

## Preface to the Second Edition

Mathematical demography has a distinguished early history, intertwined with discoveries by the great figures of mathematics. Our generation of demographers learned this history from the volume which we now in large part republish. David Smith and Nathan Keyfitz in their collection of 1977 made the founding works available to all. But this collection has long been out of print, making it far more difficult for the present generation of demographers to locate their own works within the tradition of their forerunners.

The idea of republishing “Smith and Keyfitz” arose during a symposium at the Max Planck Institute for Demographic Research in Rostock, Germany, on 27 February 2009. The symposium, held in the Süssmilch Auditorium, was convened by James Vaupel and Joshua Goldstein to inaugurate several years of celebration of the 350th birthday of demography. The birthday follows on the February 1662 appearance of the *Natural and Political Observations ... Made Upon the Bills of Mortality...* published under the name of “John Graunt, Citizen of London”. The event in Rostock also celebrated the contributions of Peter Laslett. Peter inspired and guided the fusion of mathematical demography with historical sociology and studies of aging which marks the discipline of population studies today. He also organized and edited the series of full facsimile reprintings by Gregg International Publishers of the classics of demography which have served over the intervening decades as indispensable companions to the Smith and Keyfitz volume.

The past cannot just be archived. New steps forward bring into the light new meanings for previous formulations and give new salience to what may have been obscure. Likewise, the genealogy of an idea has power to reshape its evolving future form. We hope that readers of this volume will feel encouraged to submit to current demographic journals studies of other works important to the history of mathematical demography and write about the meaning of those works in their own time and ours.

The lasting influence of Smith and Keyfitz is found not only in the works they made accessible, but even more in the commentaries they wrote about these works. These commentaries explain the terminology, notation, and intention of the original

authors and go on to situate their results in the framework of Twentieth-Century mathematical demography. The commentaries combine historical scholarship with scientific insight.

The 514 pages of the 1977 volume exceed the size desirable for a reprinting. A selection of papers to retain was made at the outset of this project. In their original collection, Smith and Keyfitz included works as late as the 1970s which are now readily available on the world-wide web and hardly need reprinting. Not all the choices of works that were recent in 1977 have stood the test of time and some then-recent works not chosen have come into the limelight now. A decision was made to omit from this reprinting the nearly contemporary works and concentrate on older already classic contributions.

A decision was also made not to reprint the section from the 1977 volume devoted to “Branching Processes and Other Stochastic Processes”. This subject remains central to mathematical demography, but our understanding of its history was subsequently transformed by the rediscovery of Bienyamé’s contributions. The story is told by Heyde and Seneta [18] and the original works are readily accessible.

We retain the full commentaries by Smith and Keyfitz including discussion of works omitted from this reprinting. New editorial notes are inserted within bold curly brackets, marked “Ed. Note:”, to alert the reader to anything omitted and to set the commentaries into the context of our own Twentyfirst Century.

The date of original publication of this collection, at the end of the 1970s, marked a watershed in the discipline. Three central themes dominate the volume – lifetables, stable populations, and measures of fertility and its component processes. These themes all go back to the early days of demography. Advances continue to be made in these areas, but by 1977 the established core was coming to completion. Stable population theory was being rounded out and turned into a versatile part of the repertory, particularly by Ansley Coale and Nathan Keyfitz himself. Digital computers were ending the need for ingenuity in numerical computations that had gone hand-in-hand with the study of lifetables and projections. The spread of sample surveys into developing countries eased the challenges for indirect measures of fertility championed by William Brass.

Today, a third of a century later, mathematical demography is enlivened by new directions, which have taken their place beside the themes featured by Smith and Keyfitz. We think of non-stable theory, demographic feedback models, heterogeneity and frailty, spatial demography, and the mathematical innovations of biodemography. These endeavors trace some of their ancestry to the founders represented in this volume, but also to other forerunners whose roles we hope future historical studies will bring to center stage.

