As another example, in Chapter 5 on the Kalman filtering process, it is assumed on page 134 that

$$(7.1\text{-}8) \qquad E(\mathbf{w}(k)\mathbf{x}(j)^T)=0,$$

for all j and k, where $\mathbf{w}(k)$ and $\mathbf{x}(j)$ are, respectively, the white measurement noise and the state vectors. However, as is well known in the Kalman filtering theory, it is sufficient to assume that

$$(7.1\text{-}8') \qquad E(\mathbf{w}(k)\mathbf{x}(0)^T)=0,$$

for all k. Indeed, that (7.1-8′) implies (7.1-8) can be easily verified by applying formulas (7.1-2) and (7.1-7) in the book. As a final example, in Chapter 8 on linear quadratic control, the dimension n of the state vector $\mathbf{x}$ in the mathematical formulation of the control system should be defined precisely.

In summary, Catlin's book is a worthwhile contribution to the literature on linear estimation theory and Kalman filtering. It could be used as a textbook for a one-semester or two-quarter course on the subject for students in mathematics and statistics. For a larger audience that includes the engineering majors, however, it is perhaps preferable to follow other texts such as [3]–[5]. For instance, in [3], a volume contributed by the present reviewers, a rigorous and complete mathematical development of the Kalman filtering theory is presented by using only linear algebra, and moreover, many related topics from real-time applications such as correlated and colored noise inputs, limiting and extended Kalman filtering algorithms, and sequential and square-root numerical schemes, as well as efficient decoupling techniques of Kalman filtering, are included with several engineering examples.

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Population System Control. *By Jian Song and Jingyuan Yu.* China Academic Publishers, Beijing; Springer-Verlag, Berlin, 1988. xii + 286 pp. $49.90. ISBN 0-387-18288-8 (US).*

1. Introduction. Of all the pure or applied mathematicians who have ever lived, which one has directly affected the lives of the largest number of people during his or her lifetime? Because so many more people are now alive (more than five billion) than were alive in the past (only one billion around 1830), the winner is almost surely a mathematician currently or recently alive. An American academic's list of top candidates might include George Dantzig (the simplex algorithm for linear programming), Richard Bellman (dynamic programming), Claude Shannon (information theory), and John von Neumann (stored-program computers). I believe the indisputable winner is Song Jian (in the Chinese order of names, surname first), an expert in optimal control theory. Song seems to be the intellectual architect of China's family planning policy of one child per couple. Since it was announced in early 1979, this policy has been enforced with varying degrees of rigor, for better or for worse, on a population that now exceeds a billion people.

Population System Control by Song and Yu explains the technical details of the argument for China's one-child policy. Song has been chairman of the State Science and Technology Commission of the People's Republic of China, Yu a professor at the Beijing Institute of Information and Control. According to the authors (pp. vi–vii), "This book aims to give an account of the latest

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results of investigations undertaken primarily by Chinese systems analysts over the past few years on population system control theory and its application.... The results of research carried out by Chinese scientists . . . , including the authors of this book, constitute the main part of this book. The data and examples given, for the most part, are taken from statistics and censuses in China."

The impact of the research described in this book is suggested by another Chinese scholar's summary (Wang [25, p. 55]) of "major recent developments in population studies in China . . . A group of Chinese scientists working in system sciences have independently developed a series of demographic estimation and projection techniques and have successfully applied their methodologies to the study of China's population. Their research has provided basic scenarios for policy makers in designing the recent population policy in China."

For students of mathematical demography who, like me, do not read Chinese, this book is probably the best single source of technical information in a European language about the research and thinking of Chinese mathematical population scientists. It collects work previously published in scattered sources, or without technical details, or in Chinese (e.g., Song and Yu [22]; Song [20]; Song, Tuan, and Yu [22], Song and Yu [23]).

Population System Control differs from standard Western books on mathematical demography in its large components of explicit ecology and explicit ideology. Before describing these features of the book, I review its main technical content.

