John Denis Sargan
1924–1996

J. D. Sargan was born on August 23, 1924, in Doncaster, Yorkshire, where he spent his childhood. He was Emeritus Professor of Econometrics at the London School of Economics when he died at his home in Theydon Bois, Essex, on Saturday 13 April, 1996. He received his secondary education at Doncaster Grammar School and, at the age of 17, gained a State Scholarship for entrance to St. Johns College, Cambridge, where he took a first in mathematics and was Senior Wrangler. Immediately after his degree, he was drafted into war work as a junior scientific officer attached to the RAF in Haverfordwest, where he provided basic statistical advice on the testing of new weapons systems. Like many of his generation Sargan's enthusiasm for economics was aroused by Keynes's *General Theory of Employment, Interest and Money* and he decided to use his knowledge of mathematics and statistics to help tackle some of the pressing economic problems that faced society in the post-war years. Accordingly, in 1946 he returned to Cambridge to do more statistics, particularly time series, and to read economics, taking advantage of regulations that enabled him to complete a BA degree in economics in a year. More detailed biographical information is given in Hendry and Phillips (2003), on which much of the following discussion draws.

Starting his professional career as a lecturer in economics at Leeds University in 1948, Sargan went on to become the leading British econometrician of his generation, playing a central role in establishing the technical basis for modern time-series econometric analysis. In a distinguished career spanning more than forty years as a teacher, researcher, and practitioner, particularly during the period that he was Professor of Econometrics at the LSE, Sargan transformed both the role of econometrics in the analysis of macroeconomic time series, and the teaching of econometrics. His influence on British econometrics was profound and continues today in the traditions he established.

Much of Sargan's research in the first decade of his career at Leeds University over 1948-1958 was devoted to economic issues associated with the distribution of wealth, duopoly, production, and growth. His paper (1957a) on the distribution of wealth is recognized to this day as the most general analytic treatment of the determination of the wealth distribution. His work (1958a, 1961a) on the instability of Leontieff's dynamic input output model also attracted attention, showing that the Leontief model is not well adapted to explaining the behavior of a decentralized economy. In addition to these researches on economic issues, he also published an early paper (1953a) on subjective probability and Bayesian thinking in economics, and another paper (1953b) on some of the statistical properties of the covariogram and periodogram.

Sargan's first foray into econometric methodology began with his paper (1957b) on "the dangers of oversimplification", a discussion of the path-breaking analysis of the Oxford Savings Survey by Malcolm Fisher. Sargan's comments revealed a concern with three issues that recurred in his later research on econometric methodology: the abstract and constrained form of economic-theory models relative to the complexities of the data under analysis; the over-simplified nature of many estimated regression equations, excluding effects that were likely to be important in practice; and the problems of interpreting tests of large numbers of hypotheses. The first two concerns may have led to his subsequent interest in estimating relatively general and unrestricted models, and the third to his ideas about 'data mining' and model selection which became manifest in later research that was published posthumously in Sargan (2001a, 2001b). This discourse on oversimplification was closely followed by two major papers in econometrics that developed a theory of instrumental variable (IV) estimation, published in *Econometrica* in 1958 and the *Journal of the Royal Statistical Society* (JRSS) in 1959.

The two IV papers broke new ground, taking several large steps forward in the analytical treatment of simultaneous equations and the econometric methodology of estimation and inference. They quickly established Sargan as a technically accomplished new thinker in the econometrics arena and they remain of lasting significance. The *Econometrica* paper laid out the methodology of IV estimation as we presently know it, provided asymptotics, related the approach to canonical correlation analysis and limited information maximum likelihood, gave tests for overidentification and under-identification, developed significance tests and confidence intervals, suggested instruments for use in practical work, and discussed the accuracy of the asymptotic theory. In the course of the latter discussion, Sargan pointed out that biases in estimation are likely to be large when the structural equation is almost unidentified, thereby foreshadowing some concerns over the effects of weak instrumentation that have occupied professional interest in recent years, following their explicit treatment in Phillips (1989), Nelson and Startz (1990) and Staiger and Stock (1997).

