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NEW SOURCES AND NEW TECHNIQUES FOR THE STUDY OF SECULAR TRENDS IN NUTRITIONAL STATUS, HEALTH, MORTALITY, AND THE PROCESS OF AGING

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ABSTRACT

The aim of this paper is to describe the full dimensions of a new and rapidly growing research program that uses new data sources on food consumption, anthropometric measures, genealogies, and life-cycle histories to shed light on secular trends in nutritional status, health, mortality, and the process of aging. The exploitation of these types of data involves integration of analytical procedures in medicine and economics with those of demography. The discussion is divided into four parts. Part one deals with sources on food consumption and with methods of exploiting these sources that involve the integration of energy cost accounting with techniques for the analysis of income distributions. The second part is concerned with sources of anthropometric information and with techniques that may be utilized to relate such information to the assessment of health and mortality. Part three involves the more complex problem of relating socioeconomic and biomedical stress suffered by individuals early in life to their work levels, health and mortality rates at middle and late ages. The final section discusses the uses of genealogies by themselves and in combination with the preceding data sources.

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New Sources and New Techniques for the Study of Secular Trends in Nutritional Status, Health, Mortality, and the Process of Aging

The aim of this paper is to describe the full dimensions of a new and rapidly growing research program focused on the exploitation of new data sources and of long-known data sources that have been underutilized until quite recently. The new program is feasible because of the sharp drop in the cost of data retrieval and processing. An important aspect of the reduced cost is the creation of software that is now part of the social capital of those seeking to explain secular trends in social and economic behavior.

In this research program data sources on food consumption, anthropometric measures, genealogies, and life-cycle histories are used separately and in conjunction with each other to shed light on secular trends in nutritional status, health, mortality, and the process of aging. The exploitation of these types of data involves the use and integration of analytical procedures in medicine and economics with those of demography. Since some of these procedures are unfamiliar, this paper attempts to integrate the discussion of the sources with a description of the procedures and with illustrations of the ways that they can be applied.

The discussion that follows is divided into four parts. Part one deals with sources on food consumption and with methods of exploiting these sources that involve the integration of energy cost accounting with techniques for the analysis of income distributions. The second part is concerned with sources of anthropometric information and with techniques that may be utilized to relate such information to the assessment of health and mortality. In parts one and two measures of nutritional status are related to morbidity and mortality at aggregate levels, either in time series or in cross section. Part three involves the more complex problem of relating socioeconomic and biomedical stress suffered by individuals early in life to their work levels, health and mortality rates at middle and late ages. The problems that must be dealt with in creating such life-cycle data sets are illustrated by considering a life-cycle study based on a sample of men who were recruited into the Union Army during the American Civil War. The final section discusses the uses of genealogies by themselves and in combination with the preceding data sources.

The four parts of the paper deal with projects of increasing difficulty. Projects of the type described in parts one and two can be carried on with relatively modest budgets, quite often with the resources available to individual postgraduate students. The projects described in parts 3 and 4 are collective enterprises and require large budgets.

1. Food Consumption (Diet) and Energy Cost Accounting

One of the unfortunate aspects of some past studies of the contribution of improvements in nutritional status to the secular decline in mortality has been the implicit assumption that *diet* by itself determines *nutritional status*. However, epidemiologists and nutritionists are careful to distinguish between these terms. To them *nutritional status* denotes the balance between the intake of nutrients and the claims against it. It follows that an adequate level of nutrition is not determined solely by *diet*, which is the level of nutrient intake, but varies with individual circumstances. Whether the diet of a particular individual is nutritionally adequate depends on such matters as his level of physical activity, the climate of the region in which he lives, and the extent of his exposure to various diseases. As Nevin S. Scrimshaw put it, the adequacy of a given level of iron consumption depends critically on whether an individual has hookworm.[1] Thus, it is possible that the nutritional status of a population may decline even though that population's consumption of nutrients is rising if the extent of exposure to infection or the degree of physical activity is rising more rapidly. It follows that the assessment of the contribution of nutrition to the decline in mortality requires measures not only of food consumption but also of the balance between food consumption and the claims on that consumption. To avoid confusion, in the remainder of this paper I will use the terms "diet" and "gross nutrition" to designate nutrient intake only. All other references to nutrition, such as "nutritional status," "net nutrition," "nutrition," "malnutrition," and "undernutrition" will designate the balance between nutrient intake and the claims on that intake.

1.1 Energy Cost Accounting

In developed countries today, and even more so in the less developed nations of both the past and the present, the basal metabolic rate (BMR) is the principal component of the total energy requirement. The BMR, which varies with age, sex, and body weight is the amount of energy required to maintain the body while at rest: it is the amount of energy required to maintain body temperature and to sustain the functioning of the heart, liver, brain, and other organs. For adult males aged 20-39 living today in moderate climates, BMR normally ranges between 1,350 and 2,000 depending on height and weight (FAO/WHO/UNU 1985, 71-72; Davidson et al. 1979, 19-25); Quenouille et al. 1951) and for reasonably well-fed persons normally represents somewhere in the range of 45 to 65 percent of total calorie requirements (FAO/WHO/UNU 1985, 71-77). Since the BMR does not allow for the energy required to eat and digest food, nor for essential hygiene, an individual cannot survive on the calories needed for basal metabolism. The energy required for these additional essential activities over a period of 24 hours is estimated at 0.27 of BMR or 0.4 of BMR during waking hours. In other words, a survival diet is 1.27 BMR.[2] Such a diet, it should be emphasized, contains no allowance for the energy required to earn a living, prepare food, or any movements beyond those connected with eating and essential hygiene. It is not sufficient to maintain long-term health but represents the short-term maintenance level "of totally inactive dependent people" (FAO/WHO/UNU 1985, 73).

Energy requirements beyond maintenance depend primarily on how individuals spend their time beyond sleeping, eating, and essential hygiene. This residual time will normally be divided between work and such discretionary activities as walking, community activities, games, optional household tasks, and athletics or other forms of exercise. For a typical well-fed adult male engaged in heavy work, BMR and maintenance require about 60 percent of energy consumption, work 39 percent, and discretionary activity just 1 percent. For a well-fed adult male engaged in sedentary work (such as an office clerk), a typical distribution would be: BMR and maintenance 83 percent, work 5 percent, discretionary activity 13 percent. For a 25-year old adult male engaged in subsistence farming in contemporary Asia, a typical distribution would be: BMR and maintenance 71 percent, work 21 percent, and discretionary activity 8 percent. Similar distributions of energy requirements have been developed for women as well as for children and adolescents of both sexes. In addition, the energy requirements of a large number of specific activities (expressed as a multiple of the BMR requirement per minute of an activity) have been worked out (see Table 1 for some examples).

In order to standardize for the age and sex distribution of a population, it is convenient to convert the per capita consumption of calories into consumption per equivalent adult males aged 20-39 (which is referred to as a consuming unit). This transformation involves weighting persons at each age and sex relative to adult males aged 20-39. Table 2 gives an example of this

Table 1

Examples of the Energy Requirements of Common Activities Expressed as a Multiple of the Basal Metabolic Rate (BMR) for Males and Females

Activity	Males	Females
Sleeping	1.0	1.0 (ie. BMR x 1.0)
Standing quietly	1.4	1.5
Strolling	2.5	2.4
Walking at normal pace	3.2	3.4
Walking with 10-kg load	3.5	4.0
Walking uphill at normal pace	5.7	4.6
Sitting and sewing	1.5	1.4
Sitting and sharpening machete	2.2	--
Cooking	1.8	1.8
Tailoring	2.5	--
Carpentry	3.5	--
Common labor in building trade	5.2	--
Milking cows by hand	2.9	--
Hoeing	--	5.3-7.5
Collecting and spreading manure	6.4	--
Binding sheaves	5.4-7.5	3.3-5.4
Uprooting sweet potatoes	3.5	3.1
Weeding	2.5-5.0	2.9
Ploughing	4.6-6.8	--
Cleaning house	--	2.2
Child care	--	2.2
Threshing	--	4.2
Cutting grass with machete	--	5.0
Laundry work	--	3.4
Felling trees	7.5	--

NOTE: Sources are FAO/WHO/UNU 1985, 76-78, 186-191; Durnin and Passmore 1967, 31, 66, 67, 72. Rates in Durnin and Passmore given in kcal/min were converted into multiples of BMR, using kcal per min of a 65 kg man and a 55 kg woman of average build (31).

procedure for the French population of 1806. In this case it turns out that the average individual was equal to about 0.77 of an equivalent adult male in 1806.[3] Toutain (1971, p. 1,977) has estimated that average caloric consumption in France c. 1806 was 1,846 calories per capita, which amounts to about 2,400 calories per consuming unit.

Energy cost accounting is usually worked forward, going from a list of activities to an estimate of the average daily caloric requirement. But such accounting can also be worked backward, going from the average caloric intake to the residual (after deducting the survival level of energy) available for work and discretionary activities.

1.2 Sources of Information on Diet

Historical estimates of mean caloric consumption per capita have been derived from several principal sources: national food balance sheets; household consumption surveys; food allotments in hospitals, poor houses, prisons, the armed forces and other lower class institutions; food entitlements to widows in wills; and food allotments in noble households, abbeys, and similar wealthy institutions. National food balance sheets estimate the national supply of food by subtracting from the national annual production of each crop, allowances for seed and feed, losses in processing, changes in inventories, and net exports (positive or negative) to obtain a residual of grains and vegetables available for consumption. In the case of meats the estimates begin with the stock of livestock, which is turned into an annual flow of meat by using estimates of the annual slaughter ratio and live weight of each type of livestock. To estimate the meat available for consumption it is necessary to estimate the ratio of

Table 2

An Example of the Procedure for Computing the Factor to Convert Caloric Consumption per Capita to Caloric Consumption per Equivalent Adult Male: France 1806

1 Age Intervals	2 Proportion of persons in each age interval in 1806	3 Average caloric consumption of males at given ages as a proportion of that of males aged 20-39	4 Average caloric consumption of females at given ages as a proportion of that of males aged 20-39	5 Both sexes combined (0.5 Co. 3) +0.5 Co. 4)	6 Col. 2 x Col. 5
0-4	0.1224	0.4413	0.4367	0.4400	0.0539
5-9	0.1067	0.7100	0.6667	0.6883	0.0734
10-14	0.0984	0.9000	0.8000	0.8500	0.0836
15-19	0.0908	1.0167	0.7833	0.9000	0.0817
20-39	0.2875	1.0000	0.7333	0.8667	0.2492
40-49	0.1170	0.9500	0.6967	0.8233	0.0963
50-59	0.0894	0.9000	0.6600	0.7800	0.0697
60-69	0.0553	0.8000	0.5867	0.6933	0.0383
70+	0.0324	0.7000	0.5133	0.6067	0.0197
Factor for converting to consumption per equivalent adult male (Σ col. 6).					0.7659

SOURCES AND NOTES: Column 2: Computed from Bourgeois-Pichat 1965, p. 498. Columns 3 and 4: Computed from FAO/WHO 1971, pp. 34, 80. Entries in Column 5 may not always be equal to 0.5 x column 3 + 0.5 x column 4 because of rounding errors.

dressed to carcass weight, as well as the distribution of dressed weight among lean meat, fat, and bones (Fogel and Engerman 1974, II, pp. 91-99).

Household surveys are based upon interviews with families who are asked to recall their diets for a period as short as one day (the previous day) or their average diet over a period of a week, a month, a year, or an undefined period designated by their "normal diet." In recent times, such surveys may be based on a daily record of the food consumed, which is kept either by a member of the family or by a professional investigator. Institutional food allowances are based on food allotments for each class of individuals laid down as a guide for provisions purchased by the institution (as in the case of victualling allowances for military organizations and daily diet schedules adopted in abbeys, noble households, schools, workhouses, hospitals, and prisons) as well as descriptions of meals actually served and actual purchases of food for given numbers of individuals over particular time periods (Oddy 1970; Appleby 1979; Morell 1983; Dyer 1983). Food entitlements of widows and aged parents were specified in wills and contracts for maintenance between parents and children or other heirs (in anticipation of the surrender of a customary holding to an heir). Such food entitlements have been analyzed for England, France, the United States, and other countries at intermittent dates between the thirteenth century and the present (Bernard [1969] 1975; Dyer 1983; McMahon 1981; for some studies of other countries see Hémardinquer 1970 and Fogel 1986c).

Although these sources of information on the average consumption of nutrients contain valuable information, they are also fraught with difficulties. In the case of the national food balance sheets, for example, the accuracy of the estimates depends in the first instance on the accuracy of the production figures and on the various coefficients used to transform outputs of grains and stocks of animals into food available for human consumption. However, even if the outputs and factors used to produce the national food supply are accurate, the average amount of nutrients produced is not necessarily equal to the average amount consumed. Not only are there storage and food processing losses before the supply reaches the household, but within the household as well. There is also the question of the amount of food put on an individual's plate that is not consumed (plate waste and feeding to pets).

Analysis of the estimates of average daily caloric consumption for recent times in nations for which there exist both national food balance sheets (FBS) and household consumption studies (HCS) not only indicate the FBS estimates generally exceed the HCS estimates of caloric consumption, but that the gap is positively correlated with the level of income. As the food distribution system becomes more complex, it apparently becomes more difficult to correct FBS estimates for losses as food passes through the system. On the other hand it is possible that at low levels of income both FBS and HCS underestimate food consumption because they do not adequately reflect such foods as wild nuts, fish, and game (Dowler and Seo 1985; FAO 1983).

Household consumption surveys, especially those of past times, have their own set of problems. They are focused largely on lower-class diets and are generally judgement samples. Hence, it is difficult to know precisely where they are located in the national distributions of calories and other nutrients. Since these surveys sometimes include information on the income of households, it is possible to relate the average consumption of diets to the average income (or expenditures) of households. Such studies for English budgets generally indicate an income elasticity of the demand for food between the 1780s and the mid 1850s that is at the high end of those found for less developed nations today, which is not inconsistent with estimates of English per capita income for that period. However, scholars are in disagreement over whether these households were below or above the middle of the English income distribution for their period or whether the reported income understates or overstates the true household income. Although information on the size distribution of income before World War I is sparse, that which is available can be used to locate households in nutrient distributions (Crafts 1981; Woodward 1981; Shammas 1983, 1984, and 1990; Fogel 1987).

Sources of information about food allotments in institutions and of food entitlements in wills often suffer from a common problem: lack of information on the age and sex of the recipients. As Table 2 indicates, caloric requirements vary so significantly by age and sex, that failure to standardize for these characteristics may cause misleading interpretations of the adequacy of diets, and shifts in the age-sex structure over time may bias the estimated trends in nutrition. Food wasting varied greatly by institutions so that the proportion of the food supply actually consumed was much lower in noble households than in poor households. No one, for example, could have consumed regularly the daily allowance at the royal households in Sweden of foods containing 6,400 calories (Heckscher 1954, pp. 21-22, 68-70). Even allowing for heavy work and cold climate, a third to a half of the allowance must have been wasted in storage, in preparation, and on the plate.

These and other problems make it clear that sources of evidence on nutrient consumption are strewn with pitfalls, but problematic sources are not special to energy cost accounting. As with national income accounting, energy cost accounting provides a systematic framework for bringing together the diverse pieces of evidence bearing on energy intake and output, for examining the consistency of the various bits with each other, and for making informed judgements on how best to interpret the available evidence.

1.2 Size Distributions of Calories

While national food balance sheets, such as those constructed by Toutain (1971) for France over the period 1781-1952, provide mean values of per capita caloric consumption, they do not produce estimates of the size distribution of calories. However, it is necessary to estimate size distributions in order to assess the implications of a given average level of caloric consumption for morbidity and mortality rates. Size distributions are also effective tools in assessing whether particular estimates of mean caloric consumption are tenable. It is, in principle, possible to construct size distributions of calories from household consumption surveys. However, most of these surveys during the nineteenth century were focused on the lower classes. Hence, in order to make use of these surveys it is necessary to know from what centiles of either the national caloric or the national income distribution the surveyed households belong.

Three factors make it possible to estimate the size distributions of calories from the patchy evidence available to historians. First, studies covering a wide range of countries indicate that distributions of calories are well described by the lognormal distribution. Second, the variation in the distribution of calories (as measured by the coefficient of variation [$s/\bar{X}$] or the Gini [G] ratio) is far more limited than the distribution of income. In contradistinction to income, the bottom tail of the caloric distribution is sharply restricted by the requirement for basal metabolism and the prevailing death rate. At the top end it is restricted by the human capacity to use energy and the distribution of body builds. Consequently, the extent of the inequality of caloric distributions is pretty well bounded by $0.4 \geq (s/\bar{X}) \geq 0.2$ $(0.22 \geq G$

≥ 0.11) (FAO 1977; U.S. Nat. Cent. Health Stat. 1977; Lipton 1983; Aitchison and Brown 1966).

Third, when the mean of the distribution is known, the coefficient of variation (which together with the mean determines the distribution), can be estimated from information in either of the tails of the distribution. Fortunately, even in places and periods where little is known about ordinary people, there is a relative abundance of information about the rich. Although much remains to be learned about the ultra poor, much has already been learned about them during the past quarter century and such information is also helpful in resolving the identification problem. However, at the bottom end, it is demographic information, particularly the death rate, which rather tightly constrains the proportion of the population whose average daily consumption of calories could have been below BMR or the baseline maintenance requirement.

Table 3 presents three possible size distributions of calories in France circa 1785 (see the appendix for procedures employed in construction of these distributions). They are all lognormal distributions and they are denominated in daily caloric consumption per consuming unit. They all have the same mean (2,290 kcal) but differ in their coefficients of variation. Distributions B and C are more egalitarian than the distribution of calories that exists in the United States today, for reasons that will become clear in the discussion that follows, although the U.S. distribution of calories is far more egalitarian than that of its income or of the income of any major nation in the world today (Paukert 1973; Sawyer 1976; Kuznets 1966). The degree of egalitarianism is measured by the coefficient of variation and the Gini ratio, which are closely related to each other. Distribution A is the least egalitarian in its

Table 3

Three Alternative French Distributions of the Daily Consumption of 2,290 kcal Per Consumer unit c.1785, on the Assumption of High, Medium, and Low Levels of Egalitarianism

	A Low egalitarianism $(s/\bar{X}) = 0.4$		B Medium egalitarianism $(s/\bar{X}) = 0.3$		C High egalitarianism $(s/\bar{X}) = 0.20$	
Decile (1)	Daily kcal Consumption (2)	Cumulative % (3)	Daily kcal Consumption (4)	Cumulative % (5)	Daily kcal Consumption (6)	Cumulative % (7)
1. Highest	4,181	100.00	3,672	100.00	3,179	100.00
2. Ninth	3,180	81.67	2,981	83.95	2,762	86.04
3. Eighth	2,760	67.74	2,676	70.93	2,568	73.92
4. Seventh	2,468	55.64	2,457	59.23	2,424	62.65
5. Sixth	2,232	44.83	2,276	48.49	2,202	52.01
6. Fifth	2,025	35.05	2,114	38.43	2,109	42.34
7. Fourth	1,832	26.17	1,958	29.19	2,080	32.73
8. Third	1,638	18.14	1,798	20.64	1,965	23.60
9. Second	1,422	10.96	1,614	12.78	1,826	14.98
10. First	1,081	4.37	1,310	5.72	1,586	6.96

<u>SOURCES AND NOTES:</u> The estimate of per capita consumption c.1785 is from Toutain (1971, p. 1,977). His figure of 1,753 calories per capita was converted into 2,290 calories per consuming unit on the assumption of 0.7659 consuming units per capita (see Table 2, above).

distribution of calories, although with a Gini ratio of 0.22 it is far more egalitarian than the income distribution of any major nation. Distribution B, which has about the same coefficient of variation as the Philippines in 1965 (G = 0.17), is one of the most egalitarian of the known caloric distributions for less developed nations today. Distribution C, with a coefficient of variation of 0.20 and a Gini ratio of 0.11, is considerably more egalitarian than any of the national distributions of calories currently available (FAO 1977; U.S. Nat. Cent. Health Stat. 1977; Lipton 1983).

Consideration of Table 3 makes it possible to illustrate how the patchy evidence can be brought to bear in choosing which of the three distributions comes closest to representing the situation in France c.1785. Table 3 yields an important implication, even before we consider its consistency with the available historical evidence, an implication that is robust to any plausible assumption about the egalitarianism of the French calorie distribution on the eve of the French Revolution. The bottom tenth of French housholds lacked the energy to participate regularly in the labor force. Another robust point is that the average caloric consumption of the middle classes (fourth through the eighth deciles) is largely independent of the assumption about the egalitarianism of the caloric distribution. Their mean consumption is virtually the same under distributions A and C (2,263 and 2,276) and only slightly higher (2,301) under distribution B. The effect of the assumptions about the degree of egalitarianism in the diet of the late <u>ancien régime</u> have their cutting edge on the two highest and the two lowest deciles.

Allowing for efficient adaptation of the lowest classes to their status, absolutely no waste of any food, and assuming energy balance at exceedingly low body masses (BMI = 17),[4] about 1,250 calories would still have been required for

BMR and about 1,500 calories for long-term survival of inactive equivalent adults.[5] Consequently, distribution A not only implies that the poorest 20 percent of French households had no energy available even for minimal sustained work, but that the majority of these two deciles were starving to death--more than a third of them quite rapidly because their intake was below basal metabolism.[6] Such high proportions of starvation diets during normal times is inconsistent with what is known about the condition of the French lower classes during this period (Goubert 1973; Jones 1988; Dupâquier 1989).

Distribution C, on the other hand, implies levels of consumption in the highest decile that are inconsistent with what is known about the conditions of _rentiers_ as well as of the nobility and their retainers who made up the that decile of consumers of calories. Since they held the bulk of all grain inventories, even if they were personally thrifty in their consumption of food, inventory losses alone would have cut their actual intake to about 2,700 calories per equivalent adult. Thus, distribution C implies that France's richest tenth had only enough energy for about 5 hours of moderate activity per day (McCloskey and Nash 1974; Goubert 1973; Quenouille _et al._ 1951; FAO/WHO/UNU, 1985).[7] Thus, high egalitarianism because of its implications about the diet of the rich is as implausible as low egalitarianism because of its implications for the diet of the poor.