2. Mathematical demography. Populations change their size and composition only as a result of birth, death, migration, and aging, or the passage of time. Conventional formal or mathematical demography largely concerns how rates of birth, death, and migration and the passage of time determine or explain population size and composition. An age-structured population is one in which individuals are distinguished according to their age. In this book, as in most books on mathematical demography, the behavior in the course of time of a female age-structured population is described by classical linear models. The standard demographic model where time and age are treated as continuous variables uses a partial differential equation, due to McKendrick in 1926, sometimes known as the von Foerster equation. The standard demographic model for discrete time and age uses the so-called Leslie matrix, which dates back to Bernardelli in 1941. Song and Yu develop both continuous and discrete approaches in parallel and in very great detail. They emphasize the McKendrick equation for theoretical analyses, and the Leslie matrix for numerical computations.

Perhaps 90 percent of their exposition of the theory of age-structured populations is well known to Western demographers from the granddaddy of mathematical demography texts (Lotka [16]) and its offspring (such as Keyfitz [11], [12] and later editions of both; Coale [3], Pollard [18], Metz and Diekmann [17]; Inaba [10]). Song and Yu give leisurely accounts of mortality and fertility rates, sex ratios, and many demographic indices, most of them standard and a few novel. Perhaps because the text is translated from the Chinese, or perhaps intentionally, the terminology used for some of the standard demographic indices is not quite standard. The notation frequently differs from the conventional notation of Western demography. Song and Yu re-prove that there is a critical total fertility rate (in China in 1978, an average of 2.19 children per woman) such that, in the long run, if the total fertility rate persists above that critical rate, the population will grow indefinitely; if below, the population will decline toward extinction.

This exposition contributes a more systematic marriage of classical demographic theory with systems analysis. Compared with the standard treatments in Western texts, the dynamic analysis here of the McKendrick equation is novel in its extensive use of Laplace transforms and transfer functions, though these techniques are standard in engineering and other applied contexts. Also novel is the use of the McKendrick equation to describe demographic stochasticity (fluctuations in the number of births or deaths for given, fixed rates of occurrence), paralleling Pollard's use of the Leslie matrix to analyze demographic stochasticity.

A major innovation of this book compared to Western demographic texts is the central place given to the optimal control of population policy, following pioneering but little-known papers by Falkenburg [5] and Kwakernaak [13]. In this optimal control problem, the discrete equation for a population closed to migration is

$$(2.1) \quad x(t+1) = Hx(t) + \beta(t)Bx(t), \qquad x(0) = x_0,$$

where t runs over the nonnegative integers and 0 is an arbitrary initial time; x_0 and $x(t)$ are m-element nonnegative vectors in which the ith element gives the numbers of individuals in age-class i at times 0 and t respectively; H is an $m \times m$ matrix in which all elements are zero except the subdiagonal elements $h_{i+1,i}$, $i = 1, \cdots, m-1$, which give the fractions of individuals of age-class i who survive one time-unit to be counted in age-class $i+1$; B is an $m \times m$ matrix in which all elements are zero except the elements $b_{1,i}$ of the first row, which give the fraction of the total fertility rate attributable to individuals of age-class i; and $\beta(t)$ is the total fertility rate at time-unit t. The conventional Leslie matrix at time t is $L(t) = H + \beta(t)B$. The novelty here is that $\beta(t)$ is taken as a controllable variable.

Song and Yu posit the existence of an optimal population vector x^* (with an implied optimal total population size $\sum_i x_i^*$ of 700 million Chinese) and an objective function, or criterion of optimal control,

$$(2.2) \quad J(T) = \min_{\beta(t)} \sum_{t=0}^{T-1} \sum_{i=1}^{m} [x_i(t) - x_i^*]^2.$$

(They also consider other objective functions, such as minimizing the time needed to attain the desired population vector x^*.) They impose certain constraints on the optimal trajectory $\{\beta(t)\}$ of the total fertility rate. First, $\beta(t) \geqq 1$, "because it is hardly acceptable to the population not to bear any children at all" (p. 258). On the other side, the total fertility rate should not exceed the total fertility rate required for replacement, which Song and Yu set at 2.16 after allowing for improvements in survival. In addition, the total population size should not exceed a certain prescribed maximum (for China, 1.2 billion by the year 2000). The "social dependency ratio" (the number of elderly and children who depend on each worker) should not exceed 1. The "ageing index" (the ratio of the mean age of the whole population to the expectation of life at birth) should not exceed 0.7. How the numerical values of some of these constraints are determined is not explained, nor is the choice of these to the exclusion of other possible constraints.

