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# CHANGES IN AMERICAN AND BRITISH STATURE SINCE THE MID-EIGHTEENTH CENTURY: A PRELIMINARY REPORT ON THE USEFULNESS OF DATA ON HEIGHT FOR THE ANALYSIS OF SECULAR TRENDS IN NUTRITION, LABOR PRODUCTIVITY, AND LABOR WELFARE*

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# Changes in American and British Stature Since the Mid-Eighteenth Century: A Preliminary Report on the Usefulness of Data on Height for the Analysis of Secular Trends in Nutrition, Labor Productivity, and Labor Welfare

## Abstract

This paper is a progress report on the usefulness of data on physical height for the analysis of long-term changes in the level of nutrition and health on economic, social, and demographic behavior. It is based on a set of samples covering the U.S. and several other nations over the years from 1750 to the present. The preliminary results indicate that native-born Americans reached modern levels of height and nutrition by the time of the American Revolution, but there were long periods of declining nutrition and height during the 19th century. Similar cycling has been established for England. A variety of factors, including crop mix, urbanization, occupation, intensity of labor, and immigration affected the level of height and nutrition, although the relative importance of these factors has changed over time. There is evidence that nutrition affected labor productivity. In one of the samples individuals who were one standard deviation above the mean height (holding weight per inch of height constant) were about 8% more productive than individuals one standard deviation below the mean height. Another finding is that death did not choose people at random. Analysis of data for Trinidad indicates that the annual death rate for the shortest quintile of males was more than twice as great as for the tallest quintile of males.

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# Changes in American and British Stature Since the Mid-Eighteenth Century: A Preliminary Report on the Usefulness of Data on Height for the Analysis of Secular Trends in Nutrition, Labor Productivity, and Labor Welfare

## 1. Nutrition and Human Capital

It is now well established that investment in human capital, especially through education, has made an important contribution to the increase of labor productivity and per capita income during the twentieth century (Schultz, Abramovitz, Denison, Becker, Griliches, Jorgenson and Griliches, Kuznets, Nelson and Phelps, Fishlow, Hanson). Although not as fully researched, several economists as early as Irving Fisher have also called attention to improved nutrition, public sanitation, and improved health as significant forms of investment in human capital (Weisbrod, Mushkin, Kuznets, Fuchs, Perlman, Barlow, Grossman, Meeker 1972 and 1974, Higgs, Fogel and Engerman 1974, Cain). Nevertheless, until quite recently, the general tendency of economists was to treat improvements in nutrition and health more as background influences than as main factors in the explanation of the long-term growth of per capita income in the U.S. and in other industrialized nations.

Several recent developments have called new attention to the possibility that improvements in nutrition and health may have been far more central to the process of economic growth than is usually presumed--not only for the eighteenth and nineteenth centuries, but for the twentieth century as well. One is the debate over the explanation of the decline in mortality since 1800 in Great Britain, the United States, and other industrialized nations (Blaug; Coale and Hoover, Easterlin 1977, Eversley, Flinn, Habakkuk, Higgs, McKeown and Brown, McKeown 1976 and 1978, Meeker 1972, Razell 1974 and 1977, Schofield, van Bathe, van de Walle, Wrigley). Another is the emergence of development economics, which has also turned attention to the economics of nutrition and health. It was rapidly recognized that improvements in nutrition and health were central to the alleviation of poverty in underdeveloped nations. This finding stimulated the growth of a subfield in the economics of food and nutrition (see the review articles by Taylor and Johnston), which is concerned with such issues as the impact of systems of food production and distribution on food consumption within families; the links between malnutrition and income distribution; the effect of malnutrition on the supply of labor; the effect of food subsidies, not only on demand and supply in the market for food, but also on demand and supply in non-food markets; and optimal governmental strategies for improving nutrition and health.

A third development is the emergence of a new emphasis on the effect of improved nutrition on labor productivity. This line of analysis has been stimulated by a series of advances in the fields of nutrition, development economics, labor economics, and economic history. During the post-World War II period, nutritionists developed estimates of caloric and nutrient requirements for various occupations and labor tasks (FAO 1957 and 1962, Durnin and Passmore, Davidson _et al_). Investigations of the effect of malnutrition, and of its elimination, on labor productivity have been performed both in laboratory studies of human subjects (Keys _et al_) and in observational studies of laborers in actual work situations (Wyndham _et al_, Kraut, Lehmann _et al_, Lowenstein, FAO 1962, Belvady, Areskog _et al_). These reveal that malnutrition results in a reduction in the number of days at work as well as in substantial declines (as much as 50 percent) in work capacity while at work. Such findings have led economists to explore the theoretical implications of including consumption as an argument of firm and aggregate production functions (Leibenstein, Correa and Cummins, Mirrlees, Stiglitz, Bliss and Stern). The paper by Bliss and Stern, the most comprehensive examination of the question to date, includes a section on the possibility of econometric measurement of the contribution of nutrition to production. One of the major obstacles, as they point out, is the difficulty of obtaining an adequate index of the level of nutrition.

