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Representation in Econometrics: A Historical Perspective

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Abstract

Measurement forms the substance of econometrics. This chapter outlines the history of econometrics from a measurement perspective – how have measurement errors been dealt with and how, from a methodological standpoint, did econometrics evolve so as to represent theory more adequately in relation to data? The evolution is organized in terms of four phases: 'theory and measurement', 'measurement and theory', 'measurement with theory' and 'measurement without theory'. The question of how measurement research has helped in the advancement of knowledge advance is discussed in the light of this history.

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1 Prologue

Frisch (1933) defined econometrics as 'a unification of the theoretical-quantitative and the empirical-quantitative approach to economic problems … by constructive and rigorous thinking similar to that which has come to dominate in the natural sciences'. Measurement has occupied a central place in econometrics and the econometric approach to measurement attempted to emulate that of physics.[1] However, the road to achieving adequate econometric measurements has been bumpy and tortuous, as economics, obliged in the main to rely in non-controllable data, is distinctly different from physics, see e.g. (Boumans, 2005). Questions and problems include: What to measure? by what instruments? How to evaluate the measured products, particularly against observed data as well as available theories?

We chart the evolution of econometrics to demonstrate how the above questions have been tackled by econometricians. In other words, we offer a brief historical narrative organized with respect to a measurement perspective. It is not our intention to provide a comprehensive history of econometrics. Rather, our objective is to develop an account of the way in which measurement research in econometrics has helped knowledge advancement. As such, the account is presented from a largely retrospective angle.

There is no unanimous approach to measurement and representation in econometrics. From the measurement viewpoint, we can categorize the evolution of econometrics into three approaches:

- the orthodox structural approach which closely follows the measurement approach of hard science;

[1] There was a strong sense to make 'modern economics' 'scientific', as apposed to humanity, e.g. see (Schumpeter, 1933) and (Mirowski, 1989).

- the reformist approach which places measurement in a soft system but does not diverge methodologically from the scientific approach; and
- the heterodox approach which we discuss as ‘measurement without theory’.

An initial distinction is between data measurement and theory measurement. The fundamental difference between data measurement and theory measurement is that the former purports to make fact-like statements as to how the world is while the latter is concerned with the quantification of counterfactual statements about how the world might otherwise be. Although we acknowledge that data are always measured relative to and within a theoretical framework, data measurement takes these theoretical constructs as given while theory measurement moves those issues to the foreground and takes the data measurement instruments as being both reliable and neutral with respect to competing theories. This allows us to rely on the modern distinction between economic statistics (data measurement) and econometrics (theory measurement) and focus only on the latter. Within an econometric context, measurement theory focuses on the identification of those measurable attributes of the observed phenomena which reflect economically interesting (in the sense of lawful and invariant) properties of the phenomena, e.g. see (Luce *et al* 1990) and also Chapter 6 and Chapter 9 in (Boumans, 2007). Data measurement is the subject of Chapter 8 in (Boumans, 2007).

Both econometric theory and practice have adapted over time in the face of problems with previous theory and practice (such as residual serial correlation and poor forecasting performance), new questions (for example, those generated by the Rational Expectations hypothesis) and fresh challenges (such as the availability of large data sets and fast computers). Some of these demands forced econometricians to re-hone their tools to be able to respond in the new situations – tool adaptation. In other instances, it was not the tools that needed to be adapted by rather the models on which the tools were employed. It was model adaptation which forced the most dramatic changes in the econometric approach to measurement.

2 Economic Theory and Measurement[2]

Economists have been concerned with quantification from at least the nineteenth century. Morgan's (1990) history of econometrics starts with W.S. Jevons' attempts to relate business cycles to sunspots (Jevons, 1884). Jevons (1871) was also the first economist to 'fit' a demand equation although Morgan (1990) attributes the first empirical demand function to C. Davenant (1699) at the end of the seventeenth century. Klein (2001) documents measurement of cyclical phenomena commencing with W. Playfair's studies of the rise and decline of nations published during the Napoleonic War (Playfair, 1801, 1805). Hoover and Dowell (2001) discuss the history of measurement of the general price level starting from a digression in Adam Smith's *Wealth of Nations* (Smith, 1776).

