Chapter 1: Oxford's Contributions to Econometrics

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Abstract

Faculty and graduates of Oxford University have played a significant role in the history of econometrics from an early date. The term econometrics was only formulated by Ragnar Frisch in the 1930s, but in the 17th Century, William Petty created a discipline that he called *Political Arithmetick*, a forerunner of quantitative economics that led to the more specialized statistical approach of econometrics. During the first half of the 20th Century, Oxford scholars like Colin Clark made major advances in creating aggregate economic measurements. From the late 1970s, the focus was primarily on macro-econometrics for the remainder of that century, buttressed by research on methods for analyzing dynamic panels. In the 21st century, micro-econometrics was added to the portfolio. The most recent addition is Climate Econometrics, developing and applying econometric tools for analyzing climate data, which is driven by human economic behavior so faces much the same slew of problems as macroeconomic time series.

Keywords: Econometrics, quantitative economics, aggregate economic data, econometric software, Oxford Institute of Statistics, *Oxford Bulletin*, Nuffield College, climate econometrics.

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1 Introduction

The name econometrics was a neologism created by Ragnar Frisch to characterize a discipline concerned with advancing economic theory in its relation to statistics and mathematics. As a founding member of the Econometric Society and its journal *Econometrica* in the early1930s, Frisch wanted to promote research that unified `the theoretical-quantitative and the empirical-quantitative approach to economic problems' (Frisch, 1933). Since then, however, the term econometrics has come to signify just the statistical aspects of quantitative economics research as with *A Textbook of Econometrics* (Lawrence Klein, 1953) or just *Econometrics* (as in Stefan Valavanis, 1959). There remained a branch emphasizing the more general aspect, in that textbooks were titled *Statistical Methods of Econometrics* (see Edmond Malinvaud, 1966), which was also the name of the main econometrics course for the Master of Philosophy (MPhil) degree in economics at Oxford University when the first author arrived there in 1982.

Given the relatively recent definition of econometrics, and its subsequent narrowing, much of the early history of the discipline must be conceptualized as economics in relation to statistics, as we do here, including the creation and curation of observations on economic phenomena. Moreover, `statistics' still refers both to the discipline which studies methods of statistical analysis (as in a department of statistics) and to summary measures of observations (as in the statistics of crime). Joseph Schumpeter (1933) claimed that in contrast to the physical sciences that had to create their measures, `Some of the most fundamental economic facts, on the contrary, already present themselves to our observation as quantities made numerical by life itself'. However, that still requires that such facts be recorded and combined over events, time and people to be useful for analysis. We include researchers who undertake such invaluable tasks as econometricians, which leads to a surprisingly rich history of the subject at Oxford University before the 1930s.

General histories of econometrics are provided by Mary Morgan (1990), and Duo Qin (1993, 2013), with an overview and selected reprints of key papers in the foundations of econometrics by Hendry and Morgan (1995). Jim Thomas (2018) records the important role the London School of Economics (LSE) played in the development of econometrics in the 20th Century and also in beginning the history of econometrics. Oxford econometricians continued that development of the history of their discipline. In addition to the two books by Qin and that by Hendry and Morgan, see Qin and Christopher Gilbert (2001) and Gilbert and Qin (2006, 2007), both of whom had been doctoral students or faculty at Oxford.

The structure of this chapter is as follows. Section 2 describes the early history of contributions to quantitative economics as embryonic econometrics from the

17th–19th centuries. Section 3 discusses econometrics at Oxford over 1900–1980, including major advances in creating aggregate economic measurements. Section 4 updates the history from 1980 to 2000, before Section 5 records Oxford Econometrics in the 21st Century till about 2010, after which point it is no longer `history', although such time divisions are arbitrary and many individuals span several of these sections. Then Section 6 describes contributions to data provision in the 21st Century before Section 7 considers the most recent addition of Climate Econometrics, developing and applying econometric tools for analyzing climate data, which is driven by human economic behavior and so faces much the same slew of econometric problems as macroeconomic time series. The Appendix notes research funding awards for econometrics.

2 Early days: 17th—19th Century contributions

Sir William Petty

One of the earliest records of advances in economics related to statistics, later to become econometrics, can be attributed to the Oxford graduate Sir William Petty (1632–1687). Petty came from a relatively humble background and was largely self-taught initially, sufficient to study medicine at Oxford University, and indeed become anatomy tutor at Brasenose College as well as being a physician. As antecedents, he had acted as personal secretary to Thomas Hobbes through whom he was able to meet many of the prominent European philosophers of the time. At Oxford, he became a friend of Robert Boyle and was a member of the Oxford Philosophical Club, a precursor to the Royal Society of London of which he was a founding fellow. He seems to have been influenced by the empirical scientific approach of Francis Bacon, so Petty was a man with wide interests: see https://en.wikipedia.org/wiki/William_Petty.

However, it was only after moving permanently to Ireland that he became interested in economics. These earlier influences had led to Petty deciding that `mathematics and the senses must be the basis of all rational sciences'. A desire to achieve that goal focused his interests on empirical phenomena that were measurable and so could be quantified, rather than merely described, leading to the creation of a new discipline that he called *Political Arithmetick*, published posthumously in a book of that title in 1690. Consequently, Petty has a strong claim to be viewed as one of the first quantitative economists. He discerned what he viewed as a seven-year business cycle, suggesting a possible basis for systematic economic forecasts, although historically, cycles `vary greatly in duration and intensity': see Victor Zarnowitz, (2004). Petty was later to prove a considerable influence on Colin Clark, as we discuss in Section 3.