We are left with moderate egalitarianism (distribution B) as a plausible assumption. Under that distribution only the bottom decile of households is entirely unproductive, and those subject to rapid starvation are less than 3 percent of the population, which if concentrated among the old and children under 5 are consistent with what is known about mortality rates during the _ancien régime_ (Goubert 1973; Bourgeois-Pichat 1965; INED 1977; Flinn 1981; Weir 1984 and the third quarter of the eighteenth century revealed that the average ration provided for parents in complete pensions contained about 1,674 calories. Since the average age of a male parent at the marriage of his first surviving child was about 59, the preceding figure implies a diet of about 2,146 calories per consuming unit (Fogel 1987). That figure falls at the 47th centile of the estimated French distribution, which is quite consistent with the class of peasants described by Bernard.

The two estimates are also consistent with the death rates of each nation. The crude death rate in France c. 1790 was about 36.1 per thousand while the figure for England c. 1790 was about 26.7 (Blayo 1975; INED 1977; Weir 1984; Dupâquier 1989; Wrigley and Schofield 1981). It is plausible that much of the difference was due to the larger proportion of French than English who were literally starving (Scrimshaw 1987). The French distribution of calories implies that 2.48 percent of the population had caloric consumption below basal metabolism (the minimum energy required for the functioning of the body). Table 4 implies that proportion of the English below basal metabolism was 0.66 percent. If a quarter of these starving individuals died each year (see Fogel 1987), they would account for about a fifth (6.6 per 1000) of the French crude death rate, but only about a sixteenth of the English rate (1.7 per 1000) and for about half of the gap between the crude death rates of the two nations.[8]

What, then, are the principal provisional findings about caloric consumption at the end of the eighteenth century in France and England implied by Table 4? One is the exceedingly low level of food production, especially in France, at the start of the Industrial Revolution. Another is the exceeding low level of work capacity permitted by the food supply, even after allowing for the reduced requirements for maintenance because of small stature and reduced body mass (cf. Freudenberger and Cummins 1976). In France the bottom 10 percent of the labor force lacked the energy for regular work and the next 10 percent had enough energy for less than 3 hours of light work daily (0.52 hours of heavy work). Although the English situation was somewhat better, the bottom 3 percent of its labor force lacked the energy for any work, but the balance of the bottom 20 percent had enough energy for about 6 hours of light work (1.09 hours of heavy work) each day.[9]

Table 4 also has a bearing on recent attempts to estimate the changes in the English and French supplies of food during the eighteenth century. Recent estimates suggest that the annual rate of growth in the English supply of food exceeded population growth by about 0.07 percent during 1701-1786 (Wrigley and Schofield 1981; Crafts 1985; cf. Allen 1991). The comparable figure for France during 1701-1710 and 1781-1791 was about 0.05 percent per annum (Mitchell 1975; Le Roy Ladurie 1979). These figures imply that the mean daily consumption in France c.1700 was about 94 calories less than c.1785. The comparable reduction for England is about 165 calories. These amounts seem modest, especially in the French case. However, a reduction of 94 calories per day would have increased the share of the French population whose consumption was below basal metabolism by more than 50 percent.

2. Stature and Body Mass Indexes as Predictors of Morbidity and Mortality

Extensive clinical and epidemiological studies over the past two decades have shown that height at given ages, weight at given ages, and weight-for-height (a body mass index) are effective predictors of the risk of morbidity and mortality. Until recently most of the studies have focused on children under 5, using one or more of the anthropometric indicators at these ages to assess risks of morbidity and mortality in early childhood and it was at these ages that the relevance of anthropometric measures were established most firmly (Sommer and Lowenstein 1975; Chen, Chowdhury, and Huffman 1980; Billewicz and MacGregor 1982; Kielmann _et al._ 1983; Martorell 1985). During the last few years, however, a considerable body of evidence has accumulated suggesting that height at maturity is also an important predictor of the probability of dying and of developing chronic diseases at middle and late ages (Marmot, Shipley, and Rose 1984; Waaler 1984; John 1989; Fogel _et al._ 1991). Body mass indexes have similar predictive properties (Heywood 1983; Waaler 1984; Martorell 1985; Payne 1991; Osmani 1991).

Height and body mass indexes measure different aspects of malnutrition and health. Height is a net rather than a gross measure of nutrition. Moreover, although changes in height during the growing years are sensitive to current levels of nutrition, mean final height reflects the accumulated past nutritional experience of individuals over all of their growing years including the fetal period. Thus, it follows that when final heights are used to explain differences in adult mortality rates, they reveal the effect, not of adult levels of nutrition on adult mortality rates, but of nutritional levels during infancy, childhood, and adolescence on adult mortality rates. A weight-for-height index, on the other hand, reflects primarily the current nutritional status. It is also a net measure in the sense that a body mass index (BMI) reflects the balance between intakes and the claims on those intakes. Although height is determined by the cumulative nutritional status during an entire developmental age span, the BMI fluctuates with the current balance between nutrient intakes and energy demands. A person whose height is short relative to the modern U.S. or West European standard is referred to as "stunted." Those with low BMIs are referred to as "wasted."

The relative importance of environmental and genetic factors in explaining individual variations in height is still a matter of some debate. For most well-fed contemporary populations, however, systematic genetic influences appear to have little impact on mean heights. Thus, the mean heights of well-fed West Europeans, North American whites, and North American blacks are quite similar. There are some ethnic groups in which mean adult heights of well-fed persons today do differ significantly from the West European or North American averages, presumably due to genetic factors. However, since such ethnic groups have represented a miniscule proportion of European populations, they are irrelevant to an explanation of the secular trends in mean adult heights in the various European nations since 1700 (Eveleth and Tanner 1976 and 1990; Fogel _et al._ 1983).

The secular trend in heights over the past 200 years provides further evidence of the central importance of environmental factors in explaining deviations from modern height standards, not only of population means but also of individual heights. Consider the issue of shortness. If shortness is defined as a given number of S.D.s below a changing mean (i.e. short is 2 S.D.s below the mean, whether the mean is 164 cm or 183 cm), then genetic and environmental factors may be difficult to disentangle. If, however, shortness is defined in absolute terms, say as applying to all males with heights below 168 cm, then it is quite clear that most shortness in Europe and America during the eighteenth and much of the nineteenth centuries was determined by environmental rather than genetic factors.

The point at issue can be clarified by considering the experience of the Netherlands. Shortness has virtually disappeared from that country during the past century and a half. Today, less than 2 percent of young adult males are below 168 cm, but in c. 1855 about two-thirds were below that height.[10] Since there has been little change in the gene pool of the Dutch during the period, it must have been changes in environmental circumstances, nutrition, and health that eliminated about 95 percent of all short males from the Dutch population (Van Wieringen 1986). Given current growth rates in the mean final height of the Netherlands, the remaining men shorter than 168 cm may yet be virtually eliminated from the Dutch population.

The Dutch case illustrates the general secular pattern of physical growth in the nations of Western Europe. The secular increase in mean final heights, which ranged between 10 and 20 centimeters (between 4 and 8 inches) over the past 200 years, cannot be attributed to natural selection or genetic drift, since these processes require much longer time spans. Nor can it be attributed to heterosis (hybrid vigor), because the populations in question have remained relatively homogeneous and because the effects of heterosis in human populations have been shown both empirically and theoretically to be quite small (Cavalli-Sforza and Bodmer 1971; Damon 1965; Van Wieringen 1978; Fogel _et al._ 1983; Martorell 1985; Mueller 1986). Only the top 6 percent of the Dutch height distribution of c. 1855 overlaps with the bottom 6 percent of the current distribution of final heights. Since the Dutch mean is still increasing, and we do not yet know the maximum mean genetically obtainable (often referred to as the genetic potential), it may well be that even the 6 percent overlap between the distribution of final heights in the c. 1855 generation and that of the latest generation will be cut in the next few decades, perhaps by as much as half.

2.1 Waaler Curves and Surfaces

A number of recent studies have established the predictive power of height and BMI with respect to morbidity and mortality. The results of two of these studies are summarized in Figures 1 and 2. Part A of Figure 1 reproduces a diagram by Waaler (1984) and the Appendix discusses the methods of constructing such curves. It shows that short Norwegian men aged 40-59 at risk between 1963 and 1979 were much more likely to die than tall men. Indeed, the risk of mortality for men with heights of 165 cm (65.0 inches) was on average 71 percent greater than that of men who measure 182.5 cm (71.9 inches). Part B shows that height is also an important predictor of the relative likelihood that men aged 23-49 would be rejected from the Union Army during 1861-1865 because of chronic diseases. Despite significant differences in mean heights, ethnicities, environmental circumstances, the array and severity of diseases, and time, the functional relationship between height and relative risk are strikingly similar. Both the Norwegian curve and the U.S. all-causes curve have relative risks that reach a minimum of between 0.6 and 0.7 at a height of about 187.5 cm. Both reach a relative risk of about 2 at about 152.5 cm. The similarity of the two risk curves in Figure 1, despite the differences in conditions and attendant circumstances, suggests that the relative risk of morbidity and mortality depends not on the deviation of height from the current mean, but from an ideal mean: the mean associated with full genetic potential.[11]

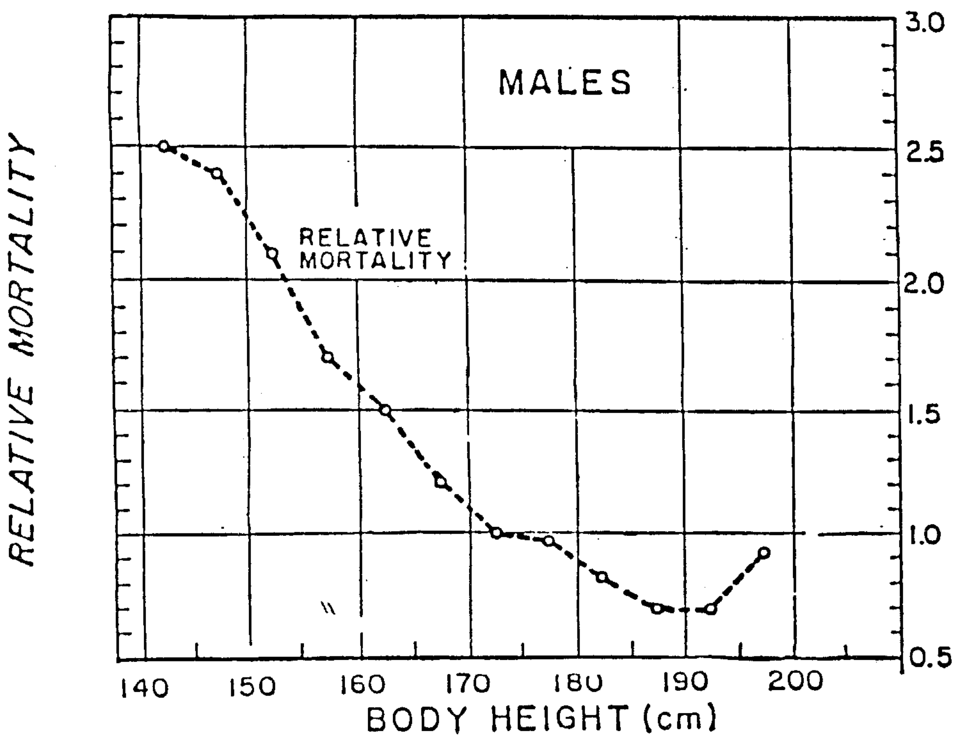
Waaler (1984) has also studied the relationship in Norway between a BMI and the risk of death in a sample of 1.7 million individuals. Curves summarizing his findings are shown in Figure 2 for both men and women. Although the observed values of the BMI (kg/m^2) ranged between 17 and 39, over 80 percent of the males over age 40 had BMI's within the range 21-29. Within the range 22-28, the curve is relatively flat, with the relative risk of mortality hovering close to 1.0. However, at BMI's of less than 22 and over 28, the risk of death rises quite sharply as the BMI moves away from its mean value. It will be noticed that the

FIGURE 1

A COMPARISON OF THE RELATIONSHIP BETWEEN BODY HEIGHT AND RELATIVE RISK IN TWO POPULATIONS

PART A

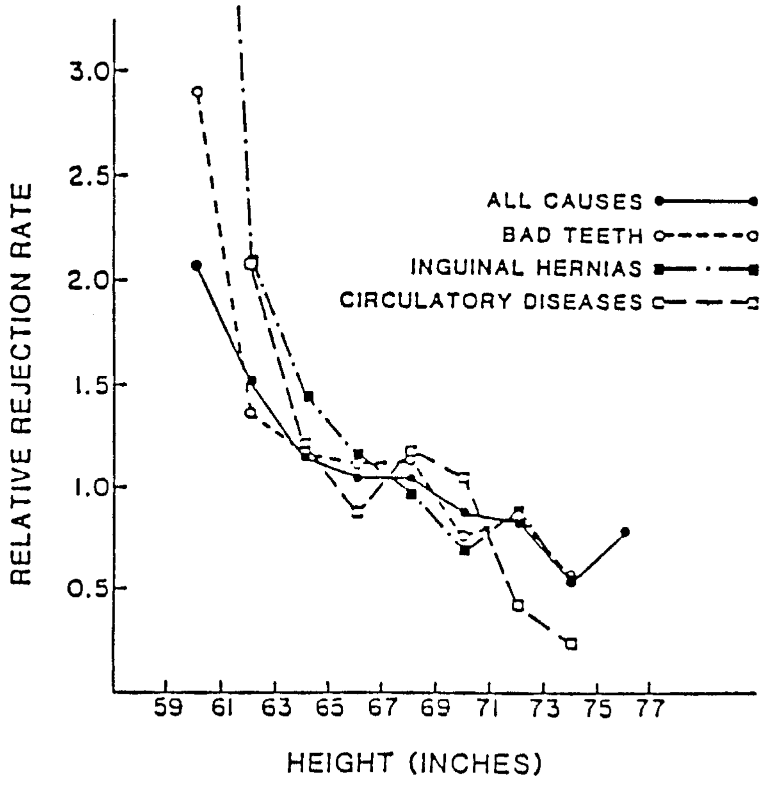
Relative mortality rates among Norwegian men aged 40-59, between 1963 and 1979



SOURCE: WAALER 1984

PART B

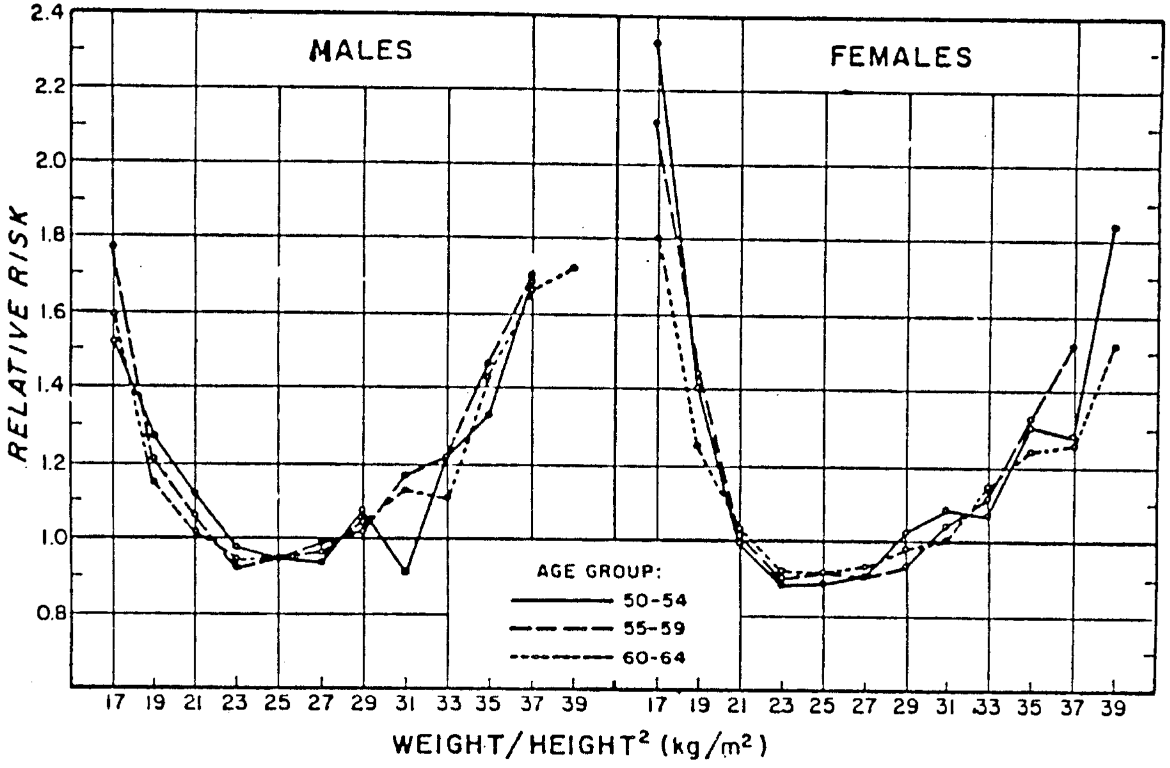
Relative rejection rates for chronic conditions in a sample of 4245 men aged 23-49 examined for the Union Army



SOURCE: FOGEL ET AL., 1986

FIGURE 2

THE RELATIONSHIP BETWEEN BMI AND PROSPECTIVE RISK AMONG NORWEGIAN ADULTS AGED 50-64 AT RISK BETWEEN 1963 & 1979



SOURCE: WAALER 1984

BMI curves are much more symmetrical than the height curves in Figure 1, which indicates that high BMI's are as risky as low ones.

Although Figures 1 and 2 are revealing, neither one singly, nor both together, are sufficient to shed light on the debate over whether moderate stunting impairs health when weight-for-height is adequate, since Figure 1 is only partially controlled for weight and Figure 2 is only partially controlled for height (Fogel 1987).[12] To get at the "small-but-healthy" issue one needs an iso-mortality surface that relates the risk of death to both height and weight simultaneously.[13] Such a surface, presented in Figure 3, was fitted to Waaler's data by a procedure described in the Appendix. Transecting the iso-mortality map are lines which give the locus of BMI between 19 and 31, and a curve giving the weights that minimize risk at each height.

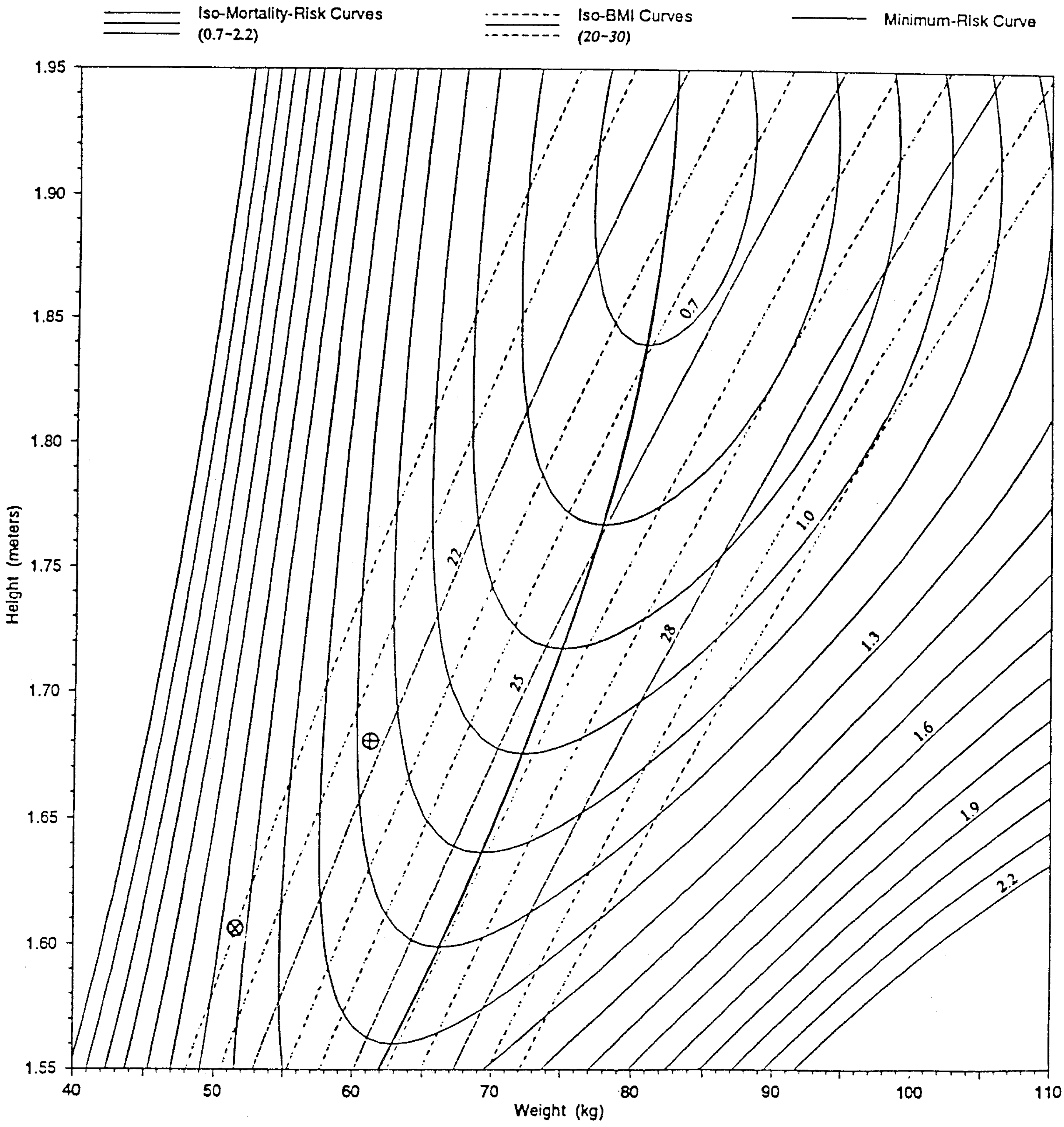
Figure 3 shows that even when body weight is maintained at what Figure 2 indicates is an "ideal" level (BMI = 25), short men are at substantially greater risk of death than tall men. Thus, an adult male with a BMI of 25 who is 164 cm tall is at about 55 percent greater risk of death than a male at 183 cm who also has a BMI of 25. Figure 3 also shows that the "ideal" BMI (the BMI that minimizes the risk of death) varies with height. A BMI of 25 is "ideal" for men in the neighborhood of 175 cm, but for tall men (greater than 183 cm) the ideal BMI is between 22 and 24, while for short men (under 168 cm) the "ideal" BMI is about 26.

