DENIS SARGAN *London School of Economics*

John Denis Sargan
1924–1996

DENIS SARGAN was 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, Denis transformed both the role of econometrics in the analysis of macroeconomic time series, and the teaching of econometrics. 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.

John Denis Sargan was born on 23 August 1924, in Doncaster, Yorkshire, where he spent his childhood. His paternal grandfather was a blacksmith and wheelwright, who also kept cattle on a small-holding in Conisburgh near Doncaster. Denis's father, Harry, was the youngest of eight surviving children, all brought up on the farm and smithy. Harry gained a place at the local grammar school—which was at Mexborough—but the family could not afford further education for him. As Harry had always had a great love of horses, and the corresponding ability to handle them, on the outbreak of war in 1914, he joined the Cavalry, in the Life Guards. When peace returned in 1918, Harry became a mounted policeman in Doncaster.

Denis's maternal grandfather was the organist and choirmaster of the parish church at Askern (a village near Doncaster), where he managed the Spa Baths. Denis's mother, Gertrude Porter, one of four children, was

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musically gifted; she had voice training, and although she never took up a career in singing, she loved to sing in church.

While a mounted policeman was at least employed, the pay was meagre. Denis and his only sister (two years older than himself) were adequately fed, clothed and housed, but were brought up in a household where money had to be carefully budgeted. The mounted police were always on duty when horse racing took place in the neighbourhood of Doncaster: the big race there was (and still is) the St Leger, the oldest Classic, having been run at Town Moor for over two hundred years. Sometimes Denis and his sister would visit their father when he was on duty at the St Leger. Denis recalled later the colourful scenes, including a tipster, complete in fancy dress and featured head-dress calling himself 'Prince Monolulu'.

After a brief period at the nearby state infants' school, Denis attended the local Church of England primary school. Concerned at the state of children's health and well-being, the government had decreed that primary school children should each day receive half a pint of milk. Denis, with his fellow school children at six or seven years of age, appeared in a group photograph in the local paper. The children were sucking milk through straws from the small bottle each was holding: the caption under the photo read 'each enjoying his ha'porth of nourishment'. Denis's parents were very surprised when the teachers at the primary school told them that he was a boy of exceptional ability, particularly at mathematics. He won a place at Danum School (Doncaster Grammar School). His sister had also successfully obtained a place at the girl's grammar school, and the provision of uniforms for both children made a big hole in the family budget. However, his parents took this difficulty in their stride, and both children did well at school. The extended family of Denis's aunts, uncles, and their children kept in touch, with family meetings and parties in each other's homes, as well as visits to an aunt and uncle who were tenant farmers on the Castle Howard Estate. As a teenager at the start of the 1939–45 war, Denis, with his parents and sister, would cycle to his grandfather's farm at Conisburgh to help with the harvest.

At Doncaster Grammar School Denis flourished in all academic subjects: he read widely, and was a frequent borrower from the school and local libraries. There was an exceptionally good mathematics teacher, who greatly encouraged and fostered Denis's ability in that field. He was, and remained, interested in everything of an intellectual and cultural nature. He taught himself to play the piano, and derived much joy from this

accomplishment throughout this life: even as a poor student later in Cambridge, he hired a piano to have in his rooms. He was never keen on sports, but the school both taught sports of various kinds and made the boys (it was a single-sex school) take part. They had to go for long runs, which Denis neither enjoyed nor excelled at. On one occasion, he was so slow that he was the last of the runners, and so far behind the boy in front of him, that an aged spectator (an old boy of the school) cheered Denis on, congratulating him for leading the whole field.

At the age of seventeen, Denis gained a State Scholarship for entrance to St John's College, Cambridge. Coincidentally, St John's was also the college of choice for Sir David Cox and Jim Durbin (of the Durbin–Watson test, *inter alia*), a surprising concordance of world-renowned statisticians. Denis read mathematics, but as it was wartime, he took his degree in two years, becoming a Senior Wrangler. His college years were a tremendous change, plunging Denis into new traditions, many of which he disliked. Naturally the war dominated life: he did not have much money, but there were few things to spend it on anyway. Even purchasing all the books he wanted was a problem, despite the severe restrictions on the quality of the paper on which any new editions were printed.

Immediately after his degree, like most of his generation, Denis was drafted into war work. Unusually for the military—given his mathematical abilities—Denis was assigned to a task for which his knowledge was useful. As a junior scientific officer, he was attached to the RAF and stationed for a considerable period in Haverfordwest, where he provided basic statistical advice on the testing of new weapons systems. Although technically a civilian and a quiet, shy person, he was welcomed in the officers' mess. There was a piano there and a squadron leader who had a musical dog which would 'sing' when the piano was played, usually by its master. Denis enjoyed piano playing with others there, and much later, during their days in Leeds, he and Joan Brown (Professor Arthur Brown's wife) often used to play duets. She was a good violinist, and their efforts provided a sight that Mary Sargan and Arthur Brown were delighted to watch, as well as listen to, since in difficult passages, whilst Denis became immersed in sight reading and interpreting his score, Joan would wiggle her toes in her sandals in time to the music.

At Haverfordwest, Denis's work also involved trips in RAF rescue launches and in submarines. He was a poor sailor and was much relieved when he had to go down in submarines, as there were no rough waves in the depths of the sea. When leave came round, he was sometimes given a lift by one of the pilots in their aircraft, which was a big help in getting

home, as trains were usually few, packed and slow, particularly if there was a raid going on, or expected, *en route*.

Towards the end of the war, Denis was posted to Coastal Command at Northwood, Middlesex. Although they had not yet met, his wife-to-be Mary Millard was then working at Mount Vernon Hospital. She had even been one of the University of London students evacuated to Cambridge when Denis was there, but on neither occasion did their paths knowingly cross.