The *JRSS* paper advanced the analysis of IV estimation by considering the more general case where the structural coefficients $a = a(\theta)$ satisfied some analytic constraints and could be functionalized on a vector of fundamental parameters θ, applying the theory to the case of structural models with autoregressive errors, constructing statistical tests and confidence intervals, and again looking at overidentified and unidentified cases. The framework of this paper made it possible to consider problems of dynamic specification in a rigorous manner by means of statistical testing in a nonlinear in parameters context, thereby laying a foundation for much subsequent research in econometric methodology including Sargan's own later work (1980) on dynamic simplification.

Sargan took up a Fulbright scholarship in the USA for two years from 1958, spending the first academic year at the University of Minnesota, teaching summer school at Stanford University, moving to the University of Chicago for 1959–60 and visiting the Cowles Foundation at Yale in 1960. These visits firmly focused his growing interest on the econometric theory of estimating structural economic models from time-series data and, together with the publication of his two papers on IV estimation, brought his work in econometrics to the attention of the North American academic community. From this point forward, Sargan's career fell under the grip of a deep fascination with the design of statistical methods suitable for studying empirical economic problems and the intellectual problems involved in working out their finite sample and asymptotic properties.

In July 1960, Sargan returned to Leeds University to a Readership, and his growing reputation for insightful, rigorous and powerful analyses led to his election to a Fellowship of the Econometric Society in 1963. In the same year, he was recruited by the London School of Economics as a Reader in Statistics, in the same department as Jim Durbin, before joining A. W. H. (Bill) Phillips (already famous for the Phillips machine and the Phillips curve) in the Economics department as Professor of Econometrics in 1965.

The period of the early 1960s saw the publication of some of Sargan's most influential papers, and the formation of fundamental ideas that would play a major role in his later research. Two articles in *Econometrica* (1961b, 1964a) studied maximum likelihood estimation of structural systems. The first set up a framework that enabled structural estimation in the presence of autoregressive errors, thereby accomplishing a marriage of two earlier theories. The second elegantly established the asymptotic equivalence of full information maximum likelihood (FIML) and three stage least squares (3SLS), thereby confirming the asymptotic efficiency of the latter. A third paper, presented at the Copenhagen meetings of the Econometric Society in 1963 and later abstracted in *Econometrica* (1964b), conceived the notion of approximating the distributions of econometric estimators by means of

Edgeworth expansions. This paper was never published, but it gradually evolved into a major research program concerned with the theory and application of Edgeworth expansions, formally beginning nearly a decade later with the publication of Sargan and Mikhail (1971).

A fourth paper was prepared for the Colston Society conference on National Economic Planning held at Bristol University in 1963 and was published in 1964. This 'Colston paper', as it has become known, is possibly Sargan's most famous paper and is certainly his most important contribution to empirical econometric methodology. The paper laid out the conceptual basis of the so-called 'LSE approach' to econometric modelling, so Sargan is justly credited with the foundation of that approach. The main characteristics of the 'LSE approach to econometric modelling' (which in fact draws on work from many other institutions) are blending prior economic theory ideas with thorough data analysis to develop empirical models consistent with both sources of information, but with neither having precedence. In the context of time series, this led to an emphasis on commencing empirical modelling from relatively general dynamic equations capable of capturing the properties of the data while representing the relevant economic theories, rather than estimating stochastic implementations of theory models. Few papers can have contained so many novel ideas, each of which really deserved a separate article.