As this reprinting was in preparation, Nathan Keyfitz passed away at the age of 96. A few months before his death, speaking with him by telephone, one of us (KWW) told him about plans for this project. He was delighted. He still took an active interest in mathematical demography, and in the whole range of demographic thinking, and he looked forward to having this cherished work back in print. In preparing it we have benefited from encouragement and advice from Barbara

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Keyfitz. We also salute David R. Smith, who took the lead in crafting the original 1977 volume. We dedicate this reprinting to Nathan. His own works are classics in our field.

Berkeley, California, June 2013  
Paris, June 2013

Kenneth W. Wachter  
Hervé Le Bras



# Preface to the First Edition

This volume is an effort to bring together important contributions to the mathematical development of demography and to suggest briefly their historical context. We have tried to find who first thought of the several concepts and devices commonly used by demographers, what sort of problem he was facing to which the device or concept seemed the solution, and how his invention developed subsequently in the hands of others.

Historically, the book starts with a Roman table of life expectancies from the third century a.d. about which we know little, and with John Graunt's explorations in an area that was still popularly suspect when he wrote in 1662. These are followed by the astronomer Halley, who looked into the field long enough to invent the life table and to notice that Their Majesties would take a sizeable loss on the annuity scheme they had just launched; and by Euler, who was first to devise the formulas of stable population theory and to apply them to filling gaps in data. To these we add the handful of further contributions in the 19th century and many pieces from the explosion of contributions that began in this century with Lotka. We doubt that we have managed to trace everything back to its ultimate beginning, and suspect that our nominees in some cases have been anticipated by predecessors who will be turned up by other students.

The works we include form a living heritage in demography: Graunt; Halley; Euler; Lotka; Milne, who formalized life table construction; Lexis, who was preoccupied with the way members of a population are situated simultaneously in age and in time, and showed how a plane chart, now known as a Lexis diagram, can help analysis. Much less alive, and largely excluded here, are such notions as that of George King, that graduation of data for a life table was more accurate from pivotal death rates calculated at five-year intervals; John Graunt's belief that the right way to describe the dynamics of a population was as the *ratio* of births to deaths, without considering age; and devices that once reduced the labor of numerical calculation but are obsolete in a computer age. These and many other ideas that have proved to be dead ends and are now of merely antiquarian interest we tried to distinguish from those that were part of a chain of development that is still advancing. As far as we could discriminate our excerpts are confined to the latter.

To determine which works most deserve attention among the large number written has not been easy, and we have undoubtedly made mistakes both of inclusion and of omission. We were far from insisting on subtle mathematical

ideas, but did look for the effective uses of mathematics that have come to be assimilated into population work. Articles that profess to deal with population but whose main interest was mathematics we tried to avoid, and we avoided them doubly if they were a mere import from some other subject that seemed unlikely ever to be naturalized in population analysis. Some ideas and techniques have a kind of *droit de la cité* in contemporary population study, and we hope these are the ones that predominate in our selections.

To find passages that were self-contained and suitable for contemporary reading was occasionally difficult. Writers often used symbols well known to their place and time, and their immediate readership had no need for definitions we would now miss. To this the earlier works add key formulas with no hint as to how they are derived. Where we expect readers to have trouble as a result, because we did, we include a brief explanation of what is being done.

The choice of excerpts from the classic articles and books rather than complete reprints in all cases was dictated partly by economy of publication, but this was not the only constraint. Benjamin Gompertz fairly compactly introduces his Law of mortality, but spends above fifty pages fitting it to life tables and working out its implications for annuity payments. Harro Bernardelli published the first article on the use of matrices in population projection in the *Journal of the Burma Research Society*, which is not a source that most of us would come across in our ordinary reading. He has top priority for inclusion, but he deals partly with problems of the Burmese economy under British colonial rule and with speculations on cyclic events that do not carry much interest for readers today. Leslie, whose reading in a sickbed had taken him deep into the mathematical properties of matrices, went into cogredient and contragredient transformations that are unlikely to have demographic application. We saw no need to burden the reader with these only to have him discover at the end that he would never need them.