Leeds and the USA

When peace came, and Denis was able to browse again at leisure in bookshops, he came across John Maynard Keynes's *General Theory of Employment, Interest and Money* and his enthusiasm for economics was aroused. He was so struck with Keynes's ideas for tackling mass unemployment that 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. Since service personnel were permitted to return to university for further study at the State's expense, Denis opted to do so, and returned to Cambridge to read Economics, completing his BA degree in a year.

Throughout this period, and obviously unbeknown to Denis at that time, the first formulations of the idea that was to be a major focus of his career were taking place: the first well to the east, another closer to home, and a third far to the west. In Oslo in 1941, to solve a problem with the then important approach known as confluence analysis, Olav Reiersøl invented a method called 'instrumental sets of variables' (although he attributed the name to Ragnar Frisch, for whom he was working as a research assistant). Later, Frisch was the first recipient of the Nobel Prize in Economics with Jan Tinbergen. The notion was to use variables that were not in an equation, but were related to the variables that were, to help estimate the parameters of interest when the data were contaminated by measurement errors. In Ireland in 1942, Roy Geary independently formulated a related idea, but using higher-order data moments. And in Chicago at the Cowles Commission, following a letter from M. A. Girshick in 1945, Ted Anderson and Herman Rubin developed a method for estimating the parameters of a single equation in a complete system of equations, which later was seen to be a member of the instrumental-variables class. The war probably precluded communica-

tion between most of those involved, and it was some time before a synthesis was to emerge. To digress briefly, it is extraordinary that most of the conceptual and methodological foundations of econometrics were developed in this brief period by four Norwegians, the two others being Trygve Haavelmo (Nobel prize winner in 1989) working in the USA, and Herman Wold, then at Uppsala University in Sweden.

On leaving Cambridge, Denis set about getting a job, and first applied to the Civil Service, where he was interviewed by C. P. Snow. Although achieving high scores, he opted for a lectureship at Leeds University, which then had a small but active Economics Department. This had the benefit that Denis was able to stay for a time with relatives at nearby Rawdon. Leeds had trams, and Mary, who had been appointed a tutor in the Social Studies Department, used to alight from a tram at the university stop, having watched Denis trying not to get wedged into the tram lines when arriving at the same place on his motorised pedal bike. Two other young men had been appointed at the same time as lecturers in the Economics Department, and a further two young women had been appointed simultaneously as tutors in the Department of Social Studies. Both departments were small, and they shared an old converted building, consisting of some rather fine terrace houses. Denis and Mary had rooms opposite each other, and after some time all three couples had married.

Denis and Mary married in 1953; both wanted children, so they quickly set about having a family. Their first child, John was born a year later, and another son (David) and then a daughter (Barbara) followed soon after, so they had three children under four. Barbara was born with Down's Syndrome, and at that time little was known about the effect of this condition, its care or its management. Denis was a patient and supportive husband, and the Sargans got through this period without too much interference in Denis's work and career. It was hard work for both, as they had little money, but the children brought great joy as well as 'worries'.

In 1948 he commenced research into the distribution of wealth, duopoly, production, and growth. These were the initial topics on which he published, although statistical time-series problems were also considered. His first foray into econometric methodology did not appear until the *Bulletin of the Oxford Institute of Statistics* in 1957, a discussion of the path-breaking analysis of the Oxford Savings Survey by Malcolm Fisher. The other discussants of Fisher's paper were Franco Modigliani, Albert Ando, Milton Friedman, Trygve Haavelmo, Lawrence Klein, and

James Tobin (five of whom were later awarded Nobel Prizes). Denis was already concerned with three issues that recurred in his later research on 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 perhaps led to his interest in estimating relatively general and unrestricted models, and the third to his ideas about 'data mining', all considered below. This work was closely followed by a major paper on the theory of instrumental variables, published in *Econometrica* in 1958.

That same year, Denis was awarded a Fulbright scholarship, and determined that the whole family should embark on this 'great adventure' to the USA—indeed neither he nor Mary could have contemplated splitting the family up. However, they had a nerve-racking ordeal in persuading the immigration authorities in the USA to allow them to take Barbara. They travelled to the USA on the *Queen Elizabeth*, all five of them sharing a small lower-deck cabin: it was a memorable, if not an easy, experience. Denis accepted the cramped conditions in the cabin, but was irked by the rule that only first-class passengers were allowed to use the ship's swimming pool, located, of course, in the first-class quarters; although no sportsman, Denis enjoyed swimming. Arriving in New York, they were delighted by the warm welcome and great kindness of their American hosts, and had an introduction to the country arranged for Fulbright visitors at the Sarah Lawrence College.

There followed nearly two years of great interest and happiness. The Economics Department at the University of Minnesota welcomed Denis, and he was happily involved in pursuing his teaching, research, and writing. His powers of concentration were tremendous: Mary recalls frequently returning home to find Denis lying on the floor deep in pages of algebra, with the television or a record on, and the children playing around him. He always had pen and paper with him, and spent many an hour of waiting (e.g., at airports) happily scribbling down solutions to econometric problems. Despite working in such circumstances, the results of his labours were path-breaking, such as Edgeworth expansions to approximate the distributions of estimators and tests. In fact, these results did not appear for some time, but their existence was noted by the (typically modest) remark, that: 'The author has derived small-sample approximations to their distributions, which are too lengthy to report here.' These approximations were based on a general approach he developed to

check the usefulness of estimators in samples of the size common in time-series econometrics, and became the subject of several later papers: a major intellectual effort underpinned this casual comment.