The paper is characteristically self-effacing and modest about its many practical contributions, though technically brilliant and economical in its execution. First, as a framework for constructing models, Sargan considered the use of 'long-run' economic analysis to specify the equilibrium of a model and introduced 'equilibrium-correction' mechanisms as a behavioural dynamic, following some earlier work (particularly Phillips, 1954) on trade cycle adjustment mechanisms. In doing so, Sargan established what is now perhaps the most widely-used form of time-series econometric equation in empirical work. Second, Sargan viewed the presence of autoregressive errors in time-series models as a simplification (by virtue of the implicit factorization) of more general system dynamic reactions, and he constructed mis-specification tests that were valid even after estimating dynamic equations. This work translated into Sargan's later concern (1980) for direct tests of dynamic specification and simplification strategies in inference. To address another practical problem of empirical research, the Colston paper formulated a procedure for comparing linear against logarithmic specifications, and investigated the impact of data transformations on the selection of models. The paper further proposed a non-linear in parameters IV estimator for models where the data were subject to measurement errors, devised and implemented operational computer programs for the new econometric methods, and included a proof that the required iterative computations would converge. Finally, the paper illustrated the methodology by matching the econometric theory to the specific, topical and difficult empirical problem of wage and price determination in the United Kingdom. Previous models had related the changes in the variables, namely, wage inflation and price inflation. Such formulations precluded any relationship between the levels of wages and prices, which could therefore drift apart over time. Sargan argued that economic agents are concerned about the level of real wages, not just price inflation, so he formulated a model with a long-run equilibrium and incorporated real wages in the wage equation, thereby distinguishing the equation from many other models, including the Phillips curve. The paper also included a data-based proxy for 'inflation expectations', which was called 'an extrapolation of past price movements into the future' and the disequilibrium of real wages from its target depended on unemployment, productivity and political factors. In modern parlance, the levels variables were integrated whereas the differences and the equilibrium errors were not, so the equation implicitly required cointegration between the levels. Sargan's analysis highlighted the role of real-wage resistance in wage bargains, interpreting the equilibrium correction—the deviation of real wages from a productivity trend—as a 'catch-up' mechanism for recouping losses incurred from unanticipated inflation. As the 1960s proceeded, this real-wage resistance proved to be an insuperable barrier to the successful implementation of incomes policy in the UK. The Colston paper also included a policy discussion in which permanent and transitory effects were distinguished to ascertain which changes would persist and which fade out (such as devaluations).

Prior to Sargan's Colston paper, it was common in empirical econometric practice to test for residual autocorrelation (e.g., by the Durbin–Watson statistic), and if it were shown to be present, estimate a 'generalized' model that allowed for an autoregressive-error process. Sargan reversed this convention, interpreting autoregressive errors as a restriction on the dynamic specification of a model that, when valid, permitted the adoption of a more parsimonious representation. He also stressed that empirical specifications should be stringently evaluated, and formulated tests for the validity of the instrumental variables used in estimation and for higher-order autoregressive errors based on the residuals from the estimated equations. Despite the existence of this test, which was valid in dynamic equations, the Durbin–Watson test continued to be widely and invalidly used for many years in dynamic systems. Regarding computation, the paper carefully addressed the logic of the calculations both to embed all of the estimators in a common framework and to ensure as efficient an iterative procedure as possible, including good selections of the initial values and step lengths, and checks for multiple optima. Sargan's demonstration that the step-wise iterative computations converged to a local optimum was the first of its kind in econometrics and reflected his keen interest in numerical analysis.

Thus, in matters of econometric theory, empirical methodology, numerical computation, empirical application and the integration of economic ideas and econometric technique, the Colston paper was a watershed of new ideas and stands as one of the classic works of econometrics. Many new avenues of research were opened up, leading through equilibrium correction to cointegration analysis, encompassing, general-to-specific modelling, and a greater emphasis on model evaluation (Hendry, 1995 provides an overview).

While the Colston paper constituted Sargan's most influential work from the perspective of empirical practice, the challenges that fired his intellectual passion principally lay elsewhere – in advanced theory. His greatest theoretical interest was in developing a finite sample distribution theory of estimation and inference, perhaps the most technically demanding field of econometric analysis. His main contributions in this area began with the publication of Sargan and Mikhail (1971), continued throughout the 1970s and 1980s, and covered all approaches – exact analytical derivation, asymptotic series approximations of both distributions and moments, and simulation-based methods. Despite the near-intractable nature of the manifold problems in this field, Sargan devoted a huge effort to produce solutions, pushing the frontiers of knowledge forward in remarkable ways in each of the main approaches.