More focused empirical studies occurred during the first three decades of the twentieth century. These studies explored various ways of how to best characterise certain economic phenomena, e.g. the demand for a certain product, or its price movement, or the cyclical movement of a composite price index by means of mathematical/statistical measures which would represent certain regular attribute of the phenomena concerned, e.g. see (Morgan, 1990), (Gilbert and Qin, 2006) and the Chapter 11 in (Boumans, 2007). These studies demonstrate a concerted endeavour to transform economics into a scientific discipline through the development of precise and quantifiable measures for the loose and unquantified concepts and ideas widely used in traditional economic discussions.

[2] This is from the title of the Cowles Commission twenty year research report, see (Christ, 1952).

This broad conception of the role of econometrics continues to be reflected in textbooks written in the first two post-war decades in which econometrics was equated to empirical economics, with emphasis on the measurability in economic relationships. Klein (1974; p.1) commences the second edition of his 1952 textbook by stating 'Measurement in economics is the subject matter of this volume'. In (Klein, 1962; p.1) he says 'The main objective of econometrics is to give empirical content to a priori reasoning in econometrics'. This view of econometrics, which encompassed specification issues and issues of measurement as well as statistical estimation, lagged formal developments in the statistical theory of econometrics.

The formalisation of econometrics was rooted directly in the 'structural method' proposed by Frisch in the late 1930s (1937, 1938). Much of the formalisation was stimulated by the famous Keynes-Tinbergen debate, see (Hendry and Morgan, 1995; part VI), and resulted econometrics becoming a distinct sub-discipline of economics. Essentially, the ground work of the formalisation comprised a detailed theoretical scheme laid out by Haavelmo (1944) on the basis of probability theory and the work of the Cowles Commission (CC) which elaborated technical aspects of Haavelmo's scheme, see (Koopmans, 1950) and (Hood and Koopmans, 1953).[3]

The Haavelmo-CC edifice defines the core of orthodox econometrics. It is often referred to as the structural approach and may be summarized from several perspectives. At a broad methodological level, it attempted to systematically bridge theory and empirical research in a logically rigorous manner. Specifically, the CC research principle was to make all assumptions explicit in order to facilitate discovery of problems and revision of the assumptions in the light of problems that might subsequently emerge. The assumptions should be as consistent as possible with knowledge of human behaviour and

[3] For more detailed historical description, see (Qin, 1993) and (Gilbert and Qin, 2006).

are classified into two types: the first are those assumptions which are statistically testable and the second are provisional working hypotheses, see (Marschak, 1946).

At the level of the economics discipline, demarcation between the economists and the econometricians assigned the job of formulating theoretic models to the economists while the econometricians were to specify and estimate structural models deriving from the economists' theoretical models. This demarcation is explicit, for example, in (Malinvaud, 1964) who states (p. vii) 'Econometrics may be broadly interpreted to include very application of mathematics or of statistical methods to the study of economic phenomena. … we shall adopt a narrower interpretation and define the aim of econometrics to be the empirical determination of economic laws'. Johnston (1963; p. 3) offers an even clearer distinction: 'Economic theory consists of the study of … relations which are supposed to describe the functioning of … an economic system. The task of econometric work is to estimate these relationships statistically …'. For both Malinvaud and Johnston, the measurement problem in econometrics was equated with the statistical estimation of parameters of law-like relationships.

At the technical level, the CC researchers formalized econometric procedure on the assumption that they were starting from known and accepted theoretical models relayed to them by economists. The modelling procedure was formulated in terms of a simultaneous-equations model (SEM), which was regarded as the most general (linear) theoretical model form since it encompasses a dynamically extended Walrasian system:

(2.1) $$A_0 x_t = \sum_{i=1}^{p} A_i x_{t-i} + \varepsilon_t$$

The econometric procedure comprised model specification, identification and estimation. Specification amounted to adoption of the normal distribution for ε_t following the forceful arguments given by Haavelmo (1944). Identification amounted to formalization of the conditions under which the structural parameters of interest, crucially those found in the (generally) non-diagonal matrix A_0, are uniquely estimable.[4] The issue was demonstrated via a transformation of the structural model (2.1) into what is now known as the 'reduced-form':

$$x_t = \sum_{i=1}^{p} A_0^{-1} A_i x_{t-i} + A_0^{-1}\varepsilon_t = \sum_{i=1}^{p} \Pi_i x_{t-i} + u_t \tag{2.2}$$

Identification requires that structural parameters A_i should be implied uniquely once the non-structural parameters, Π_i, are estimated from data. The role of structural estimation was to deal with the nonlinear nature of the transformation of $\Pi_i \rightarrow A_i$. The principle method adopted was maximum likelihood (ML) estimation. Ideally, the full-information maximum likelihood (FIML) estimator was to be used but a computationally more convenient method, known as limited-information maximum likelihood (LIML) estimator, was developed.