Being determined to see San Francisco, they spent a wonderful few weeks at Stanford University while Denis taught summer school. Then they moved to Chicago for 1959–60. The intellectual quality of the Economics Department at the University of Chicago must have tempted Denis to stay on at the end of that academic year, as that university wished him to, no doubt impressed by his next major paper in the *Journal of the Royal Statistical Society* in 1959. However, both he and Mary had their roots in England and wanted their children to grow up to an English way of life. When Leeds University offered Denis a Readership, they sailed home in July 1960 on the Cunard ship *Saxonia*. These visits to the Universities of Minnesota and Chicago focused Denis's growing interest on the econometric theory of estimating economic models from time-series data; and, from this point onwards, his career fell under the grip of a deep fascination with the design of statistical methods suitable for studying empirical economic problems.

The Colston paper

Denis had rapidly established a reputation for insightful, rigorous, and powerful analyses, and this research, mainly published in *Econometrica*, led to his election to a Fellowship of the Econometric Society in 1963. In that year, Denis 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 (possibly apocryphal) story was that during a visit to Moscow, Lionel Robbins learned that Denis Sargan ranked among the most respected British economists there, and on his return to the LSE, arranged for an offer; in reality, one suspects that Bill Phillips and Jim Durbin were well aware of Denis's important contributions. In particular, Durbin was a discussant of what was to become perhaps Denis's most famous paper, which had been prepared for the Colston Society conference on National Economic Planning held at Bristol University in 1963.

The 'Colston paper' laid out the conceptual basis of the so-called 'LSE approach' to econometric modelling, so Denis can be 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 with thorough data analysis to develop empirical models consistent with both main 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. Nevertheless, like its author, the paper was self-effacing and modest, though technically brilliant. Denis considered the use of 'long-run' economic analysis to specify the equilibrium of a model, introducing 'equilibrium-correction' mechanisms into behavioural dynamic econometric models—now perhaps the most widely used form of time-series econometric equation. He developed his interpretation of autoregressive errors in time-series models as a simplification of dynamic reactions, and constructed mis-specification tests that were valid even after estimating dynamic equations; he formulated a procedure for comparing linear against logarithmic specifications, and investigated the impact of data transformations on the selection of models. He proposed a non-linear in parameters instrumental variables estimator for models where the data were subject to measurement errors. He implemented operational computer programs for the new econometric methods, and included a proof that the required iterative computations would converge with near certainty; and he matched the econometric theory to the empirical problem.

Prior to Denis's Colston paper, it was common in econometrics to test for residual autocorrelation (e.g., by the Durbin–Watson statistic), and if it was present, to estimate a 'generalized' model with an autoregressive-error process. Denis built on his earlier papers on this topic, which had shown that autoregressive errors were a restriction on a dynamic model that, when valid, permitted the adoption of a more parsimonious representation. Thus, he reversed the conventional interpretation. 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 a test that was valid in dynamic equations, the Durbin–Watson test—which did not follow its tabulated distribution if applied to such models—continued to be

widely used for many years, although it would often fail to reveal significant mis-specification.

Denis's criterion for choice of functional form between log and linear specifications simply converted the respective equation standard errors to be proportions of the level of the dependent variable, then selected the smaller. Previous models of wages and prices used annual changes, but doing so induced autocorrelated errors, and distorted inference. Consequently, Denis argued for selecting the data transformations that led to an equation with 'errors which are independent in different time periods'. Despite the primitive nature of the available computing facilities, he devoted considerable effort to programming the new econometric methods, physically rewiring the computer to ensure the answers were correct. He carefully addressed the logic of the calculations both to embed all of his 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. He tried several optimisers, analysed their speeds of convergence, investigated possible multiple optima, and proved that his step-wise iterative computations would converge with near certainty to a local optimum. The latter development was the first of its kind in econometrics and reflected Denis's keen interest in numerical analysis. Overall, he set a high standard of scholarship for the treatment of computing in empirical research, in marked contrast to many later investigators who do not even cite the software they use.

Having developed the dynamic models, estimators, tests, algorithms, and computer programs, Denis applied this new analytical apparatus to the near-intractable problem of 1960s UK wage-price inflation. Previous models had related the changes in the variables, namely, wage inflation, and price inflation. Such a formulation precluded any relationship between the levels of wages and prices, hence they could drift apart over time. Denis argued that economic agents would be concerned about the level of real wages and not just price inflation, so he formulated a model with long-run equilibria. His wage equation was formulated in terms of real wages, unlike say, the Phillips curve: in workshops at LSE, he and Bill Phillips would debate the relative merits of that model versus the Phillips curve, although both questioned the existence of any stable 'trade-off' between inflation and unemployment. Denis also included a data-based proxy for 'inflation expectations', which he called 'an extrapolation of past price movements into the future'. The disequilibrium of real wages from target depended on unemployment, productivity and political factors. In modern parlance, the levels were integrated whereas

the differences and the equilibrium were not, so the latter required co-integration between the levels. His 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 was the rock on which many incomes policies foundered. It was typical of his modesty that it was not Denis Sargan, but Sir John Hicks, whose name became associated with that concept. There is no evidence that Hicks was aware of Denis's technical work, but still the latter's prior claim is beyond doubt. Denis's interest in wage-price inflation was reflected in his later work for the Ball Committee on Policy Optimization.

In his policy discussion, permanent and transitory effects were distinguished to ascertain which changes would persist and which fade out (such as devaluations). And he checked that his model adequately described the evidence by testing for various mis-specifications against the hypothesis that the residuals were white noise and independent of the instruments. Although not yet named, his model was an equilibrium-correction mechanism with explicit adjustment dynamics, embodying both derivative and proportional control, as in Bill Phillips's earlier work. At the time, and for many years afterwards, it was not known just how susceptible such 'equilibrium-correction models' were to shifts in the coefficients of intercepts and/or trends. Incomes polices, wage freezes and other related governmental interventions all induced such shifts, so over longer samples, the original specification will fail unless appropriate variables are added to characterise the changed process.