In editing we did not strip down our authors to the point of losing the context of their contribution to our subject. We learned much of an incidental character in our reading and have tried to retain that richness. Where substantive omissions are made we note these for the reader's benefit.

Several topics that fall in the province of demography are not included, among them treatments of human spatial ecology, urbanization, and migration. Omission is partly due to space limitations, and partly to lack of confidence in our ability to decide what is basic in fields whose mathematical explorations are recent and expanding rapidly.

We expect from the reader at least some background in calculus and matrix algebra, and several papers will require an understanding of stochastic processes. The reader lacking a background in elementary mathematics will find the greater part of the book difficult.

Secondary accounts of much of what we present can be found in Keyfitz (1968), and stochastic processes are well handled in Feller (1968) and Chiang (1968). Our chief sources for the early histories given here are Hendriks (1852, 1853), Westergaard (1969), and Lorimer (1959).

## Nathan Keyfitz: A Biographical Sketch

Nathan Keyfitz was the world's leading figure in mathematical demography in the second half of the Twentieth Century. His books *Introduction to the Mathematics of Population* in 1968 and *Applied Mathematical Demography* in 1977, with expanded editions in 1985 and 2005, defined the subject for generations of students and scientists. They were accompanied by other major volumes, the collection *World Population: An Analysis of Vital Data* from 1968 with Wilhelm Flieger, with successor volumes in 1972 and 1991, as well as *Causes of Death: Life Tables for National Populations* with Samuel Preston and Robert Schoen, and the collection from 1977 with David Smith, *Mathematical Demography: Selected Papers*, reprinted here. These works tied together practical demography with mathematical analysis and continue in use today.

Nathan Keyfitz was born on 29 June 1913 in Montreal, Canada. His family had emigrated from Mogilev, now in Belarus, around 1900. After taking a degree in Mathematics at McGill University in 1934, he looked for an academic position, but there were few if any opportunities at that time of great depression. For some months he worked in life insurance societies. In 1936 he was hired as a clerk at the Dominion Bureau of Statistics in Ottawa (later Statistics Canada) where he had to correct the inconsistencies in the individual census results, a monotonous and boring activity. Taking an interest in the data themselves, comparing results from the Canadian census with those from the American and English censuses, led to admonishment by his immediate chief. But it attracted the attention of R.H. Coats, head of the Bureau, and Coats encouraged Keyfitz' vocation as a researcher alongside his mundane duties.

John Robbins, head of education statistics at the Bureau, encouraged Keyfitz to consider studying for a Ph.D. and directed him toward an opportunity at the University of Chicago. William Ogburn, head of the Sociology Department at Chicago offered him a Carnegie Foundation Fellowship, and in 1942 Keyfitz began graduate study there. After a year, Keyfitz returned to the Dominion Bureau of Statistics but continued work on a dissertation and received a Ph.D. in Sociology from the University of Chicago in 1952. In Chicago, he attended lectures by Louise

Wirth and Ernest Burgess, leaders of what became known as the Chicago School of urban sociology.

In 1946, Keyfitz was sent to Raleigh, North Carolina, to a six week session of courses in statistics taught by Ronald Fischer, Abraham Wald, William Cochran, and Frank Yates. It was the beginning of what he called “chance meetings that establish firm friendships” which he enjoyed throughout his long life. A year later he was sent to Geneva to represent Canada at a United Nations subcommission on sampling, meeting such great statisticians as Fisher, Prasanta Chandra Mahalanobis and Georges Darmonis.

Having climbed a number of steps in the hierarchy of the Dominion Bureau of Statistics, Keyfitz was taken as an expert to advise South Asian statistical and census offices: in 1951 in Burma where he became friends with travel writer Norman Lewis; in Indonesia in 1952–1953 where he met his life-long friend, the French mathematician and academician Marc-Paul Schützenberger. At that time Schützenberger was serving as a medical expert for the World Health Organization. All his life Keyfitz remained a lover of Indonesia and he returned in 1964, 1979, 1984, and 1989 for long stays.