Florence Nightingale

In his *History of Oxford Statistics* written to celebrate its 25th anniversary in 2013, Professor John Gittins notes: "Florence Nightingale, the pioneer of modern nursing, following her experiences during the Crimean war, was also an enthusiast for statistical methods. In the 1870s she discussed the possibility with her friend Benjamin Jowett, Master of Balliol College, of endowing a Professorship of Statistics in Oxford to which they both agreed to contribute, and later further

discussed the idea with Francis Galton, another pioneer of applied statistics. In a letter to Galton in 1891, she suggested that the professorship should address the need for statistics relating to education, penology, workhouses and India. In his response, Galton stressed the importance of the new professor doing research as well as teaching, and also questioned the suitability of Oxford as the home for this venture. Neither comment blended well with Miss Nightingale's vision and, partly for these reasons, sadly the proposal foundered.''

Nevertheless, the Department of Statistics at Oxford University now has a Florence Nightingale Bicentennial Fellowship and Tutor in Statistics and Probability as well as a Florence Nightingale Lecture. Her role in statistics is not as well known as that in nursing, but Nightingale was a pioneer in using graphical presentations of statistical data, such as the pie chart, to convey persuasive messages. She is credited with developing the polar-area diagram (which she called a `coxcomb') to illustrate seasonal mortality in the Crimean War hospital she managed. Nightingale was elected the first female member of the Royal Statistical Society in 1859 and became an honorary member of the American Statistical Association in 1874.

Francis Yesidro Edgeworth

However, Oxford University did appoint someone we would now call an econometrician to a chair in 1891, namely Francis Ysidro Edgeworth (see Arthur Bowley, 1934). This was not to a chair in statistics, but as the Drummond Professor of Political Economy at All Souls College where he joined James Joseph Sylvester who had only just become the Savilian Professor of Geometry in 1883 at almost 70, a lack of ageism the University would do well to adopt again. Edgeworth was an Irish philosopher and political economist who had previously been Tooke Professor of Economic Science and Statistics in London and made many significant contributions to statistical methods. Earlier in life, Edgeworth had been a student in philosophy at Balliol College, Oxford from 1867–69, so was doubly connected with the University. In statistics, Edgeworth's name is remembered through Edgeworth series, which approximate a probability density function in terms of its cumulants. He published many papers on statistics and his principle of maximum probability is an early version of likelihood: see Edgeworth (1887). He also contributed to index number analysis. Stephen Stigler (1978) viewed Edgeworth's plan as to `adapt the statistical methods of the theory of errors to the quantification of uncertainty in the social, particularly economic, sciences' and provides an excellent discussion of its implementation. The Royal Statistical Society awarded Edgeworth the Guy Medal in 1907 and he served as its president during 1912–14. Edgeworth was also influential in the development of neo-classical economics, perhaps best known for the Edgeworth–Bowley box diagram. In 1891 he was appointed as the founding editor of *The Economic Journal*, where he continued as editor or joint editor until his death 35 years later (for more detail, see Chapter 12 by John Creedy).

3 Econometrics at Oxford 1900–1980

Colin Clark

Colin Clark is the next important econometrician at Oxford. Clark compiled the first modern set of national income accounts for the United Kingdom and pursued

data collection on a world-wide scale. He was born in London and studied chemistry at Brasenose College (1924−8), William Petty's old college, where he became a Fellow for a time, and later was Director of the Institute of Agricultural Economics at Oxford University. His hero was indeed Petty, and like Petty, he started academically as a scientist so was self-taught in economics, with a similar creative imagination, also displaying brilliance and originality from an early age. Clark was first appointed Lecturer in Statistics at Cambridge University in 1931, before moving to Australia, where he spent a year at the Universities of Melbourne and Sydney, then as Director of the Queensland Bureau of Industry and as the Queensland Government Statistician between 1938 and 1953 before he returned to England, but settled permanently in Australia from 1978.

His Herculean data collection efforts in the 1930s remain unparalleled to the modern day. He was inspired by Bowley (1895, 1913), and built on key contributions by Alfred Marshall (1890), who had considered an aggregate idea of National Income, leading to the modern measure of Gross Domestic Product (GDP). Alfred Flux (1924, 1929) was another precursor who, with Bowley, pioneered the Census of Production to create a measure from the supply side as well as estimating the National Income, as was Josiah Stamp (1916): see Geoff Tily (2009). Tily and Alexander Millmow in Chapter 18 provide excellent discussions of Clark's major contributions to the development of national income accounts, and as Tily remarks: `The breadth and depth of Colin Clark's work in the 1930s—funded from his own resources, it should be added—marked him out as the most resourceful and innovative National Accountant of them all.' See Adrian Darnell (2018) for more detail on Bowley.

Clark is credited with inventing the concept of Gross National Product before Simon Kuznets (1946) invented Gross Domestic Product, and later was influential in setting up the National Accounts for Australia. He produced many journal papers and books, including *The National Income*, 1924−31 published in 1932, and *National Income and Outlay* in 1937. He also developed a system of equations explaining the United States trade cycle, 1921−41 (*Econometrica*, 1949), an embryonic macroeconomic model and contributed to development studies (see Angus Maddison, 2004).

Oxford Institute of Statistics (IES)

The next significant step in the development of Oxford statistics was again by its economists, who were increasingly keen to build economic theory on a foundation of sound data analysis. This led to the creation in 1935 of an Institute of Statistics financed by the Rockefeller Foundation with a director holding a new Readership in Statistics (see Chapter 5 by Jan Toporowski). As Oxford's first research institute in statistics, the new institute was concerned with economics as well as statistics in relation to economic data, features made more obvious in 1962 when the institute was renamed the Institute of Economics and Statistics (IES). Norman Chester (1986) provides a history of IES to 1985.

The first director of the Institute of Statistics in 1935 was the econometrician Jacob Marschak, who had been born in Kiev in 1898 as the son of a Jewish jeweller. Marschak had lived an eventful life in Russia and Germany until coming to Oxford University fleeing Hitler. He moved to the USA in 1938 where he had a distinguished career at the Cowles Commission.