The dynamics (2.1), the target population x^*, the objective function (2.2), and the constraints on $\{\beta(t)\}$ specify an optimization problem. Song and Yu describe algorithms and numerical procedures for solving this problem. They then solve the problem and present results for three cases, in which the lower limit of $\beta(t)$ is 1, or 1.5, or 1.7, respectively. They conclude (pp. 276–277):

> The above results of calculations demonstrate that, if we want to reduce and stabilize the total population of China at 700 million, only the first program is favourable. For the happiness of our descendants, it is necessary for the present generation to make some sacrifice and bear fewer children. But this program will face difficulties in practice, especially in the countryside. The second and third programs are feasible, but both need to reduce the mean fertility rate a great deal in the next one or two decades. . . . Thus both of the population projections and the population optimization have shown that the only way to reduce China's population to an appropriate size is to continue to reduce the mean [total] fertility rate within the next ten or twenty years. This is the basic reason why the Chinese government is resolute in promoting the single-child family policy today.

These conclusions, and Song's effectiveness in seeing these conclusions translated into policy, give this book its practical importance. That importance could well motivate students to learn the mathematical apparatus that occupies most of the book. Because of the potential use of the book as a text, I mention some topics of contemporary mathematical demography that are overlooked or are given inadequate treatment. First, though real human populations have males as well as females, the nonlinear interactions of the two sexes are ignored here, as they are in most standard demographic texts. (A rare exception is Chapter 10 of

Caswell's book [2]. Second, the uncertainty of population projections, viewed as predictions, is seriously underplayed. Though the book briefly discusses demographic stochasticity, it ignores environmental stochasticity (random fluctuations in the underlying rates of birth and death) along with recent stochastic models that yield plausible confidence intervals for population projections (e.g., Cohen [4], Tuljapurkar [24], Caswell [2, Chap. 8]). Third, though China has many ethnic minorities and regional differences in population density and demographic rates, the book pays almost no attention to local heterogeneity in vital rates, though models and methods for analyzing such heterogeneity are well developed (e.g., Rogers [19]; Ledent and Rogers [14]). The book also omits topics more often applied to nonhuman than to human populations, such as density-dependent models, stage-structured models, eigenvalue sensitivity analysis, and evolutionary demography (see [2] for treatments of all of these).

Another omission is more important in practical terms than any of these. The book contains no recognition of, nor any response to, an apparently superior alternative to the one-child policy that was proposed by Bongaarts and Greenhalgh [1] three years before this book was published. Bongaarts and Greenhalgh proposed a birth-control policy with three elements: a strict maximum of two children per couple; a minimum age of mother at first birth (not at marriage) of 25 years (or in variants of the policy, of 27 or 29 years); and a minimum spacing between births of four years (or, in variants of the policy, of six or eight years). Population projections computed on the basis of this policy and the one-child policy showed that (p. 604)" . . . limiting population size to less than 1.2 billion in 2000 is possible under a strictly enforced stop-at-two policy with a minimum age at first birth of as low as 25 years . . . up to the mid–twenty-first century there are only minor differences between a one-child policy and a stop-at-two policy with a minimum age at first birth of 27 years." The proposed policy of Bongaarts and Greenhalgh takes full advantage of the major difference, in a nonstationary population, between the total fertility rate of a cohort (a group of real people followed through time) and the total fertility rate of a period (a synthetic estimate based on the fertility rates of different age groups at a given time), a difference that Song and Yu appear to neglect.

Greenhalgh and Bongaarts [8, p. 1167] systematically compared the one-child policy with five alternatives, including the one suggested previously, and found that "the least desirable strategy is to retain the present policy; all the two-child alternatives perform better than the current one-child policy in achieving the policy goals considered."