2.2 Sources of Information on Height and Weight

Data on height begin to become plentiful early in the eighteenth century. Most of the early height data are derived from military records, since military authorities found such data useful in connection with the procurement of uniforms, the identification of runaways, and as a control over the quality of

Figure 3

Iso-Mortality Curves of Relative Risk
for Height and Weight Among Norwegian Males Aged 50-64



Note: ⊕ - the possible location of adult Englishmales aged 25-34 c. 1785 on the iso-mortality map.
⊗ - the possible location of comparable French males c. 1790.
All risks are measured relative to the average risk of mortality (calculated over all heights and weights) among Norwegian males aged 50-64.

recruits. Information on the heights of slaves were collected from the early nineteenth century on, largely as a result of abolitionist efforts to suppress the international slave trade. Scattered height data on students may be found in the eighteenth and early nineteenth century, but do not become widespread in Western Europe or America until the last quarter of the nineteenth century. Due to the work of reformers there are some bodies of data, especially in England, on the heights of child laborers and other working class children that go back to the mid-eighteenth century. There are scattered measurements of birth length from the mid-eighteenth century but such measurements did not start to become routine practice in hospitals in Europe and America until the second half of the nineteenth century. Numerous investigators have collected height data from these sources since the mid 1970s. At present the number of observations on height in machine readable form for the period between 1700 and World War I, covering 26 nations or ethnicities in Europe, Africa, and the Americas, is over half a million (Tanner 1981; Higman 1984; Eltis 1982; Steckel 1986; Fogel 1986a and 1986b; Komlos 1990 and 1989; Mokyr and O'Gráda 1991; Åkerman, Högberg, and Danielsson 1988; Floud, Wachter, and Gregory 1990; Fogel and Floud 1991).

Data on weight during the eighteenth and nineteenth centuries are more scanty than those on height. Military organizations, the principal source of the early height data, did not begin routine weighing of recruits until late in the third quarter of the nineteenth century. However, early medical reformers and other auxological investigators began collecting data on weight in the second quarter of the nineteenth century--Quetelet for Belgium, Villermé for France, Chadwick and his associates for working-class children in England. Small percentages of recruits were occasionally weighed before the late 1860s, and scattered estimates of birth weights are available going back to the mid-eighteenth century (Tanner 1981; Gould 1869; Goldin and Margo 1989; Ward 1988; Komlos 1990). The records of benevolent societies in both Europe and America, which are just beginning to be exploited, are another important source of data on anthropometric measures and appear to have included information on weight during the second half of the nineteenth century.

Inferring mean population heights from these historical data sets poses a number of complex problems, especially when the source is military records. Use of military data raises questions about the extent to which soldiers and sailors were representative of the populations from which they were drawn. The problem is more severe in volunteer than in conscript armies. Volunteer armies, especially in peacetime, are selective in their admission criteria and often have minimum height requirements. Consequently, even if information on rejectees exists, the question of the extent to which applicants are self-screened remains.

In many conscript armies, virtually every male of eligible age, including those who offer substitutes or are otherwise excused, were examined and measured. However, there is clear evidence of self-selection bias in volunteer armies. Persons of foreign birth and native-born laborers living in cities are overrepresented, whereas native-born individuals living in rural areas are underrepresented. Since there are significant differences in height among these groups, it is necessary to standardize for these characteristics in estimating the trend in average heights. The necessary weights are obtainable from federal censuses and similar sources. Much of the interest turns on secular trends in the heights of particular groups that, even if underrepresented, are nevertheless present in sufficient numbers to permit analysis.

There is the issue of whether volunteers in particular subgroups (ie. blue-collar urban laborers aged 20-25) are representative of the class from which they are drawn. One approach to this question is to compare the characteristics of the volunteers in the peacetime army with individuals of the same subgroups in three other types of data sets. In the American case, for example, there are wartime armies subject to conscription (World War II), armies in which a very high proportion of those of military age were examined (the Civil War), and scientifically designed random samples such as the U.S. national sample of 1960-1962 (U.S. National Center of Health Statistics, 1965). In the Union Army information on the height and social characteristics is available not only for those actually recruited, but also for those rejected, for those who provided substitutes, and for the substitutes. Analysis of these data revealed that the recruits from farm households, for example, covered virtually the full range of household wealth in this sector, and that the mean of the sample of parental wealth (adjusted for age) differed from that of a random sample of farm households in the 1860 census by less than 0.25 S.D. (Fogel *et al.* 1986; Fogel 1986b; p. 57, below; cf. Floud, Wachter, and Gregory 1990).

The finding that subgroups in military organization are socially representative of the classes from which they were drawn does not imply the absence of a height bias. Indeed, the curve of rejection by height shown in Figure 1, part B, implies not only that such a bias exists but that the degree of overestimation of the population heights from military heights will vary with the mean height of the underlying population. In the case of the Union Army, where about 30 percent of the examinees were rejected for chronic diseases, rejectees were about 0.6 inches shorter than the recruits, which implies that the true population mean is about 0.18 inches (0.46 cm) less than the mean of the recruits. Even if uncorrected, biases of this magnitude will not seriously distort the evaluation of secular trends. Moreover, if the proportion of eligible males who were rejected is known, the curve in Part B of Figure 1 can be used to estimate and correct the rejection bias.

In addition to sample selection biases, there are a series of measurement issues pertaining to the use of military data. Some relate to the accuracy of the age information, some to the accuracy of the information on height. Issues regarding age include whether ages were heaped, were reported to the nearest or the last birthday, or were arbitrarily assigned on the basis of height. Issues regarding height include whether heights were rounded to the nearest inch (or fraction of an inch) rather than to the last full inch (or fraction thereof), and whether individuals were measured with or without shoes.

Accuracy in age has little bearing on the determination of the secular trend in final heights, since it is of little importance whether a person classified as 30 is actually 28 or 32. Such heaping is of some importance during the growing years. There is evidence of age heaping at ages 10 and 20, and at the minimum age for recruitment into military organizations. Although such heaping will add perturbation to the height-velocity profile, it does not usually affect the determination of the age at which the profile peaks. A more serious issue is posed by the data sets, such as those involving slaves, where it has been suggested that ages were arbitrarily assigned on the basis of height. If that were true, however, the standard deviation of height would not have the characteristic pattern of increasing and then decreasing as the peak of the growth spurt is approached and surpassed (Trussell and Steckel 1978). Thus, by examining the variation of the S.D. of height by age it is possible to determine whether ages were arbitrarily assigned according to height.

Heaping on even inches is evident even when the measurement is conducted by qualified personnel (as in U.S. National Center on Health Statistics 1965).

In military organizations with minimum height requirements, there is further evidence of heaping at the inch just above the cutoff. Simulation models indicate that even-number heaping does not introduce a systematic bias. Even large amounts of heaping, in the range of 15-30 percent, only affects the mean by around one tenth of an inch, although it may affect the standard error of the mean. With respect to rounding, from the earliest date for which records are available, the standard practice was to round to the nearest inch or fraction of an inch. A study of actual practice in World War II revealed a slight tendency to round downward, which introduced an average error of -0.2 inches (-0.5 cm). There is no reason to assume that this tendency has changed over time. Analysis of the data in the Union Army records indicates that the bias may be due mainly to a tendency to round the heights of tall persons who should have been measured at fractional inches downward to the nearest inch. In this case, as in the case of the rejection bias, the magnitude of the error is too small to distort secular trends, nor should it significantly affect the cross-sectional analysis of the relationship between height and economic or demographic factors (cf. U.S. National Center for Health Statistics 1965; Karpinos 1958). It is worth noting that rounding bias almost exactly offsets the rejection bias.

From the mid-eighteenth century on, military regulations required the measurement of recruits without shoes. Two samples in which it was thought that these regulations were ignored were tested against correspnding groups known to have been measured without shoes. The tests revealed no significant difference between the control groups and the suspected samples. Tests of the heights of slaves reported in the U.S. coastwise manifest against ex-slaves of the same birth cohorts measured in the Union Army also resulted in the rejection of the hypothesis that the slaves were measured in shoes. Indeed, it seems unlikely that in those cases where the recording of height was intended for purposes of later identification, that shoes would have been kept on. However, measurements for insurance purposes and of students were often made with shoes on. Use of such data sets require estimates of average heel heights when statistics calculated from them are employed (Fogel et al. 1983; U.S.D.A. 1960).

The most difficult problems of estimation arise from measurements made by organizations that had varying minimum height requirements for entry. This situation prevailed not only in military organizations such as the regular armed forces of Great Britain but also in such charitable organizations as the Marine Society of London, whose records contain the longest continuous series on the heights of adolescents. These organizations set minimum height limits at different times, varying with needs, sometimes shifting frequently, and sometimes ranging above the mean height of the populations from which they were recruiting. Minimum height standards were flexibly enforced, so that very sharp cutoffs are not usually apparent in the data. It appears that in some cases 30 or 40 percent of the small heights in the underlying distribution may be missing. Such undersampling would destroy the usefulness of the data unless reliable statistical procedures are employed to correct for the problem.

The development of estimators capable of performing reliably in the presence of large undersampling of small heights (accompanied by such additional distortions as heaping on even inches and flexible enforcement of standards) was approached at two levels. One issue was the estimation of the mean of an underlying distribution for men old enough to have attained their final heights. A Gaussian distribution for final heights is both well established for contemporary data and consistent with preliminary examination of our files, and the assumption of normality for the underlying distribution places the problem into a well-defined parametric framework. Somewhat more complex was the problem of how to estimate the mean of a distribution of height at a given age during the ages of growth. Modern data indicate that the underlying distributions during adolescence are at first skewed to the right, as early maturers attain peak growth velocity, and then skewed to the left, when only late maturers still await their growth spurt.

The two principal methods developed for correcting left-tail truncation, the quantile bend method (QBE) and the maximum likelihood method (RSMLE) are described in Wachter (1981) and Wachter and Trussell (1982). Extension of the RSMLE method to regression analysis is reported in Trussell and Wachter (1984). These methods have been tested extensively both by Monte Carlo techniques and by simulation techniques on actual distributions of heights. The tests have shown both to be generally reliable, both in the presence of the moderate skewing and when such skewing is combined with pronounced heaping (Fogel *et al.*, 1983).

The statistical issues involved in exploiting weight data are analogous to heights, but generally less severe, partly because measurement of weight generally began at a later date. When instituted in military organizations, weight was measured on platform scales of high quality that were calibrated to the nearest quarter pound. Men were sometimes weighed in pants and underwear, but samples of the clothing were weighed to obtain adjustment factors (Gould 1869). Although there were often upper and lower weight limits, these were generally far less constraining then height limits. For example, less than two out of 100 men were rejected from the Union Army for unsatisfactory body build (Baxter 1875). However, weights taken in schools and for insurance purposes involved errors introduced by the wearing of shoes and of varying amounts of outer garments (U.S.D.A. 1960).

2.3 Uses of Anthropometric Measures to Explain Secular Trends in Mortality Rates

The available anthropometric data tend to confirm the basic results of the analysis based on energy cost accounting: chronic malnutrition was widespread in Europe during the eighteenth and nineteenth centuries. Furthermore, such malnutrition seems to have been responsible for much of the very high mortality rates during this period. Moreover, nearly all of the decline in mortality rates betweeen 1750 and 1875 in England and France appears to be explained by the marked improvement in anthropometric measures of malnutrition. This section summarizes some early findings on the relationship between mortality and two anthropometric measures--height at maturity and the body mass index (BMI)--that is discussed in more detail elsewhere (Fogel 1986a, 1987, 1991a and b; Fogel, Galantine, and Manning 1991, ch. 47; Fogel and Floud 1991). The preliminary nature of some of the estimates presented in this section need to be emphasized. Because the ongoing research may result in significant changes in these estimates, what follows should be viewed primarily as illustrations of the procedure. Since height-specific and weight-specific mortality rates are measured relative to the crude death rate (cdr) for the population as a whole, short-term shifts in the cdr by themselves will not shift the surface (see the Appendix). However, fundamental shifts in environment, including changes in medical technology, may shift the risk surface. One way of ascertaining whether there has been a shift in the risk surface is by determining what part of the decline in mortality rates can be explained merely by movements along the surface (i.e. merely by changes in height and weight on the assumption that the surface has been stable since 1750).

Table 5 reports the average final heights of men in several European countries over the period from 1750 to modern times. It will be seen that during the eighteenth century these Europeans were severely stunted by modern standards (see line 6 of Table 5). The French cohort of 18-IV is the most stunted, measuring only 160.5 cm (63.2 inches). The two next shortest cohorts are those of Norway for 18-III and Hungary for 18-IV, which measured 163.9 cm (64.5 inches). Britain and Sweden were the tallest populations between 1775 and 1875, although by the end of the period, Norway nearly matched the leaders.

France may have experienced the most rapid early growth rate of any nation shown in Table 5, with stature increasing by 1.24 cm per decade between 18-IV and 19-II. However, French heights declined slightly over the next quarter century and hovered between 165.3 and 166.7 until the turn of the twentieth century (Floud 1983a). British heights also increased quite rapidly (0.76 cm per decade) and for a longer period than the French. The increase over the first 75 years (18-III to 19-II) was 5.7 cm, more than three-fifths of the total increase in British heights between 18-III and the current generation of adults. However, British heights, like those of the French, declined slightly with the cohort of 19-III and also remained on a plateau for about half a century (Floud, Wachter, and Gregory 1990). Swedish heights appear to have declined during the last half of the eighteenth century but then rose sharply beginning with the second quarter of the nineteenth century, initiating the marked secular increases in Swedish heights that have continued down to the present day.

Indeed over the last century the three Scandinavian countries (shown in Table 5) and the Netherlands (Chamla 1983) have had the most vigorous and sustained increases in stature in the Western World, outpacing Britain and the United States (Fogel 1986b). Hungary's growth pattern differs from that of all the other European nations (Komlos 1990). Its cohort of 18-III was taller than

Table 5

Estimated Average Final Heights of Men Who Reached Maturity Between 1750 and 1875 in Six European Populations, by Quarter Centuries (cm)

(1) Date of maturity by century and quarter	(2) Great Britain	(3) Norway	(4) Sweden	(5) France	(6) Denmark	(7) Hungary
1. 18-III	165.9	163.9	168.1	--	--	168.7
2. 18-IV	167.9	--	166.7	160.5	165.7	165.8
3. 19-I	168.0	--	166.7	165.1	165.4	163.9
4. 19-II	171.6	--	168.0	166.7	166.8	164.2
5. 19-III	169.3	168.6	169.5	166.4	165.3	--
6. 20-III	175.0	178.3	177.6	172.0	176.0	170.9

Sources: Fogel 1987, Table 7.

that of Sweden, but then Hungarian heights declined sharply for half a century and, despite a turnabout in the nineteenth century, remains one of the shortest populations in Europe. Its mean height today is below the level achieved by the British cohort of 19-II.

Data on body mass indexes for France and Great Britain during the late eighteenth and most of the nineteenth centuries are much more patchy than those on stature. Consequently attempts to compare British and French BMIs during this period are necessarily conjectural. It appears that c. 1790 the average English BMI for males about age 30 was between 21 and 22, which is about 10 percent below current levels. The corresponding figure for French males c. 1785 may only have been about 20, which is about 20 percent below current levels (Fogel 1987). The conjectural nature of these figures makes the attempt to go from the anthropometric data to differential mortality rates more illustrative than substantive. However, Figure 3 indicates the apparent location of French and English males of 18-IV on the iso-mortality map generated from Waaler's data. These points imply that the French mortality rate should have been about 38 percent higher than that of the English, which is quite close to the estimated ratio of mortality rates for the two countries.[14] In other words, the available data suggest that in 18-IV both France and Great Britain were characterized by the same mortality risk surface (i.e. the same mortality regimen) and that differences in their average mortality rates are explained largely by differences in their distributions of height and weight-for-height.

This preliminary result raises the question as to how much of the decline in European mortality rate since 18-IV can be explained merely by increases in stature and BMIs, that is, merely by movements along an unchanging mortality risk surface. For the three countries for which even patchy data are currently available -- England, France, and Sweden -- it appears that nearly all of the decline in mortality between 18-IV and 19-III was due to movements along the Waaler mortality surface, since the estimated changes in height and BMI appear to explain virtually the entire decline in mortality during this three-quarters of a century. However, movements along the Waaler surface appear to explain only about 50 to 60 percent of the decline in mortality rates after 1875. After 1875 increases in longevity involved factors other than those that exercise their influence through stature and body mass.

Section 3. Early-Age Stress as A Predictor of Specific Chronic Diseases, Work Levels, and Elapsed Time to Death at Middle and Late Ages

The discussion in section 2 implied that stress early in life (in utero or during the first three years after birth) has a long reach, affecting health and the odds of dying throughout the life cycle. A difficulty with the aggregate data discussed so far is that they can only be linked to mortality rates at aggregate levels (Preston 1975 and 1980; Fogel 1986b and 1991a). Although such analyses are revealing and have advanced understanding of the factors responsible for the secular decline in mortality, they are not well suited to the resolution of some of the issues they have been tossed up by the aggregate analysis. For example, how much of the stunting of males during the eighteenth and nineteenth centuries was due to excessive claims on the diet? To what extent were the incidence, timing, and severity of specific chronic diseases of middle and late life affected by biomedical or socioeconomic stress during developmental ages?

To answer such questions it is necessary to develop data sets that follow individuals over the entire course of the life cycle and that relate nutritional status and other specific socioeconomic and biomedical factors at developmental ages and early adulthood to the medical histories of these individuals at middle and late ages and to their death records. Recent advances in computer technology make it feasible to create data sets which cover the whole life cycle by linking together information from a large number of sources.

3.1 Creating a Life-Cycle Data Set

One such project, sponsored by the National Bureau of Economic Research and the Center for Population Economics at the University of Chicago, is called "Early Indicators of Later Work Levels, Disease, and Deaths." The project focuses on a random sample of 39,616 white males who were mustered into 331 companies of the Union Army during the U.S. Civil War. The majority of these men were born between 1835 and 1845. About half of the recruits survived into the twentieth century. The aim of the project, as the title suggests, is the measurement of the effect of socioeconomic and biomedical stress early in life on the development of specific chronic diseases at middle and late ages, on the reduction in work levels at these ages, and on the elapsed time to death. A unique feature of the project is the measurement of wartime stress on the deterioration of health and work capacity at middle and late ages and on the life expectation of wartime survivors.

The project is divided into five parts. The core of the project is the creation of a public-use tape containing information on virtually the entire life cycle of the Union Army recruits that is suitable for the prospective study of aging among the cohorts of white males who served in the Union Army. The creation of such a sample involves linking together information about the recruits from ten different sources. When complete the tape will include information on the socioeconomic characteristics of the households in which the recruits were raised; measures of the prevalence of specific diseases, water supplies, and other public health conditions in the localities in which they lived during their developmental ages; combat and medical histories during the war; and their medical, occupational, income, residential, and demographic histories between 1865 and their deaths.

Four subprojects will use the information in the tape to investigate such issues as: (1) The effect of nutritional status, socioeconomic factors, and exposure to diseases (including wartime stress) during developmental and middle ages on the morbidity and mortality rates of white males at middle and late ages. (2) The effect of host and environmental conditions on the probability that recruits would contract specific diseases before being mustered out. (3) The effect of youthful exposure to virulent environments on the likelihood of developing specific chronic diseases and on the capacity to work at midadult and late ages, with controls for socioeconomic and other environmental conditions, age at exposure, and the duration of exposure. (4) The effect of specific chronic diseases on labor force participation and relative earnings at late ages during a period when the culture encouraged individuals at late ages to be as self-supporting as possible. (5) The nature, cost, and effectiveness of arrangements for the care of the aged by the nature of their disabilities and by the occupations, family circumstances, and residence of those with whom they lodged. (6) The contribution of economic, social, technological, political, and cultural factors to the sharp increase after 1890 in the income elasticity of the demand for leisure at older ages, and the explanation for the secular pattern of that increase.

Other features of the project including the wide range of diseases to which the men in the sample were exposed, the capacity to follow highly mobile individuals over their life-cycles, the wide variations in the socioeconomic characteristics and environmental circumstances of the individuals, and the relatively low cost of the information per observation. Because of the nature of the nineteenth century diseases, the project also bears on the epidemiology of less developed countries.

To determine the feasibility of the project and to estimate the cost, a judgement subsample of 20 companies was drawn from the 331 companies that comprise the random sample of Union Army recruits. The subsample was chosen in such a way as to guarantee that most of the problems that beset linking would be confronted. The 2,357 men in this subsample (6 percent of the intended total) were then linked through all of the sources needed to create the life-cycle histories.

Substantial progress has been made in analyzing the characteristics of this life-cycle subsample. Table 6 indicates the 10 principal data sources from which the linked sample was constructed. It also summarizes the main variable or categories of variables that are included in this life-cycle sample and indicates the main sources for particular categories. The category entitled "conditions diagnosed at each examination" represents numerous diseases which could not all be listed since it would take several pages to do so. Further elaboration on the medical conditions of the veterans is given in Table 12, which presents the principal classes of the diseases reported in the surgeons' certificates.