During the war years, the acting director of the Institute was Sir Arthur Bowley, the distinguished economic statistician who had recently retired from a chair at the London School of Economics. Although not primarily a statistician, Michael Kalecki was also housed at the IES from 1939 to 1945 where he contributed to analysing data on many aspects of World War II, publishing in the *Bulletin*. Hubert Henderson, Acting Director of the IES at the time recorded the Institute's appreciation for Kalecki when he left: 'the repute that the Institute has won as a war-time centre of lively, yet scientific and realistic economic study, owes much to your stimulating influence.' (see Toporowski, 2018, Chapter 8). David Worswick (See Chapter 21 by Rosalind Seneca) was at the IES from 1940–60, but did not regard econometrics favourably, arguing that it made `pretend-tools' while trying to achieve Frisch's aims.

The readership was then filled by David Champernowne, who also became director of the Institute from 1945 to 1948 and Professor of Statistics from 1948 to 1959, after which he returned to Cambridge where he had read mathematics and then economics, graduating in 1934. Champernowne went on to do research on income distribution, for which he was the first to provide a statistical model. In 1937 this work earned him a prize fellowship at King's College Cambridge. He continued to work on income distribution for the rest of his academic career: see Mauro Boianovsky (2016) for more details.

The Oxford Institute of Statistics then became home to a steady stream of distinguished economic statisticians and econometricians. In roughly chronological order, Frank Burchardt was the director after Champernowne in 1948, and he helped attract Lawrence Klein, later a Nobel Prize winner. Klein worked at the Institute from 1954 to 1958 during the McCarthy era, and helped develop the first UK macro-econometric model with Arthur Hazlewood, James Ball and Peter Vandome. Klein spoke of his association with the Institute in its early days in his Nobel Prize autobiography.[2]

Some of the papers related to Klein's macro-economic modelling were published in the *Bulletin of the Oxford Institute of Economics and Statistics*, established in 1939, changing its name in 1973 to the *Oxford Bulletin of Economics and Statistics*. Ball, Hazlewood and Klein published 'Econometric Forecasts for 1959' (for the United Kingdom) in the February issue of 1959, while the February 1961 contained 'Reestimation of the Econometric Model of the U.K. and Forecasts for 1961' by Klein, Hazlewood and Vandome. That issue also published 'A Post-Mortem on Econometric Forecasts for 1959' by Hazlewood and Vandome.

Next, the IES was home to Gerhard Stuvel (see e.g., Stuvel, 1965), Christopher Winsten (whose serial correlation correction method in a 1954 Cowles discussion paper with Sig Prais became widely cited), N. Schwartz, and John Hammersley (at Oxford from 1961 and whose excellent book on Monte Carlo with David Handscomb, 1964, helped Hendry and Pravin Trivedi develop their 1972 paper). They were followed by a non-econometrician Teddy Jackson as director, then Hendry (who was director from 1982 to 1984) and Stephen Nickell, who was its final director from 1984–1997.

[2] www.nobelprize.org/nobel_prizes/economics/laureates/1980/klein_autobio.html

James Meade

James Meade (later another Nobel Prize Laureate) was born in Swanage, Dorset in 1907 and attended Oriel College, Oxford in 1926 to read Greats, but switched to Philosophy, Politics and Economics and gained an outstanding first. During 1930−31 he was a post-graduate at Christ's and Trinity Colleges Cambridge where he had discussions with Dennis Robertson and John Maynard Keynes among other distinguished economists. Meade was a lecturer at Hertford College, Oxford from 1931 to 1937 before going to the League of Nations, then during World War II was a member of the Economic Section of the War Cabinet Secretariat. It was in that role that together with Richard Stone (see Terry Barker, 2016), they developed estimates of UK National Income accounts (NIAs) under Keynes, who perhaps had understood the crucial role of data from his (1920) calculations of the impossibility of Germany paying the Reparations imposed in the Treaty of Versailles, as well as Keynes's desire to know what resources the UK had available to fight World War II: see Susan Howson (2016) for more details.

The Oxford Savings Surveys were another major data resource, first analyzed by Malcolm Fisher (1956), reinforcing Oxford economics role in data curation. That paper led to the complete May 1957 issue of the *Bulletin* being devoted to empirical studies of the consumption function with a galaxy of contributors including Albert Ando and Franco Modigliani, Milton Friedman, Trygve Haavelmo, Lawrence Klein, Denis Sargan and James Tobin, making five Nobel Laureates: Hendry and Peter Phillips (2018) provide more detail about Sargan.

Martin Feldstein

Martin Feldstein was a Fellow of Nuffield from 1964 to 1967, the year in which he received his DPhil (doctorate) supervised by Terence Gorman (and later became an Honorary Fellow). Feldstein's research pioneered the empirical analysis of production functions for hospitals using differences in location and time within the National Health Service (NHS) to estimate the costs and benefits of various medical procedures. His findings were published in both medical and economics journals, as well as a book (Feldstein, 1967), helping shift analyses of healthcare productivity from studies of specific cases to population data sets: see https://voxeu.org/article/ideas-and-influence-martin-feldstein-1939-2019.

Grayham Ernest Mizon

Grayham Mizon was the RTZ Research Fellow at St. Catherine's College, Oxford from 1970—73 during which time he published important research on estimation and inferential procedures in nonlinear models, before returning to LSE: see Mizon (1974, 1977). He remained a long-term collaborator of Hendry and was a key participant in most of the ESRC-funded econometrics research programs at Nuffield College from 1988−2002 (see Appendix 1), and an Associate, Institute for New Economic Thinking at the Oxford Martin School, 2012−18.