## 2. Objectives, Procedures, and Sources of Data

This paper is a progress report on a collaborative project aimed at investigating the usefulness of data on physical height for the analysis of long-term changes in the level of nutrition and health on economic, social and demographic behavior. The project, which was initiated in 1978, is now in mid-course. The findings reported here cover research completed through the end of 1981. Section 2 of the paper summarizes the principal research objectives, the principal samples on which the project is based and the procedures employed in the analysis of the data contained in these samples. Section 3 presents the principal findings through 1981. Section 4 discusses some possible implications of these findings for the understanding of long-term changes in economic and demographic behavior. Appendix A summarizes previous research by anthropologists, physiologist, biologists, nutritionists, and others on the relationship between human growth and socioeconomic conditions. Appendix B deals with various tests of the samples listed in Table 1 and with the procedures that have been employed for the detection and correction of biases that might distort our estimates of secular trends in heights.

### 2.1 Detailed Objectives

In pursuit of the general goal of this project, the following detailed objectives have been formulated: (1) to establish and compare secular trends in the level of nutrition in the United States, and in the main nations from which the U.S. population was drawn, over the period from the mid-eighteenth century to the present; (2) to measure secular changes in the differences in nutritional levels between various socioeconomic classes; (3) to assess the validity of various real wage indexes now employed as measures of the improvement in the economic welfare of laboring classes; (4) to assess the impact of improved nutrition on labor productivity; and (5) to assess the impact of nutrition on demographic rates.

2.2 Procedures

This project relies on measures of height as the principal index of the level of nutrition. Both laboratory experiments on animal populations and observational studies of human populations have led physiologists and nutritionists to the conclusion that anthropometric measurements are reliable indexes of the extent of malnutrition among the socioeconomic classes of particular populations.[1] Measures of height and weight at given ages, the age at which growth of stature terminates, attained final heights, and especially the rate of change in height or weight during the growing ages "reflect accurately the state of a nation's public health and the average nutritional status of its citizens" (Eveleth and Tanner). Consequently, these measures are now widely used by the World Health Organization and other agencies to assess the nutritional status of the populations of underdeveloped nations.

Use of anthropometric measures as measures of nutrition rest on a well-defined pattern of human growth between childhood and maturity. The average annual increase in height (velocity) is greatest during infancy, falls sharply up to age 3, and then more slowly through the remaining pre-adolescent years. During adolescence velocity rises sharply to a peak which is approximately one-half of the velocity during infancy, then falls sharply and reaches zero at maturity. In girls the adolescent growth sput begins about two years earlier, and the magnitude of the spurt is slightly smaller than in boys. Girls and boys are about the same height prior to the spurt and the difference in adult size between men and women is largely due to differences in the adolescent spurt.

This growth pattern reflects the interaction of genetic, environmental,

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[1]See Appendix A which summarizes the findings of the principal studies. For more extensive descriptions see Tanner 1978 and 1981. The relationship between height, per capita income, and the distribution of income is analysed by Steckel (1982) for a cross section of 163 present-day populations for which the required data are available. Frisancho summarizes the evidence on the relationship between anthropometric measures, nutrition, and health.

and socioeconomic factors during the period of growth. According to Eveleth and Tanner:

> Such interaction may be complex. The genotypes which produce the same adult heights under optimal environmental circumstances may produce different heights under circumstances of privation. Thus two children who would be the same height in a well-off community may not only be smaller under poor economic conditions, but one may be significantly smaller than the other....If a particular environmental stimulus is lacking at a time when it is essential for the child (times known as 'sensitive periods'), then the child's development may be shunted, as it were, from one line to another.

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 very little impact on the mean heights. For example, the mean heights of well-fed West Europeans, North American whites and North American blacks are nearly idential. There are, of course, some ethnic groups in which mean final heights of well-fed persons today differ significantly from the West European or North American standard. In these cases the deviation from the European standard appers to be due to genetic factors. But such ethnic groups have represented a miniscule proportion of the U.S. and European populations. Consequently, they are irrelevant to an explanation of the observed secular trends in mean final heights in the U.S. and in the various European nations since 1750; nor can they account for the differences at various points of time between the means in the final heights of the U.S. population and the principal populations from which it was drawn.[2] In this connection, it should be noted that today the mean final heights of well-fed males in the main African nations from which the U.S. black population is derived also fall within the narrow band designated as the West European standard (Eveleth and Tanner; Appendix A).

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[2]The belief that heterosis (hybrid vigor) would make Americans substantially taller than the ethnic groups from which they were drawn has not been sustained by previous anthropometric research. See Cavalli-Sforza and Bodmer for a theoretical argument as to why the effect of heterosis in human populations is small. Our investigations have failed to yield consistent signs on dummy variables for either males or females born of mixed unions. The magnitude of the positive coefficients for adults, not all of which are statistically significant, fall in the range of 0.17 to 0.66 inches. The average of all the coefficients so far estimated for adults (N = 9) is 0.19 inches.