3.2 Some Characteristics of Union Army Recruits as A Sample of the Northern White Male Population

The aggregate figure for recruits into the Union Army is about 2,659,000, of whom 2,480,000 were white. However, these figures are not of individuals but of enlistments. Some individuals re-enlisted one or more times. It is estimated

Table 6

The Sources and Principal Variables (or Categories of Variable) of the Life-Cycle Subsample

Part A

The Principal Data Sources from Which the Variables are Obtained

Main Sources

C50 = manuscript schedules of U.S. census of 1850
C60 = manuscript schedules of U.S. census of 1860
C00 = manuscript schedules of U.S. census of 1900
C10 = manuscript schedules of U.S. census of 1910
CMR = carded medical service records
MSR = military service records
PE = pension records
PHR = public health records
RH = regimental histories
RR = descriptive books of Union Army regiments

Supplementary Sources

MO = muster-out rolls
PA = pension payout cards
RE = rejection rolls
S55 = state censuses for 1855
S65 = state censuses for 1865
S75 = state censuses for 1875

Part B

Principal Variables (or Categories of Variables) in the Linked Life-Cycle Data Set

Preservice data

A) **for individual and his family (C50, C60, RR, PE)**
- year of birth
- age at enlistment
- height at enlistment
- geographic origin (urban/rural, county/state/region)
- place of birth & of enlistment
- occupation in 1850, 1860, and at enlistment
- date of enlistment (early/ middle/late in war)
- household wealth in 1850, 1860
- ethnicity of parents
- family size in 1850 and 1860
- birth order among surviving siblings
- migration history of parental family
- literacy of individual and family member

B) **ecological variables (C50, C60, S55, S65, PHR)**
- causes of mortality and morbidity in nation as whole
- causes of mortality and morbidity in locality from early childhood to recruitment
- nature of water supply and sewage system
- soil characteristics (including prevalence of marshes and swamps

C) **rejection data (RE)**
- causes of rejection
- relation to above

Table 6 (concluded)

Service Record

A) morbidity and mortality (RR, CSR, MSR, PE)
- illnesses and hospitalizations (cause, treatment duration, outcome)
- battle injuries
- other accidents and trauma

B) potential stress (RR, MSR, CMR, MO, PE, RH)
- rank at enlistment
- combat experience
  - killed
  - wounded (no. of battles)
  - fired on (no. of battles)
  - in zone (no. of battles)
  - severity of each battle
  - movement of company between battles
  - total losses in company & in regiment
  - cumulative score

- POW
  - when
  - where
  - duration
  - conditions
- Tour of Duty
  - duration
  - stage of war
  - transfers
- Record
  - desertion or AWOL
  - citations for bravery
  - reprimands or punishments
- type discharge
  - promotions/demotions

C) status (see above) (RR, MSR, MO, PE)
- rank over time
- duties over time

Post service data

A) Health of veteran (PE)
- testimonial history of health before pension application
- complaints of veteran at each examination by Bureau surgeons
- height, weight, pulse, respiration, urinalysis at each exam by surgeons
- conditions diagnosed at each examination
- date of becoming bedridden
- dates of admission to veterans hospitals or homes & the diagnoses on entry
- date & cause of death

B) Occupations and work (PE, COO, C10)
- occupations at each exam and in 1900 & 1910
- surgeons' estimates at each exam of degree of impairment for manual labor (from 1/32 to 32/32)
- Pension Bureau's estimate of overall impairment for manual labor (after each application)
- months worked in 1900 & 1910

C) Personal & family (PE, PA, COO, C10)
- marriages, divorces, deaths of spouses

- births & deaths of children
- residences at examinations & when receiving payments from Pension Bureau
- household structure in 1900 & 1910

that there were about 370,000 white re-enlistments, so that the total number of white individuals who served in the Union Army is about 2,110,000 (Gould 1869, p. 25). Recruiting was organized at the state level, and the state was broken into recruiting districts that corresponded to Congressional districts. Quotas for recruits were established for each Congressional district based on estimates of available males of military age (18-45). During the first two years of the war, recruiting was conducted on a voluntary basis, with large bounties (often in excess of per capita income) offered to those who signed up. In March, 1863 Congress enacted a law making all men aged 20-45, except in certain exempt categories, subject to a draft. The principal grounds for exemption were previous service, poor health, payment of a commutation fee, and presentation of a substitute (U.S. Provost Marshall General 1866).

Of approximately 5,080,000 white males of military age during 1861-1865 who were at risk to serve in the Union Army, about 1,650,000 were exempt for reasons of health. About 87,000 were exempt by payment of the commutation fee and 144,000 provided substitutes. Additional numbers were exempt because of family dependents, religious scruples, and alien status. Faced with a choice of being drafted without a bounty or volunteering and receiving a bounty, volunteers remained the principal form of recruiting from March 1863 through the end of the war. All told, less than 65,000 men were drafted into service (Gould 1869, pp. 2-4; Baxter 1875, II, Table 16; U.S. Provost Marshal General 1866, pp. 39-46; Murdock 1971).

Aside from health, the principal basis for the selection of recruits was age. Table 7 shows the 9 cohorts most at risk to be examined by surgeons for service were born between 1837 and 1845. The proportions of these age cohorts that were examined ranged from 61 percent (for those born in 1837) to about 98

Table 7

The Estimated Share of the White Male Population of the North During 1861-1865 that was Examined by Surgeons and Mustered into the Union Army, by Birth Cohort

1 Year of birth	2 Age in 1861	3 Number at Risk to be recruited	4 Percentage examined	5 Percentage accepted
1845	16	229,700	63.8	55.4
1844	17	227,090	78.0	66.4
1843	18	224,670	97.7	81.4
1842	19	221,250	84.6	68.9
1841	20	217,300	80.2	63.2
1840	21	213,310	75.1	57.8
1839	22	209,290	70.0	52.6
1838	23	205,270	65.2	47.8
1837	24	201,090	60.8	43.5
1832-1836	25-29	941,410	52.3	33.6
1827-1831	30-34	826,630	41.0	23.4
1822-1826	35-39	701,070	41.6	19.6

Sources: Columns 3 and 5 computed from Gould 1869, pp. 80-81; column 4 computed from column 5, using the average rejection rate for disease in Baxter 1875 (II, Table 16) and an age adjustment schedule from the least-square regression reported in Table 9 of Fogel *et al.* (1991). About 10 percent of white northerners who enlisted were born after 1845 or before 1822.

percent (for those born in 1843). Among those in the 9 prime birth cohorts, an average of 75 percent was examined and 4 out of 5 of these men were mustered into service. Men in these age cohorts accounted for about 55 percent of the soldiers of the Union Army. Most of the remainder were born between 1822 and 1832. Of these older age cohorts, about 50 percent were examined by surgeons, but more than 1 out of 2 of these older examinees were rejected for reasons of health.

Men who paid commutation fees or provided substitutes generally were not examined, but they presumably were in good health since they could have requested an examination prior to being called for service if they expected to be exempt by reason of health. All men offered as substitutes were identified as such; so the variable "substitute" can enter into the analysis of rejects and of recruits.

Most of the information on how the recruits compared with the total northern white male population of military depends on samples discussed in more detail in the next two subsections. The main findings are that the foreign-born served in approximately the same proportions as natives. The recruits came from households with the same average wealth as the northern male population as a whole. They also reflected the geographic distribution of the northern population.

3.3 The Cluster Sample of 331 Companies and Its Representativeness With Respect to the White Population of the Union Army

The starting point for the construction of the life-cycle sample was the drawing of a sample of white recruits who were mustered into the Union Army. Such a sample was randomly drawn from the surviving regimental records of the Union Army at the National Archives in Washington. The technique employed was a one-stage cluster sampling procedure. As is well known, a cluster sampling procedure does not bias the estimates of the parameters of the population being sampled, but it makes the sample variance larger than it would be in a sample based on the individual recruits (Cochran 1953). However, a sample based on companies has three advantages over one based on individual recruits. First, since the principal objective of this project is not point or interval estimates of means or comparable descriptive statistics, but of multivariate analysis of the relationship between factors inducing early age stress and variables reflecting middle and late age health and behavior, moderately increased variance in the sample is an asset rather than a liability. Second, sampling by companies rather than individuals greatly reduces the cost of linking individuals to other military records and to the pension records. Third, a sample of companies makes it possible to separate company effects of exposure to military stress from individual effects.

The sampling frame was the complete set of companies in the complete list of white regiments and other independent organizations presented in Dyer (1908). A number was assigned to each of more than 20,000 companies and these numbers were arranged in the order in which they were drawn from a random number generator. The descriptive books of the regiments containing the designated companies were requested from the National Archives in the order that they were drawn. If a particular book had not survived, the book corresponding to the next random number was called. This process was continued until a sample of about 40,000 recruits was obtained.

The result of this work yielded 331 companies in 284 regiments, so that about 11 percent of the regiments and other independent organizations, covering all of the states except Rhode Island from which the Union Army recruited white troops, are represented. The 39,616 individuals are a 1.6 percent random sample of all whites mustered into the Union Army (Dyer 1908). This sample of 331 companies with 39,616 recruits will hereafter be referred to as the "recruits" sample.

Table 8 presents a number of statistics that can be used to assess how representative the recruits sample is of the Union Army. Lines 1-6 compare estimates of some key behavioral characteristics. In each of these comparisons the difference between the sample estimate and the figure obtained from the aggregate source is less than one percent (varying between 1 and 9 per thousand). Lines 7-10, which compare the geographic distribution in the recruits sample and in the aggregate source, show that the North Central region is somewhat overrepresented and New England is somewhat underrepresented. This was due to the differences in the proportion of the regiments in the two regions whose descriptive books were deposited in the National Archives. The issue could be addressed either by postweighting or by adding additional New England companies (chosen by a random procedure) to the recruit sample. However, for the multivariate procedures currently contemplated, the size of the New England subsample is adequate. Various experiments with postweighting produced results that were virtually the same as the internal weights, a finding anticipated by the closeness of the statistics computed from the recruit sample to those in the aggregate sources reported in lines 1-6 of Table 8.

3.4 Sample Selection Biases Due to Linkage Failure

Not all of the individuals in the recruits sample can be linked across the 10 data sets which together comprise the life-cycle sample. The investigators in this project and members of the site committee were concerned with possible biases that might arise from linkage failure. To investigate these issues and to determine linkage rates, a judgement subsample of twenty companies was chosen from the 331 companies in the recruits sample in a way that would reflect the

Table 8

The Representativeness of the Recruits Sample With Respect to White Population of the Union Army

Test statistic sources	1 Estimated from recruits sample	2 Estimated from aggregate source
1. Proportion of recruits who are native-born (percent)	74.9	75.5
2. Desertion rate (percent)	9.08	9.16
3. Mean height of recruits aged 25-29 (inches)	68.04	68.01
4. Mean height of recruits aged 30-34 (inches)	68.08	68.05
5. Mean height of recruits aged 35 or over (inches)	67.89	67.96
6. Proportion of recruits who died during war (percent)	11.96	12.05
7. Proportion of recruits from New England (percent)	6.3	12.8
8. Proportion of recruits from Middle Atlantic (percent)	29.2	31.7
9. Proportion of recruits from North Central (percent)	54.2	45.7
10. Proportion of recruits from all other states and territories (percent)	10.1	9.9

Note: The first 3 regions are defined as follows: New England, ME, NH, VT, MA, RI, CT; Middle Atlantic, NY, NJ, PA; North Central, OH, IN, IL, MI, WI, MN, IA, MO, KA.

Sources: All of the entries in column 2, except for lines 2 and 6, were computed from Gould 1869, p. 27. The numerator of entry in column 2, line 2 is from U. S. Provost Marshal General 1866, p. 89, the denominator is from Gould 1869, pp. 25-26 and consists of the sum of the different white soldiers plus black soldiers from states subject to the draft since the aggregate source did not report desertions by race. Line 6 of column 2 is computed from Dyer 1908, p. 11.

full range of linkage problems. Table 9 indicates the percentage of the individuals at risk to be linked in each of the other nine data sets that comprise the life-cycle sample.

The first three lines indicate that linking rates from the recruits to the other three military data sets are very high, varying between 86 and 100 percent. Line 4 shows that the linkage rate to the pension sample is also high, with 85 percent of the eligible recruits having been found (the ineligible groups were mainly deserters and persons who died during service without eligible dependents). It may be that some of the 15 percent deemed eligible-to-be-linked but not found were in fact ineligible, falling into such categories as "died between the end of the War and the Act of 1890" (which made persons without a war-related disability eligible for a pension). Some of the linkage failures are due to disappearance of the pension records from the Archives and errors in the Pension Bureau indexes which link the names of the veterans to the number of their record file in the Pension Bureau.

Lines 5 to 8 give the linkage rates to the manuscript schedules of the four federal censuses. Contrary to some expectation the linkage rates are higher in the 1900 and 1910 censuses (73 and 65 percent respectively) than in the 1860 and 1850 censuses (47 and 42 percent respectively). Use is currently being made of the pension pay-out records, which were not located until quite recently. It is expected that with these records, which indicate the addresses to which the monthly pension checks were sent, the linkage rates for the 1900 and 1910 censuses will be raised to the 75 to 85 percent range.

It should be noted that some of the eligible individuals linked to the 1900 census were not linked to the 1910 census and vice versa. The proportion of eligible individuals linked to at least one of these two censuses is 82 percent.

TABLE 9

Linkage Rates For The Nine Data Sets Which Together With The Recruits Sample Form the Life-Cycle Sample

	Data Set	1 Number at risk to be linked	2 Number linked so far	3 Percentage linked (Col. 2 ÷ Col. 1) x 100
1.	Military service record (MSR)	2,357	2,311	98
2.	Carded medical record (CMR)	2,240	1,933	86
3.	Regimental histories (RH)	2,357	2,357	100
4.	Pension record (PE)	1,957	1,672	85
5.	U.S. Census of 1910 (C10)	593	385	65
6.	U.S. Census of 1900 (C00)	1,036	753	73
7.	U.S. Census of 1860 (C60)	2,217	914	47
8.	U.S. Census of 1850 (C50)	1,855	823	42
9.	Public health records	2,357	■	■

Similarly, the proportion of individuals who were linked to at least one of the two pre-war censuses is 60 percent.

The relatively low linkage rates for the 1860 and 1850 censuses are due to the absence of adequate soundexes for these censuses. A commercial genealogist has recently constructed soundexes for these years which will be available shortly. With these soundexes the linkage rates are expected to rise to the 55 to 65 percent range for each census, and the proportion linked to the wealth and family information in at least one of the prewar censuses should exceed the 70 percent level. That level of linkage should be adequate for the analytical purposes of the project. If for some reason it is not, the level of linkage can be increased by making use of the Civil War enrollment lists, a special census of men between ages 20 and 46 conducted in 1863 as a basis for the draft. These lists give addresses that would aid in the location of individuals not found through the soundex. The per capita cost of locating individuals via the enrollment lists will be relatively high and at present the benefits are deemed sufficiently marginal to exclude such a search from the project.

That conclusion is based on an analysis of the nature of the selection biases created by linkage failure. Table 10 presents both OLS and logit regressions aimed at identifying the factors that affect the odds of linking the individuals in the recruits sample to the other data sets in the life-cycle sample. The eleven behavioral variables used as predictors are attributes obtained from the recruits sample. The main finding of these regressions is that being foreign born was the principal nonrandom factor accounting for the failure of linkage to the 1850 and 1860 census. In linking to the 1900 and 1910

Table 10 LOGIT and OLS Regression Results for the Probability of Successful Link Across Linkable Data Sets

(Updated for 20 Companies)

Variable	CEN18 [M=57.0; N=1669]		CEN19 [M=82.3; N=859]		MSR [M=96.8; N=2317]		PEN [M=71.0; N=2317]		CMR [M=63.3; N=2317]	
	LOGIT	OLS	LOGIT	OLS	LOGIT	OLS	LOGIT	OLS	LOGIT	OLS
INTERCEPT	-4.502*	-0.271	-1.684	0.676~	2.386	0.934*	-5.153*	0.186	0.610	-0.071
	(1.602)	(0.315)	(2.756)	(0.367)	(3.228)	(0.097)	(1.469)	(0.235)	(1.424)	(0.253)
AGE1861	0.013~	0.003~	-0.023	-0.004	0.003	0.000	0.035*	0.006*	0.006	0.001
	(0.008)	(0.002)	(0.014)	(0.002)	(0.016)	(0.000)	(0.007)	(0.001)	(0.006)	(0.001)
HEIGHT	0.036~	0.008~	0.020	0.003	0.014	0.000	0.035~	0.006~	0.026	0.005
	(0.021)	(0.005)	(0.039)	(0.006)	(0.048)	(0.001)	(0.020)	(0.004)	(0.018)	(0.004)
FREQFNAM	0.020	0.004	0.002	0.000	-0.059^	-0.002^	-0.007	-0.001	-0.004	-0.001
	(0.013)	(0.003)	(0.022)	(0.003)	(0.026)	(0.001)	(0.012)	(0.002)	(0.011)	(0.002)
FREQLNAM	0.273^	0.059	0.174	0.025	2.302~	0.031	-0.213	-0.042	0.069	0.013
	(0.266)	(0.058)	(0.556)	(0.078)	(1.438)	(0.020)	(0.255)	(0.047)	(0.245)	(0.051)
DUMFOR	-1.431*	-0.325*	-0.244	-0.038	-0.595^	-0.022^	-0.795*	-0.154*	-0.105	-0.023
	(0.157)	(0.033)	(0.265)	(0.041)	(0.282)	(0.010)	(0.127)	(0.024)	(0.124)	(0.026)
DUMFARM	0.503*	0.114*	0.317~	0.046*	0.244	0.009	0.481*	0.085*	0.478*	0.101*
	(0.110)	(0.025)	(0.192)	(0.028)	(0.259)	(0.008)	(0.106)	(0.019)	(0.097)	(0.020)
DUMT3YRS	0.955*	0.216*	-0.044	-0.006	0.124	0.007	0.079	0.015	1.236*	0.288*
	(0.218)	(0.048)	(0.258)	(0.038)	(0.327)	(0.011)	(0.146)	(0.026)	(0.134)	(0.028)
DUMSUB	-0.974	-0.182	-1.430	-0.304		0.048	0.047	0.014	1.384	0.267^
	(0.679)	(0.124)	(1.017)	(0.192)		(0.043)	(0.551)	(0.103)	(0.651)	(0.111)
DUMDIED	-0.026	-0.004			0.414	0.009	-1.268*	-0.253*	0.172	0.029
	(0.156)	(0.034)			(0.452)	(0.011)	(0.140)	(0.027)	(0.152)	(0.029)
DUMWOUND	0.139	0.030	0.274	0.035	0.172	0.005	0.380^	0.072^	1.365*	0.226*
	(0.165)	(0.036)	(0.332)	(0.044)	(0.421)	(0.012)	(0.163)	(0.029)	(0.196)	(0.031)
DUMDES	-0.135	-0.031	-1.095*	-0.207*	0.203	0.007	-2.030*	-0.440*	-1.217*	-0.285*
	(0.203)	(0.045)	(0.400)	(0.072)	(0.447)	(0.014)	(0.177)	(0.033)	(0.167)	(0.035)
CHISQ/RSQ	143.39	10.57	17.12	2.29	19.36	0.84	318.09	14.23	221.39	12.75

Note: 17 observations with DUMSUB=1 were dropped to obtain MSR LOGIT results. For MSR, DUMSUB=1 perfectly predicts a successful link.

Table 10 (concluded)

<u>Notes:</u> The variables are defined as follows:

AGE1861 - Age on January 1, 1861 (in years).

HEIGHT - Height at enlistment (in inches).

FREQFNAM - Commonness of first name, measured by the relative frequencies in RR (in percent).

FREQLNAM - Same as above for last names (in percent).

DUMBFOR - Dummy: 1 if foreign-born; 0 otherwise.

DUMFARM - Dummy: 1 if a recruit's occupation prior to enlistment was reported to be a farmer; 0 otherwise.

DUMT3YRS - Dummy: 1 if the term of enlistment was for 3 years or more; 0 otherwise.

DUMSUB - Dummy: 1 if the recruit was a substitute; 0 otherwise.

DUMDIED - Dummy: 1 if died during the military service; 0 otherwise.

DUMWOUND - Dummy: 1 if wounded during the military service; 0 otherwise.

DUMDES - Dummy: 1 if deserted during military service; 0 otherwise.

Chi-square has 11 degrees of freedom in columns 1, 5, 7, and 9, and 10 degrees in column 3.
The RSQ is given in percent.

The symbols in column headings are:

M - mean of dependent variable (in percent)
N - number of observations
C50, C60 - the 1850 and 1860 censuses
C00, C10 - the 1900 and 1910 censuses
MSR - military service records
PE - pension records
CMR - carded medical service record

Significance levels are coded as * - 1%; ^ - 5%; ¯ - 10%

censuses, being a foreigner is much less important in explaining linkage failure than in the prewar case. The discrepancy is due primarily to the fact that about two-thirds of the foreign-born recruits arrived in the U.S after June 1, 1850 and about 7 percent arrived after June 1, 1860 and hence were not covered by the census. The behavioral factors do not explain much of the variation in the odds of linking in either the prewar or the postwar censuses. The chi-square and R-square values are especially low in the postwar census, with the behavioral factors accounting for less than 3 percent of the variation in the probability of making a link.

In the case of the pension records, "died during the war" and being a deserter are the principal reasons for nonrandom linkage failure. Deserters were in most cases ineligible for a pension and many of those who died during the war had no dependent who was eligible. The foreign dummy is also significant in part because many of the foreigners who died during the early post-war years had no eligible dependents or were used behind the front and so were less likely to incur war-related disabilities. However, those who survived to be eligible under the pension law of 1890 were as likely to be linked to pension records as natives.