Recently, Li [15] proposed that China aim for a constant stream of 20 million births a year (which is about the average number of births there in recent years), rather than aim for a given total size. If the mean age of childbearing could be increased from 26–27 to 30–31 years in the next 10–15 years, then, with a constant stream of 20 million births, China would have just over 1.2 billion people in 2000 and 1.4 billion in the 2050s. Every fecund couple could have two children and 30 percent of fecund couples could have three. A constant birth stream would eliminate completely one undesirable feature of the one-child policy, namely, wild fluctuations in the numbers of school children, workers, pensioners, and members of other specific age groups.

The proposed alternatives of Bongaarts and Greenhalgh, and of Li, seem to offer the possibility of attaining China's demographic goals with far fewer risks of devastating cultural, social, and economic effects than the one-child policy.

Though the book gives no hint of it, in fact the Chinese government is not "resolute in promoting the single-child family policy today." Contrary to Song and Yu, "The messages from several very important meetings for policy evaluation, formulation and implementation conducted by the [Chinese] Central Government during 1988 tell us clearly that . . . all the categories for allowing a second birth in rural areas combined are not far short of a two-child policy. The Chinese demographers (including the author) who participated in these policy meetings were told that the leadership does not reject the idea of a policy of two children well-spaced, but that such a policy could only be introduced gradually, based on experience in some pilot areas . . ." (Zeng [26, pp. 20–22]). A visit to the field by independent observers in October 1988 confirmed that, for example, in the rural township of Shidu in the Taihang Mountains, "couples were now allowed to have two children, spaced with a four-year gap, irrespective of the sex of their first baby. Mr. Zhang [the Chinese host] stressed that this was in the nature of an experiment, designed to show whether this extra freedom in fact resulted in more births in the long term" (Hamand [9]).

3. Ecology. Song and Yu adopt an optimal total population size of 700 million people for China in the mid–twenty-first century. I know of no prior case in which a major nation has aimed to reduce its own population size. This target, and the upper limit of 1.2 billion Chinese by the year 2000, emerge from an ecological analysis rarely found in technical discussions of mathematical demography.

Song and Yu examine the environmental factors that determine the well-being of a population. Their analysis assumes four points (pp. 227–228).

> First, space and natural resources of the Earth of [sic] which human beings rely for their existence are limited.... Second, the zero natural growth rate is an unavoidable feature of a stable ideal society.... Third, in the whole society each couple, on average, would bring up two children.... Fourth, since the population of a country or a society should not be numerically unlimited, it should also not gradually decline to extinction. For this reason, for each historical period in the development of human civilization, there must exist an appropriate population level in order to maintain a balance with the level of economic development, the amount of natural resources, and the carrying capacity of the ecosystem of the country; to study and define the appropriate total population of each country is a central task for future population control.

Following a historical review of past thinking in China and the West about the concept of an "appropriate population," Song and Yu describe a rough-and-ready method of estimating a supportable population for China a century from now. They consider factors that go far beyond the scope of traditional Western mathematical demography. These factors include, in addition to familiar economic indicators: forest coverage, ratio of arable to total land, utilization of fresh water, plant supply of oxygen and absorption of carbon dioxide, human consumption of oxygen and exhalation of carbon dioxide, grain production and requirements, livestock, marine production, land use for living, industry and farming, and human dietary requirements of plant, animal, and combined protein.

Ansley J. Coale has pointed out to Song that if a similar calculation had been made for the United States in 1880, a total population as large as 200 million might have been rejected as infeasible on the grounds that there would not be enough pasture for all the horses. The analysis of Song and Yu excludes many possibilities for technical change, such as much more economical use of water in irrigation, and the possibilities for some resource limitations to be compensated by trade, as in Hong Kong. Without doubt, China must eventually attain a long-run average population growth rate of zero, but at what population size is not yet clear.

One American observer reports that the target of 700 million people less than a century hence is no longer taken seriously in China, largely because a drop from 1.2–1.3 billion at the beginning of the twenty-first century to 700 million people in a matter of decades could be achieved only with excessively high proportions of elderly in the population. A much slower transition could avoid a lopsided age structure.

Song and Yu concede (p. 249) that "Research work on China's appropriate population has only just begun." Many readers would agree, though for widely divergent reasons. In my opinion, Song and Yu make an important contribution to mathematical demography by encouraging ecological, demographic, and economic calculations to estimate a desirable or feasible long-run stationary population size. Such estimates are likely to hold a central and vexed position in future population theory.