Physiologists, anthropologists, and nutritionists have charted the effect of nutritional deficiencies on the human growth profile. Short periods of malnutrition or prolonged periods of moderate malnutrition merely delay the adolescent growth spurt. Severe, prolonged malnutrition may completely erode the typical growth-spurt pattern and cause substantial permanent stunting. If malnutrition is prolonged and moderate, growth will continue beyond the age at which the growth of well-fed adolescents ceases. Hence, the average age at which the growth spurt peaks, the average age at which growth terminates, the mean height during adolescent ages, and the mean final height are all important indicators of mean nutritional status. Any one of them can be used to trace secular trends in nutrition. The more of these measures that are available, the more precise the determination of the severity and duration of periods of malnutrition.

Time series on height may be more reliable indicators of long-term changes in the welfare of the laboring classes than are the currently available indexes of real wages. Critics of the real wage indexes that have been computed for the eighteenth and nineteenth centuries, in both the U.S. and Great Britain, have noted the problems that beset the existing time series of nominal wages as well as the price deflators. The nominal wages for particular localities and particular occupations often remain relatively fixed over many years, sometimes even during periods of sharp fluctuations in the level of prices, so that the trend in real wages depends heavily on the choice of price indexes. Price deflators are generally lacking in information on the cost of shelter, which in the more rapidly growing cities, may have accounted for more than a quarter of the income of laborers. Efforts to turn wage indexes of particular occupations and particular localities into general regional or national wage indexes have produced nominal wage indexes whose movements are dominated for long periods of time by changes in a few occupations or localities and by discontinuities in underlying series. Von Tunzelmann's recent examination of the real wage series for England revealed that different reasonable ways of combining the individual series of nominal wage rates and the choice of different price deflators could imply either a rise of 250 percent in the national average of real wages between 1750 and 1850 or no rise at all. Data on height by occupation are more complete in their geographic scope than the wage data, especially for the lower-wage occupations, and do not need to be deflated by price indexes.

In addition to these problems of constructing an accurate and representative index of real wages, the usefulness of the series currently available is limited by a failure to distinguish between the experiences of different socioeconomic or geographically defined subpopulations. The height-by-age data have the significant advantage of allowing one to isolate a particular class of the population and observe how the movement of its nutritional experience (which was perhaps the major component of the standard of living for the economy during the early stages of development) diverged from that of other classes. Although an accurate real wage series would certainly reflect aspects of material welfare not invovled with nutrition, it should also be recognized that height captures the effects of conditions, such as the level and intensity of work, not typically encompassed by real wage data. Even when real wage indexes of high quality are available, height-by-age data constitute a valuable additional source of information on a population's standard of living, and their attractiveness is further enhanced for the U.S. during the eighteenth and nineteenth centuries by the poor quality of the existing alternative indicators. [3]

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[3] Suppose, for example, that real-wage and nutritional indexes, cleaned of measurement error, diverged. Such divergence would point to aspects of the standard of living not adequately captured by a real wage index, such as changes in the number of days worked, in the intensity of labor, or in environmental conditions not speedily reflected in prices.

Several alternative approaches are being pursued for the investigation of the effect of nutrition on labor productivity and labor supply. One is to relate the number of days of illness to final height. Published data on morbidity rates by city size and other characteristics are available for the last several decades of the nineteenth century. These can be related to the data on height through regression analysis, with cities or counties as the units of observation. We have also identified several bodies of data (see item 9 of Table 1) that permit micro-level analysis of the relationship between height and productivity using wage rates as the measure of productivity. These sources provide information not only on the height, age, sex, and wage rates of each individual, but also report education, occupation, and family wealth. A third approach involves the use of mean height as a variable in production functions estimated for both agriculture and manufacturing, with counties as the units of observation. A closely related approach involves the computation of indexes of total factor productivity for both agriculture and manufacturing industries; height will then be used as a variable in explaining the variations in these indexes for specific industries across counties. The last two procedures will be attempted first for production in 1860, making use of the height data derived from the Civil War samples and of input and output data for large samples of farms and manufacturing firms collected by previous investigators and already on computer tapes.[4]

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[4]Although income affects height and height affects productivity, and productivity affects income, the relationship is not necessarily simultaneous. Final height will generally be determined not by the present income of the individual whose height enters into the analysis of productivity, but by the incomes of the parents of that individual during his growing years and the incomes of his great-grand-parents during his parents' growing years. The intergenerational effect will be stronger, the more rapidly incomes are changing over time and the more tight the control for occupations, social class, etc.

2.3 The Principal New Samples

As shown by Table 1, the project is based on a set of thirteen samples of data containing information on height-by-age and various socioeconomic variables, and which cover the period from 1750 through 1937 for the United States, Trinidad, Great Britain, and Sweden. Cooperative arrangements will be undertaken to obtain comparable data for other nations from which the U.S. population was drawn, including Germany and France. The data in these samples will be linked with data available in both manuscript and published sources. Such linking will increase the range of variables that can be brought into the analysis and the complexity of the interrelationships between height, nutrition, and economic and social behavior that we seek to investigate.