Keyfitz served for eighteen months as technical director for the Colombo Plan for Cooperative Development. Stationed in Ceylon, now Sri Lanka, his duties took him to Laos, Vietnam, Singapore and India. At the invitation of Mahalanobis he resided some months at the Statistical Institute in Calcutta together with the geneticist J.B.S. Haldane. During these years of statistical practice, he did not abandon his desire to do research.

In 1959 he took up his first academic position at the University of Toronto in the Department of Economics, Political Science, and Sociology. He described leaving the Dominion Bureau of Statistics with more hopes than regrets. He was 45 years old, but on the threshold of what would be a prodigiously long career in academic demography.

Keyfitz remained on the faculty at Toronto until 1962, teaching the works of Weber and Durkheim among others. The next decade brought a series of moves from university to university. In 1962, figuratively speaking, he climbed Montreal’s Mont Royal to teach for a year at the French Université de Montréal. It was only a kilometer from his undergraduate university, McGill, but for a person born and educated in the English-speaking part of the city, it was a venture into unknown territory. In 1963 he returned to the University of Chicago as Professor of Sociology. From that time on, he could concentrate on mathematical demography, a field that he practically invented as he drew together into a unified whole piecemeal work from many disciplines. In 1968 he headed west to the University of California, Berkeley.

On the urging of Fred Mosteller, founder of the Statistics Department at Harvard University, Keyfitz set about writing what would become his influential *Introduction to the Mathematics of Population*. The book galvanized the field and established his reputation. He served as president of the Population Association of America in 1970 and was elected to the American Academy of Arts and Sciences in 1971 and the National Academy of Sciences, USA, in 1977. It was rapid recognition, although not quite as swift as his forerunner in demography, John Graunt, who after signing



the *Natural and Political Observations* ... in 1661 was elected a member of the Royal Society in England the same year.

The move to U.C. Berkeley came at the invitation of Kingsley Davis and Judith Blake who were leading a new Department of Demography there. The four years at Berkeley can be considered the acme of Keyfitz' scientific production. He wrote seminal papers on topics ranging from the evaluation of demographic projections and the structure of causes of mortality around the world to the number of people who have lived on the earth.

The Berkeley years were also, as he later described them, the most intense period of his broader academic life. The entire university system was under pressure from protests and demonstrations. Keyfitz felt close to students involved in condemnation of the war in Viet Nam. The department became politically polarized, especially after an arson fire struck a building in which Kingsley Davis had an office. There were tensions between Judith Blake and others, some surrounding a joint course of lectures which Keyfitz delivered on contraception and its history with John T. Noonan at the U.C. Berkeley School of Law, later a U.S. Appeals Court judge.

In the wake of turmoil at Berkeley, Keyfitz accepted an invitation by Roger Revelle to come to Harvard. Other demography faculty also departed, Samuel Preston to the University of Washington and Etienne van de Walle to the University of Pennsylvania. The Berkeley Department of Demography was abolished. It was refounded in 1978 as a Graduate Group and later again as a Department under the leadership of Eugene A. Hammel and has been known for carrying forward the tradition of mathematical demography which Keyfitz initiated.

At Harvard, Keyfitz was based partly at the Center for Population Studies led by Roger Revelle in a quaint building on Bow Street in Cambridge, Massachusetts, partly in the Department of Sociology, and partly across the Charles River at the Harvard School of Public Health. One of the editors of the present volume, Kenneth Wachter, shared an office with him at Bow Street. These were the years of the consolidation of Stable Population Theory at Keyfitz' hands and the years when his celebrated book *Applied Mathematical Demography* took shape.