From the viewpoint of measurement research, the Haavelmo-CC formalisation standardised econometrics by firmly accepting probabilistic model formulation and the application of statistical theory in relation to these probabilistic models as the instruments for measuring parameters defined in terms of economic relationships which had been postulated *a priori* and also as the criteria for assessing such measurements. The normality assumption for ε_t was the crucial link in this process since the statistically optimal properties of the ML estimators relies on this assumption. This formalisation was believed to guarantee delivery of the most reliable estimates of structural parameters of interest, in a manner comparable that to which natural scientists, in particular physicists, would aim to attain.

[4] Note that 'identification' carried far wider connotation prior to this formalisation, e.g. see (Hendry and Morgan, 1989) and (Qin, 1989).

The identification issue occupied a central position in the research agenda of structural econometrics. The research touched, and even went beyond, the demarcation boundary dividing economics and econometrics. The CC formulation of the identification problem categorized econometric models into two types – structural and non-structural (reduced-form) models – and similarly parameters were either structural parameters, which quantify behavioural causal relations, or non-structural parameters, which describe the statistical features of data samples. This demarcation implicitly established the evaluation criterion which came to underlie standard econometrics: optimal statistical measurement of structural models. However, the very fact that the most popular type of economic model, the SEM, is in general unidentifiable forces structural econometricians to deal with an additional model specification issue: 'when is an equation system complete for statistical purposes?' in (Koopmans, 1950); see also (Koopmans and Reiersøl, 1950), which essentially makes the starting point of the structural approach untenable from a practical standpoint.[5] Moreover, identification is conditioned upon the causal formulation of the model, specifically the 'causal ordering' of the variables in the SEM. Consequently, research in identification inevitably led the CC group into the territory of structural model formulation, which they had initially wished to take as given, see e.g. (Simon, 1953).

3 Measurement and Economic Theory

The CC's work set the scientific standard for econometric research. Their work was both further developed (tool adaptation) and subjected to criticism in the decades that followed.

[5] The CC group was conscious of the problem and ascribed it to the lack of good theoretical models, see (Koopmans, 1957) and also (Gilbert and Qin, 2006).

The controversy between maximum likelihood (ML) and least squares (LS) estimation methods illustrates the limits of tool adaptation. The argument is related primarily to the validity of the simultaneous representation of economic interdependence, a model formulation issue, e.g. see (Wold, 1954, 1960, 1964). The judgment or evaluation related to actual model performance, e.g. measured accuracy of modelled variables against actual values. The reversal out of ML estimation methods back to LS estimation methods provided a clear illustration of the practical limits of tools rather than model adaptation. The Klein-Goldberger model (1955) provided the test-bed, see (Christ, 1960) with (Waugh, 1961) offering the final judgement in favour of LS methods.

This was one of a number of debates which suggested that there was relatively little to be gained from more sophisticated estimation methods. An overriding concern which came to be felt among researchers was the need for statistical assessment of model validity. This amounted to a shift in focus from the measurement of structural parameters within a given model to examination of the validity if the model itself. It led to the development of a variety of specification methods and test statistics for empirical models.

One important area of research related to the examination of the classical assumptions with regard to the error term, as these sustain statistical optimality of the chosen estimators.[6] Applied research, in particular consumer demand studies, exposed a common problem: residual serial correlation in macroeconometric models, e.g. see (Orcutt, 1948). From that starting point, subsequent research took two different directions. The first was to search for more sophisticated estimators on the basis of an acceptance of a more complicated error structure but remaining within the originally postulated structural model. Thus in the case of residual serial correlation, we have the Cochrane-Orcutt procedure (1949) while in the case of residual heteroscedasticity, we

[6] For a historical account of the error term in econometrics, see (Qin and Gilbert, 2001).

have feasible general least squares (FGLS) both of which involve two stage estimation procedures. These were instances of tool adaptation. The other direction was to modify the model in such a way as to permit estimation on the basis of the classical assumptions, e.g. Brown's (1952) introduction of partial adjustment model into the consumption function, an early instance of model adaptation.