In the case of the military service records, two variables are statistically significant at the 5 percent level, but the magnitude of the coefficients is small and the chi-square and R-square values are very low, indicating the linkage failure was due almost exclusively to random factors, such as loss of records. In the case of the medical service records, desertion is the principal nonrandom factor accounting for linkage failure, due largely to the short period that deserters were at risk to require medical care in service. The predictability of the factors which explain linkage failure suggests that any biases introduced by censoring can be corrected by reweighting subsamples having the relevant characteristics (this applies to subgroups overrepresented as well as those underrepresented). However, tests revealed that reweighting had very little effect on estimates of key parameters. For example, the height at enlistment of those who were linked to the 1900 and 1910 samples differed from those who were not by just one-tenth of an inch and the standard deviations were quite similar. Since virtually the full range of variation remains, and censoring had very little effect on means (which reenforces the conclusion that linkage failures were due overwhelmingly to random factors), it is unlikely that the multivariate procedures that will be employed in the analyses of the data will be significantly affected by the linkage failures.

Several other tests of the representativeness of the linked sample were undertaken. One of these concerned the wealth distribution of all adult males (age 20 and over) in the households to which the recruits were linked in the 1860 census. The mean wealth was $2,187 (ln = 7.69) and the SD of the logs is 1.45. These figures are quite close to Soltow's (1975) random sample of northern males (age 20 and over) in 1860: mean = $2,040 (ln = 7.62) and SD of logs = 1.87. Although the variation is somewhat reduced in the recruit subsample, the mean is not significantly changed. Moreover, the range of wealth covered by the linked sample extends from zero to the top 4 hundredths of one percent of Soltow's distribution (i.e. less than the top 0.04 percent of the wealth distribution is missing).

Still another test of the linked subsample can be performed by comparing the causes of death among aged veterans c.1910 with the causes of death reported by the death registration states in 1910. The result is shown in Table 11. The chi-square value for the differences between the two distributions (7.79 with 5

Table 11

Distribution of Causes of Death of White Males Ages 70 - 74

Cause of Death	1 Death registration area in 1910		2 Veteran's sample c.1910	
	number	%	number	%
Infectious diseases	1,194	7.1	12	8.0
Neoplasms	1,836	10.9	10	6.7
Cardiovascular	10,044	59.4	85	56.7
Influenza, pneumonia, bronchitis	2,536	15.0	32	21.3
Diarrheal	278	2.6	2	1.3
Violence, including motor vehicles	1,008	6.0	9	6.0
Total classified (does not include other and unknown)	16,896	100.0	150	100.0

<u>NOTE:</u> *Column 1*. The source is Preston, Keyfitz, and Schoen 1972.

degrees of freedom) is not significant at the 0.10 level or higher.

Although linkage failure to the censuses appears to be largely random with respect to the variables considered here, we do not assume that this situation will pertain to other key variables, and will reweight should the evidence indicate that such a procedure is called for.

The most difficult problems of inference related to screening problems stem from the varying date of entry into the pension records. The governing principle in dealing with such data is that individuals are not at risk for most purposes until they applied for the pension. Life tables constructed on this principle for the period circa 1900 are similar to the mortality schedules constructed from the death registration data but somewhat lower, as is to be expected, since the areas covered by death registration in 1900 were still concentrated in the high-mortality states and cities (Preston, Keyfitz, and Schoen 1972; Preston and Haines 1991).

3.5 Problems in the Classification of Diseases

The problems in the classification of diseases have turned out to be less severe than they originally appeared. After collecting and examining more than 1600 surgeons certificates, which diagnose about 6400 conditions, it has been possible to classify them into 21 categories (see table 12), the elements of which can generally be linked quite directly to the categories in the International Classification of Diseases (9th Rev.). The classes of Table 12 have been designed by the team of physicians working in the project with, when necessary, consultation with other specialists.

Table 12

Disease Screens

	1 Disease Classification	2 Estimated number of diagnoses in the 20-company sample
1.	Blood diseases	2
2.	Cardiovascular disease	768
3.	Central & Peripheral Nervous System disorders	135
4.	Diseases of the Rectum including hemorrhoids	350
5.	Diarrhea	422
6.	Ear disease	141
7.	Endocrine disorders	1
8.	Eye disorders	312
9.	Gastrointestinal disease	141
10.	Genito-urinary problems	147
11.	Hernia	269
12.	Infectious diseases	122
13.	Injury & Gun Shot Wound	1,046
14.	Liver, Gallbladder and Spleen disorders	98
15.	Neoplasms	8
16.	Nutritional and metabolic disease	25
17.	Respiratory diseases	461
18.	Rheumatism	784
19.	Skin diseases	14
20.	Tooth & gum diseases	0
21.	Varicose Veins	100

Note to column 2: The estimated number of diagnoses is based on 17 of the 20 companies

On the basis of these classifications, a software has been developed to guide data collectors in the extraction of the information on each condition described in the surgeons certificate. For each of the categories listed in Table 12 a screen has been developed which directs the data collector to information on that condition that needs to be entered. Each screen is designed as a series of questions that a consulting specialist might put to another physician about a patient. Table 13 presents an example of this procedure for the category "Cardiovascular." These questions come onto the screen one at a time, together with a list of alternative answers and instructions on how to proceed in the event that any particular answer is given. A spelling checker, still in the process of development, is available to deal with arcane or otherwise unclear terms and to give the most likely words when abbreviations are used or some of the letters in a word are illegible.

It is the judgment of the physicians in the project that the diagnoses of the pension surgeons are comparable to the quality of clinical diagnoses such as might be conducted today by American physicians working under field conditions in a rural, third-world country without access to blood or tissue analysis (urine is analyzed from 1900 on).

The principal problem in linking the diagnostic information to the International Classification of Diseases (9th Rev.) is the level of detail. In many cases links can be made at the fourth or fifth digit level. However, in other cases the level of detail is more limited. In the case of neoplasms, for example, the information is limited primarily to the sizes, sites, and rates of growth of the neoplasms.

Similarly, it is not possible to disaggregate most of the diarrheal diseases by the nature of the infectious agent. However, the loss of such detail

Table 13

Questions for the Screen on Cardiovascular Disease

1.Give the pulse rates using qualifying (sitting, standing, after exercise) words:

2.Is heartbeat (heart action, impulse, force, rhythm etc.) normal, irregular, rapid, feeble, or weak? Give these or synonymous conditions.

3.Are there MURMURS? [Y/N]:

[YES]
a.What is the INTERVAL of the murmur?:

b.Is the murmur REGURGITANT or INSUFFICIENT?:

c. Is the murmur identified with a VALVE [Y/N]:

(1) Name specific valve mentioned:

d. Do thrills accompany heart action? [Y/N]:

4. Is there HYPERTROPHY, DILATATION, or ENLARGEMENT?:

5. Does odema, oedema, edema, swelling, puffiness exist? [Y/N]:

[YES]
a. How SEVERE is it?:

b. WHERE does odema exist?

6. Does cyanosis (blueing from lack of oxygen) exist? [Y/N]:

7. Describe when dyspnoea, dyspnea, shortness of breath occurs:

8. How long has patient had heart condition?:

9. Heart RATING:

10. RELATED DISEASES (causing/resulting) to heart
(*be sure to use qualifying words*)

is not a serious impediment to the analysis that will be undertaken in this project. The severity and duration of diarrhea is more important in determining its immediate and long term consequences than the organism responsible (Chen and Scrimshaw 1983). Moreover, information is available on the presence of blood and mucous in the stool to permit distinguishing between diarrhea and dysentery. The effects of the latter are even more serious.

3.6 Some Preliminary Findings

Some preliminary findings of life-cycle effects on mortality rates at middle and late ages are reported by Costa (1991). Her analysis, which is based on the 20-company sample described in section 3.4, focuses on the factors affecting mortality among men who were age 55 or older. Several different specifications are employed in the analysis. One uses ordinary least squares to estimate the determinants of life expectation at age 55 among men who entered the pension system before that age. Another uses logistic regressions to estimate the probability of dying between 1895 and 1901 among men who were in the pension before 1895.

In both specifications Costa finds that early-age variables have predictive value. One of the most significant finding is that many persons whose war wounds did not incapacitate them (in the sense that were immediately eligible for pensions) still suffered reductions in life expectation at later ages, although the issue of the effect of war trauma on chronic diseases and longevity appears to be more complex than might be expected. She also found that to the extent that living in unhealthy urban slums during developmental ages affected longevity, its effect is reflected mainly through stunting. Costa also computed a Waaler curve for the risk of dying between 1895 and 1901 as a function of height, with results similar to that shown in Figure 1, part A, above. The increased risk of dying due to stunting in Costa's data set is similar to that found by Waaler for Norway.

4. Genealogies Separately and in Combination With Life-Cycle Samples

There are at least 60,000 published family histories that contain information on over 100 million people who have lived in North America. The largest collection, with 24,000 volumes, is in the Library of Congress, but the New York Public Library, the Library of American Antiquarian Society, the Genealogical Society Library in Salt Lake City, and the Newberry Library have extensive collections. Most of the family histories begin with an immigrant to North America or some other individual who may be viewed as a patriarchal or matriarchal figure. The book then records the descendants of this initial individual so that a descending tree or a pyramid is described within the family history. Dates of birth, death, and marriages are recorded in the family history, along with the place of each vital event, although omission of some vital information is common.

Although genealogies have been used from time to time for demographic analysis, until recently investigators have doubted that they were an adequate source for the estimation of secular trends in key variables. A priori considerations suggest that genealogies are likely to be a biased source of information on demographic and other socioeconomic characteristics. For example, it seems reasonable to assume that the probability that a family history will be constructed is proportional to the fertility of the family and inversely proportional to its mortality. It follows that genealogies may yield upward-biased estimates of fertility rates and downward-biased estimates of mortality rates.

Several investigations during the 1970s and 1980s have suggested that, despite a priori arguments, genealogies are sufficiently representative of underlying populations to be useful (Norton 1980; Knodel and Shorter 1976; Bean, May, and Skolnick 1978). Two large-scale investigations of the usefulness of genealogies were launched in the late 1970s and early 1980s. One is sponsored by the laboratory for demographic history at the Ecole des Hautes Etudes en Science Sociales. It aims to use a representative sample of 3,000 couples constituted during the First Empire to analyze social and economic mobility in France between 1806 and the present (Dupâquier 1986). The other, sponsored by the National Bureau of Economic Research, the Center for Population Economics of the University of Chicago, and the College of Social Science of Brigham Young University, has focused on the analysis of secular trends in mortality in North America since 1640 (hereafter the NBER/CPE/BYU project).

4.1 Tests of the Representativeness of Genealogies

To investigate the properties of published genealogies for the analysis of trends in vital rates, the investigators in the NBER/CPE/BYU project have put into machine-readable form a sample of family histories drawn from over 300 books and containing over 100,000 individuals. They have used a number of approaches to investigate the representativeness of the data in this sample. One approach has been to run a series of regressions of the form:

$$(1) \qquad D_j = g_j(X_{ij}, B_{ij}),$$

where

D_j = a dichotomous variable for persons in the *j*th age group that takes the value one in the event of a death,

X_{ij} = the *i*th behavioral factor affecting the mortality rate of the *j*th group,

B_{ij} = the *i*th distortion in the data set which spuriously affects the probability of dying in the *j*th group.

The regressions described by equation (1) can be used to produce values of ${}_nQ_x$ corrected for the biases measured by the B_{ij}. At the present time only a proportion of the potential X_{ij} variables have been brought into analysis. Nevertheless, the initial runs on age-specific risk death (for each sex, on each of the seven age intervals, for each of four birth cohorts) are rather promising. Birth order is statistically significant and has a relatively large impact on the probability of dying in most of the age intervals, with first and last births having a higher probability of dying than intermediate births in families with at least four live births. Place of birth has a significant impact on the probability of dying, and the high-risk regions change over time.

The bias variables (B_{ij}) indicate that practices by the compilers of genealogies had a small but statistically significant effect on the measured level of risk. So far these biases do not appear to have had much effect on the coefficients of the X_{ij}, generally changing the values only of the second or third significant digit. Much remains to be done, however, on investigating alternative ways in which the bias variables may be introduced into the regressions. But so far the impact of the various biases identified on a priori grounds appears to be small in well chosen and carefully screened genealogies. Even in the case of wealth, the upward bias in the genealogies is smaller than had been conjectured. Adams and Kasakoff (1984) have collected a sample of genealogies for northern states which they linked with the manuscript schedules of the 1850 census. They then computed mean wealth of the men in their sample who were age 20 or over in 1850, by occupation. Table 14 compares their results with the means reported by Soltow (1975) for his random sample from the 1850 census schedules. Table 14 shows that although the means in the sample of Adams and Kasakoff (1984) are biased upward as one would expect, the differences in

Table 14

The Mean Value of Real Estate of Native-Born Males Age 20 and Over in 1850 in Two Samples (in Dollars)

	Genealogical Sample			Random Sample of 1850 Census		
	N	Mean	S.D.	N	Mean	S.D.
Farmers	325	1,547	1870	n.a.*	1,401	n.a.
Nonfarmers	276	1,037	2803	n.a.	805	n.a.

*Not available.

SOURCE: Adams and Kasakoff 1984.

means are not very large. Moreover, the large standard deviations indicate that the genealogies cover virtually the whole range of wealth holders.[15] Consequently, by including wealth as an argument of equation (1) it is possible to adjust for errors in estimates of mean mortality rates due to the overrepresentation of rich individuals and underrepresentation of poor ones.

Potential biases in the mortality rates because of the nature of different categories of genealogies raise more troublesome issues. One of the first issues investigated was whether the family histories were truly family histories or merely pedigrees. Family histories include all of the descendants of the patriarch but pedigrees include only the direct ancestors of the compiler (his father, his grandfather, his great grandfather, and so on). Quite clearly pedigrees would bias mortality rates downward severely since the individuals in a pedigree had to live at least long enough to have procreated. The creation of a pedigree is the first step in the compilation of a family history since the compiler must trace his lineage to the patriarch. Only then can he come forward in time to construct a complete family history. The simplest test of whether a book is a family history or a pedigree is to observe the fullness of the tree. Some books can be discarded because it is obvious that the compiler traced only a few lines. Such inspection will not, however, reveal more subtle omissions. To get at these other tests were devised, such as whether the number of lines that died out in a given genealogy was consistent with the predictions generated by reasonable guesses at appropriate life tables and fertilty schedules. The results of the various tests have indicated that the majority of the family histories in the sample are indeed what they purport to be. It appears that once they determined who their patriarchs were, the compilers usually sought to fill in the entire family tree, although they were not always completely successful.

Other tests of potential bias have involved evaluation of the behavior of various fertility and mortality statistics in order to determine if they conform to patterns observed in comparable populations. For example, age-specific fertility schedules and the mean birth intervals at various parities were compared with those obtained from a variety of family reconstitutions and were found to be normal for noncontraceptive populations. Both period and cohort life tables from the data in the sample have been computed in order to determine whether the internal structures of these tables are consistent with known characteristics of life tables and these are (Bourne et al. 1984; Wahl 1986).

One such life table has been constructed for 920 native-born white males in the pilot sample who were at risk to die during the decade of the 1850s (see panel A of Table 15). It should be emphasized that during the pilot phase of data collection the individuals included in the sample have been chosen in such a way as to be representative of the collections of genealogies that have been the focus of our concern. Consequently, the observations in the pilot sample are not necessarily representative of the national population to which the final sample will pertain. Although the individuals at risk during the 1850s come from all of the major regions, the Northeast is overrepresented and the South and Midwest are underrepresented. The rural areas are also overrepresented and urban areas are underrepresented. Samples that are approximately reweighted give results quite similar to the unweighted samples (Pope 1991).

Panel B of Table 15 presents the average of the 1850 and 1860 life tables recently estimated by Haines (1979) from the data in the censuses of mortality for these two years. Because these censuses suffer from substantial underreporting, Haines fitted model life schedules to data for persons aged 5-19,

Table 15

A Comparison of a Period Life Table for United States Males Derived from the Genealogical Sample with Two Other Period Life Tables

Age (years)	A Native-Born Whites, 1850-60, Derived from the Genealogical Sample			B All Whites, 1850-60, Average of Haines's Tables for 1850 and 1860			C All Whites, 1900, Registration States		
	$1000Q_x$	l_x	e_x	$1000Q_x$	l_x	e_x	$1000Q_x$	l_x	e_x
10	29.4	1000	46.7	48.6	1000	46.6	38.3	1000	49.5
20	253.7	971	37.9	192.8	951	38.7	155.2	962	41.3
40	280.2	724	27.4	328.2	763	25.8	289.9	812	27.1
60	344.3	521	14.2	360.0	512	13.5	346.3	577	14.0
70	539.7	342	9.0	656.9	328	8.3	603.6	377	8.8
80	1000.0	157	4.5	1000.0	113	4.4	1000.0	149	4.7

SOURCES AND NOTES: *Panel A:* See the text for the sources. The number of observations on which each ${}_nQ_x$ value was computed ranged between 126 and 212. The value of e_{80} was computed from the approximation in Coale and Demeny (1966, p. 20). *Panel B:* This table was built up from the average of the ${}_nQ_x$ values in the unpublished tables for 1850 and 1860 of Haines (1979). Since Haines did not estimate the ${}_{10}Q_{70}$, I used the value of ${}_{10}Q_{70}$ in Model West (Coale and Demeny 1966) consistent with $e_{10} = 46.6$. *Panel C:* Constructed from the ${}_nQ_x$ values in the 1900 life table in Preston, Keyfitz, and Schoen 1972. The use of longer age intervals in the estimation of l_x resulted in a value of e_{10} slightly below that reported in the source.

ages during which the reporting tends to be most complete. Nevertheless, it is still likely that the mortality rates in his tables are to some degree biased downward. The downward bias is likely to be present even at the ages he focused on because underreporting was severe in urban areas at all ages (cf. Kahn 1978; Condran and Crimmins 1980). Panel C presents the life table for 1900 constructed by the Bureau of the Census for the 10 original death registration states. Unlike the Haines tables it is difficult to know the direction of bias in this table because the biases run in both directions. The exclusion of the South from the original registration states tends to bias mortality rates downward. It was not until 1933 that all 48 states were included in the death registration system (United States Bureau of the Census, 1975, p. 44). On the other hand, the states included in the original registration area are overrepresented, in comparison with the nation as a whole, in two high-risk groups: the foreign born and residents of large cities.

Table 15 indicates that life expectation at age 10 during the decade of the 1850s in the genealogical sample is 46.7 years, which is almost identical with the corresponding figure in the average of the Haines tables for 1850 and 1860 (46.6 years) and about 3 years less than that indicted by the 1900 table (49.5 years). These results are generally consistent with what is known about the extent of improvement in mortality between the 1850s and 1900. There are some differences in the ${}_nQ_x$ values between the genealogical sample and the average of the Haines tables, but because of the relatively small sample sizes, these are within the range of sampling variability. All in all, the life tables derived from the genealogies conform well to those derived from registration data and other sources even before adjusting the sample for the underrepresentation of various sections of the reference population (cf. Pope 1991).

4.2 Genealogies Linked to Life-Cycle Histories (Including Medical Histories)

Clayne Pope has begun work on a project to link a subsample of the NBER/CPE/BYU genealogical sample to the life-cycle sample of Union Army recruits described in section 3. The recruits in this new sample (hereafter called ILAS, for intergenerationally linked aging sample) will be linked to all 10 of the data sets described in Table 6 plus the 1870 and 1880 federal censuses. It is estimated that about 40 percent of the ILAS men served in the Union Army. The other 60 percent will be linked only to the 6 federal censuses.

The ILAS sample will differ from the core sample in three principal respects. First, it will contain men of military age from the same families, some of whom served in the Union Army and some of whom did not. Second, it will be possible to trace not only the men who served, but also those who did not, from birth to death. Thus it will, for example, be possible to compute separate ten-year survivor curves for veterans and nonveterans who lived to be age 60, taking account of information on health status, wealth, occupation, and other characteristics of the individuals before age 60. Third, it will be possible to bring a number of familial and intergenerational variables into the analysis of aging, including birth order, mother's age at the birth of each of her children, completed family size, the proportion of siblings who died in infancy and early childhood, the health status of parents and siblings who survived to the 1880 census, the age at death (and, in some cases, cause of death) of parents and grandparents, the number of generations native-born, and the wealth of parents and other siblings at the end of their lives. The ILAS sample will be especially useful in assessing the information in the core sample regarding the effect of wartime stress and exposure to diseases on the aging process by providing controls that will separate war effects from cohort and environmental effects.

Pope is compiling the ILAS sample with the aim of investigating three principal issues. The first is to control for the effect of wartime stress by comparing subsequent morbidity and mortality among those who served in the Union Army with those who did not. This will be done in several ways, starting with life tables for recruits and non-recruits that can be used to create cohort life tables that combine recruits and non-recruits with the appropriate weights. These life tables will form the basis for the measurement of cohort effects. Programs to create these tables are already in use. Military service will be entered as an independent variable in the "waiting time" regressions or hazards models where the individual is the unit of analysis and explanatory variables such as the individual's height, military service and disease history, occupation, residence and wealth are introduced. More refined military variables such as battle participation and disease exposure will also be used.[16]

His second objective is to measure family effects on aging and mortality experience. This will be done by including intergenerational variables in the analysis in a variety of ways. The death ages of parents and grandparents will be entered into the micro models as explanatory variables. Presumably, early death ages of parents and other ancestors will imply early death ages for sons when cohort effects are controlled. In addition to death age, many other intergenerational variables are readily available from the family histories. They include parents' occupation, wealth, residential history, number of children, place or region of birth, and migration history. These variables will also be tested for their power in explaining patterns of aging and mortality. Pope will conduct similar tests on all of the family history data to give a crosscheck on the measurement of these intergenerational effects.