Harvard was not Keyfitz' final harbor. He taught there from 1972 to 1983. He had a part-time position at the Ohio State University between 1981 and 1983, and a little later spent three months at Stanford working with Marc Feldman, Brian Arthur, and Paul Ehrlich. In 1984 he took on leadership of the population program at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg outside Vienna, Austria. IIASA had been founded to promote East-West scientific cooperation under the shadow of the Cold War. Keyfitz made it a center for creative mathematical demography, fostering the work of a new generation of leaders including James W. Vaupel. While based at IIASA up to 1993, Keyfitz travelled throughout eastern Europe, although he never obtained the opportunity of visiting Mogilev, the cradle of his ancestors.

After 1995, Keyfitz returned to live by the Charles River in Cambridge, Massachusetts. He remained intellectually active. There was hardly a week without a visit to his former department at Harvard and phone-calls and exchanges with a

wide scientific circle. Each year a reflective and thought-provoking Christmas letter from the Keyfitz family was eagerly awaited by their many friends.

Keyfitz married Beatrice Orkin in 1939. They were a devoted couple throughout their life, until her death in 2009. His achievements would have been unthinkable without her love, support, and intellectual stimulation, and the welcome she gave to the many people whose lives they both touched. Their daughter Barbara was born in 1944 and their son Robert in 1947. Barbara went on to be Professor of Mathematics at Ohio State University and Robert to be Senior Economist at the World Bank and at the International Monetary Fund.

By grasping opportunities offered partly by chance, Keyfitz found himself able to combine the very different aspects of being a demographer. As a sociologist, he wrote on the role of the middle class in the developed as well as in the developing world. As a statistician, he had 23 years of practice in a national statistical office. As a mathematician, he gave a new unity to the mathematical study of populations. Interested in biology, he was one of the founders of the journal *Theoretical Population Biology*. He was engaged with economics and wrote on family allowances and on retirement schemes.

In this variety, Keyfitz was helped by the diversity of his friends around the world, by his ability to collaborate, and by his sense of balance. He could converse on the one hand with Paul Ehrlich, who at one time advocated a maximum population of a billion humans, and on the other with Roger Revelle who did not exclude the possibility of feeding forty billion humans. He was on friendly terms with spokespersons for the theory of evolution and with critics of it, with Stephen Jay Gould and with Marc-Paul Schützenberger. It was too much, perhaps, to hope at Berkeley to reconcile Judith Blake with John T. Noonan. But for him what was important was not to reach the same opinion but to engage in free discussion.

Keyfitz had a strong sense of history. In collaboration with David Smith, he hearkened back to founding works of demographic theory and method, gave them careful scholarly readings, and thought hard about their relationship to the progress of his own time. The collection which is reprinted here represents the fruits of this collaboration and this endeavor. It stands as a tribute to Nathan Keyfitz' legacy.

(Principal sources for Nathan Keyfitz' life are the Memoir that he wrote, available on the Keyfitz family website at [www.keyfitz.org](http://www.keyfitz.org), and the bibliography posted by Harvard University at [oasis.lib.harvard.edu](http://oasis.lib.harvard.edu). The editors have also drawn on their own reminiscences for this brief sketch.)

# David P. Smith: A Biographical Sketch

David P. Smith became well-known in the demographic world already as a Harvard graduate student in 1977 when he edited, together with Nathan Keyfitz, the collection reprinted here. He went on to a notable career in applied demography at the World Fertility Survey and the University of Texas at Houston. Retiring in 2005, he remains active in the field.

David Paul Smith was born on 26 September 1944 in Detroit, Michigan. He matriculated at Albion College in 1962, where he took classes and came to know John A. Ross, who was a professor at Albion at the time. In 1964, Smith transferred to the University of California, Berkeley and completed a B.A. in the study of developing nations in 1966. He joined the Peace Corps for two years, serving in Turkey and renewing his friendship with the Ross family, who were stationed in Ankara with the Population Council. After his Peace Corps service, Smith spent a semester at the School of Public Health at the University of Michigan. He then arranged to work for the Population Council in Seoul, working on family planning surveys and data analysis with John Ross in the Korean Family Planning Program. *Mathematical Demography: Selected papers* would later be dedicated to John Ross.