In later decades, it was model adaptation which came to dominate, especially in the field of time-series econometrics. Statistically, this was facilitated by the ease of transition between model-based tool adaptation and tool-based model adaptation. Methodologically, it was due to a lack of theoretical models which clearly met identification criteria as well as to the increasing dissatisfaction with the performance of estimated structural models, despite their improved statistical rigour in the estimators of the supposedly structural parameters.

The accumulating scepticism over, and distrust of, the CC structural approach stimulated a move towards as data-instigated model search. Liu (1960) advocated the use of reduced-form models for forecasting. Nelson (1972) used simple autoregressive-integrated-moving average (ARIMA) models of the Box-Jenkins (1970) type to compare the forecasting performance of the structural model jointly developed by the Federal Reserve Board, MIT and the University of Pennsylvania. He found that the ARIMA time-series models enjoyed a superior forecasting performance. Reviews of the then existing structural macroeconometric models threw up evidence of unsatisfactory forecasts and these were taken as a strong indicator of internal model weakness, see e.g. (Evans, 1966), (Griliches, 1968), (Gordon, 1970).

In terms of tool making, the changed focus on model modification led to development of statistical measures for the evaluation of model performance, rather than directly for parameter measurement. Examples are diagnostic tests, such as the DW test

(Durbin and Watson, 1950, 1951) and the Chow test (Chow, 1960). In acknowledgement of the recurrent need for model respecification, Theil (1957, 1958) incorporated the then available test measures into a step-by-step model misspecification analysis procedure, further loosening the grip of economic theory over the measurement procedures. This movement was later reinforced by the Granger causality (Granger, 1969) and the Hausman misspecification tests (Hausman, 1978), both of which allowed model specification to be determined by statistical fit instead of conformity with theory.

The traffic was two-way and developments in macroeconomics were in part a response to the erosion of the foundations of macroeconometrics in economic theory. Theorists devoted substantial effort to the development of models which would combine a firm basis in individual optimizing behaviour with the flexibility of the data-instigated macroeconometric models. This culminated in the rational expectations (RE) movement of the 1970s. At this point, it became apparent that it was no longer practically tenable to carry out econometric modelling under the strict CC assumption of a known structural model. The practical problem centred on finding the best possible model rather than on measuring the parameters of pre-acknowledged model.

4 Measurement with Economic Theory

This section sets out how the second generation of econometricians put model search as the focus of their research.

The RE movement, and especially the component associated with the Lucas (1976) critique, posed a profound methodological challenge to then current approaches to macroeconometrics. Because expectations of endogenous variables are not directly observed by the econometrician but must be inferred from forecasts generated from the solved model, RE forced econometric researchers to abandon the pretence that true models were known up to the values of the structural parameters. The focus became that of dealing squarely and systematically with the issue of ‘model choice’. ‘Test, test, test’ became the golden rule of macroeconometric research (Hendry, 1980). Three prominent schools of methodology emerged from this trend: the Bayesian approach, the VAR (vector autoregression) approach and the so-called LSE (London School of Economics) approach.

Despite some vocal disagreements, the three approaches shared considerable common ground: in particular the perception that there are serious limitations on the extent to which a priori knowledge is useful in assisting model search. In the macroeconomic context, no matter what level of generality claimed by the theory, this is seldom sufficient to provide econometrician with adequate guidance to fit actual data. Hence, a combination of judgement and computer-based statistical tools tend to play the decisive role during model search at the expense of theory.

The Bayesian approach to econometrics was initially elaborated to enhance the internal consistency of the CC paradigm, see (Qin, 1996). The focus was on the treatment of unknown parameters, which the Bayesians believed should be regarded as random rather than deterministic. However, early results showed that ‘for many (perhaps most) statistical problems which arise in practice the difference between Bayesian methods and traditional methods is too small to worry about and that when the two methods differ it is usually a result of making strongly different assumptions about the problem’ (Rothenberg, 1971; p195). This may be crudely parsed as ‘economic specification is more important than statistical estimation’. Over time, these disappointments induced a change in direction on the part of the Bayesian camp culminating in Leamer’s influential book *Specification Searches* (1978). The book opened up a new direction for Bayesian econometrics and gained it the reputation of being an independent approach to econometric methodology rivalling the CC paradigm – see (Pagan, 1987).