Although forty years have elapsed since Denis first worked on it, his Colston paper still merits rereading.

The London School of Economics

The LSE that Denis joined was home to at least three distinct approaches to economics, the first of which may have appeared rather antithetical to econometrics. In his 1932 *Essay on the Nature and Significance of Economic Science*, Lionel Robbins had claimed that economic theory provided general, formal explanations which were applicable always and everywhere that resource allocation mattered. Moreover, only theory (as distinct from studies of empirical reality) could provide a core understanding of economic activity and behaviour:

> Realistic studies may suggest the problem to be solved. They may test the range of applicability of the answer when it is forthcoming. They may suggest assumptions for further theoretical elaboration. But it is theory and theory alone that is capable of supplying the solution.' (Robbins, 1932, p. 120)

Since the assumptions of economics were 'self-evidently true' and the logic impeccable, the conclusions must be correct. However, such insights as economics delivered could not be given quantitative expression, since causes were non-uniform over both time and space. Robbins argued, therefore, that statistical relationships in economics would change when the world did, so the discipline could never boast 'statistical laws' like the natural sciences. Robbins's approach was sustained at the LSE by the work of Friedrich von Hayek. In principle, economic theory could indeed apply even when there were no quantitative laws, although such 'explanations' would be somewhat unsatisfactory—like predicting calm seas as the norm after a storm, to borrow from Keynes. Moreover, Robbins's positive argument for the power of economic theory explanations only becomes a negative one for econometrics on substantiating the claim that useful empirical regularities do not exist. Certainly, Dr Blank's nebulous demand function for herrings could only last the test of time if many factors other than price and income were included in the model, but such additional factors are not precluded a priori. When Terence Hutchinson launched his critical attack on Robbins in 1938, he made a similar argument and proposed instead a move towards 'positive economics'. Nevertheless, since Robbins was one of LSE's most eminent economists, the LSE might seem an unpromising location for an econometrician, particularly one with an interest in econometric methodology.

However, the post-war period saw a second movement at LSE, implementing the 'positivist' philosophical standpoint within economics. The LSE had a strong tradition in the philosophy of science with Karl Popper, continued by Imre Lakatos, so 'falsification' was already under discussion. The interested group in economics included Chris Archibald, Kurt Klappholz, and Richard Lipsey, all of whom published on economic methodology. The famous Phillips Curve was first presented and discussed at the Staff Seminar on Methodology, Measurement and Testing (M^2T). The appointment of an engineer–economist like Bill Phillips, who stressed empirical evidence, signalled that the mood was less inimical to econometric modelling than the heritage of Robbins might suggest. Indeed, important antecedents were already in place. Both Phillips and Rex Bergstrom (also then at LSE) considered models that were essentially equilibrium-adjustment mechanisms.

In any case, Denis's first appointment at the LSE was in the Statistics Department, where Roy Allen and Jim Durbin played major roles. Durbin had significant career-long interests in the application of statistical methods in economics and in the development of econometric theory. Allen admired Phillips's earlier work on control theory, and had included an explanation of integral, derivative, and proportional control in his textbook. Denis initiated the third approach, although he was a somewhat unlikely candidate in an unlikely setting to revolutionise econometric methodology. Specifically, his initial research had been on mathematical economics as we noted above, and the majority of Denis's later publications were to be in what he called 'advanced econometric theory', particularly attempting to establish the same rigorous inferential basis for its application to small samples that Student's famous *t*-distribution paper had done for statistics. Methodology almost seemed a sideline.

Denis's appointment at the LSE took its econometrics group to the technical forefront in research. Perhaps as importantly, he helped attract a vibrant group of young faculty and many able students, many of the latter coming to study for the redesigned M.Sc. in Mathematical Economics and Econometrics. This was an important part of a major change in the School's programme of postgraduate training of economists: in 1965, the 'new' M.Sc. courses in Economics and Econometrics were introduced to provide a thorough training for professional economists, and achieved previously unattained heights of advanced teaching. Denis can be credited with the creation of a generation of econometricians trained to high technical levels in all aspects of quantitative economics. When Zvi Griliches of Harvard introduced Denis on the occasion of his Presidential address to the Econometric Society at Aix-en-Provence in 1980, Griliches characterised one of Denis's greatest achievements as his single-handed effort in producing a teaching programme in econometrics that rivalled the output of the best schools in North America.

Denis's teaching of the undergraduate and graduate econometric theory courses at the LSE was legendary. The content was from the research frontiers—which in itself provided students with a significant challenge—but that challenge was increased by his habit of changing notation part-way through a lecture, sometimes on several occasions. Students would joke that if he ever seemed to lose his way in a lecture, he would simply take a Taylor series expansion and get things back on the intended track. Equally impressively though, Denis would lecture almost without notes and remember from week to week exactly what

topic he was discussing. His teaching would not please the current vogue for assessing 'quality': from his few notes, the most arcane mathematics would flow with inadvertent changes of notation and key steps treated as obvious. While problematic for the weakest students, the overall effect was to force his students to rework the material completely—from which ensued understanding and technical expertise that would last a lifetime. He was equally prone to alter notation, or assume familiarity with his own LSE lectures, during Plenary presentations at international conferences!