Table 1 also shows the progress of the work toward the retrieval of the data and its transcription into machine-readable form. The number of observations currently in such form exceeds or is close to the original targets for samples 1, 2, 6, 7, 10, 11, and 13. Retrieval is in midstream for samples 5 and 12 and is at an early stage or yet to begin for samples 3, 4, 8, and 9.

When the total number of observations in a given source was sufficiently small, all of the surviving data were collected. For larger bodies of data, samples were drawn by random techniques. For example, in the case of the sample designated as "Union army, whites (item 1 of Table 1), a cluster sampling procedure was employed. A number was first assigned to each of the approximately 25,000 white companies in the Union army. A random number generator was used to draw about 1,000 companies from the total. The records of about 75 percent of the selected companies have been found; the remainder were destroyed by accident or lost before reaching the National Archives. Similar procedures have

Table 1
THE PRINCIPAL SAMPLES

| Title of Samples | 1<br>Number of Observations Originally Planned | 2<br>Number of Observations Currently on Tape | 3<br>Main Categories of Information Included | 4<br>Investigators Responsible for Retrieval and/or Analysis |
|---|---|---|---|---|
| | | Civil War Samples (1-4) | | |
| 1. Union army, white | 40,000 | 53,000 | height, age, mortality, cause of death, various socioeconomic characteristics; covers mainly ages 18-45 | Engerman/Fogel/Margo |
| 2. Union army, blacks | 5,000 | 10,000 | same as 1, plus complexion, previous status | Engerman/Fogel/Margo |
| 3. Confederate army | 5,000 | 0 | same as 1 | Engerman/Fogel |
| 4. Union army, rejects | 5,000 | 0 | same as 1 (except mortality information) plus reason for rejection | Engerman/Fogel |
| | | Other U.S. Samples (5-9) | | |
| 5. Regular U.S. army, 1790-1910 | 100,000 | 43,000 | same as 1 | Villaflor |
| 6. Coastwise manifests, 1810-1863 | 30,000 | 51,000 | height, age, color, sex dates and points embarkation and arrival; covers all ages of both males and females | Steckel |
| 7. Colonial muster rolls, 1750-1783 | 20,000 | 14,000 | same as 1, except no mortality information | Engerman/Sokoloff/ Villalfor |
| 8. Fall River Survey, 1906-1907 | 3,000 | 0 | height by age and sex by various socioeconomic characteristics for working children of school age | |

Table 1 (cont)
THE PRINCIPAL SAMPLES

| Title of Samples | 1<br>Number of Observations Originally Planned | 2<br>Number of Observations Currently on Tape | 3<br>Main Categories of Information Included | 4<br>Investigators Responsible for Retrieval and/or Analysis |
|---|---|---|---|---|
| 9. Cost of living surveys, 1934-1937 | 10,000 | 0 | height for all family members by age, sex, and various socioeconomic characteristics including occupation, wages, days ill, education and family wealth | Goldin |
| 10. Trinidad, 1815-1831 | 30,000 | 25,000 | height, age, color, births, deaths, and various other socioeconomic variables for all ages and both sexes | Engerman/Friedman |
| | | British Samples (11 and 12) | | |
| 11. Marine Society, boys, 1750-1910 | 70,000 | 50,000 | height, age, and various socioeconomic characteristics including father's occupation, literacy and vaccination; ages mainly 12-18 | Floud |
| 12. Military recruitment records 1750-1910 | 110,000 | 31,000 | same as 11, except for father's occupation; mainly for males aged 16-45 | Floud |
| 13. Swedish conscript rolls, 1750-1910 | 30,000 | 30,000 | height by age, years of service, and various socioeconomic characteristics for males. | Sandberg/Steckel |

been, or are being, worked out for the samples designated as "Union army, blacks," "Union army rejects," "regular U.S. army," and "British military recruitment records" (items 2, 4, 5, and 12 of Table 1).[5] In the cases of the "colonial muster rolls," and "Trinidad" (items 7 and 10 of Table 1) all surviving records with information on height and age have been included. The problem in the case of the colonial samples has been to ensure that the search for surviving records has been exhaustive. In the case of the "coastwise manifests" (item 6 of Table 1), all the surviving records for Savannah were included and a judgment sample (of about 16,000 observations) was chosen from the Mobile and New Orleans record sets.
We will not be able to determine our sampling procedure for the "Confederate army" sample (item 3, of Table 1) until we complete the survey of southern archives and determine the volume and condition of surviving records.

The use of these samples to infer secular trends in mean adolescent heights and in the mean final heights of particular subgroups of the U.S. and other populations presents a number of statistical problems, some of which are novel. Much effort during the past four years has been devoted to the assessment of the selection biases inherent in the data sources and to the development of robust procedures capable, not only of detecting them, but also of making the appropriate adjustments. Tests of the procedures so far developed indicate that they are quite effective. The nature of the biases, the procedures that have been devised with them, and results of tests are discussed in Appendix B and in the sources cited there.