From the measurement standpoint, Leamer's manifesto may be seen as an attempt to use Bayesian priors as the means to explicitly express the uncertainty involved in apparently arbitrary 'data mining' practice, i.e. the ad hoc and seemingly personal methods for dealing with the 'model choice' issue in applied contexts. Leamer offered a broad four-way classification of model specification search activities – interpretation search, hypothesis testing search, simplification search and post-data model construction (i.e. hypothesis-seeking search). The classification and the Bayesian representation of these searches helped expose and alert modellers to the pitfalls and arbitrariness in these practices. But Leamer was unable to offer a systematic alternative strategy for model specification search. Instead, he developed the quasi-Bayesian method of 'extreme-bounds analysis' as a measure of model and/or parameter fragility resulting from specification uncertainty.

Extreme bounds analysis was a retreat from the model specification issue back into parameter measurement, an admission that specification uncertainty severely limits the precision to which economists can measure structural parameters together with a claim that traditional approaches exaggerate the precision they obtain, see also Chapter 12 in (Boumans, 2007). The Bayesian approach was unable to offer a systematic solution to specification uncertainty because, in the absence of theoretically given structural parameters, the Bayesian lacked a well-defined domain over which to define his prior distribution.

The VAR approach was the outcome of fusion of the CC tradition and time series statistical methods developed during the 1960s and 1970s, with the RE movement acting as midwife, see (Qin, 2006). In spite of the provocative statements made in Sims' (1980) paper, now commonly regarded as the methodological manifesto of the VAR approach, the approach essentially offered the first systematic solution to the issue of 'model choice' which had become endemic in macroeconometrics. The result, contrary to Sims' declared objectives, was to restore the credibility of structural models.

The VAR approach consisted of four steps. The initial step was to set up an unrestricted (reduced-form) VAR model which could adequately characterise the dynamic features of the data. The second step was to simplify the model (by reducing lag lengths, where possible) while the third was to structure the original VAR through the imposition of a causal ordering. In both cases, the objective was identification of a data-coherent structural VAR (SVAR). The second and third steps were preconditions for the final step – transformation of the simplified VAR model into the moving average (MA) representation since, with this ordering in place, the model could then be used for policy simulations, see (Sargent and Sims, 1977), (Sims, 1980) and (Sargent, 1981).

The second and third of these steps are those to which VAR econometricians have devoted most of their efforts, placing the issue of structural identification at the top of their research agenda. This reflects maintenance of the CC tradition of developing structural models for policy analysis while the dynamic simplification component was inherited from the time series focus on in forecasting.

Relative to the CC tradition, the connotation of identification was enhanced in the VAR approach to include the notion of identification taken from Box and Jenkins (1970), see section 5. It indicates a partial shift of methodological focus towards data and away from theory. However, VAR theorists continued to maintain faith in structural models, as best seen from Sims' view of 'ideal model', which is one which 'contains a fully explicit formal behavioural interpretation of all parameters', 'connects to the data in detail', 'takes account of the range of uncertainty about the behavioural hypotheses invoked' and 'includes a believable probability model that can be used to evaluate the plausibility, given the data, of various behavioural interpretations' (1989). Moreover, the model remains within the SEM framework, virtually the same as in the CC tradition, see (Qin, 2006).

In retrospect, the so-called LSE approach to macroeconometrics may be seen as a pragmatic variant of VAR modelling. That claim may seem odd in view of the LSE focus on single equation models whereas the VAR approach is to model the entire closed system. However, a single equation can always be thought of as simply the first equation of a system, and often modellers in the LSE tradition embedded equations of interest in just such a system. Further, because VAR modellers impose a diagonal A_0 matrix on the SEM and LSE modellers have typically opted for conditional representations, the choice of single equation versus system modelling does not have any implications for estimation. Both approaches make heavy use of simplification searches, but these are more structured in the VAR context. Both rely on post-estimation diagnostic testing to gauge model validity. From a practical standpoint, LSE modellers have often regarded VAR models as over-parameterized and likely to be vulnerable to structural breaks, while VAR modellers have questioned the LSE type of models as what they see to be arbitrary (i.e. completely data-based) specification simplifications.