A plethora of doctoral students

The influx to the new M.Sc.s was followed by a considerable expansion in the number of Ph.D. students working in theoretical economics and econometrics. Denis supervised an extraordinary number of doctoral students simultaneously: the publication gap of seven years between 1964 and 1971 was undoubtedly due to his assiduously looking after so many theses. As the number of econometrics doctoral students he was supervising simultaneously increased rapidly in the late 1960s to a dozen, Denis created a research workshop for presentation and discussion of research output, which provided a model for many to follow in their own teaching careers. These first few cohorts of his students worked on a wide range of theoretical topics: inference in continuous-time dynamic models (Cliff Wymer, Peter Phillips); the development of small-sample distribution theory and higher-order asymptotic expansions to provide better approximations to distribution functions (William Mikhail); principles for hypothesis testing in systems of equations (Ray Byron); formulation, estimation, and testing of dynamic models (David Hendry); the development and use of nonlinear estimation methods (Ross Williams, Grayham Mizon); the treatment of missing observations in multivariate time-series models (Emmanuel Drettakis); semi-parametric estimation of systems with spectral estimates of the error covariance matrix (Toni Espasa); and moving-average errors (Pravin Trivedi). A distinctive feature of much of the research conducted on these topics was the fact that it was embedded in applied econometric studies. Areas of application included models of wages and prices (Keith Vernon, Toni Espasa), aggregate durable consumer expenditure (Ross Williams), consumer demand systems (Ray Byron, Julia Hebden), aggregate production (Grayham Mizon, Eleftherios Charatsis), factor-demand behaviour, especially investment (Robin

Rowley), and inventory demand (Pravin Trivedi), the rubber industry (Kee Cheong), import and export determination (Michael Feiner, Madan Handa), and small aggregate-demand systems (David Hendry, Emmanuel Drettakis). By the later 1970s, the theoretical topics had evolved to time-varying parameters (Michael Fitzpatrick), seemingly unrelated regressions (Tony Hall), reduced-form estimation (Esfandiar Maasoumi), unobservable indicators (Kirti Mehta), dynamic models with measurement errors (Bahram Pesaran), and numerical optimisation (Jerzy Sylwestrowicz); whereas the empirical themes included international travel (Michael Fitzpatrick) and consumer demand (Ranjan Ray). The 1980s saw another ten theses ranging over Edgeworth approximations (Yiu Tse, Steve Satchell), finite-sample distributions (Ignacio Mauleón), expectations (John Hunter), time-varying parameters (Louisa Franzini), non-nested hypothesis tests (Neil Ericsson), non-linear systems (Yock Chong), instrumental variables estimation (Julia Campos), tests of models in levels versus first differences (Alok Bhargava), and dynamic panel-data models (Manuel Arellano).

His devotion to teaching and research training was exemplary, and in total he supervised thirty-six successful doctorates, his past students currently occupy chairs at a host of the world's distinguished universities. Denis had a very 'modern' view of dissertation research as a process by which students learnt the practice of research. That required more intimate involvement on the part of a supervisor. To start such a process, Denis would just pull open a desk drawer and hand out his earlier analysis of a problem from the abundant supply of his unpublished papers that were awaiting the time for further development, most of which were innovative and some essentially complete already. He had a deep and sincere desire to help people that was manifest in the assistance he gave to all his Ph.D. students and younger colleagues, often writing out pages of mathematical derivations to help them formulate a problem and overcome technical obstacles. Although he did not have a doctorate, he could have earned many had he wished. 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 personal story we heard from one of his students relates, that being unable to prove a result vital to his dissertation, he handed in a seriously flawed proof that worked backwards from the desired result: after a couple of weeks, Denis gave him a new proof, saying simply 'I don't think the original one quite worked.' His modesty camouflaged a brilliant and creative mind whose greatest difficulty was to comprehend how little most of us really knew,

as his own views on doctoral supervision, expressed in the 'ET Interview', reveal:

> I've been lucky that the department [at LSE] has attracted a large number of very good students with suitable qualifications for starting research in this field. It is of course very difficult to accumulate an appropriate theoretical background. And also an interest and real knowledge in economic models is usually required as part of a Ph.D. student's background for the empirical sections of his research. I've always tried to encourage students to combine applied work with theoretical work with the feeling that for the majority of students the choice of an ultimate research field may be motivated by practical considerations, for example, the possibilities of employment. . . . However, for a minority of my students it is certainly clear that a good student will himself find a field that interests him and then complete within [a] relatively short period. . . . I'm very happy then for the student to take charge of the field and work on his own to a large extent.

One seeks in vain for any remarks by him suggesting that he played a crucial, or indeed any, role. Denis's compassion for his students and his generosity in terms of ideas, methods, and results continued to grow with the years, being reflected in the increasing number of joint articles that he published with his doctoral students as he approached retirement.

The years of advanced theory

The focus above on Denis's contributions to methodology is not intended to detract from his important theoretical analyses, that in truth were his real passion. Returning to the 1960s, prior to leaving Leeds he published an analysis of simultaneous systems with vector autoregressive disturbances, which also considered a closed model—where all the variables are determined endogenously—now the popular class of vector autoregressive (VAR) models. He then established the equivalence in large samples between the full-information maximum likelihood (FIML) estimator of dynamic simultaneous systems (viewed by the Cowles Commission as perhaps the 'gold standard') and the corresponding instrumental variables estimator, called three-stage least squares (3SLS) after the number of steps needed to compute it. In very large samples, distributions of even complicated methods often simplify dramatically (to the normal), and sometimes the differences between methods (that may be important in small samples) vanish or 'collapse' to a point.

We have noted the long publication gap after the Colston paper, although abstracts of unpublished papers by him reveal important steps

towards tackling the distributions of econometric estimators in samples of a size likely to be encountered empirically.[1] Since economic systems are dynamic and simultaneous, small-sample distributions of estimators can be extremely complicated. Yet without some approximations, economists must remain in the dark as to how good their answers are in any given setting. Denis hoped that general approximation formulae could be incorporated into regression software and used to adjust critical values and improve inference, but that has not yet occurred for most relevant situations, partly because available approximations are rarely accurate enough. In retrospect, this seems less surprising since even the usual large sample distributions for dynamic models progressively break down as the non-stationarity zone is approached, and most macro-economic time series appear to be non-stationary.

