and what we believe to be a 95% confidence interval may really be a 75% confidence interval, etc.. Pre-testing isn't necessarily a "bad" thing - in some cases it is preferable to other strategies. However, it affects our inferences in complicated ways, and we need to be aware of this.

We routinely use other pre-test strategies in applied econometrics, such as when we check for autocorrelation with the Durbin-Watson test, and report either O.L.S. estimates Cochrane-Orcutt estimates, depending on the outcome of the test. Other pre-test estimators arise when using a Chow test or Hausman's test for the independence of the regressors and the error term. Good discussions of pre-testing in econometrics are given by Judge and Bock (1978,1983), Wallace (1977), Wallace and Ashar (1972), and in a special 1984 issue of the *Journal of Econometrics*. Recent exact analytical finite-sample results emphasise inequality restrictions (Judge and Yancey (1986)); the regression scale parameter (Clarke *et al.* (1987a, 1987b)); multi-stage pre-testing (Ozcam and Judge (1988)); pre-testing in of models which are already mis-specified (Giles (1986b), Giles and Clarke (1989)); models with non-Normal disturbances (Clarke (1988)); and full sampling distributions (Giles (1988)).

It is difficult to offer many explicit prescriptions in this area because mostly these depend on the unknown parameters of the model, but the pre-testing literature is certainly relevant to applied researchers. Applied economists do pre-test when estimating their models, and they should appreciate that the properties of their results may be different from what the researcher (and the trusting reader!) imagines.

5.6 Mis-Specification Analysis :

A lot of what distinguishes econometrics from basic regression analysis and the other "...metrics" is the emphasis on the breakdown of the underlying assumptions. We focus on error term properties, and the consequences of autocorrelation, heteroscedasticity and the like; on stochastic regressors, especially in the context of simultaneous structures and errors in variables; and on ways of drawing inferences in the context of dynamic non-linear models and highly collinear data.

Mis-specification analysis can be defined as the investigation of the consequences of misapplying some inferential procedure. Showing that the omission of relevant regressors from a regression biases the O.L.S. estimator while improving its precision, is an example of mis-specification analysis. From the applied researcher's point of view, it could be argued that this aspect of econometrics is one of the most relevant. It is crucial to know the underlying assumptions and to know how sensitive our standard results are to departures from them. Every empirical model is mis-specified to some degree, so how much weight should be put on "textbook results"?

To illustrate the need for caution, consider a simple example. Under the classical assumptions and using O.L.S. estimation, wrongly omitting a regressor from the model biases the estimators of the parameters but reduces their variability. So, in Mean Squared Error (M.S.E.) terms, things can be either better or worse than if we had retained the regressor, depending on the true parameter values (Toro-Vizcarrando and Wallace (1968)). On the other hand, correctly omitting a regressor from the model unambiguously improves things in terms of M.S.E.. This presupposes that the underlying model is properly specified in other respects. What if several other relevant regressors have been unwittingly omitted from the model? In this case, the above results don't necessarily hold. For example, in such a situation, if we now correctly omit an irrelevant regressor, whether we are better or worse off in terms of M.S.E. is ambiguous, and depends on the unobservable features of the problem (Ohtani (1983), Mittelhammer (1984)). In practice we work with mis-specified models, no matter how careful we are. The literal applicability of most elementary econometric theory needs to be questioned accordingly.

Phillips (1983, 501-503) discusses the finite-sample properties of simultaneous equations estimators when the model is mis-specified. As examples of the sort of results that emerge, there is evidence (Rhodes and Westbrook (1981)) that wrongly omitting regressors from such a model may actually reduce both the bias and the variability of O.L.S. and T.S.L.S., and that in a M.S.E. sense O.L.S. may be superior to the latter. Note that this result relates to just one specific I.V. estimator. (See also Hale et al. (1980) and Mariano and Ramage (1983), and Skeels (1986)). There is also a range of asymptotic results along these lines for mis-specified simultaneous equations models (e.g., Fisher (1961), Mallela and Bhargava (1983), Dijkstra (1984)); for models with general stochastic regressors (Giles (1984)); and for quite general models estimated by maximum likelihood (White (1982,1984)).