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[5] Of the 10,000 observations on tape in item 2, about 2,000 are from a random sample and 8,000 are from a judgment sample. We expect to expand the random sample to 5,000 observations, although for many issues the characteristics of the random and judgment samples are sufficiently close to yield similar conclusions.

## 3. Preliminary Findings

Although the major portion of the work over the past three years has been devoted to solving problems of data retrieval, data management, and the development of appropriate statistical procedures, preliminary analyses of the data have already yielded striking findings regarding secular trends in heights, in nutrition and health, and in the welfare implications of these trends. The secular pattern of native-born U.S. whites prior to 1910 appears to be substantially different from that of most European populations. Similarly, the experience of U.S. blacks diverged from that of blacks born in the Caribbean or in Africa.

### 3.1 The Early Achievement of Modern Stature and Improved Nutrition in the U.S.

By the time of the American Revolution, native-born whites appear to have achieved nearly modern final heights. The analysis of a sample of recruits from the Revolutionary army(1775-1783) indicates that the final height of native-born white males age 25-35 averaged 68.2 inches. This figure is not only 1 to 4 inches greater than the final height of European males reported for several nations during the late seventeenth and early eighteenth centuries, but is virtually identical with final heights in the Union army during the Civil War and in the U.S. army during World War II (see Table 2).[6] Extending the analysis to a sample of recruits during the French and Indian War (1756-1763) indicates that final heights were increasing during the middle of the eighteenth century. After

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[6]The evidence on adult heights in Europe during the eighteenth and early nineteenth centuries have not generally been analyzed for secular trends and in some cases have not yet been adequately analysed for truncation bias. The principal studies of European heights during this period are cited in Appendix A. Only the series for Norway (Kiil) and the sample of Swedish heights recently retrieved and analysed by Sandberg and Steckel provide continuous series that reach back to the first half of the eighteenth century.

Table 2

Mean Final Heights of U.S. Native-Born White Males in Three Wars

| | Age Category | Sample size | Sample mean (inches) | Standard error (inches) |
|---|---|---|---|---|
| American Revolution | 24-35 | 968 | 68.2 | 0.08 |
| Civil War | | | | |
| Gould sample | 25-30 | 123,472 | 68.2 | 0.01 |
| Baxter sample | 25-34 | 54,931 | 68.2 | -- |
| World War II | 20-24 | 119,443 | 68.2 | 0.01 |

Note: Computed from data in colonial muster rolls, Gould, Baxter and Karpinos. The Revolutionary, Gould, and Baxter samples are based on inductees. The World War II sample includes rejectees. Maximum mean height in the World War II sample falls in the 20-24 age category. The data in Baxter's summary do not permit the calculation of the standard error of the mean. Data presented by Karpinos indicate that inductees were about 0.09 inches taller than examinees. Data presented by Baxter indicate that inductees were 0.03 inches taller than examinees. None of these averages are corrected for truncation bias, but the preliminary analyses indicate that such corrections would not reduce the figures shown by more than 0.2 inches.

controlling for place of birth, place of residence, and occupation, cohorts born between 1740 and 1765 were 0.4 inches taller (t = 2.4) than those born between 1715 and 1739. Since cohorts born before 1740 still attained final heights that averaged above 67.5 inches, it appears likely that improvements in nutrition began early and were quite rapid in America.

This inference is supported by data on food consumption in Massachusetts discovered by McMahon. Wills deposited in Middlesex county between 1654 and 1830 indicate a sharp rise in the average amount of meat allotted to widows annually for their consumption. Between c.1675 and c.1750 the average allotment increased from about 80 to about 165 pounds per annum. Over the next 75 years allotments rose more gradually, reaching 200 pounds at the end of the first quarter of the nineteenth century. Both the evidence on stature and on food allotments suggest that Americans achieved an average level of meat consumption by the middle of the eighteenth century that was not achieved in Europe until well into the twentieth century (cf. U.S.D.A.).