Nevertheless, despite the near-intractable nature of the problem, Denis devoted huge effort to solving it. To the uninitiated, a Sargan working paper often looked like an impenetrable jungle of mathematics and conceptual exposition. Formulae run for pages, algebraic symbols carry strange decorations, notation might be assumed and undefined, unusual branches of mathematics might be called upon without remark, theorems might be cited without reference as if they were as familiar to the reader as to the author, and the mathematics might be entangled in a high-level discussion that confronted some deep conceptual issues of econometric modelling. His papers required a sustained effort to read and an enormous commitment to master, often involving months of devoted line-by-line reading. There are four basic approaches, and he advanced them all, pushing the frontiers of knowledge forward in remarkable ways in each of them.

First, one can adopt computer-intensive methods, simulating distributions for a wide range of states of nature. At a more sophisticated level, this involves Monte Carlo methods, and Denis helped in the development and implementation of ideas that made such an approach viable and computationally efficient. Even so, it is impossible to cover all cases, so the second approach, of theoretical derivations of approximating moments, has many attractions. Denis's papers on this and the next topic are filled with technical innovations and show little sign of aging even after decades of subsequent research. Thirdly, and at least as difficult, one

[1] In fact, Denis's long publication gap was actually ended by a paper on production functions, which introduced the idea since known as the trans-log function, where the traditional Cobb–Douglas form is generalised by including interaction terms.

could use an asymptotic expansion, the first term of which was the large-sample outcome, the next a term which vanished slowly as the sample size increased, and so on. Edgeworth expansions provided a natural mechanism for achieving this goal, and his famous Walras–Bowley lecture in 1976 set about providing the justifications of, and the formulae for, this implementation, supplementing the idea of analytic expansions with a simulation-based approach (originally due to George Barnard) now recognised as a version of the modern parametric bootstrap.[2] In a summary discussion of density expansions in the general setting that intrigued Denis, the various steps in his derivation of the Edgeworth expansion are given, revealing the simple form of the dependence of the correction terms on the statistic and the cumulants of the sample moments on which the statistic depended. Although asymptotic expansions have been found an unreliable means of improving inferential accuracy, Denis'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.

Finally, the exact distribution might be obtained, though this has rarely occurred in econometrics: exact methods are generally of too limited applicability, rely on strong distributional assumptions and do not extend to dynamic settings because of formidable mathematical complexity. Nevertheless, some important features of the exact distribution may be established even in the absence of a complete distribution theory. For example, the exact small-sample distribution of a statistic may be shown to possess no finite-order integral moments (mean, variance etc.) signifying that its distribution has 'fat tails'. Even so, all moments of an approximating density could be finite, and in such cases, the finite moments of the approximating representation become pseudo-moments, sometimes called Nagar approximations. In his 1974 work, Denis developed criteria for the validity of such approximations, and extended the theory to a general setting. In 1982, he used pseudo-moment expansions of this type to help interpret the descriptive moment statistics conventionally reported in Monte Carlo experiments. When the moments of the underlying distribution are infinite, he showed 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

[2] The Walras–Bowley lecture of the Econometric Society is the main invited plenary address at its North American annual meeting, usually published in *Econometrica*.

on the sample size and the number of replications. This resolved a major potential worry, since many simulation experiments are conducted in settings where the existence of moments has not been established.

His 1975 *International Economic Review* paper on 'large models' still stands as the 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 that symposium. Denis had a fertile mathematical imagination when it came to the development of any subject, but here it was especially evident in his considering an asymptotic theory for large numbers of equations. Large sample theory had been quite well developed for cases where there were large numbers of parameters (for instance, many lagged variables in a regression equation), but this was the first time it had been done in the context of a growing number of equations. Denis recognised that as more data became available, there was always more detail to explain in economic activity, especially at the macro level where models had become progressively larger over the years, reaching many hundreds of equations by the late 1960s. The growing ambition of empirical investigators in macro modelling was ultimately to be tested by the reality of data limitations, and Denis looked precisely at the question of what might reasonably be accomplished in terms of such growth as the data set expanded. He constructed a 'feasible efficient structural equation estimator', lending rigour to the development. Peter Robinson has analysed this paper in the third memorial volume noted at the end of this essay, and his analysis convincingly demonstrates that Denis's ideas on large simultaneous equations systems remain relevant to the semi-parametric methods that are commonplace in twenty-first-century econometrics.

Early researchers on simultaneous equations methodology had recognised the importance of, but practical difficulties in assessing, identification. Tests for under-identification were a manifestation of this concern. Denis developed a version of such a test that was applicable with instrumental variables estimation in his 1959 paper. In practical work, however, these tests are seldom used, and most empirical research proceeds by assuming an equation is identified by order conditions. Denis recognised that, in the event of near lack of identification, the asymptotic properties of econometric estimators and tests would be affected. In a paper presented to a Royal Statistical Society study group in 1975, that was eventually published in his 1988 collection, Denis explored the relationship between identification and consistent estimability in systems of simultaneous stochastic equations. In his Presidential address to the

Econometric Society in 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 shape conditions held so that there was still identification. In singular cases like these, he found that the conventional asymptotic theory for instrumental variables estimation broke down, with lower rates of convergence and a non-normal large-sample theory applying. He later showed that similar problems of singularity occurred in dynamic models with autoregressive errors. Although a general limiting distribution theory was not given in that case, Denis remarked that: '. . . in finite samples the distributions of estimators derived from models which are almost singular tend to approximate those from models which are exactly singular'. This work on near lack of identification anticipated much 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 instrumental variables that are introduced to deal with endogenous regressors are sometimes themselves 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. The impact of such weak (or nearly irrelevant) instruments in applied econometric work is now an intensive area of research.