Following (Sargan, 1964), LSE theorists have often adopted so-called error correction specifications, on the intuition that any well-behaved system would require either or both level and integral controls – see (Phillips, 1954, 1957), (Gilbert, 1989) and (Hendry, 1995). That belief was reinforced by practical experience of use of macroeconometric models in forecasting and policy simulation but lacked any clear theoretical underpinning. This was to come from the 'discovery' of cointegration which rationalized error correction through the Granger Representation Theorem (Engle and Granger, 1987). Johansen (1988) was responsible for the system analysis of cointegration which turned out to fit naturally into a VAR framework. This opened the door to the development of structural VARs involving cointegrated variables. Both LSE and VAR modellers agreed that equilibrium structure is embodied in Johansens's $\alpha\beta$' matrix. At this point, the differences between the LSE and VAR modellers were reduced to one of style and not substance.

5 Measurement without Theory[7]

Data exploration has always been a strong objective in econometric research. It has never been the case that research has been constrained to areas where economic theories are established already waiting for conformational measurement.

Most of the early atheoretical econometric modelling activities were clustered in empirical business cycle studies. The Harvard barometer was one of the earliest leading indicators of this type of data-instigated research, see (Persons, 1916, 1919).[8] Persons' approach was greatly enhanced in the voluminous business cycle studies carried out by Burns and Mitchell (1946) of the National Bureau of Economic Research (NBER). However, their work induced strong methodological criticisms from the CC group as 'measurement without theory', see (Koopmans, 1947) and also (Vining, 1949). The CC structural approach became dominant among newly trained modellers from the 1950s, following the example of the Klein-Goldberger model (1955).

Despite this, exploratory econometric studies have by no means receded, albeit away from the mainstream. The lack of adequate economic theory tended to provide modellers with the incentive to look for parameter measures of statistical models and attempt, where possible, to provide and interpretable justification of these in terms 'common sense' economics. Structural models based on the economic optimization rationale were never regarded as a prerequisite for modelling, nor as delivering the final

[7] This is the title of (Koopmans, 1947).
[8] See also (Gilbert and Qin, 2006) for a summary of the data-instigated researches in the 1930s.

judgment on model validity. Research in this tradition has been fostered by steady advances in statistics, increasing data availability and the rapid progress of computing technology. In much applied work in government, finance and industry, it was also driven by the requirement for usable results, see also Chapter 13 in (Boumans, 2007).

Time-series analysis is the area in which so-called data-mining activities have been most contentious. An interesting example is the use of spectral analysis. This could be traced back to the uses of periodograms and Fourier frequency analysis for the business cycle studies in the early 1900s, e.g. (Moore, 1914) and (Beveridge, 1921). However, the frequency approach soon fell from favour and was widely seen not useful for the analysis of economic time series, e.g. see (Greenstein, 1935), before econometrics settled on the time-domain representation models in the 1940s. However, the approach was revitalised by Morgenstern (1961), who delegated the research to Granger, see (Phillips, 1997). Thanks to J.W. Tukey's work on cross-spectral analysis to enable frequency analysis to multivariate cases, see (Brillinger, 2002), spectral analysis was re-established as a powerful device for economic time-series analysis by Granger and Hatanaka (1964). Notably, the spectral perspective assisted Granger in the derivation of his well-known causality test (1969), which not only totally relies on posterior data information but also abandons the simultaneity connotation of causality which has been a cornerstone of the CC structural model approach. The Granger-causality test was used as a key tool in the simplification process of RE models in the form of VARs, see e.g. (Sent, 1998; Chapter 3).

As discussed in sections 3 and 4, the time-series approach made a comeback into applied macroeconometric modelling during the 1970s under the impact of the Box-Jenkins' methodology (1970). A striking feature of the Box-Jenkins' approach is their concept of identification, which differs significantly from that concept of the CC's paradigm described in section 2. Instead of seeking unique estimates of theoretical parameters, identification in the Box-Jenkins' framework filters out data features to assist model reduction, a process which aims to obtain a parsimonious model through iterative use of identification, estimation and diagnostic testing. As the final model is for forecasting, data coherence becomes the primal criterion for model acceptance, rather than theory confirmation. The impact of this methodology is clearly discernible in the development of the VAR and the LSE schools described in the previous section.