Alan Brown

Alan Brown moved to Oxford in 1970 and was associated with the IES and as editor of the *Bulletin* till his death in 1984 (see e.g., John Aitchison and Brown,

1957, and Brown and Angus Deaton, 1972). Stone (1985) refers to Brown as `a mainstay of advanced studies in econometrics and development economics' and Creedy (2008) admired him as a thesis supervisor (Brown had examined Hendry's PhD thesis).

Other faculty

Other faculty who also taught econometrics at Oxford before (and after) 1980 included Michael Dempster who did so during the 1970s, as did Michael Surrey (see Surrey, 1971), Robert Bacon (see e.g., Bacon, 1991), followed by David Begg (see e.g., Robert Corker and Begg, 1985), and Christopher Gilbert (see e.g., Gilbert, 1976, 1986). Jerry Hausman was a doctoral student then, graduating in 1973 (see e.g., Hausman, 1974—later also an Honorary Fellow of Nuffield). As a lead into the next section, Jim Poterba was a doctoral student supervised by Hendry, graduating in 1983 when he was already a Junior Research Fellow at Nuffield (see e.g., Poterba and Lawrence Summers, 1983).

4 Oxford Econometrics 1980–2000

When Teddy Jackson retired as IES director in 1982 after focusing on development economics, the University proposed closing the Institute as part of the savings it needed, but offered the first author (newly arrived from LSE) the chance to run it (unpaid) to see if it could pay its way. By renegotiating the royalties accruing to its *Bulletin* sufficiently to fund a full-time director, in 1984 Steve Nickell (see Jan Ours, 2018, for more detail) was attracted to that role, which he held until the IES was merged into the new Department of Economics. The IES and *Bulletin* quickly returned to their statistical roots by being at the forefront of the cointegration wave, and by 1986 the *Bulletin* was becoming one of the most cited 'statistics' journals, though read by few non-economics statisticians! See Chapter 4 by Anindya Banerjee for a history of the *Oxford Bulletin of Economics and Statistics*. While he was Director, Hendry started a tradition of fortnightly econometrics lunches where all interested faculty and graduate students could meet and discuss their teaching and research, which still continues. Throughout there has also been a fortnightly econometrics seminar as a venue for non-Oxford speakers.

It often surprises readers that despite being founded in the 12th Century, Oxford University did not have a department of economics until almost the end of the 20th Century (for a brief history, see https://www.economics.ox.ac.uk/about/about-homepage). Before 1997, economics teaching was College based, with colleges having their own Fellows who taught PPE (the Politics, Philosophy and Economics undergraduate degree: see Chapter 6 by Warren Young). There was a taught BPhil degree for graduates from 1945, which became an MPhil in 1979, with much more technical economics and econometrics content. Over this period, economics had a `sub-faculty' status with the IES and Nuffield College being focal points. By way of comparison, the Department of Statistics was only created in 1988.

Nuffield College

Somewhat earlier, Nuffield College had been founded in 1937 as a graduate college of the University specialising in the social sciences, particularly economics, politics (especially psephology), and sociology. Nuffield had close ties with the

IES, many of whose members were fellows of the College. Before the creation of an Economics Department, Nuffield acted in lieu of a Department as it had the largest number of economics faculty, with many of the main graduate lecture courses taught in the College. Statisticians and econometricians have also often served as its Warden including Sir David Cox, 1988–1994, Sir Tony Atkinson, 1995–2005 (see Stephen Jenkins, 2016 for more detail), Sir Stephen Nickell 2006–2012 and Sir Andrew Dilnot since then. Other statisticians who were fellows have included Klim McPherson, Clive Payne, Lucy Carpenter, David Firth, Garett Fitzmaurice and Tom Snijders; and its econometricians included Terence Gorman (see Chapter 23 by Peter Neary and Patrick Honohan), John Muellbauer (see Chapter 28 by John Duca), Hendry (see Chapter 27 by Neil Ericsson) and Bent Nielsen (see e.g., Ingrid Harbo, Søren Johansen, Nielsen and Anders Rahbek, 1998, and Johansen and Nielsen, 2009) in addition to those mentioned elsewhere. Nielsen has collaborated with many other Oxford faculty (see e.g., Hendry and Nielsen, 2007, and Vanessa Berenguer-Rico and Nielsen, 2019) and contributed to a wide range of econometric theory developments as well as to teaching.

Neil Ericsson joined Nuffield from LSE in 1982 as a Research Officer on an ESRC award with Hendry, starting another long collaboration from Hendry and Ericsson (1983), eventually published in 1991. Adrian Neale followed in 1986, helping develop a menu-driven program for Monte Carlo simulation experiments (see Hendry and Neale, 1987). Olympia Bover was a Research Officer 1985–1987 then Research Fellow, 1987-1989 at Nuffield, and Manuel Arellano was also a Research Fellow at Nuffield, 1986–1989 and Research Lecturer at IES, 1985–1989. Together with Steve Bond, Fellow at Nuffield since 1990 and previously a student there from 1984, they published the much-cited Arellano and Bond (1991) paper. This provided an estimation method for dynamic panels where the time-series dimension was relatively short. Gavin Cameron came in 1992 and mainly published with Muellbauer (see Muellbauer and Cameron, 1998). Hans-Martin Krolzig joined as a Research Officer at IES and an associate at Nuffield for a decade from 1995 and published extensively on Markov-switching and business-cycle modelling (see Krolzig, 1997) as well on econometric modelling with Hendry (see e.g., Hendry and Krolzig, 1999). Stan Hurn, 1996-1998, and Katy Graddy also researched econometrics.

Two other long collaborations for Hendry that began in the IES were with Michael Clements and Jurgen Doornik. That with Clements started with his Doctorate, leading to Clements and Hendry, 1993 (where the discussion was longer than the paper!), and numerous publications since, as well as his participating in many of the ESRC research programs at Nuffield (see Clements and Hendry, 1998). That with Doornik began in 1989, initially as a Research Officer on ESRC research programs and then a Research Fellow at Nuffield College from 1996 on, developing Ox (see https://doornik.com/ox/, leading to Doornik and Hendry, 1992, applied in Hendry and Doornik, 1994: also see the much used test in Doornik and Hansen, 2008).