The return to methodology

Although many of the ingredients of the 'LSE methodology' were in place at the completion of his Colston paper, a great deal of detailed research remained to be done. First, starting from a general specification was at best implicit in the formulation of the model against which the autoregressive error form was to be tested. Moreover, Denis's 'practical methodology' still included experimenting with a variety of specifications of variables, lag lengths, indicators, and data transformations, probably because samples were too small to sustain useful estimates of any large nesting model, and computer power was then very limited. Like many empirical investigators, Denis scrutinised the internal consistency of his results and the relationships between them, an aspect eventually

formalised by encompassing. It also remained unclear how to generalise the treatment of autoregressive errors to higher orders. The impact of model selection procedures and repeated testing needed investigation. Operational software required writing and testing. The small-sample distributions of estimators and tests were unknown, but we have described above his efforts to improve that aspect. Finally, although a variety of tests for model mis-specification had been developed and implemented, it was not obvious whether these provided a comprehensive evaluation—or were even well behaved.

Much of Denis's analysis in the Colston paper had concerned the role of autocorrelated errors, which he regarded as likely in models estimated from aggregate quarterly data. Such concerns were also prominent in the interests of his colleague Bill Phillips, and were reflected in the research of his doctoral students. Both autoregressive and moving-average error processes were of interest, as were vector generalisations thereof. Two issues were involved: selecting the longest lag needed to induce white-noise errors in models; and 'allocating' the dynamics between systematic components (which affected the mean lag) and error dynamics (which did not). The Colston paper had addressed both, but essentially in the context of first-order autoregressive errors.

In 1975 Denis generalised the estimation of scalar dynamic equations with first-order autoregressive errors to higher-order errors on equations which also had longer lags. Toni Espasa has related the anecdote that helped prompt this development, which well illustrates Denis's intellectual capacity and genial manner. The first author was presenting a generalisation of Denis's Colston test for the validity of a first-order autoregressive error representation. At the end of the seminar, Denis remarked that he did not understand the paper, and requested a repeat delivery the following week. At this second session, Denis suddenly pointed out that the proposed approach was inappropriate by implicitly testing from the specific to the general. Within a few weeks, he had implemented his common factor idea, drawing on mathematics that was new to almost everyone who read the paper. The central achievement was developing a practical algorithm to determine the largest number of common factors that could be extracted from the lag polynomials, taking account of the possibility of complex roots in the polynomials. The resulting formulation was not published until 1980, although expositions appeared in advance.

His 1957 paper had illustrated Denis's early interest in the problems of interpreting large numbers of hypothesis tests. There were three aspects to

his comments at that time: the large number of coefficients being compared; the choice of significance levels for each of the individual tests; and the role of non-normal distributions (presumably ones with fatter tails than the normal). Denis did not explicitly return to the 'repeated testing' problem until 1973, when he showed that the impact of chance significance in repeated testing from a *t*-distribution could be controlled even with many additional irrelevant variables. He also presented an overview paper on model selection to the LSE econometrics workshop in 1981, and although neither paper appeared in print till 2001, both substantively influenced subsequent research.

The later years and honours

Election as President of the Econometric Society came in time for its 1980 World Congress at Aix-en-Provence, and he was made a Fellow of the British Academy in 1981. Denis only returned once more to the USA, in 1982 as a Visiting Professor at the University of Florida, although he continued to travel widely to conferences overseas, including Econometric Society meetings in Australia. From 1982–4, he was Tooke Professor of Economic Science and Statistics at the LSE. On retirement in 1984, he became Emeritus Professor of Economic Science and Statistics at the University of London, at which time an international conference was held in his honour at Oxford University. He continued to help with the supervision of Ph.D. students at LSE for some years after, and to correspond with a number of his then recent doctoral students about their research.

The wide range of Denis's own research work is celebrated by the topics addressed in *Econometrics and Quantitative Economics* (D. F. Hendry and K. F. Wallis (eds.), Basil Blackwell) which commemorated his sixtieth birthday. 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 an honorary doctorate by the University of Carlos III, Madrid in 1993, where another conference was held in his honour. Essie Maasoumi edited his collected works (*Contributions to Econometrics*, Cambridge University Press, 1988) which, together with Denis's *Lectures on Advanced Econometric Theory* (edited by Meghnad Desai, Basil Blackwell, 1988), well illustrate the systematic rigour of his fine mind.

Given his quiet, unassuming approach, and his location at what had earlier been a central location for the denigration of econometric evidence,

Denis Sargan at the LSE was an unlikely candidate to radically alter the econometric approach of a generation. Yet without doubt he did so, establishing a powerful approach to empirical modelling of economic time series. Denis wrote a personal reminiscence of his thirty years at the LSE, including a thoughtful discussion of his own research, that of his students and colleagues, and the role of econometrics in public policy. It contains a fascinating personal account of the LSE from someone who was intimately involved in its emergence during the twentieth century as one of the world's great centres of econometrics. Denis speaks candidly about the LSE, its histories and transitions, those who peopled it, and its many educational and research contributions.

Denis had an enormous intellectual influence within the UK, both on the training of econometric theorists and on econometric practice. Outside the UK, Denis's influence has not been as strong as his research accomplishments warrant. The Colston volume was an obscure source for economists—and Denis was certainly not a propagandist. His choice of problems sometimes did not co-relate well with the immediate concerns of empirical researchers or other econometricians—Denis had his own vision of what the subject needed, and he pursued that vision with determination. Certainly, in North America, it is fair to say that his intellectual influence was not as strong: different traditions prevailed. Denis himself would be among the first to acknowledge that there is no achievable holy grail of empirical econometric methodology and, as he enjoined his audience in his after-dinner retirement speech held at Oxford University in 1984, the subject is all the richer if we go out and individually do our own thing.