In 1971, after two years in Korea, Smith applied for graduate study at Berkeley, but the Demography Department was being closed down. Nathan Keyfitz had moved to Harvard. John Ross recommended Smith to Keyfitz, who invited Smith to visit. Smith immediately drove from Michigan to Massachusetts, and after an hour's conversation with Keyfitz was admitted to Harvard's graduate program in Sociology. His classes included Keyfitz' memorable introduction to mathematical demography. As Smith recently recalled,

The book got written because Nathan mentioned in class one day that he had a collection of the pioneering papers in mathematical demography he was hoping to put into a book. I went to his office to find out who the pioneers were, thinking it was one of the things a graduate student in demography ought to know. After a short

conversation I left with a stack of xeroxes and a vague commitment to help him on the book. By the next summer I was starting to edit papers to get them down to essential content, filling in some holes in the collection, tracking down the originals in Widener Library to be photographed, and starting on the chapter introductions.

Smith's dissertation, completed in 1978 under Keyfitz' supervision, tested empirical evidence for the theory put forward by Richard Easterlin to explain cycles in U.S. fertility. Papers based on the dissertation in *Population Studies* and *Theoretical Population Biology* played an important role in empirical critiques of Easterlin's theory. At the time, mathematical understanding of the population dynamics implied by Easterlin-style systems of demographic feedback was limited, but would flourish in the following decade.

While at Harvard, Smith married Joan M. Smith and moved to Hartford a couple of years before his Ph.D. was awarded in 1979. Stepsons Kenneth Clair Smith and Russell L. Smith had been born in 1965 and 1968. From Hartford, David Smith commuted periodically to Cambridge, Massachusetts to assist in classes Keyfitz was teaching. Then Smith was hired by the World Fertility Survey and moved to London, where he implemented methods for computing fertility measures, family planning indices, and life table estimates from computerized files of survey responses.

In 1981 Smith returned to the United States and joined the faculty of the University of Texas at the Health Science Center in Houston as Associate Professor of Demography. He served at Texas throughout the next 24 years of his career. Early research at Texas included studies of duration of breastfeeding in Sri Lanka and in the United States and patterns of prevalence of ischemic heart disease. From 1989 to 1994 he served as Director and Principal Investigator of the TexNet Project funded by the Hogg Foundation. The TexNet Project was devoted to improving the quality of evaluation research in the analysis of teen service programs in Texas relating to pregnancy. Guides for assisting programs in analyzing data and appreciating the limitations that small non-random samples place on statistical analysis were published in 1992 and 1994.

Over the next decade Smith continued his contributions to evaluation research, including analysis of the Episcopal Health Charities Healthy Communities Project with funding from the Center for Health Policy Studies at the University of Texas, Houston, analysis of substance abuse prevention programs in San Antonio directed at pregnant and parenting teens, and a major assessment of perinatal health needs at the turn of the millenium.

In 1992, Smith returned to his early interests in mathematical demography, publishing the volume *Formal Demography* with Plenum Press. Toward the end of the decade, in collaboration with Hélène Rossert, he completed a translation of Alfred Lotka's *Théorie Analytique des Associations Biologique*, a volume in which Lotka summed up his discoveries and a valuable supplement to the papers by Lotka reprinted in the present volume.

In the following years, in collaboration with Benjamin Bradshaw, Smith undertook an extensive project on the estimation of cause-specific death rates for 72 causes of death, by Hispanic and non-Hispanic ethnicity, race, and age. This work, commissioned by the National Center for Health Statistics, led Smith to focus on the role of inconsistencies in self-identification of ethnicity between Census returns and death certificates. It culminated in an important paper by Smith and Bradshaw in 2006, “Rethinking the Hispanic Paradox”, in the *American Journal of Public Health*. The extent to which apparently favorable health and survival outcomes among U.S. Hispanics reflect artifacts of the estimation process, a question much in the public eye, continues to be a focus of Smith’s research.

(The authors are grateful to David Smith for supplying information and bibliographic data on which this biographical sketch is based.)



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