Since economic systems are typically dynamic and/or simultaneous, the finite sample distributions of most econometric estimators and tests are extremely complicated and the exact derivation of these distributions is a technically daunting task in all but the most trivial cases. Even when an exact theory is developed, the final results are often of limited applicability, rely on strong distributional assumptions and do not extend to dynamic settings because of formidable mathematical complexity. Sargan (1976, Appendix A) provided the first general exact results for the distribution of the IV estimator in a structural equation, but he was able to resolve the distribution in closed form (as distinct from integral form) only in the just identified case. The general overidentified case was resolved subsequently in Phillips (1980).

Even in cases where the exact distribution itself is unattainable, certain interesting features of the distribution may be established, such as the existence or non-existence of moments. In this regard, Sargan (1970/1988) gave an elegant demonstration of the fact that structural form FIML estimators, for instance, have no finite integral-order moments (mean, variance etc.), thereby establishing that that these distributions typically have thick tails. By contrast, IV estimators generally have finite moments up to an order that is determined by the degree of overidentification of the structural equation and, on this topic, Sargan (1978) provided a definitive analysis of moment existence for the 3SLS estimator. In related work that was eventually published in his collected papers, Sargan (1975/1988) examined the tail behavior of reduced form estimators and here showed that FIML estimators have finite moments to a certain order (determined by the sample size) whereas IV estimators like 3SLS typically have no finite reduced form moments in overidentified cases. These exact results reveal that FIML procedures can offer some advantages, in terms of reduced outlier activity, when the fitted reduced form is used, for example in prediction.

More general results can be obtained using series expansion and other approximations. Indeed, Sargan hoped that general approximation formulae using Edgeworth asymptotic series could be developed and incorporated into regression software, possibly with the use of computerized algebra, and then used to adjust critical values and improve inference. That goal has not yet been realized and, even with the advent of more recent bootstrap technology, continues to be elusive, partly because available approximations are rarely accurate enough and partly because major difficulties are encountered with all approaches in time series models as the zone of non-stationarity is approached.

In terms of computer-intensive methods, Sargan helped at an early stage in the development and implementation of ideas (such as the use of antithetic and control variates) that made simulation methods viable and computationally efficient (Sargan, 1976, Appendix D). He also made important headway in validating approaches based on moment approximations (Sargan, 1974), even considering the complex case where Monte Carlo estimates and moment approximations are developed in cases where the actual moments fail to exist (Sargan, 1982), so that the approximations characterize pseudo-moments (or moments of suitable approximating distributions). Pseudo-moment expansions of this type provide an intriguing way of interpreting the descriptive moment statistics conventionally reported in Monte Carlo experiments. When the moments of the underlying distribution are infinite, Sargan's results reveal that such simulation-based moment statistics can be validly interpreted as estimates of the actual moments of the Edgeworth approximating distributions up to a certain order, depending on the sample size and the number of replications. This work resolved a major potential concern in the reporting of simulation-based research, since many simulation experiments are conducted in settings where the existence of moments has not been established.

Sargan's work on asymptotic expansions of the finite sample distributions of econometric estimators and test statistics was extraordinary in its coverage and its generality, dealing with IV estimators (Sargan and Mikhail, 1971), full information maximum likelihood (Sargan, 1970/1988), k-class estimators (Sargan, 1975), asymptotic chi-squared criteria (Sargan, 1980), and the theory of validity of the expansions in econometric contexts (Sargan and Satchell, 1986) together with formulae and algorithms for implementation of the approach (Sargan, 1976). The final reference in this list is Sargan's famous Walras–Bowley lecture, which was presented at the 1974 San Franciso meetings of the Econometric Society and contained a multifaceted analytical development of the subject complete with four long technical appendices dealing with different approaches and detailing formulae that must have been obtained over many years of research. In a lucid discussion of density expansions in a general setting, this paper gave explicit formulae for the components of the Edgeworth expansion for a general form of econometric statistic and revealed the dependence of the correction terms on the form of the statistic and the cumulants of the sample moments on which the statistic depended. Importantly, given subsequent research, the paper also supplemented the idea of analytic expansions with a simulation-based approach (originally due to George Barnard) that is now recognized as a version of the modern parametric bootstrap.