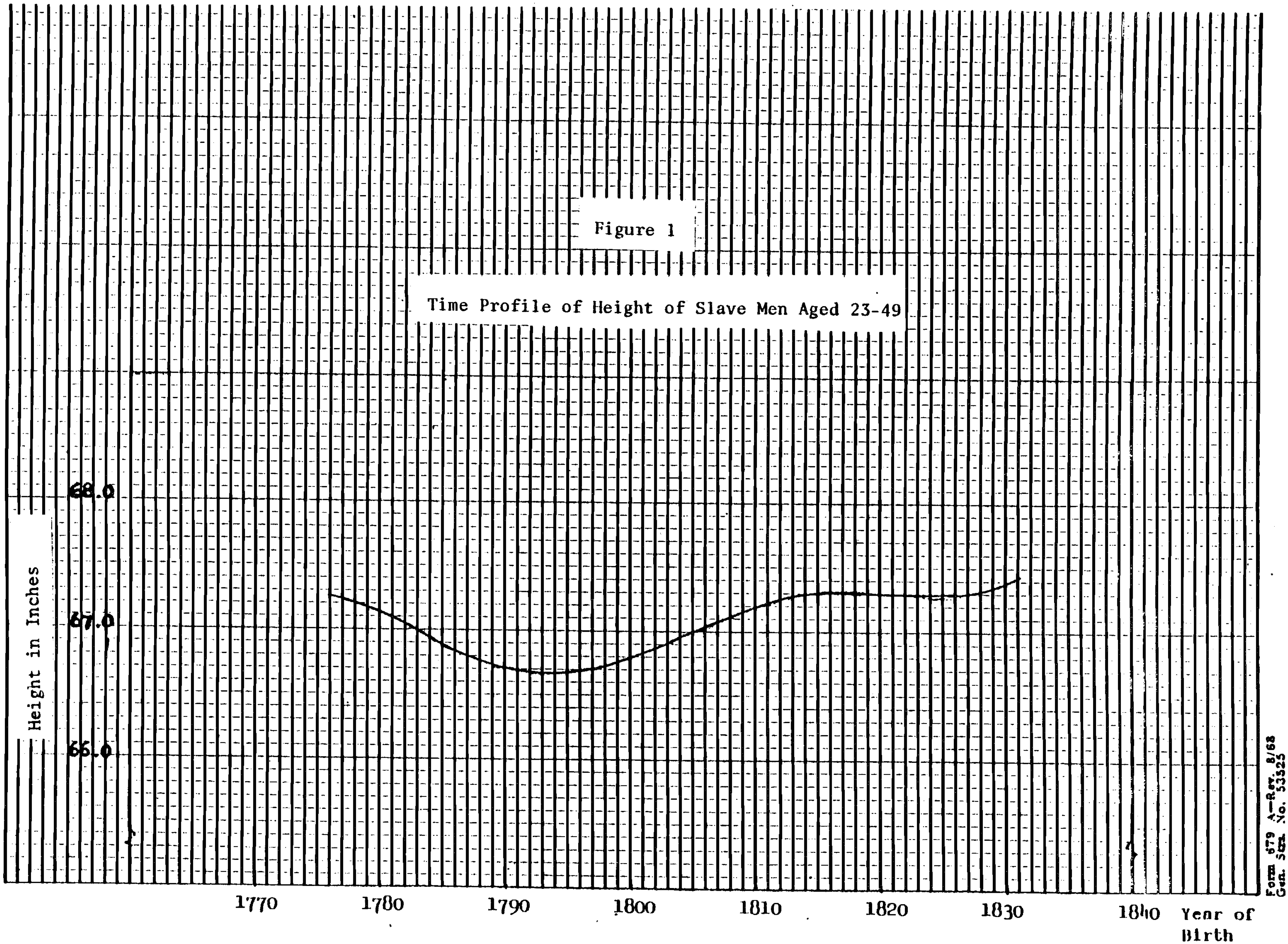
## 3.2 Cycles in Height

The estimated mean final heights of males for the three wars reported in Table 2 do not necessarily imply a perfectly flat secular trend between c.1778 and c.1943. Contrary to the popular impression that there have been continuous secular improvements in nutrition and increases in height, the evidence thus far analysed in this project indicates that there may actually have been cycles in height of both native-born whites and blacks residing (but not necessarily born) in the United States.

Analysis of information contained in the coastwise manifests indicates that the final heights of slaves born in the early 1790s was about a half inch less than those born in the late 1770s (see Figure 1). The final heights of cohorts born after 1790 increased for about 20 years, so that cohorts born after 1815 were slightly taller than cohorts born during the late 1770s and 1780s.

Figure 1

Time Profile of Height of Slave Men Aged 23-49




Source: Slave manifests.

Thereafter final heights remained fairly steady at about 67.3 inches for cohorts born through the early 1830s. The data in the manifests now available is too sparse to carry the analysis of this time-trend beyond cohorts born in the early 1830s. But the data on blacks taken from the Union Army muster rolls, which mesh quite well with the results from slave manifests for overlapping cohorts, indicate that cohorts born in the late 1830s and early 1840s may have experienced a decline in final heights that was even sharper than that experienced for cohorts born between 1780 and 1795.[7]

The time trend in the final height of northern, native-born whites is somewhat different from that of U.S. slaves. The rising trend observed for cohorts born before the Revolution levels off and appears to have remained fairly steady for cohorts born between the Revolution and the end of the 1790s. The regular army data needed to continue the trend from 1800 to 1819 have not yet been processed, but the preliminary analysis of a subsample (N = 773) of Union army records bearing on this period, which covers only the last few years of the teens, suggests that cohorts born during the first two decades may have experienced increasing final heights. It also appears that their upward trend leveled during the 1820s and then declined (see Figure 2). Over a period of 15 years the decline in the final heights of native-born whites appears to have been about one inch.