4. Ideology. The discrete dynamic equation (2.1) is just the Leslie model, or the standard demographic cohort-component projection method, in the special case where death rates and the distribution of fertility by age are assumed to be constant and only the total fertility rate $\beta(t)$ is assumed to vary. It seems totally innocent of ideology. But when $\beta(t)$ is viewed literally as a controllable variable, as an instrument of governmental policy, then the equation takes on a new look: it means imposing the decision of the leaders in Beijing on the family life of every Wang, Chen, and Zhou in town, or out of town.

The ideology that makes possible this interpretation of (2.1) pervades *Population System Control.* The first five references of Chapter 1 are to works of Engels, Marx, and Lenin. These well-known mathematical demographers vanish from the references of the technical chapters 2–6, but reappear in the references of the last two chapters, on population structure in an ideal society and on optimal control of population processes.

In their preface, Song and Yu first warn of the errors of the past, then boast of rising above them (pp. v–vi): "Almost all past works on population studies . . . were tinged with writers' personal feelings or other sentiments such as class interests, national prejudice or religious ethics. . . . few people are able to write without reflecting the attributes of their times and images of their own personalities, and even fewer could rise above national and class prejudice. . . . [But in the glorious present] population theory has been included among modern sciences, mainly with the emergence of demographic statistics and censuses. Using statistical and quantitative research methodologies, population studies has been freed from the interference of human emotions and the damaging effect of popular ethics."

Song and Yu review the fluctuations and past errors of Chinese population policies (see also [1]). This history suggests a more cautious view of the immutability of the population policies derived from the calculations in this book, which are (usually) correct, as mathematics. But mathematics alone does not answer some difficult questions. For example, in (2.1), the fertility rate is adjusted for the mortality of infants between the moment of their birth and the time of censusing; the model, and sloppily collected statistics, are indifferent between infanticide and reduced fertility. Are people indifferent? Do the constraints that Song and Yu impose on the optimization problem really reflect all the factors that Chinese leaders and workers and peasants want to consider when they ask or encourage couples to have a single child? Is our present knowledge of the world a century hence firm enough that a dramatic sacrifice should be imposed on millions of families now for a possible benefit then? These questions may have various answers, depending on whom one asks. Greenhalgh [6], [7] reviews the evolving Chinese answers. The linkage between mathematical calculations and social policy may not be as simple and straightforward as Song and Yu suggest.

Western readers should thank Song and Yu for making their ideology at least partly explicit. The shock of seeing (2.1) in the context of their ideology reveals that the same equation also carries an ideology, but almost never an explicit one, in Western texts of mathematical demography. In those texts, much attention is devoted to the theory of stable populations, meaning populations that grow exponentially with fixed birth and death rates. In stable population theory, $\beta(t)$ is assumed to be constant, on average, as the result of independent, individual decisions; possible constraints on population growth are assumed to be too remote to consider. That perspective, too, is ideology. The book by Song and Yu should stimulate Western demographers to become more self-conscious about their own work.

Ultimately, the mathematical models of demography (in combination with the equally dubious models of ecology, economics, meteorology, and the other earth sciences) are the best and only tools people have for peering into a dimly understood future; weak tools, indeed! Song and Yu succeeded in convincing the Chinese leaders to attend to the prospects hinted at by those models, a remarkable achievement. Mathematics provides only the skeletons of those models. The flesh that clothes and moves their bones is very human.

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Wave Propagation in Solids and Fluids. *By J. L. Davis.* Springer-Verlag, New York, 1988. x + 386 pp. $75.00. ISBN 0-387-96739-7.

This book deals with a mathematical treatment of wave propagation. It is stated in the Preface that the purpose of the book is "to present a clear and systematic account of the *mathematical methods* (italics by the reviewer) of wave phenomena in solids, gases, and water." Although various wave propagation phenomena are discussed, the book falls short of presenting the mathematical methods in a clear manner. Methods are discussed, but not always as thoroughly as to be useful to a student or a practitioner. For details the reader would have to look elsewhere. Several references are provided. But