Neil Shephard was a Fellow of Nuffield over 1991–2013 and Professor of Economics, 1999–2013, actively researching financial econometrics (see e.g., Ole Barndorff-Nielsen and Shephard, 2002, 2004a,b, 2006, and 2001, for which he received the Royal Statistical Society's Guy Medal in Silver). He contributed importantly to econometric modelling of realized volatility, and developed stochastic volatility models, as well methods for handling jumps in financial time

series in research linked to similar advances for modelling breaks in macroeconomic data. He also formulated methods for non-Gaussian and non-linear models, and with Michael Pitt, developed filtering by simulation using auxiliary particle filters (see Pitt and Shephard, 1999). While at Nuffield, he was awarded a number of ESRC grants where Tina Rydberg (see e.g., Rydberg and Shephard, 2003) and Frank Gerhard (see Gerhard and Nikolaus Hautsch, 2002) were Research Officers, He co-founded the *Econometrics Journal* with David Hendry and his later research is discussed in Section 5.

Richard Spady was an Official Fellow of Nuffield over 1992−1999, and a regular visitor since then, researching non- and semi-parametric methods. Oliver Linton, a Research Fellow there from 1991−1993, also researched non-parametric methods. Bronwyn Hall, Professor of Economics and Professorial Fellow, Nuffield College, 1996−2001 brought a strong interest in Econometric computing, and her TSP software was linked into OxMetrics.

Doctoral students

A major driving force behind advances in econometrics across a vast range of topics during the period from 1980 was a succession of brilliant DPhil students adding to those mentioned above, including Anindya Banerjee (later a Fellow of Wadham College), Gregor Smith, John Galbraith, and Juan Dolado (see e.g., Banerjee *et al,* 1986, 1993), Kate Desbarats, Carlo Favero (see Favero and Hendry, 1992), Andreas Fischer (see Fischer, 1989), Kivilcim Metin (see Metin, 1995), Karim Abadir (see e.g., Abadir, 1992), Rebecca Emerson (see Emerson and Hendry, 1996), Steven Cook (see Cook and Hendry, 1993), Claudio Lupi (see Giorgio Brunello, Lupi, and Patrizia Ordine, 2001), Pekka Pere (see Pere, 2000), and Edmund Cannon (see Cannon and Ian Tonks, 2004).

In addition, some of the DPhil econometricians went in to the commercial and public sectors, including Fritz Struth (State-space Modelling), Massimo Fuggetta (Financial Econometrics: founder of Bayes Investments), Ian Harnett (Consumption Expenditure: founder of Absolute Strategy Research) and Lamin Leigh (Money demand: who joined the IMF).

Research funding

Over the period 1984−2000, numerous ESRC funded research grants were attracted to Nuffield by research teams including various econometricians from Arellano, Banerjee, Clements, Doornik, Hendry, Mizon, Muellbauer, Nielsen, Shephard and John Walker, totalling almost £2 million in nominal terms (see Appendix 1 for details). In rough chronological order from 1984, grants investigated included *Expectational Variables and Feedback Mechanisms*, *Structural Change*, *Model Evaluation*, *Economic Policy*, *Cointegration*, *Modelling Non-stationarity*, *Financial Econometrics* and *Forecasting*, the last of which was then supported by a 5-year Leverhulme Personal Research Professorship for Hendry. Appendix 1 also records more recent research funding to document the wide range of topics supported.

Links to economic historians continued to be important to the econometricians, especially with major data creators like Charles Feinstein (see Feinstein, 1972)

and Stephen Broadberry (see Section 6 and Chapter 2 by Avner Offer), including joint teaching of a quantitative approach to the UK's inter-war experience.

Nuffield also acted as a venue for many visiting econometricians, including several visits by (amongst others) Clive Granger, Rob Engle, Adrian Pagan who was also a Nuffield Fellow for a period (see their interviews in *Econometric Theory*), Paul Ruud, Tom Rothenberg, Rahbek and Gunnar Bårdsen.

5 Oxford Econometrics in the 21st Century

With the creation of the Department of Economics in Manor Road, the institutional framework for Oxford econometrics changed. At the same time, the number of graduate students grew dramatically across the University and in Economics, where a new M.Sc. in Financial Economics was created jointly with the Saïd Business School in 2003. The Nuffield post-doc program expanded as a joint venture with the Department. At the same time a compulsory econometrics component was introduced in the undergraduate PPE program.

The econometricians who arrived in Oxford at the faculty level over this period included Valérie Lechene 1999-2006, Adrian Pagan 2000-2003, Kevin Shephard 2004, Martin Browning 2006-19, Debopam Bhattacharya 2009-15, Jennifer Castle 2009, Sophocles Mavroeidis 2011, Michael Keane 2012-17, James Wolter 2013-18, Vanessa Berenguer-Rico 2015, James Duffy 2016, Anders Kock 2017, Frank DiTraglia 2019, Max Kasy 2020. At the same time, there has been a constant flow of post docs in econometrics including Ola Elerian 2001-02, Jeremy Large 2005-08, Jennifer Castle 2006-09, Brendan Beare 2007-08, Mika Meitz 2006-08, Shin Kanaya 2008-12, Vitaliy Oryshchenko 2011-14, Vanessa Berenguer-Rico 2012-15, Daniel Gutknecht 2012-15, James Wolter 2012-13, Liang Chen 2013-16, Yingying Lee 2013-16, Marianne Bruins 2014-18, James Duffy 2014-16, Ryoko Ito 2015-17, Felix Pretis 2015-18, Stefan Hubner 2016, Sander Barendse 2018, Xiyu Jiao 2019, and Susanna Martins 2019. Research Officers included Marianne Sensier, Anthony Murphy and Luca Nunziato. Following the 2008 financial crisis, Hendry received funding from the Institute for New Economic Thinking to set up a Program for Economic Modelling and to develop tools for forecasting after crises, which partly funded a number of the post docs.