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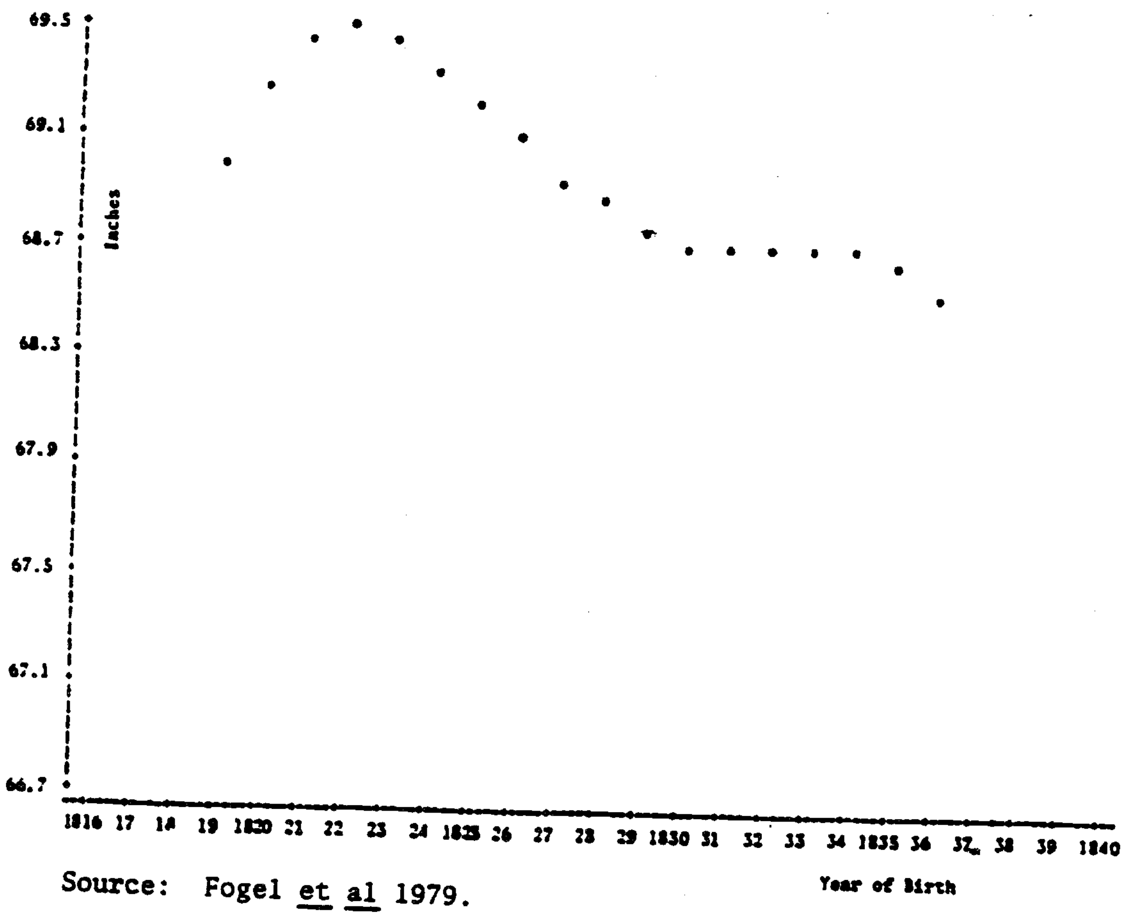
[7]Analysis of trends in heights of adolescent slaves confirm the general pattern revealed by adult heights, except that the amplitude of the cycles in adolescent heights are even greater than in final heights (cf. Steckel 1979a). Taken together the evidence on adolescents and adults suggests that there were periods of deterioration in nutrition and health of slaves that substantially retarded their rate of development during adolescence, but that this loss in tempo was partly compensated by a longer period of growth that permitted some "catching up."

Figure 2

AN INDEX OF THE TREND IN THE MEAN FINAL HEIGHTS OF U.S. NATIVE-BORN WHITES, BY BIRTH COHORT, 1819- 1836

(estimated from data on recruits into the Union Army who were between ages 25 and 44 at the time of measurement)




Source: Fogel <u>et al</u> 1979.

There is also evidence of a cycle in stature between the Civil War and World War II. When data in Karpinos and in U.S.D.H.E.W. (1965) are arranged by birth cohorts, it is possible to calculate the growth rate of mean final height for cohorts born between c.1906 and c.1931. Table 3 shows that final height increased at a rate of 1.2 inches per generation between the cohorts born c.1906 and c.1921; between the c.1921 and c.1931 cohorts, the rate was 2.7 inches per generation. Obviously, even the 1.2 inch rate could not have extended back to the Civil War. That would require the final height of c.1863 to have been about two inches below the level indicated by the Gould and Baxter samples. Indeed, since the final height of the c.1906 cohort is about a half inch below the final height shown in the Civil War data, it seems that sometime between c.1863 and c.1926 (1906 + 20), final height declined.