Sargan's Walras Bowley lecture and several of his other papers in this demanding field are filled with technical innovations and show little sign of aging even after decades of subsequent research. Although asymptotic expansions have been found an unreliable means of improving inferential accuracy, Sargan's theoretical contributions helped blaze the trail of finite-sample theory in the 1970s and early 1980s, and they furnish a substantial body of results that have improved our understanding of the properties of econometric estimators and tests. Edgeworth expansions of the sort Sargan sought to validate and implement are now routinely used (e.g. Hall, 1992, Horowitz, 2001) to validate the improvements delivered by bootstrap methods in practical econometric applications.

In addition to the main themes of his research outlined above, Sargan made several other intriguing contributions to econometric theory. His work (1975) on 'large models', for instance, still stands as a lone pioneering piece of technical analysis of the consequences of having a system whose size is large relative to the available data base, and was strangely unlike any of the other papers published in the symposium on large macroeconometric models in which it appeared. Instead, as Robinson (2003) has argued recently, Sargan's ideas on large simultaneous systems are more relevant to the semi-parametric methods that are now commonplace in econometrics.

Sargan's (1974) work on continuous time stochastic models represents another major contribution, again in a very different field. This paper provided the first formal asymptotic study of the effects of approximating open-loop linear differential equation systems with discrete time simultaneous equations. Such discrete approximations were in use in practical work, and later have become more popular through the use of Euler approximations of differential equations in financial econometrics. Sargan's work built on an earlier study by Bergstom (1966) and analyzed the order of magnitude, in terms of the sampling interval, of the inconsistency in various IV and FIML econometric estimates of the coefficients in the continuous system. The paper also examined more applied issues such as the impact of this bias on forecasting.

In other important research, Sargan (1980) addressed the thorny issue of the effects of near unidentification on modeling and inference. Early researchers on simultaneous equations methodology had recognized the importance of, but practical difficulties in assessing, identification. Tests for under-identification (such as those in Sargan, 1958b) were a manifestation of this concern. In practical work, however, these tests are seldom used, and most empirical research proceeds by assuming an equation is identified by order conditions. Sargan recognised that, in the event of near lack of identification, the asymptotic properties of econometric estimators and tests would be affected – in fact, in an early discussion, Sargan (1959, section 6) hints at some of the possibilities, including slower rates of convergence than the usual $\sqrt{n}$ rate for a sample of size n. Subsequently, Sargan (1975/1988) explored the relationship between identification and consistent estimability in systems of simultaneous stochastic equations. Then, in his Presidential address to the Econometric Society (1980), he considered non-linear in parameter models that were 'nearly unidentified', in the sense that the first-order rank condition for local identification failed, but higher-order defining shape conditions held so that there was still identification. In singular cases like these, which followed up on the earlier discussion in the 1959 paper, Sargan found that the conventional asymptotic theory for IV estimation broke down, with slower rates of convergence and a non-normal limit theory applying. Sargan (1983b) later showed that similar problems of singularity occur in dynamic models with autoregressive errors. This work on near lack of identification anticipated future research and its arena of application has proved to be far wider than may originally have been envisaged. It is especially relevant, for instance, in micro-econometric applications where the relevance condition is weak and the IVs are sometimes barely correlated with the regressors. A prominent example in this field has been the study of the impact of schooling on earnings, where intrinsic ability affects both, is unmeasured and therefore contaminates the equation error. In such cases, the search for an instrumental variable that satisfies orthogonality with the error can lead to some arcane choices that end up being only weakly correlated with the regressors they service (Angrist and Krueger, 1991). The impact of such weak (or nearly irrelevant) instruments in applied econometric work is now an intensive area of research – see Andrews and Stock (2005) for an overview.

While Sargan retired before unit root and cointegration theory revolutionized time series econometrics in the 1980s, he had studied Gaussian random walks, presenting an early paper on the subject at the UK econometric study group held at LSE in 1973, some results of which later appeared in joint work with Bhargava (1983a) in *Econometrica*. In further work, Sargan and Bhargava (1983b) showed that in regression models with moving average errors where there is a root on or near the unity circle, the likelihood function can have a local maximum at unity with reasonably high probability and that the limit theory is nonnormal in the unit root case, invalidating conventional tests. Accordingly, their paper argued against the empirical practice of checking for overdifferencing and in support of a most powerful invariant test of independence based on the Berenblut–Webb (1973) statistic. This approach has subsequently received much attention in the unit root testing context.