Stemming from earlier work by Huber (1964, 1981), there has been a good deal of interest in econometric estimators which are "robust" to departures from the assumed underlying stochastic conditions. For example, in the standard linear model with independent Normal errors we know that the O.L.S. estimator of the coefficients is the M.L.E., and hence is Best Asymptotically Normal. But what if the errors are not independent Normal? In such cases, O.L.S. may have rather poor limiting properties and there is a motivation to seek alternative robust estimators. Huber's "M-Estimator" is one such example, and other approaches are discussed by Koenker (1982), Gourieroux et al. (1984) and Bierens (1981)), for example. Another important example of a robust estimator is White's (1980) error covariance estimator which is consistent even if the errors are heteroskedastic in quite general ways. Many econometrics packages such as TSP and SHAZAM allow regression standard errors to be calculated in this way, protecting the user against mis-specification of this type.

Traditionally in econometric modelling we use "parametric" models - ones involving specific functional forms and a finite number of unknown parameters. Some researchers question whether the underlying economic theory is capable of conveying sufficient information to enable us to take parametric statistical formulations seriously, and instead have proposed less restrictive "non-parametric" (e.g., Ullah (1988a,1988b)) or "semi-parametric" approaches to the problem (e.g., Robinson (1988)). In this way it is hoped that specification error, and the generally negative implications for inference, may be avoided.

6. COMPUTATIONAL ISSUES :

Developments in computing were mentioned in Section 1. For the first time in the history of our discipline, it is possible for any student or researcher in econometrics to implement any of the tools that they acquire. Moreover, this is possible with minimal cost and high precision, so there is no excuse for anyone who fails to undertake empirical economic analysis properly.

Accordingly, economists must be familiar with the available econometrics packages, the best of which come in compatible mainframe and personal computer versions, so identical commands apply in each case. These include TSP, SHAZAM, SORITEC, and RATS and are derived from earlier mainframe versions. This shows in their design and command structure. Other packages have been written from a P.C. perspective (e.g., PC-GIVE, and DATAFIT). Some packages (e.g., TSP and SHAZAM) emphasise conventional but up to date structural estimation, while others (e.g., RATS) emphasise alternative types of modelling, such as Vector Autoregressions.

Still others (e.g., RATS, PC-GIVE and DATAFIT) are the flag-bearers of specific methodologies, and this should be kept in mind when using them.

Finally, transportability of information is important. The packages have their strengths and weaknesses and to some degree they are compatible with each other and with spreadsheet and graphical packages. It is important that the actual physical handling of data (and the potential for error) be minimised. Data files must be transportable <u>in machine-readable form</u>, preferably in the ASCII character set so they can be transmitted by electronic mail.

7. CONCLUDING REMARKS :

This paper urges economists engaging in empirical work to acknowledge and use the developments in econometrics in the past ten to fifteen years. These developments touch on all aspects of econometrics, and have implications for any empirical economic analysis, no matter how modest its intent. Major advances have occurred in model formulation, data gathering, estimation, hypothesis testing, specification analysis, and computing. In short, the application of econometric tools is now a far more sophisticated business than it was at the time when many of our favourite undergraduate econometrics textbooks were written. At the same time, the difficulties associated with accessing and implementing these tools have become relatively trivial when compared over the same time-span. As has been stressed, there is no excuse for not doing the job properly.

The fact that we can employ increasingly sophisticated techniques more easily, brings with it new responsibilities. There is a trap - it is very easy to treat the computer package as a "black box" and mindlessly generate results based on an estimation procedure which has all of the whistles and bells we ever craved for, together with test statisics whose names leave us dreaming of far-away places, while not having the faintest idea what we are, or whether it has any relevance to the economics of our problem! The job must be done <u>properly</u>, not simply done.

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