DPhil students in econometrics included Sule Akkoyunlu, Mavroeidis, Domenico Lombardi, Michael Massmann, Guillaume Chevillon, Castle, Carlos Santos, James Reade, Nicholas Fawcett, Julia Giese, Sonja Keller Canto, Pretis, Andrew Martinez, Oleg Kitov, Michael Pitt, Carlos Caceras, Taka Kurita, Diaa Noureldin, Qianzi Zeng, Heiko Hesse, Jiao and Matthias Qian.

Neil Shephard's research in financial econometrics continued to flourish. The returns of financial assets were modelled using volatility models driven by Lévy process (see Barndorff-Nielsen and Shephard, 2002). These are processes allowing a continuous component and both large and many small jumps. The jumps could be estimated by power and bipower variation (see Barndorff-Nielsen and Shephard, 2004a) and multivariate features could be estimated by realised covariation (see Barndorff-Nielsen and Shephard, 2004b). Shephard was involved in the creation of the M.Sc. in Financial Econometrics and also in teaching the core financial economics paper. He attracted funding from the MAN hedge fund to found

the Oxford-Man Institute to study quantitative finance, and was its first director in 2007-11. Neil is currently chair of the Department of Statistics at Harvard University.

Software development

The research in econometric computing took a new direction with the development of automated software for model selection and detection of outliers and step shifts. Inspired by Hoover & Perez (1999), Hendry and Krolzig (1999, 2005) developed the PcGets software, later replaced by Autometrics by Doornik (2008) and accompanied by Gets in R by Pretis, Reade & Genarro Sucarrat (2018). An asymptotic theory for outlier detection was initiated by Hendry, Johansen, and Carlos Santos (2008) and Johansen and Nielsen (2009). The model selection project continues and involves a number of other researchers, students, post docs and faculty, including Berenguer-Rico, Castle, Jiao and Qian.

Several new teaching courses were introduced including Quantitative Economics in 2009 and Environmental Economics and Climate Change for PPE, and an M.Sc. in Financial Economics with a financial econometrics core course. Research funding (documented in Appendix 1) matched the change in emphasis to *Economic Forecasting*, *Modelling, Forecasting and Policy in the Evolving Macro-economy, Economic Modelling in a Rapidly Changing World, Rebalancing Theory and Evidence in Macroeconomics*, *Automatic Tests of Model Specification, Extending the Boundaries of Econometric Modelling*, *Our World in Data*, and *Climate Econometrics.*

Easter Schools

Over the period 2001-08, Hendry, Nielsen and Shephard organized a series of annual Easter Schools in econometrics funded by the Royal Economic Society and ESRC. The Easter Schools had prominent speakers and attracted many students from across the world:
Financial Econometrics: Enrique Sentana & Neil Shephard
Micro econometrics: Martin Browning & Hidehiko Ichimura
Linear and non-linear non-stationary time series: Søren Johansen & Anders Rahbek
Financial Econometrics: Torben Andersen, Tim Bollerslev & Nour Medahi
Causality: David Cox, Nancy Cartwright, David Hendry, Jim Heckman & Steffen Lauritzen
Panel Data: Manuel Arellano & Steve Bond
Model Selection: Kevin Hoover, David Hendry, Benedikt Pötscher & Halbert White
Identification in macro economics-New Keynesian Phillips curve: Sophocles Mavroeidis.

6 Contributions to Data Provision in the 21st Century

Oxford econometrics has continued its interest in data construction and organisation. The vast, easily accessed and immensely useful provision in https://ourworldindata.org/ by Max Roser and his team is a major contribution to understanding the evolution of the world. Their database has curated many thousands of time series and maps from Age through Antibiotics and Biodiversity

to Working Hours, covering economics, politics, climate, health, gender, sustainability, poverty and inequality all beautifully presented graphically.