This brief summary of Sargan's theoretical contributions to econometrics show the enormous range of his research interests. While almost all of the econometric theory he developed related to time series models fitted by time domain methods, he also worked on adapting frequency domain methods to simultaneous equations models in econometrics (Espasa and Sargan, 1977), missing data (Sargan and Drettakis, 1974) and took some interest in panel data problems (Sargan and Bhargava, 1983). By the time he retired in 1984, he had worked on most of the important problems and research areas in econometrics of his generation.

Sargan's appointment at the LSE in 1965 took its econometrics group to the technical forefront in research. He can be credited with the creation of a generation of econometricians in the UK who were trained to high technical levels in all aspects of quantitative economics but who were especially strong in econometric theory and methodology. His devotion to teaching and research training was exemplary. In total he supervised 36 successful doctorates in a host of fields covering much of the discipline of econometric method and many of its applications. Sargan held a 'modern' view of dissertation research as a process by which students learnt the practice of research by means of intimate involvement on the part of a supervisor. In this regard, his generosity to his students and colleagues was famous at the LSE and beyond, and undoubtedly played a major role in attracting doctoral students in econometrics. A full listing of his graduate students and their dissertation titles is contained in Sargan (1988).

Sargan's contributions earned him international distinction and honors. In 1980, he served as President of the Econometric Society presiding over the World Congress of the Society at Aix-en-Provence. He was made a Fellow of the British Academy in 1981 and assumed the Tooke Professorship of Economic Science and Statistics at the LSE in 1982. On retirement in 1984, he became Emeritus Professor of Economic Science and Statistics at the University of London, and an international conference was held in his honor at Oxford University. He became an honorary foreign member of the American Academy of Arts and Sciences in 1987, was awarded a Fellowship of the LSE in 1990, and received an honorary doctorate from the University of Carlos III, Madrid in 1993, where a further celebratory conference was held for him.

The wide range of Sargan's research is celebrated by the topics addressed in the volume edited by Hendry and Wallis (1984) which commemorated his 60th birthday. He was interviewed for the journal *Econometric Theory* by Phillips (1985). Maasoumi edited his collected works, published as Sargan (1988), which, together with his advanced econometrics lecture notes, Sargan (1988b), edited by Desai well illustrate his analytic rigor and intellect. Three issues of econometrics journals have appeared in his memory: one in *Journal of Applied Econometrics*, 2001, on empirical macro-econometrics; another in *Econometric Reviews*, 2001, gave a biographical history of Sargan's career and printed several of his still unpublished papers; a third, in *Econometric Theory*, 2003, brought together two of Denis Sargan's essays on econometrics published for the first time, a laudation by Antoni Espasa, and three memorial essays offering an intellectual overview of his work.

Sargan had an enormous intellectual influence within the UK, both on the training of econometric theorists and on econometric practice. Outside the UK, his influence has not been as strong and, particularly in North America, different traditions and interests have prevailed. The Colston volume was an obscure source for economists and this undoubtedly delimited the impact of his work on econometric methodology; and his choice of problems in econometric theory also did not always co-relate well with the immediate concerns of empirical researchers or other econometricians – he had his own vision of what the subject needed, and he pursued that vision with determination. Yet, when the history of eocnometrics in the second half of the twentieth century is written, Sargan's place among the leaders of the econometric profession in that era is assured. The research agenda that he initiated has proved to be of tremendous scope, affecting almost every major area of the discipline. His scientific works show a remarkable durability, some of them (like the Colston paper and Walras Bowley lecture) having the status of enduring classics. The world of econometric theory and its applications has moved on, but the themes of Sargan's research program persist in ongoing work and his technical accomplishments remain part of the edifice of theory, technique and methodology that we collectively call econometrics.

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