Brothers in ILAS share a common pre-war environment as well a common genetic heritage. (They may also share a common war experience.) This common genetic heritage and environment is not fully captured by the intergenerational variables mentioned above since heritability is composed of the many different dimensions included in genetics and environment. However, common family effects may be measurable. One approach, following the techniques used to measure the effect of family background on income or earnings (Kearl and Pope, 1986; Chamberlain and Griliches, 1975) is to use a regression with death age (for a cohort of men reaching some age such as twenty) as the dependent variable and variables such as occupation, wealth, residence and so on to "sweep out" the effects of observed variables on death age. The covariance of the errors or residuals in the brothers' estimated death ages from the regression is then a measure of the common family effect on death age. This covariance is a measure of the effect of any unobserved common family background that the brothers share compared to any two males from the Civil War cohort. It should be noted that family background could have some influence on the observed variables such as occupation so that the covariance of the residuals is dependent on the specification of the sweeping regression.

This covariance measurement need not be limited to brothers with different wartime experience since it would also be of interest to know the interaction of the family effect with wartime experience. For example, one might find that the medical effects of battle stress were closely associated with family background. This result can be measured through the covariance in brothers' medical histories controlling for military experience.

As an alternative to the residual-covariance approach, a kindred-frailty model (Vaupel 1990a) could be used where brothers share a level of frailty. Then, with assumptions about the structure of the frailty distribution, the parameters of a hazard function and a frailty distribution could be estimated. The variance in death ages would be due to variance in frailty and variance in death ages of people who share the same frailty but have different life experience (Vaupel 1990b). We could attempt a decomposition of the variance in lifetimes into these components.

ILAS and the core recruit sample will be compared to check the representative character of ILAS in order to determine whether the family histories are representative of the population and that these are properly controlled for the effects of military service in our analysis of the core public use tape. If this comparison shows that the two samples have similar levels and distributions for the variables of interest such as wealth, occupational distribution, fertility, morbidity, and mortality then one can have confidence in the estimates since the recruits sample is randomly drawn from the population. If the family histories are not completely representative with respect to a particular characteristic, post-weighting will be used to correct for the degree of bias. The analysis to date suggests that these biases will be quite small. An important aspect of this project lies in the synergism between the ILAS and recruits (core) samples. The core recruits sample makes it possible to check on how representative the family histories are of the population, while ILAS makes it possible to control for military service and other phenomena when studying the patterns of aging.

NOTES

1. From comments made at the Bellagio Conference on Hunger and History, June 1982.

2. The factor 1.27 is obtained on the assumption that 8 hours are spent at sleep or at least in bed at a factor of 1.0 BMR, and that essential minimal movements during waking hours have a factor of 1.4 BMR. Hence, over 24 hours the factor is $0.6667 \times 1.4 + 0.3333 \times 1.0 = 1.27$.

3. In Table 2, for economy of presentation, I assumed that the sex ratio was equal to 100 at every age. The French census of 1806 did report population by sex and age. When age-specific deviations of the sex ratio from 100 are taken into account, the correction factor changes from 0.7659 to 0.7631.

4. See pp. 22-26 and the Appendix for the definition and a discussion of BMI.

5. The no-waste assumption is consistent both with descriptions of lower class food habits of the period and recent investigations of the extent of food waste among the lower classes today (Dowler and Seo 1985). The energy requirements are from (Quenouille _et al._ 1951; FAO 1977; Payne 1987). To allow for efficient adjustment of the maintenance component among those in the two lowest deciles, I assumed a mean maintenance factor of 1.2 instead of 1.27 (see Payne 1987).

6. See the Appendix for notes to Table 3 giving the procedures used in the

estimation of σ and μ in distributions A, B, and C. In distribution A, the ln of 1250 is 1.38 S.D.s below μ.

7. For the top decile it is assumed that the mean height is 168 cm (which, using the Dutch S.D. for c. 1855 specified in n. 3, is about one S.D. above the mean French height in 18-IV reported in Table 5) and the BMI is 25. Thus, BMR requires about 1,620 kcals and the baseline is about 2,060 kcals.

8. This discussion only takes account of the incidence of mortality among those in each country whose consumption of calories was below basal metabolism. However, there were many other individuals who were at increased risk of death because they were malnourished, even though the degree of malnourishment was less extreme. Cf. the discussion of Figure 3, below, including n. 14.

9. Even small amounts of common agricultural or urban manual labor would have put such malnourished individuals on a path toward consuming their own tissue, and if continued long enough, would have, sooner or later, resulted in death. These are the people who constitute Marx's lumpenproletariat, Mayhew's "street folk," Huxley's "substrata," King's "unproductive classes" consuming more than they produced, and the French gens de néant (Himmelfarb, 1983; Laslett, [1965] 1984).

10. The S.D. of Dutch final heights in 1983 (6.59 cm) was inferred from (Van Wieringan 1986, p. 318). The mean height c.1855 is estimated from the same source using the information that about 32 percent of the male

population in c.1855 was below 157 cm. The S.D. of height in 1865 (7.41 cm) was estimated from the same source and applied to the information on the proportion rejected in order to obtain the mean height of recruits in c.1855. Final height (161.4 cm) was estimated by adding 0.9 cm to the age 20 height (see p. 50 above and Floud, Wachter, and Gregory 1990).

11. For a further discussion of this possibility see Fogel 1987. It is important to keep in mind that the denominators of the relative risk curves in both parts of Figure 1 are the average mortality or morbidity rate computed over all heights (see the Appendix). Consequently, the curves shown here will not necessarily shift merely because of a change in because the overall crude death rate or the corresponding morbidity rate.

12. The body mass index used here, often called the Quetelet index, is weight measured in kilograms divided by height measured in meters squared. The power to which height is raised was chosen by epidemiologists on the basis of studies which showed that in cross-section the correlation between the Quetelet index and height reached a minimum (as the power of height was varied) when the power was about 2. However, even though the correlation between height is low in cross-section it appears to be strong in time series for some countries (Fogel 1987).

13. See Osmani (1991) for a description of the controversy. Cf. Gopalan (1991) and Payne (1991).

14. The English cdr for 11 years centered on 1790 is 26.7 and 1.38 times that

number is 36.8, which is close to the French cdr derived from Weir's data for the 11 years centered on 1790.

15. About 43 percent of males age 10 and over had zero real wealth. The largest endowment in the linked genealogical sample thus far is about $200,000 which falls into the top 0.01 percent of the national distribution estimated by Soltow (1975) for 1850.

16. With some modifications, this paragraph and the next five paragraphs were drawn from pp. 255-257 of Fogel _et al._ (1991), which were written by Clayne Pope.

APPENDIX

This appendix provides the details of the mathematical and statistical procedures that lie behind Tables 3 and 4 and Figures 1, 2, and 3. The material in Figure 3 is also presented in tabular form, which will relieve potential users of the struggling to estimate particular points from the diagram.

Notes to Table 3

In estimating the means and bounds of each decile in caloric distributions A, B, and C, in Table 3, use was made of the following relationships between the parameters of the lognormal distribution and the mean and standard deviation of the corresponding distribution of the logs (Aitchison and Brown 1966, pp. 8-9):

$$(1) \quad M_d = e^{\mu}$$

$$(2) \quad \overline{X} = e^{\mu + 0.5\sigma^2}$$

$$(3) \quad s^2 = e^{\sigma^2 + 2\mu}(e^{\sigma^2} - 1)$$

$$(4) \quad \frac{s}{\overline{X}} = (e^{\sigma^2} - 1)^{0.5}$$

$$(5) \quad M_o = e^{\mu - \sigma^2}$$

where
μ = the mean of the distribution of logs
σ = the S.D. of the distribution of logs
M_d = the median of the lognormal distribution

$\overline{X}$ = the mean of the lognormal distribution
s = the S.D. of the lognormal distribution
M_o = the mode of the lognormal distribution

It follows that if the coefficient of variation in the lognormal distribution is known, σ follows immediately from equation (4). If $\bar{X}$ and σ are known, μ follows immediately from equation (2). Once σ and μ are known M_d and M_o follow from equation (1) and (5). The lower bounds of deciles 2-10 in the lognormal distribution can be obtained from the unit normal distribution, making use of the following relationships:

$$(6) \quad \frac{\log d_i - \mu}{\sigma} = Z_i$$

where d_i = the lower bound of the ith lognormal quantile ($i = m, \ldots, n$; $0<m<n$)

Z_i = the Z score of $\log d_i$

Since Z_i, σ, and μ are known, d_i follows immediately from equation (6). The means of each decile of the lognormal distribution is obtained from:

$$(7) \quad Z_{mi} = \frac{N}{(2\pi)^{0.5}} \int_{Z_i}^{Z_{i+j}} Z e^{-0.5Z^2} \partial Z$$

$$(8) \quad \bar{X}_i = e^{Z_{mi}\sigma + \mu}$$

where Z_{mi} = the Z score of the mean of the ith decile in the normal distribution

$\bar{X}_i$ = the mean of the ith decile in the lognormal distribution

N = the reciprocal of the area between Z_i and Z_{i+j} (which in this case is 10)

Equation 8 implies that the values Z_{mi} for each of the ten deciles are as follows:

Decile	Z_{mi}
Highest	1.7549
Ninth	1.0448
Eighth	0.6773
Seventh	0.3865
Sixth	0.1260
Fifth	-0.1260
Fourth	-0.3865
Third	-0.6773
Second	-1.0448
First	-1.7549

Notes to Table 4

The procedures for the estimation of the English distribution of calories c.1790 are similar to those used for the French in Table 3 and are discussed in detail in Fogel and Floud (1991). The principal difference in the procedures for the two countries stem from the use of national food balance sheets in the French case, while the English distribution is derived from the household consumption studies of lower-class familes. Consequently, in the English case it is necessary to determine how the mean caloric consumption of these lower class families differed from that of the nation as a whole.

The two household consumption studies available are the Davies survey of c.1790 and the Eden study of c.1794. Since both studies focused mainly on agricultural and non-agricultural rural laborers, they omitted both the prosperous and the very poor households. None of the households had annual incomes of less than £15 nor as much as £70 per year.[1] The mean annual expenditure on all items in the Davies study was £27 per household c.1790 (about 72 percent of which was for food) and £39.84 per household in the Eden study c.1794 (with about 74 percent spent on food) (Stigler 1954). The expenditures in both studies have been converted to prices of 1759 to make them comparable (prices rose rapidly over the period covered by the two studies, especially after the outbreak of the war with France). The annual expenditure figures in prices of 1759 are £21.8 in the Davies survey and £29.3 in the Eden survey.[2]

English political arithmeticians produced estimates of the social distribution of income in England c.1759 (by Massie) and for c.1801 (by Colquhoun). These tables have been revised and converted into size distributions of income by Lindert and Williamson (1982). The revised Massie distribution has been further corrected for an underestimate of the proportion of the population that was ultra poor.[3]

The procedure for identifying the parameters of the lognormal distribution that fits the revised Massie table is somewhat different from those fitting procedures employed in the construction of Table 3. There the specification of the coefficient of variation determined σ. And σ, plus Toutain's estimate of mean caloric consumption (2,290 kcals in consuming units), determined μ. The two equations used in Table 3 were:

$$\frac{\sigma^2}{2}+\mu-\log\bar{x} \tag{9}$$

$$\frac{\sigma}{\bar{x}}=e^{\sigma^2}-1 \tag{10}$$

In the case of the revised Massie social table, $s/\bar{x}$ is not known. However, the proposition that 21.4 percent of English households were ultra poor (paupers and vagrants) and that this class was defined by incomes of £10 or less takes the place of equation (10). The information in the preceding sentence implies equation (11):

$$(11) \qquad \frac{2.3026-\mu}{\sigma}=-0.79$$

where 2.3026 in the natural log of 10 and -0.79 is the Z score corresponding to 21.4 percent. Since $\bar{X}$ is known (£46.37, and its natural log is 3.8367), equations (9) and (11) imply the following quadratic in σ:

$$(12) \qquad \sigma^2+1.58\sigma-3.07=0.$$

Solving equation (12) gives a value for σ of 1.13, which when substituted in equation (11) yields $\mu = 3.20$.[4]

Thus, the median income in the Massie distribution is £24.53, well below the mean income of £46.37. Moreover, the average household income of the Eden's survey was at the 56th centile of the Massie distribution, while the mean income of households in the Davies survey was at the 44th centile. Thus, it appears that reformers who conducted the two surveys focused on houses with incomes in the neighborhood of one-half of the mean income, which appears to have been their concept of the "poverty line." However, none of the sampled households was so poor that they fell below the ultra-poverty line, which encompassed paupers and vagrants.

The finding that households in the two surveys had incomes well below the English national average does not imply that their caloric consumption (2,716 calories per consuming unit) was also below the average for England. Since size distributions of calories are generally much more equal than those of income, the centile of the caloric distribution at which average caloric consumption is reached is much lower than the centile (71) of the income distribution at which the average income is reached. In rural India of 1971-1972, for example, the average consumption of calories was achieved by households in the 49th centile of the income distribution. Since calories usually were relatively cheap in England during the last half of the eighteenth century, and its income distribution was far more skewed than that of rural India in the 1970s, the caloric consumption of median-income familes was probably slightly above the mean caloric consumption of English households in 1790.[5] If the mean consumption of calories was achieved by households at the 49th centile of the income distribution, and if the income elasticity for calories was about that for food as a whole, than the mean English consumption per consumer unit was about 2,700 (Crafts 1980; Shammas 1984 and 1990).

Figure 1

Part A. The relative mortality rate (R_i) at a given height is defined as:

$$(13) \qquad R_i = M_i / (\Sigma N_i M_i / N) = M_i / \overline{M},$$

where M_i is the average death rate among men of the i^{th} height interval, N_i is the number of individuals at the i^{th} height, $N = \Sigma N_i$, and $\overline{M}$ is mean death rate over all heights.

Part B. The relative rejection rate is defined as $R_{ij}/\overline{R}_j$, where R_{ij} is rejection rate for the j^{th} cause at the i^{th} height interval and $\overline{R}_j$ is the mean rejection rate for the j^{th} cause over all heights in the sample.

Figure 2

The relative mortality rate is defined separately for men and women. For each sex it is:

$$(14) \qquad R_i = D_i / (\Sigma N_i D_i / N) = D_i / \overline{D},$$

where D_i is the average death rate among individuals at the i^{th} BMI interval and $\overline{D}$ is the mean death rate over all BMIs for the given sex.

Figure 3[6]

Table IV in Waaler (1984) contains relative mortality rates for Norwegian males aged 50 to 64, averaged over height intervals of ten centimeters and weight intervals of ten kilograms. Attempts to fit iso-risk curves to these averages produced unsatisfactory results. Since we did not at the time have access to the data from which these averages were derived, it seemed reasonable to 'fill in' the table by polynomial interpolation and use the generated data to estimate the risk-height-weight relationship.

The interpolation was done in two steps. The first step consisted of taking the relative mortality rates given in the table and using standard least-squares regressions to fit polynomials in weight to each column of risk values (corresponding to given levels of height), and polynomials in height to each row (corresponding to given levels of weight). These polynomials, which were each of the maximum order permitted by the number of entries in the corresponding row or column, were then used to generate values across each row and down each column of the table in intervals of whole centimeters and kilograms. This step generated 700 data points.

To further increase the available data, the rows and columns generated in the first step were used as the data for the second round of polynomial interpolations. The methodology was the same as that used in the first round, and brought the total number of data points to 70,000.

These 70,000 triplets of height, weight, and relative mortality rates were then used to estimate a cubic response surface, or production function of risk for inputs of height and weight:

$$(15) \qquad R=F(H,W)+\epsilon,$$

where

$$(16) \qquad F(H,W)=\sum\nolimits_{0\le i+k\le 3} \beta_{ik} H^i W^k,$$

R = relative mortality risk, H = height in meters, W = weight in kilograms, β_{ik} is the coefficient on H^iW^k, and ϵ is a random disturbance term. Polynomials of degrees four and higher improved the fit only marginally at considerable computational expense, yielding surfaces whose contour plots were all almost identical to the cubic's. The quadratic form was rejected because of the severe restrictions it imposes--it has a straight minimum-risk curve, which in general forces the estimated minimum-risk curve to lie to the right of the true curve.

The minimum-risk curve is defined as the locus of (H, W) pairs such that W minimizes the relative mortality risk, given H. Hence, given an estimated response surface $\hat{R} = \hat{F}(H, W)\$$, its equation is derived as

$$(17) \qquad 0=\frac{\partial\hat{R}}{\partial W}=\frac{\partial}{\partial W}\hat{F}(H,W),$$

from which it is easily seen that a quadratic $\hat{F}$ would necessarily have a linear minimum-risk curve.

Finally, an iso-risk curve on which $\hat{R} = r$ is simply

$$(18) \quad \hat{F}(H,W)-r=0$$

while an iso-BMI curve for BMI = b is by definition

$$(19) \quad W-bH^2=0.$$

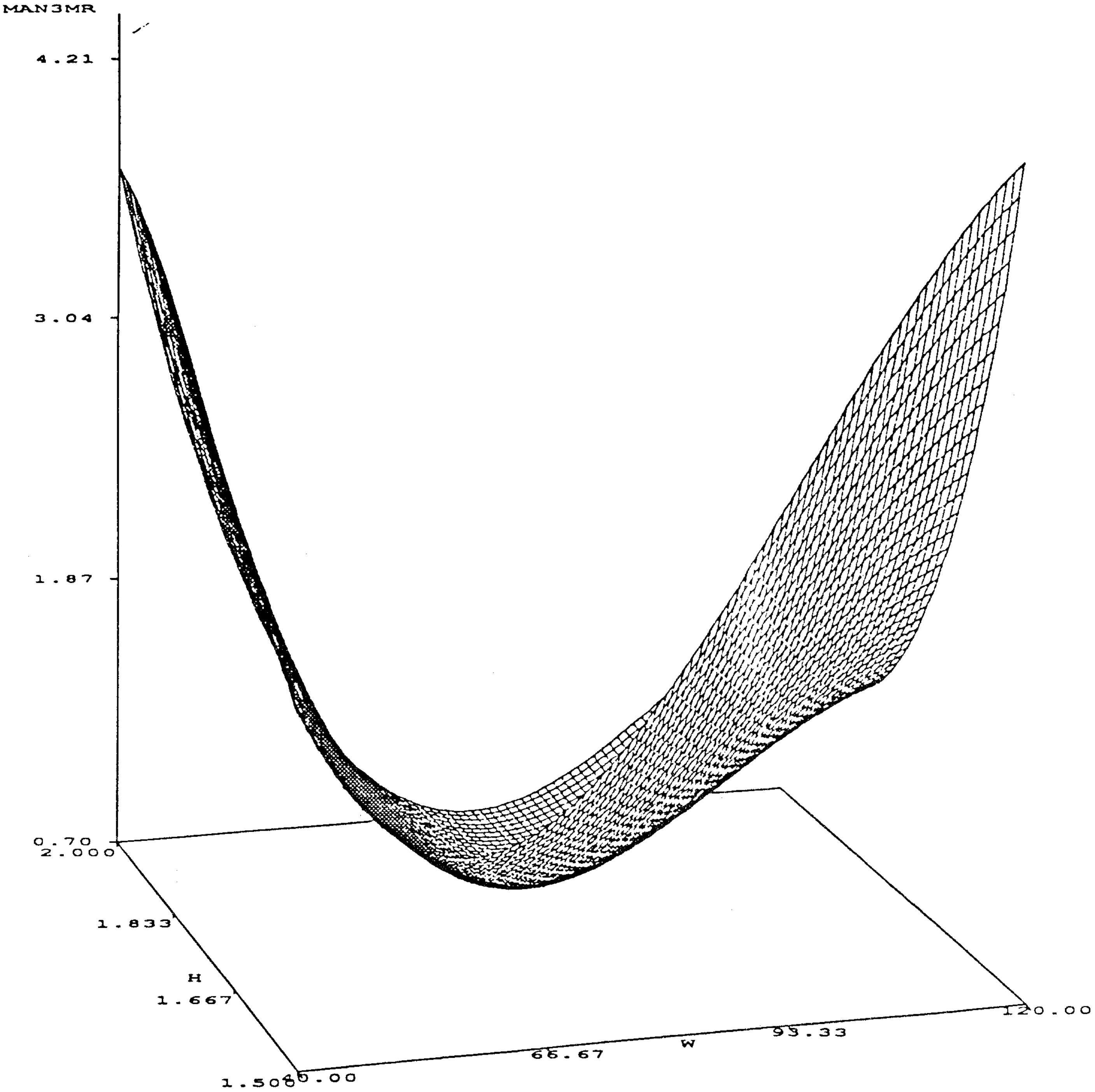
While it is possible to produce a diagram such as Figure 3 entirely within an application package such as SAS, we did it in a way that seemed to us the easiest and most flexible. Each of the three different types of curves in the diagram was produced separately as a PostScript file by SAS. These files were then merged and edited to overlay the curves and alter their appearance. Finally, some PostScript code was added to produce the the axes, symbols, and text, and the resulting file was sent to a PostScript laser printer. Further details can be obtained by writing John Kim, Center for Population Economics, University of Chicago, 1101 East 58th St., Chicago, IL 60637.

Figure A1 shows the mortality risk surface which corresponds to Figure 3 in the text. Table A1 gives the relative mortality risks by weight and height. Table A2 gives the relative mortality risk by BMI and height. It also shows the optimal BMI and the corresponding risk for each height.

Figure A1

MORTALITY RISK SURFACE

Height in Meters, Weight in Kilograms



NOTE: Figure A1 is a three-dimensional representation of the function given in the notes to Figure 3 for values of height and weight covered by Waaler's table.