Remembrance

In some ways, Denis resembled the absent-minded professor of cartoons and stories. Mary Sargan recounts many examples, fortunately most of which had a happy outcome, and in retrospect are amusing, even if at the time they were somewhat embarrassing or worrying. Of course, he lost numerous umbrellas, some briefcases, the odd raincoat, and forgot to pack ties, pyjamas etc., on visits away: usually such things turned up or were replaceable. The most memorable instances of his forgetfulness were: to leave the train tickets for San Francisco on top of the piano in their apartment in Minneapolis (the neighbours were very surprised to see them return so soon from the station after all the fond farewells); forget-

ting where he had 'parked' the pram (with the baby in it) at San Francisco zoo; losing, then finding, a valuable camera in a Budapest hotel; and 'losing' a hired car in Padua—the last involved a lengthy (and in retrospect hilarious) interview with the local police as the Sargans spoke no Italian and the police no English or German, but they did have a female employee who spoke French. After leaving the police station, they found the car where Denis had, in fact, parked it overnight.

In academic conferences, too, his absent mindedness is fondly remembered. At one major conference in 1978 in Louvain, Denis was scheduled to give two papers and, apparently not having read the programme, he quietly embarked on the exposition of the wrong paper (to the amusement of the audience and to the dismay of the scheduled discussant), only to be prompted by the chairperson that perhaps this was not the intended paper for that session, at which point Denis shifted effortlessly in mid-sentence and without embarrassment into the exposition of his other paper.

Given Denis's prodigious memory and his age when these happenings occurred, they were certainly not 'senior moments'. Yet these foibles endeared him to everyone, reminded us of his humanity, and brought surprise and delight to the orderliness of professional conferences.

In addition to being remembered for his academic leadership and distinction, Denis was a warm and encouraging teacher and colleague, as is clear from his *ET Interview* with the second author (the first such interview to be published in the journal *Econometric Theory*). Together with his wife Mary, they entertained most hospitably at their home, fostering social interaction with students and visitors, and creating a friendly atmosphere at the School. Denis was a keen gardener, interested in painting and music, and he talked as freely about his hobbies while at the LSE as he did about econometrics. It was a pleasure to interact with both Mary and Denis at the many econometrics conferences they attended, after which they would take the opportunity to visit art galleries, museums, and archeological sites. However, Denis could only be persuaded to present a paper every other year on the econometrics programme at the Association of University Teachers of Economics meetings (now the Royal Economic Society Annual Conference): the meeting moved between 'north' and 'south', and he did not want to travel too far, since he and Mary usually came in a caravan and stayed on a nearby campsite. The photograph of Denis accompanying this memoir, shows his ever-present smile with the familiar sparkle in his eyes. At his retirement dinner, Denis also told his enthralled audience of econometricians how he began his academic career with a few ideas that he wanted to pursue in

econometrics and hoped to publish in good journals. That work was now pretty much completed, he said, and he was happy to hand over to a younger generation. One can hardly imagine a more modest way of summing up such a distinguished career.

Denis is remembered with awe, as well as affection, for the insightful solutions he suggested after a few moments thought on many problems that students and colleagues had struggled with for weeks. He has left a splendid legacy of intellectual achievement, as well as cohorts of well-trained students, many of whom have continued to advance the discipline across, and beyond, the range of topics on which he left his mark.

When the history of econometrics in the second half of the twentieth century is written, Denis Sargan will undoubtedly figure as one of its most original and influential thinkers. The research agenda that he initiated has proved to be of tremendous scope, affecting almost every major area of the discipline; and, at a time when the half life of academic research is often measured in months, his scientific works show a remarkable durability, some of them (like the Colston paper and Walras–Bowley lecture) having the status of enduring classics. If Denis had lived longer, he would surely have been a leading candidate for a Nobel economics award. Since his passing, the world of econometric theory and its many applications has moved on. But many of the themes of his research programme persist in ongoing work and his technical results will surely continue to be used and cited for decades to come.

Denis's contribution to econometrics was enormous. His research accomplishments make him one of the architects of the edifice of theory, technique, and methodology that we collectively call econometrics. His memorial lies in this scientific work, in his impact on LSE econometrics, and in the achievements of the large number of students and fellow scientists to whom he devoted so much of his time and intellectual energy. Perhaps the greatest tribute to the life of Denis Sargan is that he is greatly missed by all who knew him.

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Fellow of the Academy

PETER C. B. PHILLIPS
Yale University

Note. We are indebted to many individuals for their information and help. First and foremost, Mary Sargan filled in many of the details of Denis's early life and background. We have also drawn on reviews, obituaries, and memoirs written with, or by, Meghnad, Lord Desai, Neil Ericsson, Toni Espasa, Essie Maasoumi, Grayham Mizon, Hashem Pesaran, Peter Robinson, and Ken Wallis. Finally, we have drawn on the excellent histories of econometrics by Mary Morgan (*The History of Econometric Ideas* (Cambridge), 1990) and Qin Duo (*The Formation of Econometrics* (Oxford), 1993). In total, three special issues of econometrics journals have appeared in his memory. The first, in *Journal of Applied Econometrics*, 2001, on empirical macroeconometrics was prepared for and dedicated to him. The second, in *Econometric Reviews*, 2001, provided a biographical history of Denis Sargan's career, emphasised the breadth of his work in both theoretical and applied econometrics, listed the Ph.D. theses that he supervised, and printed several of his still unpublished papers which had nevertheless greatly influenced thinking at LSE. The third, in *Econometric Theory*, 2003, brings together two of Denis Sargan's essays on econometrics published for the first time, a laudation by Antoni Espasa, and three memorial essays written by David F. Hendry, Peter M. Robinson, and Peter C. B. Phillips respectively, offering an intellectual overview of some of his work.