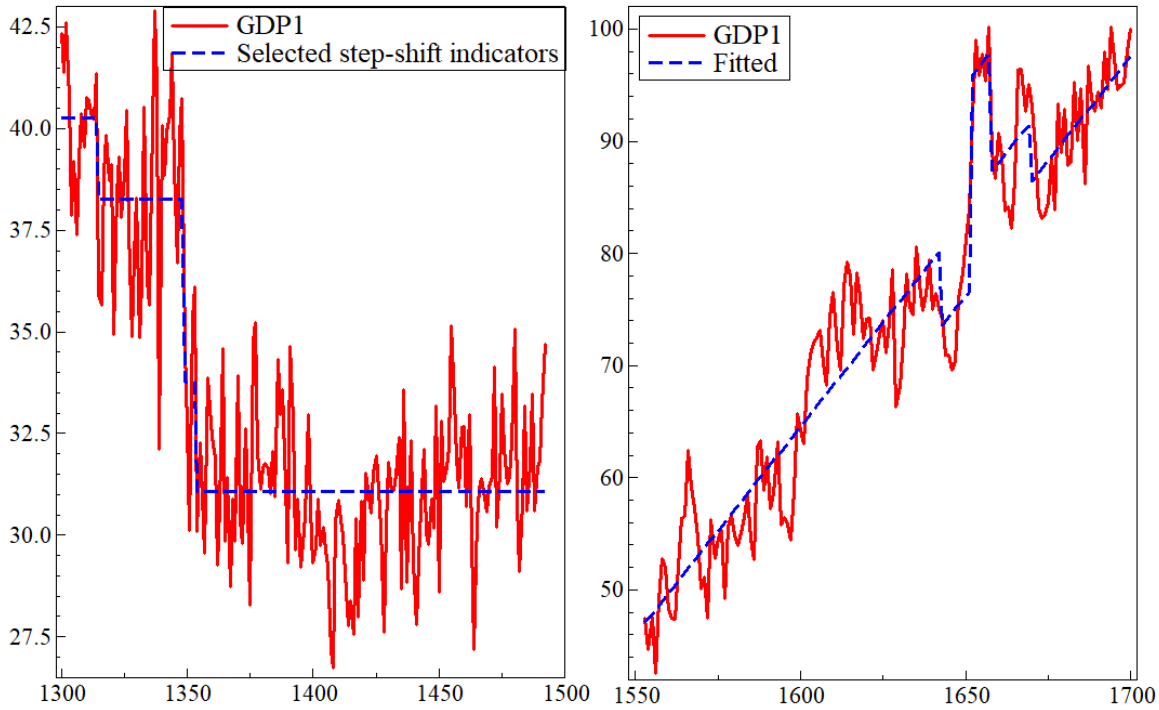

Figure 1: UK GDP reconstructions, 1300–1700

Recently, Alexander Apostolides, Stephen Broadberry, Bruce Campbell, Mark Overton, and Bas van Leeuwen (2008) have performed the enormous task of estimating English GDP from 1300–1700, providing an incredibly long-run of historical time-series data, shown for what the authors call GDP1 in Figure 1, pre and post their missing data period.[3]

The downward location shift following the Black Death starting in 1348 is very marked in the left-hand panel, as is the relative stagnation through to about 1500, both highlighted by using step-indicator saturation (SIS: see Jennifer Castle, Doornik, Hendry, and Felix Pretis, 2015). On the right-hand panel (note the different scales), the strong and relatively constant absolute growth from around 1550 onwards is equally obvious, and now SIS picks up the drop over the English Civil War 1642–1651, and the boom following its ending, as well as another boom over 1664–1672. While it may be thought to be anachronistic to create GDP data over a period where the concept was unknown, their detailed and extensive archival research is an important contribution to understanding the past, and builds on a long Oxford tradition in data curation.

[3] For an update and continuous time series, see Broadberry, Campbell, Alexander Klein, Overton, and van Leeuwen (2015).

7 Climate Econometrics

The Climate Econometrics (CE)[4] project at Nuffield (co-directed by Hendry and Pretis) brings together a multi-disciplinary group of researchers from economics, econometrics, computing, climate science, political science and geography. The aim is to develop and apply econometric tools to empirical modelling and understanding both how humanity has affected the global climate and how humanity has been affected in turn. Econometrics has proved a useful toolkit for statistically modelling high-dimensional dynamic economic systems subject to wide-sense non-stationarity (from stochastic trends and location shifts), outliers, potential non-linearities and simultaneous interactions, based on relevant but incomplete economic theory, so requiring model selection. Figure 2 illustrates the extreme wide-sense non-stationarity and huge outliers for UK domestic carbon dioxide, CO_2, emissions in tons per person per year from 1860–2017, also showing dramatic recent reductions following the Climate Change Act of 2008, now below 1860's levels when the UK was the `workshop of the world'.

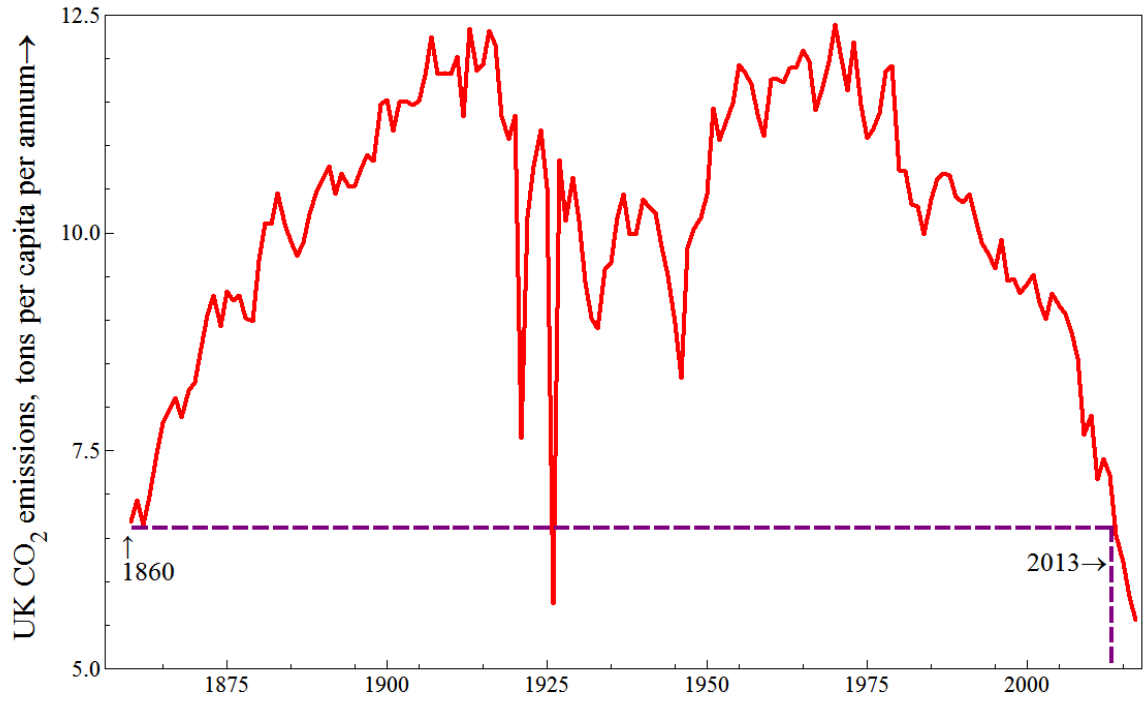

Figure 2: UK domestic CO_2 emissions in tons per person per year

Since climate change is driven by economic activity creating greenhouse gas emissions (primarily CO_2), similar econometrics modelling tools are proving valuable. Castle and Hendry (2019a) and Castle, Clements and Hendry (2019) provide no-technical explanations of the modelling tools and forecasting methods respectively. Empirical examples include linking econometric models and climate