The increasing appreciation of data-coherent modelling approaches is also embodied in the revival of Burns-Mitchell empiricist pursuit of business cycles since the late 1980s. The revival was mainly boosted up by the use of dynamic factor models (DFM) pioneered by Stock and Watson (1989, 1991, 1993), although the idea of applying dynamic factor analysis to macroeconometric models had been put forward by Sargent and Sims (1977) over a decade earlier, see also (Diebond and Rudebusch, 1996).[9] The powerful device of DFMs helps revitalise Persons' leading indicator models for forecasting during the recent years, e.g. see (Banerjee *et al*, 2003), (Camba-Mendez and Kapetanios, 2004) and (Forni *et al*, 2005).

The area where measurement without theory has been most prominent is time-series finance, e.g. see (Bollerslev *et al*, 1992). Two prominent devices developed are the generalized autoregressive conditional heteroscedasticity (GARCH) models, initiated by Engle (1982), and the stochastic regime-switching threshold models, developed originally by Hamilton (1989, 1990). Interestingly, both are initially devised for charactering macroeconomic data. Engle's original application was to a relatively low frequency macroeconomic process (U.K. inflation), whereas Hamilton proposed the regime-switching model in the context of business cycle research. The GARCH class of models, and its many variants, has been most widely applied to high-frequency financial time series to capture their volatility movement, i.e. the skedastic (or second moment) process. Regime-switching models are used to handle asymmetric conditional states of modelled variables. Typically, they depend on different sets of conditional variables which determine 'good' and 'bad' states of the system (boom versus recession, bull versus bear markets).[10]

Both the GARCH and regime-switching devices were primarily data-instigated and have encouraged econometricians to move further away from the CC's paradigm by referring as 'structural' what the parameters of these time-series models measure, in spite of the considerable gap in the behavioural connotation between these models and underlying theory. The GARCH class of models has always been open to the objection that, by contrast with stochastic volatility (SV) models, the GARCH skedastic process lacks an independent stochastic specification. The preference for GARCH over SV derived from its greater tractability and was despite the fact that SV models are more directly compatible with finance theory – see (Hull and White, 1987). Switching models are one instance of a much wider class of models which respond in a data-instigated manner to nonlinearities in economic responses – see (Granger and Teräsvirta, 1993). So long as econometricians restricted attention to linear models, slope parameters could be interpreted as (or in terms of) the first order derivatives of the supposedly underlying theoretical models. By contrast, parameters often lack clear interpretation in nonlinear models and the model must be interpreted through simulation.

6 Epilogue: Measurement and knowledge advance

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[9] The method of factor analysis in a cross-sectional setting was employed in economics as early as the 1940s, see e.g. (Waugh, 1942) and (Stone, 1947).

[10] (Shephard, 2006) provides a history of SV models.

The status of models, and hence structure, in philosophy of science, and specifically in the methodology of economics, remains controversial. Even if in some of the natural sciences, parameters may be seen as natural constants relating to universal regularities, it makes more sense in economics to see parameters as objects defined in relation to models, and not in relation either to theories or to the world itself. Econometric measurement becomes co-extensive with model specification and estimation.

The standard view is that models provide a means of interpreting theory into the world. Cartwright (1983) regards models as explications of theories. For Hausman (1992), models are definitional – they say nothing directly about the world, but may have reference to the world. Further, a theory may assert that a particular model does make such reference. These views are broadly in line with the CC conception of econometrics in which models were taken as given by the theorists.

Taking models as given proved unproductive in practice. Estimated models often performed poorly, and more sophisticated estimation (measurement) methods failed to give much improvement; identification problems were often acute; and the availability of richer datasets produced increasing evidence of misspecification in 'off the shelf' economic models. The econometrician's task shifted from model estimation to adaptation. This view was captured by Morgan (1988) who saw empirical models in the same way as intermediating theory and the world. For her, the task facing the economist was to find a satisfactory empirical model from the large number of possible models each of which would be more or less closely related to economic theory.