Table A1

Relative Mortality Risk Table for Norwegian Males
Aged 50-64, By Weight(kg) and Height(m)

kg m	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
1.55	2.18	2.10	2.02	1.95	1.88	1.81	1.75	1.70	1.65	1.60	1.56	1.52	1.48	1.45	1.42	1.40	1.38	1.36	1.35	1.34	1.33	1.33	1.32	1.33	1.33	1.34	1.35	1.36	1.37	1.39	1.41	1.43	1.46	1.48	1.51	1.54
1.56	2.22	2.14	2.06	1.98	1.91	1.84	1.78	1.72	1.66	1.61	1.57	1.52	1.49	1.45	1.42	1.39	1.37	1.35	1.33	1.32	1.31	1.30	1.30	1.30	1.30	1.31	1.31	1.32	1.34	1.35	1.37	1.39	1.41	1.43	1.46	1.48
1.57	2.27	2.18	2.09	2.01	1.94	1.86	1.80	1.74	1.68	1.63	1.58	1.53	1.49	1.45	1.42	1.39	1.36	1.34	1.32	1.31	1.29	1.28	1.28	1.28	1.27	1.28	1.28	1.29	1.30	1.31	1.33	1.34	1.36	1.38	1.41	1.43
1.58	2.31	2.22	2.13	2.04	1.97	1.89	1.82	1.76	1.70	1.64	1.59	1.54	1.50	1.46	1.42	1.39	1.36	1.33	1.31	1.29	1.28	1.27	1.26	1.25	1.25	1.25	1.25	1.26	1.26	1.27	1.29	1.30	1.32	1.34	1.36	1.38
1.59	2.35	2.26	2.16	2.08	2.00	1.92	1.85	1.78	1.72	1.66	1.60	1.55	1.50	1.46	1.42	1.39	1.36	1.33	1.30	1.28	1.26	1.25	1.24	1.23	1.23	1.22	1.22	1.23	1.23	1.24	1.25	1.26	1.28	1.29	1.31	1.33
1.60	2.40	2.30	2.20	2.11	2.03	1.95	1.87	1.80	1.74	1.67	1.62	1.56	1.51	1.47	1.43	1.39	1.35	1.32	1.30	1.27	1.25	1.24	1.22	1.21	1.20	1.20	1.20	1.20	1.20	1.21	1.21	1.22	1.24	1.25	1.27	1.29
1.61	2.44	2.34	2.24	2.15	2.06	1.98	1.90	1.83	1.76	1.69	1.63	1.57	1.52	1.47	1.43	1.39	1.35	1.32	1.29	1.26	1.24	1.22	1.21	1.19	1.18	1.18	1.17	1.17	1.17	1.17	1.18	1.19	1.20	1.21	1.23	1.24
1.62	2.49	2.38	2.28	2.18	2.09	2.01	1.93	1.85	1.78	1.71	1.65	1.59	1.53	1.48	1.44	1.39	1.35	1.32	1.29	1.26	1.23	1.21	1.19	1.18	1.16	1.15	1.15	1.14	1.14	1.14	1.15	1.15	1.16	1.17	1.19	1.20
1.63	2.53	2.42	2.32	2.22	2.13	2.04	1.96	1.88	1.80	1.73	1.66	1.60	1.55	1.49	1.44	1.40	1.35	1.32	1.28	1.25	1.22	1.20	1.18	1.16	1.15	1.13	1.13	1.12	1.12	1.12	1.12	1.12	1.13	1.14	1.15	1.16
1.64	2.58	2.47	2.36	2.26	2.16	2.07	1.98	1.90	1.82	1.75	1.68	1.62	1.56	1.50	1.45	1.40	1.36	1.32	1.28	1.25	1.22	1.19	1.17	1.15	1.13	1.12	1.11	1.10	1.09	1.09	1.09	1.09	1.10	1.10	1.11	1.13
1.65	2.63	2.51	2.40	2.30	2.20	2.10	2.01	1.93	1.85	1.77	1.70	1.63	1.57	1.51	1.46	1.41	1.36	1.32	1.28	1.24	1.21	1.18	1.16	1.14	1.12	1.10	1.09	1.08	1.07	1.07	1.06	1.06	1.07	1.07	1.08	1.09
1.66	2.67	2.56	2.44	2.34	2.23	2.14	2.04	1.96	1.87	1.80	1.72	1.65	1.59	1.53	1.47	1.42	1.37	1.32	1.28	1.24	1.21	1.18	1.15	1.12	1.10	1.09	1.07	1.06	1.05	1.04	1.04	1.04	1.04	1.04	1.05	1.06
1.67	2.72	2.60	2.49	2.38	2.27	2.17	2.08	1.99	1.90	1.82	1.74	1.67	1.60	1.54	1.48	1.42	1.37	1.33	1.28	1.24	1.20	1.17	1.14	1.12	1.09	1.07	1.06	1.04	1.03	1.02	1.02	1.01	1.01	1.01	1.02	1.02
1.68	2.77	2.65	2.53	2.42	2.31	2.21	2.11	2.01	1.93	1.84	1.76	1.69	1.62	1.55	1.49	1.43	1.38	1.33	1.28	1.24	1.20	1.17	1.14	1.11	1.08	1.06	1.04	1.03	1.01	1.00	0.99	0.99	0.99	0.99	0.99	0.99
1.69	2.82	2.69	2.57	2.46	2.35	2.24	2.14	2.04	1.95	1.87	1.79	1.71	1.64	1.57	1.50	1.44	1.39	1.34	1.29	1.24	1.20	1.17	1.13	1.10	1.07	1.05	1.03	1.01	1.00	0.98	0.98	0.97	0.96	0.96	0.96	0.97
1.70	2.87	2.74	2.61	2.50	2.38	2.28	2.17	2.08	1.98	1.89	1.81	1.73	1.65	1.58	1.52	1.46	1.40	1.34	1.29	1.25	1.20	1.16	1.13	1.10	1.07	1.04	1.02	1.00	0.98	0.97	0.96	0.95	0.94	0.94	0.94	0.94
1.71	2.92	2.78	2.66	2.54	2.42	2.31	2.21	2.11	2.01	1.92	1.83	1.75	1.67	1.60	1.53	1.47	1.41	1.35	1.30	1.25	1.21	1.16	1.13	1.09	1.06	1.03	1.01	0.99	0.97	0.95	0.94	0.93	0.92	0.92	0.92	0.92
1.72	2.97	2.83	2.70	2.58	2.46	2.35	2.24	2.14	2.04	1.95	1.86	1.77	1.69	1.62	1.55	1.48	1.42	1.36	1.31	1.25	1.21	1.16	1.13	1.09	1.06	1.03	1.00	0.98	0.96	0.94	0.93	0.91	0.90	0.90	0.89	0.89
1.73	3.02	2.88	2.75	2.62	2.50	2.39	2.27	2.17	2.07	1.97	1.88	1.80	1.71	1.64	1.56	1.50	1.43	1.37	1.31	1.26	1.21	1.17	1.13	1.09	1.05	1.02	0.99	0.97	0.95	0.93	0.91	0.90	0.89	0.88	0.88	0.87
1.74	3.06	2.93	2.79	2.66	2.54	2.42	2.31	2.20	2.10	2.00	1.91	1.82	1.74	1.66	1.58	1.51	1.44	1.38	1.32	1.27	1.22	1.17	1.13	1.09	1.05	1.02	0.99	0.96	0.94	0.92	0.90	0.89	0.87	0.86	0.86	0.85
1.75	3.11	2.97	2.84	2.71	2.58	2.46	2.34	2.23	2.13	2.03	1.93	1.84	1.76	1.68	1.60	1.53	1.46	1.39	1.33	1.28	1.22	1.17	1.13	1.09	1.05	1.01	0.98	0.95	0.93	0.91	0.89	0.87	0.86	0.85	0.84	0.83
1.76	3.16	3.02	2.88	2.75	2.62	2.50	2.38	2.27	2.16	2.06	1.96	1.87	1.78	1.70	1.62	1.54	1.47	1.40	1.34	1.28	1.23	1.18	1.13	1.09	1.05	1.01	0.98	0.95	0.92	0.90	0.88	0.86	0.85	0.83	0.83	0.82
1.77	3.21	3.07	2.93	2.79	2.66	2.54	2.42	2.30	2.19	2.09	1.99	1.89	1.80	1.72	1.64	1.56	1.49	1.42	1.35	1.29	1.24	1.19	1.14	1.09	1.05	1.01	0.98	0.95	0.92	0.89	0.87	0.85	0.84	0.82	0.81	0.80
1.78	3.26	3.12	2.97	2.83	2.70	2.57	2.45	2.34	2.22	2.12	2.02	1.92	1.83	1.74	1.66	1.58	1.50	1.43	1.37	1.30	1.25	1.19	1.14	1.09	1.05	1.01	0.98	0.94	0.91	0.89	0.86	0.84	0.83	0.81	0.80	0.79
1.79	3.31	3.16	3.02	2.88	2.74	2.61	2.49	2.37	2.26	2.15	2.04	1.94	1.85	1.76	1.68	1.59	1.52	1.45	1.38	1.31	1.26	1.20	1.15	1.10	1.05	1.01	0.98	0.94	0.91	0.88	0.86	0.84	0.82	0.80	0.79	0.78
1.80	3.36	3.21	3.06	2.92	2.78	2.65	2.53	2.40	2.29	2.18	2.07	1.97	1.87	1.78	1.70	1.61	1.54	1.46	1.39	1.33	1.27	1.21	1.15	1.10	1.06	1.02	0.98	0.94	0.91	0.88	0.85	0.83	0.81	0.79	0.78	0.77
1.81	3.41	3.26	3.11	2.96	2.82	2.69	2.56	2.44	2.32	2.21	2.10	2.00	1.90	1.81	1.72	1.63	1.55	1.48	1.41	1.34	1.28	1.22	1.16	1.11	1.06	1.02	0.98	0.94	0.91	0.88	0.85	0.83	0.81	0.79	0.77	0.76
1.82	3.46	3.31	3.15	3.01	2.86	2.73	2.60	2.47	2.35	2.24	2.13	2.02	1.92	1.83	1.74	1.65	1.57	1.49	1.42	1.35	1.29	1.23	1.17	1.12	1.07	1.02	0.98	0.94	0.91	0.88	0.85	0.82	0.80	0.78	0.77	0.75
1.83	3.51	3.35	3.20	3.05	2.91	2.77	2.63	2.51	2.39	2.27	2.16	2.05	1.95	1.85	1.76	1.67	1.59	1.51	1.44	1.37	1.30	1.24	1.18	1.13	1.08	1.03	0.99	0.95	0.91	0.88	0.85	0.82	0.80	0.78	0.76	0.74
1.84	3.56	3.40	3.24	3.09	2.95	2.81	2.67	2.54	2.42	2.30	2.19	2.08	1.98	1.88	1.78	1.69	1.61	1.53	1.45	1.38	1.31	1.25	1.19	1.13	1.08	1.03	0.99	0.95	0.91	0.88	0.85	0.82	0.80	0.77	0.76	0.74
1.85	3.61	3.45	3.29	3.13	2.99	2.84	2.71	2.58	2.45	2.33	2.22	2.11	2.00	1.90	1.80	1.71	1.63	1.55	1.47	1.40	1.33	1.26	1.20	1.14	1.09	1.04	1.00	0.95	0.92	0.88	0.85	0.82	0.79	0.77	0.75	0.74
1.86	3.66	3.49	3.33	3.18	3.03	2.88	2.75	2.61	2.48	2.36	2.25	2.13	2.03	1.92	1.83	1.74	1.65	1.56	1.49	1.41	1.34	1.27	1.21	1.15	1.10	1.05	1.00	0.96	0.92	0.88	0.85	0.82	0.79	0.77	0.75	0.73
1.87	3.71	3.54	3.38	3.22	3.07	2.92	2.78	2.65	2.52	2.39	2.28	2.16	2.05	1.95	1.85	1.76	1.67	1.58	1.50	1.43	1.35	1.29	1.22	1.16	1.11	1.06	1.01	0.97	0.92	0.89	0.85	0.82	0.80	0.77	0.75	0.73
1.88	3.76	3.58	3.42	3.26	3.11	2.96	2.82	2.68	2.55	2.43	2.30	2.19	2.08	1.97	1.87	1.78	1.69	1.60	1.52	1.44	1.37	1.30	1.24	1.18	1.12	1.07	1.02	0.97	0.93	0.89	0.86	0.83	0.80	0.77	0.75	0.73
1.89	3.80	3.63	3.46	3.30	3.15	3.00	2.85	2.72	2.58	2.46	2.33	2.22	2.11	2.00	1.90	1.80	1.71	1.62	1.54	1.46	1.38	1.31	1.25	1.19	1.13	1.08	1.03	0.98	0.94	0.90	0.86	0.83	0.80	0.77	0.75	0.73
1.90	3.85	3.67	3.51	3.34	3.19	3.04	2.89	2.75	2.62	2.49	2.36	2.25	2.13	2.02	1.92	1.82	1.73	1.64	1.56	1.48	1.40	1.33	1.26	1.20	1.14	1.09	1.03	0.99	0.94	0.90	0.87	0.83	0.80	0.78	0.75	0.73
1.91	3.90	3.72	3.55	3.38	3.23	3.07	2.93	2.78	2.65	2.52	2.39	2.27	2.16	2.05	1.94	1.84	1.75	1.66	1.57	1.49	1.42	1.34	1.28	1.21	1.15	1.10	1.04	1.00	0.95	0.91	0.87	0.84	0.81	0.78	0.76	0.74
1.92	3.94	3.76	3.59	3.42	3.26	3.11	2.96	2.82	2.68	2.55	2.42	2.30	2.19	2.07	1.97	1.87	1.77	1.68	1.59	1.51	1.43	1.36	1.29	1.23	1.16	1.11	1.05	1.01	0.96	0.92	0.88	0.85	0.81	0.79	0.76	0.74
1.93	3.99	3.81	3.63	3.46	3.30	3.15	3.00	2.85	2.71	2.58	2.45	2.33	2.21	2.10	1.99	1.89	1.79	1.70	1.61	1.53	1.45	1.37	1.30	1.24	1.18	1.12	1.07	1.02	0.97	0.93	0.89	0.85	0.82	0.79	0.77	0.74
1.94	4.03	3.85	3.67	3.50	3.34	3.18	3.03	2.89	2.75	2.61	2.48	2.36	2.24	2.12	2.02	1.91	1.81	1.72	1.63	1.55	1.47	1.39	1.32	1.25	1.19	1.13	1.08	1.03	0.98	0.94	0.90	0.86	0.83	0.80	0.77	0.75
1.95	4.08	3.89	3.71	3.54	3.38	3.22	3.07	2.92	2.78	2.64	2.51	2.38	2.26	2.15	2.04	1.93	1.83	1.74	1.65	1.56	1.48	1.41	1.33	1.27	1.20	1.14	1.09	1.04	0.99	0.94	0.90	0.87	0.83	0.80	0.78	0.75

Table A1 (concluded)

Relative Mortality Risk Table for Norwegian Males
Aged 50-64, By Weight(kg) and Height(m)

(continued—2)

kg *m*	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110
1.55	1.57	1.60	1.64	1.67	1.71	1.75	1.78	1.82	1.87	1.91	1.95	1.99	2.04	2.08	2.13	2.17	2.22	2.26	2.31	2.36	2.40	2.45	2.49	2.54	2.58	2.62	2.67	2.71	2.75	2.79	2.83	2.87	2.90	2.94	2.97
1.56	1.51	1.54	1.57	1.61	1.64	1.68	1.72	1.75	1.79	1.83	1.87	1.92	1.96	2.00	2.05	2.09	2.13	2.18	2.22	2.27	2.31	2.35	2.40	2.44	2.48	2.53	2.57	2.61	2.65	2.69	2.72	2.76	2.80	2.83	2.87
1.57	1.46	1.49	1.52	1.55	1.58	1.61	1.65	1.69	1.72	1.76	1.80	1.84	1.88	1.92	1.97	2.01	2.05	2.09	2.14	2.18	2.22	2.26	2.31	2.35	2.39	2.43	2.47	2.51	2.55	2.59	2.62	2.66	2.70	2.73	2.76
1.58	1.41	1.43	1.46	1.49	1.52	1.55	1.59	1.62	1.66	1.69	1.73	1.77	1.81	1.85	1.89	1.93	1.97	2.01	2.05	2.09	2.14	2.18	2.22	2.26	2.30	2.34	2.38	2.42	2.46	2.49	2.53	2.56	2.60	2.63	2.66
1.59	1.36	1.38	1.41	1.43	1.46	1.49	1.53	1.56	1.59	1.63	1.66	1.70	1.74	1.78	1.81	1.85	1.89	1.93	1.97	2.01	2.05	2.09	2.13	2.17	2.21	2.25	2.29	2.33	2.36	2.40	2.44	2.47	2.50	2.53	2.56
1.60	1.31	1.33	1.35	1.38	1.41	1.44	1.47	1.50	1.53	1.56	1.60	1.63	1.67	1.71	1.74	1.78	1.82	1.86	1.90	1.94	1.97	2.01	2.05	2.09	2.13	2.17	2.20	2.24	2.28	2.31	2.35	2.38	2.41	2.44	2.47
1.61	1.26	1.28	1.31	1.33	1.35	1.38	1.41	1.44	1.47	1.50	1.54	1.57	1.60	1.64	1.67	1.71	1.75	1.79	1.82	1.86	1.90	1.94	1.97	2.01	2.05	2.08	2.12	2.16	2.19	2.23	2.26	2.29	2.32	2.35	2.38
1.62	1.22	1.24	1.26	1.28	1.30	1.33	1.36	1.38	1.41	1.44	1.48	1.51	1.54	1.57	1.61	1.64	1.68	1.72	1.75	1.79	1.83	1.86	1.90	1.93	1.97	2.01	2.04	2.08	2.11	2.14	2.18	2.21	2.24	2.27	2.30
1.63	1.18	1.19	1.21	1.23	1.26	1.28	1.31	1.33	1.36	1.39	1.42	1.45	1.48	1.51	1.55	1.58	1.61	1.65	1.68	1.72	1.76	1.79	1.83	1.86	1.90	1.93	1.97	2.00	2.03	2.07	2.10	2.13	2.16	2.19	2.22
1.64	1.14	1.15	1.17	1.19	1.21	1.23	1.26	1.28	1.31	1.33	1.36	1.39	1.42	1.45	1.49	1.52	1.55	1.59	1.62	1.65	1.69	1.72	1.76	1.79	1.83	1.86	1.89	1.93	1.96	1.99	2.02	2.05	2.08	2.11	2.14
1.65	1.10	1.11	1.13	1.15	1.17	1.19	1.21	1.23	1.26	1.28	1.31	1.34	1.37	1.40	1.43	1.46	1.49	1.52	1.56	1.59	1.62	1.66	1.69	1.72	1.76	1.79	1.82	1.86	1.89	1.92	1.95	1.98	2.01	2.03	2.06
1.66	1.07	1.08	1.09	1.11	1.12	1.14	1.16	1.19	1.21	1.23	1.26	1.29	1.31	1.34	1.37	1.40	1.43	1.47	1.50	1.53	1.56	1.59	1.63	1.66	1.69	1.72	1.76	1.79	1.82	1.85	1.88	1.91	1.94	1.96	1.99
1.67	1.03	1.04	1.06	1.07	1.09	1.10	1.12	1.14	1.16	1.19	1.21	1.24	1.26	1.29	1.32	1.35	1.38	1.41	1.44	1.47	1.50	1.53	1.57	1.60	1.63	1.66	1.69	1.72	1.75	1.78	1.81	1.84	1.87	1.90	1.92
1.68	1.00	1.01	1.02	1.03	1.05	1.06	1.08	1.10	1.12	1.14	1.17	1.19	1.22	1.24	1.27	1.30	1.33	1.36	1.39	1.42	1.45	1.48	1.51	1.54	1.57	1.60	1.63	1.66	1.69	1.72	1.75	1.78	1.81	1.83	1.86
1.69	0.97	0.98	0.99	1.00	1.01	1.03	1.04	1.06	1.08	1.10	1.12	1.15	1.17	1.20	1.22	1.25	1.28	1.31	1.33	1.36	1.39	1.42	1.45	1.48	1.51	1.54	1.57	1.60	1.63	1.66	1.69	1.72	1.74	1.77	1.80
1.70	0.94	0.95	0.96	0.97	0.98	0.99	1.01	1.02	1.04	1.06	1.08	1.10	1.13	1.15	1.18	1.20	1.23	1.26	1.29	1.31	1.34	1.37	1.40	1.43	1.46	1.49	1.52	1.55	1.58	1.61	1.63	1.66	1.69	1.71	1.74
1.71	0.92	0.92	0.93	0.94	0.95	0.96	0.97	0.99	1.01	1.02	1.04	1.07	1.09	1.11	1.13	1.16	1.19	1.21	1.24	1.27	1.30	1.32	1.35	1.38	1.41	1.44	1.47	1.50	1.52	1.55	1.58	1.61	1.63	1.66	1.68
1.72	0.89	0.90	0.90	0.91	0.92	0.93	0.94	0.96	0.97	0.99	1.01	1.03	1.05	1.07	1.09	1.12	1.14	1.17	1.20	1.22	1.25	1.28	1.31	1.33	1.36	1.39	1.42	1.45	1.47	1.50	1.53	1.56	1.58	1.61	1.63
1.73	0.87	0.87	0.88	0.88	0.89	0.90	0.91	0.92	0.94	0.96	0.97	0.99	1.01	1.03	1.06	1.08	1.10	1.13	1.15	1.18	1.21	1.23	1.26	1.29	1.32	1.34	1.37	1.40	1.43	1.45	1.48	1.51	1.53	1.56	1.58
1.74	0.85	0.85	0.85	0.86	0.86	0.87	0.88	0.90	0.91	0.92	0.94	0.96	0.98	1.00	1.02	1.04	1.07	1.09	1.12	1.14	1.17	1.19	1.22	1.25	1.27	1.30	1.33	1.36	1.38	1.41	1.44	1.46	1.49	1.51	1.54
1.75	0.83	0.83	0.83	0.84	0.84	0.85	0.86	0.87	0.88	0.90	0.91	0.93	0.95	0.97	0.99	1.01	1.03	1.05	1.08	1.10	1.13	1.15	1.18	1.21	1.23	1.26	1.29	1.32	1.34	1.37	1.39	1.42	1.45	1.47	1.49
1.76	0.81	0.81	0.81	0.81	0.82	0.82	0.83	0.84	0.85	0.87	0.88	0.90	0.92	0.94	0.95	0.98	1.00	1.02	1.04	1.07	1.09	1.12	1.14	1.17	1.20	1.22	1.25	1.28	1.30	1.33	1.36	1.38	1.41	1.43	1.45
1.77	0.80	0.79	0.79	0.79	0.80	0.80	0.81	0.82	0.83	0.84	0.86	0.87	0.89	0.91	0.93	0.95	0.97	0.99	1.01	1.04	1.06	1.09	1.11	1.14	1.16	1.19	1.22	1.24	1.27	1.29	1.32	1.34	1.37	1.39	1.42
1.78	0.78	0.78	0.78	0.78	0.78	0.78	0.79	0.80	0.81	0.82	0.83	0.85	0.86	0.88	0.90	0.92	0.94	0.96	0.98	1.01	1.03	1.05	1.08	1.10	1.13	1.16	1.18	1.21	1.23	1.26	1.29	1.31	1.34	1.36	1.38
1.79	0.77	0.77	0.76	0.76	0.76	0.77	0.77	0.78	0.79	0.80	0.81	0.82	0.84	0.86	0.87	0.89	0.91	0.93	0.96	0.98	1.00	1.03	1.05	1.08	1.10	1.13	1.15	1.18	1.20	1.23	1.26	1.28	1.31	1.33	1.35
1.80	0.76	0.75	0.75	0.75	0.75	0.75	0.75	0.76	0.77	0.78	0.79	0.80	0.82	0.83	0.85	0.87	0.89	0.91	0.93	0.95	0.98	1.00	1.02	1.05	1.07	1.10	1.12	1.15	1.18	1.20	1.23	1.25	1.28	1.30	1.33
1.81	0.75	0.74	0.74	0.73	0.73	0.73	0.74	0.74	0.75	0.76	0.77	0.78	0.80	0.81	0.83	0.85	0.87	0.89	0.91	0.93	0.95	0.98	1.00	1.02	1.05	1.07	1.10	1.13	1.15	1.18	1.20	1.23	1.25	1.28	1.30
1.82	0.74	0.73	0.73	0.72	0.72	0.72	0.72	0.73	0.74	0.74	0.75	0.77	0.78	0.79	0.81	0.83	0.85	0.87	0.89	0.91	0.93	0.95	0.98	1.00	1.03	1.05	1.08	1.10	1.13	1.15	1.18	1.20	1.23	1.25	1.28
1.83	0.73	0.72	0.72	0.71	0.71	0.71	0.71	0.72	0.72	0.73	0.74	0.75	0.76	0.78	0.79	0.81	0.83	0.85	0.87	0.89	0.91	0.93	0.96	0.98	1.01	1.03	1.06	1.08	1.11	1.13	1.16	1.19	1.21	1.24	1.26
1.84	0.73	0.72	0.71	0.70	0.70	0.70	0.70	0.70	0.71	0.72	0.73	0.74	0.75	0.76	0.78	0.79	0.81	0.83	0.85	0.87	0.89	0.92	0.94	0.96	0.99	1.01	1.04	1.07	1.09	1.12	1.14	1.17	1.19	1.22	1.24
1.85	0.72	0.71	0.70	0.70	0.69	0.69	0.69	0.69	0.70	0.71	0.71	0.72	0.74	0.75	0.76	0.78	0.80	0.82	0.84	0.86	0.88	0.90	0.93	0.95	0.97	1.00	1.02	1.05	1.08	1.10	1.13	1.15	1.18	1.20	1.23
1.86	0.72	0.71	0.70	0.69	0.69	0.68	0.68	0.69	0.69	0.70	0.70	0.71	0.72	0.74	0.75	0.77	0.79	0.80	0.82	0.84	0.87	0.89	0.91	0.94	0.96	0.99	1.01	1.04	1.06	1.09	1.12	1.14	1.17	1.19	1.22
1.87	0.72	0.70	0.69	0.69	0.68	0.68	0.68	0.68	0.68	0.69	0.70	0.70	0.72	0.73	0.74	0.76	0.78	0.79	0.81	0.83	0.86	0.88	0.90	0.93	0.95	0.97	1.00	1.03	1.05	1.08	1.11	1.13	1.16	1.18	1.21
1.88	0.71	0.70	0.69	0.68	0.68	0.67	0.67	0.67	0.68	0.68	0.69	0.70	0.71	0.72	0.73	0.75	0.77	0.79	0.80	0.82	0.85	0.87	0.89	0.92	0.94	0.97	0.99	1.02	1.04	1.07	1.10	1.12	1.15	1.18	1.20
1.89	0.71	0.70	0.69	0.68	0.67	0.67	0.67	0.67	0.67	0.68	0.68	0.69	0.70	0.71	0.73	0.74	0.76	0.78	0.80	0.82	0.84	0.86	0.89	0.91	0.93	0.96	0.99	1.01	1.04	1.07	1.09	1.12	1.15	1.17	1.20
1.90	0.72	0.70	0.69	0.68	0.67	0.67	0.67	0.67	0.67	0.67	0.68	0.69	0.70	0.71	0.72	0.74	0.76	0.77	0.79	0.81	0.83	0.86	0.88	0.90	0.93	0.96	0.98	1.01	1.04	1.06	1.09	1.12	1.14	1.17	1.20
1.91	0.72	0.70	0.69	0.68	0.67	0.67	0.66	0.66	0.67	0.67	0.68	0.68	0.69	0.71	0.72	0.74	0.75	0.77	0.79	0.81	0.83	0.85	0.88	0.90	0.93	0.95	0.98	1.01	1.03	1.06	1.09	1.12	1.15	1.17	1.20
1.92	0.72	0.70	0.69	0.68	0.67	0.67	0.66	0.66	0.67	0.67	0.68	0.68	0.69	0.71	0.72	0.73	0.75	0.77	0.79	0.81	0.83	0.85	0.88	0.90	0.93	0.95	0.98	1.01	1.03	1.06	1.09	1.12	1.15	1.18	1.20
1.93	0.72	0.71	0.69	0.68	0.67	0.67	0.67	0.66	0.67	0.67	0.68	0.68	0.69	0.71	0.72	0.73	0.75	0.77	0.79	0.81	0.83	0.85	0.88	0.90	0.93	0.95	0.98	1.01	1.04	1.07	1.10	1.12	1.15	1.18	1.21
1.94	0.73	0.71	0.70	0.69	0.68	0.67	0.67	0.67	0.67	0.67	0.68	0.69	0.69	0.71	0.72	0.73	0.75	0.77	0.79	0.81	0.83	0.86	0.88	0.91	0.93	0.96	0.99	1.01	1.04	1.07	1.10	1.13	1.16	1.19	1.22
1.95	0.73	0.72	0.70	0.69	0.68	0.68	0.67	0.67	0.67	0.67	0.68	0.69	0.70	0.71	0.72	0.74	0.75	0.77	0.79	0.81	0.84	0.86	0.88	0.91	0.94	0.96	0.99	1.02	1.05	1.08	1.11	1.14	1.17	1.20	1.23