[4] Funded by the Robertson Foundation and Nuffield College: see www.climateeconometrics.org for more information.

systems (see Pretis, 2019); damages from hurricanes (see Martinez https://sites.google.com/view/andrewbmartinez/current-research/damage-prediction-tool) ; modelling data on UK and global CO2 emissions (see Figure 2 for the former, and Hendry and Pretis, 2013, for the latter); the impacts of volcanic eruptions on temperatures (see Pretis, Lea Schneider, Jason Smerdon, and Hendry 2016) and of temperature rises on output worldwide (see Pretis, Moritz Schwarz, Kevin Tang, Karsten Haustein and Myles Allen 2018); and even the role of CO_2 during past ice ages (Castle and Hendry, 2019b).

Post-doctoral researchers on the team include Doornik (econometrics and computing: see Doornik, 2008), Luke Jackson (oceanography: see Jackson and Svetlana Jevrejeva, 2016), Ryan Rafaty (climate policy: see Doyne Farmer, Cameron Hepburn, Matthew Ives, Thomas Hale, Thom Wetzer, Penny Mealy, Rafaty, Sughanda Srivastav and Rupert Way, 2019), Sam Rowan (climate policy: see Rowan, 2019), with Susana Martins (financial econometrics) and Jiao (econometrics) just joining, as well DPhil students Schwarz, Jonas Krule, and research assistant Lisa Thalheimer. Angela Wenham is the communications officer and DPhil graduate Martinez recently left (econometrics & forecasting: see Castle, Hendry, and Martinez, 2017).

Such a project also reflects a number of general developments in econometrics which have led from single topics to multi-disciplinary studies, from single authors to multiple, and spreading from being primarily economics focused to seeing applications in many other observational-data disciplines. Thomas (2018) also reflects on these developments at the LSE. An interesting future for Oxford Econometrics lies ahead.

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Appendix: Research funding awards for econometrics

The Roles of Expectational Variables and Feedback Mechanisms in Econometric Models, David F. Hendry, & John N.J. Muellbauer, £171k, ESRC, 1984—1988 (RB00220012).
https://researchcatalogue.esrc.ac.uk/grants/RB00220012/read

Appraising Model Evaluation Techniques, Manuel A. Arellano, David F. Hendry, Grayham E. Mizon & John Walker, £275k, ESRC, 1988—92 (WB01250024).
https://researchcatalogue.esrc.ac.uk/grants/WB01250024/read

Structural Change and Econometric Modelling, David F. Hendry, & John N.J. Muellbauer, £257k, ESRC, 1989—93 (R000231184).
https://researchcatalogue.esrc.ac.uk/grants/R000231184/read

The Econometrics of Economic Policy, Anindya Banerjee, David F. Hendry, & Grayham E. Mizon, £229k, ESRC, 1992—95 (R000233447).
https://researchcatalogue.esrc.ac.uk/grants/R000233447/read

Modelling Cointegrated Processes, David F. Hendry & John N.J. Muellbauer, £322k, ESRC, 1994—97 (R000234954).
https://researchcatalogue.esrc.ac.uk/grants/R000234954/read

Econometrics of Economic Forecasting, Anindya Banerjee, Michael P. Clements, David F. Hendry, & Grayham E. Mizon, £269k, ESRC, 1996—99 (L116251015).
https://researchcatalogue.esrc.ac.uk/grants/L116251015/read

Leverhulme Personal Research Professorship, David F. Hendry, 1995—2000 (Replacement teaching and travel funding).

Modelling Non-stationarity in Economic Time Series, David F. Hendry, John N.J. Muellbauer & Bent Nielsen, £355k, ESRC, 1999–2001.
https://researchcatalogue.esrc.ac.uk/grants/R000237500/read

Modelling, Forecasting and Policy in the Evolving Macro-economy, Anindya Banerjee, Michael P. Clements, David F. Hendry and Grayham E. Mizon, £289k, ESRC, 2000–02.
https://researchcatalogue.esrc.ac.uk/grants/L138251009/read

Economic Forecasting Professorial Fellowship, David F. Hendry, £314k, ESRC, 2003–06.
https://researchcatalogue.esrc.ac.uk/grants/RES-051-27-0035/read

Extending the Boundaries of Econometric Modelling, Jurgen A. Doornik & David F. Hendry, £133k, ESRC, 2004–07.
https://researchcatalogue.esrc.ac.uk/grants/RES-000-23-0539/read

Automatic Tests of Model Specification, Jennifer L. Castle & David F. Hendry, £220k, ESRC, 2006–08.
https://researchcatalogue.esrc.ac.uk/grants/RES-062-23-0061/read

Economic Modelling in a Rapidly Changing World, David F. Hendry, $10 million matching awards of half each from the Open Society Foundations and the Oxford Martin School, 2010–15.
http://www.inet.ox.ac.uk/programmes/emod/

Our World in Data, David F. Hendry & Max Roser, £75k, Nuffield Foundation, 2015–16. http://ourworldindata.org/

Climate Econometrics, David F. Hendry & Felix Pretis, £660k, Robertson Foundation, 2015–18. http://www.climateeconometrics.org/

Rebalancing Theory and Evidence in Macroeconomics, David F. Hendry & John N.J. Muellbauer, £490k, Institute for New Economic Thinking, 2015–18.
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