The alternative view of the relationship between theory and models is less linear, even messier. Morrison (1999) asserts that models are autonomous, and may draw from more than one theory or even from observed regularities rather than theories. Boumans (1999), who discusses business cycle theory, also views models as eclectic, 'integrating'

(Boumans' term) elements from different theories. In terms of our earlier, discussion, this view is more in line with the data-instigated approach to economic modelling which derives from the traditions of time series statistics. In this tradition, economic theory is often more loosely related to the estimated statistical model, and provides a guide for interpretation of the estimates rather than a basis for the specification itself.

Wherein lies the measurement problem in econometrics? Econometricians in the CC tradition saw themselves as estimating parameters of well-defined structural models. These structural parameters were often required to be invariant to changes in other parts of the system, such as those induced by policy change. Many of these parameters were first order partial derivatives. But the interpretation of any partial derivative depends on the *ceteris paribus* condition – what is being held constant? The answer depends on the entire model specification. If we follow Boumans (1999) and Morrison (1999) in regarding models as being theoretically eclectic, parameters must relate to models and not theories. The same conclusion follows from Morgan's views of the multiplicity of possible empirical models.

Subsequently, with the fading faith in the existence of a unique correct model for any specific economic structure, measurement shifted away from parameters, which are accidental to model specification, and towards responses, and in particular in time series contexts, to dynamic responses. The VAR emphasis, for example, is often on estimated impulse response functions, rather than the parameters of a particular VAR specification. Similarly, the main interest in error correction specifications is often in the characterization of the system equilibrium which will be a function of several parameters.

Models may be more or less firmly grounded in theory. The evolution of econometrics may be seen as continued efforts to pursue best possible statistical measurements for both 'principle models' and 'phenomenological models', to use the model classification suggested by Boniolo (2004).[11] The former are assiduously sought by the orthodox structural econometricians. This probably results from four major attractions of a 'principle' model, see (De Leeuw, 1990), namely it serves as an efficient medium of cumulative knowledge; it facilitates interpolation, extrapolation and prediction; it allows for deductive reasoning to derive not so apparent consequence; it enables the distilling out of stable and regular information.

Many classes of models in economic theory are deliberately and profoundly unrealistic. This is true, for example, of general equilibrium theory and much of growth theory. Such models make possible 'conceptual, logical and mathematical exploration' of the model premises. These models are useful in so far as they 'increase our conceptual resources' (Hausman, 1992; p.77) and, we would add, that they allow us to recognize similar aspects of the model behaviour which correspond to real world economic phenomena. In a sense, these models substitute for experiments which are seldom possible for entire economies.

Econometrics claims to be solely occupied with models which are realistic in the sense that they account statistically for behaviour as represented by datasets. For econometrician, the data are the world. Following Haavelmo's (1944) manifesto, Neyman-Pearson testing methodology became the established procedure for establishing congruency of models with data. But the claim to realism is problematic in that models can at best offer partial accounts of any set of phenomena. 'The striving for too much realism in a model may be an obstacle to explain the relevant phenomena' (Boumans, 1999; p.92). During the initial decades of modern econometrics, datasets were limited and sometimes relatively uninformative. Over more recent decades, econometricians have benefited both from larger and more informative datasets and from the computing

[11] The third model category in (Boiolo 2004) is 'object models', which correspond essentially to

power to analyze these data. As Leamer anticipated, these rich data would oblige a thorough-going classical econometrician to reject almost any model: '… since a large sample is presumably more informative than a small sample, and since it is apparently the case that we will reject the null hypothesis in a large sample, we might as well begin by rejecting the hypothesis and not sample at all' (Leamer, 1978; p.89). So either by the force of circumstance in the case of inadequate data, by design in the face of rich and informative data, or through the imposition of strong Bayesian priors, econometricians have abandoned realism in favour of simplicity. The situation is not very different from that of the deliberately unrealistic theory models. Econometricians measure, but measurements are model-specific and are informative about the world only in so far as the models themselves are taken as congruent with the world.

History reflects a gradual 'externalisation' of measurement in terms of Carnap's terminology (1950): the development of measurement instruments is initially for '*internal questions*' and moves gradually towards '*external questions*'. For example, parameters are internal within models, whereas the existence of models is external with respect to the parameters. Econometric research has moved from the issue of how to optimally estimate parameters to the harder issue of how to measure and hence evaluate the efficiency, fruitfulness and simplicity of the models, i.e. the relevance of models as measuring instruments.

CGE type of models outside econometrics.

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