Table A2

Relative Mortality Risk Table for Norwegian Males Aged 50–64, By BMI and Height(m);

also showing the optimal BMI and minimum risk at each height

BMI *m*	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	**Optimal BMI Minimum Risk**	
																								Opt. BMI	**Min. Risk**
1.55	2.11	1.93	1.77	1.64	1.54	1.46	1.39	1.35	1.33	1.33	1.34	1.36	1.40	1.46	1.52	1.60	1.68	1.77	1.87	1.97	2.08	2.19	2.30	**25.78**	**1.32**
1.56	2.11	1.92	1.76	1.63	1.52	1.43	1.37	1.33	1.31	1.30	1.31	1.34	1.38	1.43	1.50	1.57	1.65	1.74	1.84	1.94	2.05	2.15	2.26	**25.81**	**1.30**
1.57	2.10	1.91	1.75	1.61	1.50	1.41	1.35	1.30	1.28	1.27	1.29	1.31	1.35	1.40	1.47	1.54	1.63	1.72	1.81	1.91	2.02	2.12	2.23	**25.84**	**1.27**
1.58	2.09	1.90	1.73	1.59	1.48	1.39	1.32	1.28	1.26	1.25	1.26	1.29	1.33	1.38	1.44	1.52	1.60	1.69	1.78	1.88	1.99	2.09	2.19	**25.87**	**1.25**
1.59	2.08	1.88	1.71	1.57	1.46	1.37	1.30	1.25	1.23	1.22	1.23	1.26	1.30	1.35	1.42	1.49	1.57	1.66	1.76	1.85	1.95	2.06	2.16	**25.88**	**1.22**
1.60	2.07	1.87	1.70	1.55	1.44	1.34	1.28	1.23	1.20	1.20	1.21	1.23	1.27	1.33	1.39	1.46	1.55	1.63	1.73	1.83	1.92	2.02	2.12	**25.89**	**1.20**
1.61	2.05	1.85	1.68	1.53	1.41	1.32	1.25	1.20	1.18	1.17	1.18	1.21	1.25	1.30	1.36	1.44	1.52	1.61	1.70	1.80	1.89	1.99	2.09	**25.89**	**1.17**
1.62	2.04	1.83	1.66	1.51	1.39	1.29	1.22	1.18	1.15	1.14	1.15	1.18	1.22	1.27	1.34	1.41	1.49	1.58	1.67	1.77	1.87	1.96	2.05	**25.88**	**1.14**
1.63	2.02	1.81	1.63	1.48	1.36	1.27	1.20	1.15	1.12	1.12	1.13	1.15	1.20	1.25	1.31	1.39	1.47	1.56	1.65	1.74	1.84	1.93	2.02	**25.87**	**1.12**
1.64	2.01	1.79	1.61	1.46	1.34	1.24	1.17	1.12	1.10	1.09	1.10	1.13	1.17	1.23	1.29	1.36	1.45	1.53	1.62	1.72	1.81	1.90	1.99	**25.85**	**1.09**
1.65	1.99	1.77	1.59	1.44	1.31	1.21	1.14	1.10	1.07	1.06	1.08	1.10	1.15	1.20	1.27	1.34	1.42	1.51	1.60	1.69	1.78	1.87	1.95	**25.82**	**1.06**
1.66	1.97	1.75	1.56	1.41	1.28	1.19	1.12	1.07	1.04	1.04	1.05	1.08	1.12	1.18	1.25	1.32	1.40	1.49	1.58	1.67	1.75	1.84	1.92	**25.78**	**1.04**
1.67	1.95	1.73	1.54	1.38	1.26	1.16	1.09	1.04	1.02	1.01	1.03	1.06	1.10	1.16	1.22	1.30	1.38	1.47	1.55	1.64	1.73	1.81	1.89	**25.74**	**1.01**
1.68	1.93	1.70	1.51	1.36	1.23	1.13	1.06	1.02	0.99	0.99	1.00	1.03	1.08	1.14	1.20	1.28	1.36	1.45	1.53	1.62	1.70	1.78	1.86	**25.68**	**0.99**
1.69	1.91	1.68	1.49	1.33	1.20	1.11	1.04	0.99	0.97	0.96	0.98	1.01	1.06	1.12	1.18	1.26	1.34	1.43	1.51	1.60	1.68	1.76	1.83	**25.63**	**0.96**
1.70	1.88	1.65	1.46	1.30	1.18	1.08	1.01	0.96	0.94	0.94	0.96	0.99	1.04	1.10	1.17	1.24	1.32	1.41	1.49	1.58	1.66	1.73	1.80	**25.56**	**0.94**
1.71	1.86	1.63	1.43	1.27	1.15	1.05	0.98	0.94	0.92	0.92	0.94	0.97	1.02	1.08	1.15	1.23	1.31	1.39	1.48	1.56	1.64	1.71	1.77	**25.49**	**0.92**
1.72	1.83	1.60	1.41	1.25	1.12	1.02	0.96	0.91	0.89	0.90	0.92	0.95	1.00	1.07	1.14	1.21	1.30	1.38	1.46	1.54	1.62	1.68	1.74	**25.40**	**0.89**
1.73	1.81	1.57	1.38	1.22	1.09	1.00	0.93	0.89	0.87	0.88	0.90	0.94	0.99	1.05	1.12	1.20	1.28	1.37	1.45	1.53	1.60	1.66	1.72	**25.32**	**0.87**
1.74	1.78	1.55	1.35	1.19	1.07	0.97	0.91	0.87	0.85	0.86	0.88	0.92	0.97	1.04	1.11	1.19	1.27	1.35	1.44	1.51	1.58	1.64	1.69	**25.22**	**0.85**
1.75	1.75	1.52	1.32	1.16	1.04	0.95	0.88	0.84	0.83	0.84	0.86	0.91	0.96	1.03	1.10	1.18	1.26	1.35	1.42	1.50	1.57	1.62	1.66	**25.12**	**0.83**
1.76	1.72	1.49	1.29	1.13	1.01	0.92	0.86	0.82	0.81	0.82	0.85	0.89	0.95	1.02	1.09	1.17	1.26	1.34	1.42	1.49	1.55	1.60	1.64	**25.01**	**0.81**
1.77	1.70	1.46	1.26	1.11	0.98	0.90	0.84	0.80	0.79	0.81	0.84	0.88	0.94	1.01	1.09	1.17	1.25	1.33	1.41	1.48	1.54	1.59	1.62	**24.89**	**0.79**
1.78	1.67	1.43	1.23	1.08	0.96	0.87	0.81	0.78	0.78	0.79	0.83	0.87	0.94	1.01	1.09	1.17	1.25	1.33	1.40	1.47	1.53	1.57	1.60	**24.77**	**0.78**
1.79	1.64	1.40	1.21	1.05	0.93	0.85	0.79	0.77	0.76	0.78	0.82	0.87	0.93	1.00	1.08	1.17	1.25	1.33	1.40	1.47	1.52	1.56	1.58	**24.64**	**0.76**
1.80	1.61	1.37	1.18	1.02	0.91	0.83	0.77	0.75	0.75	0.77	0.81	0.86	0.93	1.00	1.08	1.17	1.25	1.33	1.40	1.46	1.51	1.55	1.56	**24.50**	**0.75**
1.81	1.58	1.34	1.15	1.00	0.88	0.80	0.76	0.73	0.74	0.76	0.80	0.86	0.93	1.01	1.09	1.17	1.26	1.33	1.40	1.46	1.51	1.53	1.54	**24.36**	**0.73**
1.82	1.55	1.31	1.12	0.97	0.86	0.78	0.74	0.72	0.73	0.76	0.80	0.86	0.93	1.01	1.09	1.18	1.26	1.34	1.41	1.46	1.50	1.53	1.53	**24.21**	**0.72**
1.83	1.52	1.28	1.09	0.95	0.84	0.77	0.72	0.71	0.72	0.75	0.80	0.86	0.94	1.02	1.10	1.19	1.27	1.35	1.41	1.47	1.50	1.52	1.51	**24.05**	**0.71**
1.84	1.49	1.25	1.07	0.92	0.82	0.75	0.71	0.70	0.71	0.75	0.80	0.87	0.94	1.03	1.12	1.20	1.28	1.36	1.42	1.47	1.50	1.51	1.50	**23.89**	**0.70**
1.85	1.45	1.22	1.04	0.90	0.80	0.73	0.70	0.69	0.71	0.75	0.81	0.88	0.96	1.04	1.13	1.22	1.30	1.37	1.44	1.48	1.51	1.51	1.49	**23.73**	**0.69**
1.86	1.42	1.20	1.01	0.88	0.78	0.72	0.69	0.69	0.71	0.75	0.81	0.89	0.97	1.06	1.15	1.24	1.32	1.39	1.45	1.49	1.51	1.51	1.48	**23.56**	**0.68**
1.87	1.39	1.17	0.99	0.86	0.76	0.70	0.68	0.68	0.71	0.76	0.82	0.90	0.99	1.08	1.17	1.26	1.34	1.41	1.47	1.51	1.52	1.51	1.47	**23.38**	**0.68**
1.88	1.36	1.14	0.97	0.83	0.75	0.69	0.67	0.68	0.71	0.76	0.83	0.92	1.00	1.10	1.19	1.28	1.36	1.43	1.49	1.52	1.53	1.51	1.46	**23.20**	**0.67**
1.89	1.33	1.11	0.94	0.82	0.73	0.68	0.67	0.68	0.72	0.78	0.85	0.93	1.03	1.12	1.22	1.31	1.39	1.46	1.51	1.54	1.54	1.52	1.46	**23.01**	**0.67**
1.90	1.30	1.09	0.92	0.80	0.72	0.68	0.67	0.68	0.73	0.79	0.87	0.96	1.05	1.15	1.25	1.34	1.42	1.49	1.54	1.56	1.56	1.52	1.45	**22.83**	**0.67**
1.91	1.27	1.06	0.90	0.78	0.71	0.67	0.67	0.69	0.74	0.81	0.89	0.98	1.08	1.19	1.28	1.38	1.46	1.52	1.57	1.59	1.58	1.53	1.45	**22.63**	**0.66**
1.92	1.25	1.04	0.88	0.77	0.70	0.67	0.67	0.70	0.75	0.83	0.91	1.01	1.12	1.22	1.32	1.42	1.50	1.56	1.60	1.61	1.60	1.54	1.45	**22.44**	**0.66**
1.93	1.22	1.01	0.86	0.75	0.69	0.67	0.67	0.71	0.77	0.85	0.94	1.05	1.15	1.26	1.36	1.46	1.54	1.60	1.64	1.64	1.62	1.56	1.45	**22.24**	**0.66**
1.94	1.19	0.99	0.84	0.74	0.69	0.67	0.68	0.72	0.79	0.88	0.98	1.08	1.19	1.31	1.41	1.50	1.58	1.64	1.67	1.68	1.64	1.57	1.45	**22.04**	**0.67**
1.95	1.16	0.97	0.83	0.73	0.68	0.67	0.69	0.74	0.82	0.91	1.01	1.12	1.24	1.35	1.46	1.56	1.63	1.69	1.72	1.71	1.67	1.59	1.46	**21.83**	**0.67**

NOTES TO APPENDIX

1. The upper and lower bounds were estimated by fitting lognormal curves to the distributions in Stigler (1954), after adjusting the Davies mean to 1794 prices using the index indicated in note 2, and using $\mu \pm 2.58$.

2. Using the Schumpeter-Gilboy index of consumer prices, the index number is 100 for 1759, 124 for 1790, and 136 for 1794 (Mitchell and Deane 1962, p. 469).

3. The Lindert and Williamson (1982) revision of Massie has been employed, with one correction. Their figures imply that the proportion of households that were in the class of paupers and vagrants (the ultra poor) was just 12.5 percent, although they put the proportion at 24.2 percent in 1688 and 19.9 percent in 1801 (both their 1688 and 1801 proportions are downward revisions of those estimated by King and Colquhoun). This large implied drop in the English proportion of the ultra poor during the mid-eighteenth century appears to be an artifact of their estimating procedure. They assumed that the paupers and vagrants omitted by Massie were equal to their estimate of Massie's overstatement of households in manufacturing and agriculture, less Massie's understatement of households in the building trades and mining. However, there is little evidence to support the implication that the proportion of ultra poor dropped sharply from 1699 to 1759 and then rose nearly as sharply between 1759 and 1801. Given the large military drain on manpower during 1801, one would expect the proportion of the ultra poor to have been relatively low. Various

studies indicate that the 1750s and 1760s were a troubled period for labor, with the problem of the ultra poor unabated (Marshall 1968; Lipson 1971; R. Rose 1961; Barnes 1930; Schwartz 1985; Thompson 1963). Consequently, the proportion of the ultra poor for 1759 was reestimated (21.4 percent) by interpolating between the proportions Lindert and Williamson estimate for 1688 and 1801.

4. This procedure for fitting the lognormal retains the estimates of the mean income and the household count reported by Lindert and Williamson (1982). Under these circumstances the revised estimate of the proportion who were ultra poor produces an adjustment in the share of income received by the upper classes.

An alternative procedure is to assume that the 137,066 households added to the ranks of the ultra poor represent an addition to the population. That assumption increases the total English households by 8.91 percent, no an implausible figure, and changes the variance of the distribution, in a direction that depends on the estimate of the mean and the S.D. of the income in the previously omitted ultra poor households. If one assumes that they had the same mean income, £6.735, and upper bound as the 192,310 ultra poor households specified by Lindert and Williamson, the following equations apply:

$$\frac{\sigma^2}{2}+\mu-3.7642 \tag{4.1}$$

Here 3.7642 is the log of the mean income (£43.13). It is less than the previous mean because the added households had income well below the mean; and the new Z score (-0.85) is further below zero than the score in equation (11) because adding persons to the denominator slightly reduces the share of the population that is ultra poor. Solving equations (4.1) and (4.2) yields:

$$\mu = 3.20$$

$$\sigma = 1.06$$

The consequence of the alternative procedure is to reduce slightly the inequality of the income distribution, but this change does not affect any of the major points under discussion in this paper. For example, the median of the income distribution (£24.5) is unchanged to three significant places, and the mean income of the ultra poor is also virtually unchanged (£5.5). Other reasonable alternatives for fitting the distribution demonstrated that the principal points at issue in this paper are robust to the fitting procedure.

5. Estimated from the data in Lipton (1983, p. 73). The median and other centiles of the rural income distribution were estimated by fitting a lognormal curve to the income distribution. The relationship between income and calories was estimated from an equation of the form

$$(4.2) \quad \frac{2.3026-\mu}{\sigma} = -0.85.$$

$$C = \alpha + \beta \log Y$$

where C is calories and Y is income. The equation was then used to predict the income and thus determine the centile of the income distribution at which average consumption was attained.

6. This note was written by John Kim and Richard L Manning.

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