Preliminary analysis of the British data has been focused on the trend in heights in London of adolescent boys from poor families over the period from 1770 to 1870. This analysis reveals that the mean height of boys aged 14-16 from families of laboring classes was relatively steady from c.1775 to c.1790 and then declined for two decades, the lowest point coming about 1810. The extent of the decline was about 1.5 inches. From c.1810 to c.1838 mean heights increased quite rapidly, at a rate of 2 inches per decade so that the maximum previous mean was exceeded by 1820. After c.1838 heights again appear to have declined, but the new rate of decline was only about 0.2 inches over a period of 20 years, after standardizing for socioeconomic characteristics.

The exact timing of the sharp rise in height following the close of the Napoleonic wars is still under investigation. Although future work on statistical issues might lead to an expansion or compression of the period of rapid increases in heights, it is clear that poor adolescent boys in London were about 4 inches taller after 1838 than their counterparts had been before 1790. Indeed, the adolescent poor of London in the late eighteenth century were

Table 3

TWENTIETH-CENTURY GROWTH RATES IN MEAN FINAL HEIGHT OF U.S. MALES
(estimated from cohorts measured in c.1943 and c.1961)

Part A: Mean Final Heights Arranged by Cohorts

| | Age category when measured | Sample size | Midpoint of the interval in which cohort was born | Mean height, at time of measurement |
|---|---|---|---|---|
| | | From U.S.D.H.E.W. (1965) | | |
| 1. | 25-34 | 10,281 | 1931 | 69.11 |
| 2. | 35-44 | 11,373 | 1921 | 68.11 |
| | | From Karpinos | | |
| 3. | 20-24 | 141,803 | 1921 | 68.15 |
| 4. | 25-29 | 99,786 | 1916 | 68.06 |
| 5. | 30-34 | 96,704 | 1911 | 67.81 |
| 6. | 35-38 | 53,624 | 1906.5 | 67.58 |

Part B: Growth Rates Per Generation Between Cohorts

| Interval over which growth rate is calculated, by birth of cohort | Growth rates (in inches per 30 years) |
|---|---|
| 1921-1931 | 2.7 |
| 1906.5-1921 | 1.2 |

Note: Data from longitudinal studies of stature indicate that shrinkage does not usually begin before age 50 (Tanner, privately communicated). If taller individuals were more likely to survive to a given age, the estimated growth rates would be biased downward, but the size of the bias would be small. If, for example, those who died between ages 30 and 40 were one inch shorter on average than those who survived to age 40, then (using the applicable life table in Preston, Keyfitz, and Schoen) one would have to reduce the height of the c.1921 cohort by 0.03 inches before computing the 1921-1931 growth rate. This change would increase the 1921-1931 growth rate from 2.70 to 2.77 inches per generation. Cf. sections 3.4 and 4, below.

so short that only two of 81 ethnic groups for which modern height data are available, record lower adolescent heights. These are the Lumi and Bundi of New Guinea--two exceedingly impoverished populations. Even after the period of rapid increase, poor London boys were still quite short by modern British standards; at age 14, they were about 5 inches shorter than British boys of the same age today--a gap that is due partly to the slow rate of physical maturation and partly to the low final height of the nineteenth-century boys.

### 3.3 The Influence of Economic and Social Factors on Height

Multivariate regression analysis has been applied to several of the samples of data listed in Table 1 in order to relate final heights to such economic characteristics as occupation, migration experience, urban birth or residence, race, and place of birth. At the present time, with a few exceptions, the analyses have been limited to the information about each individual contained in the records on height. However, work is now underway to link information on the individuals in the original data sources with information on the same individuals and their families in the manuscript schedules of censuses, in probate and tax lists, and other records. For example, the individuals included in the sample from the muster rolls of the Union Army are now being linked with information on their households contained in the manuscript schedules of the 1850, 1860 and 1870 censuses and with the pension records on these individuals and their heirs, usually filed late in their life or shortly after their death. In this way it is possible to obtain relevant information on the individuals, not only at the age of enlistment, but also during their growing years and in their later life. Such linking also allows the analysis of the effect of inter-generational factors (such as the ethnicity, wealth and social status of parents and grandparents) on the development of children and grandchildren. Where such interrelationships cannot be established through direct linking at the household level, it is possible to use cross-sectional regression techniques, with counties or similar geographic divisions as the unit of observation, to anslyze the nexus between height and relevant social and economic variables.

The regressions so far performed on the muster rolls of the French and Indian War, the Revolutionary War, the regular army during the early national period, and the Civil War show that in all four periods (1756-1763, 1775-1783, 1815-1820, and 1861-1865), persons of foreign birth were about an inch or more shorter than those of native birth. There was a significant shift over time in the impact of urban-rural residence on the final heights of the native born. Beginning with final heights virtually identical with native-born persons of urban birth, native-born persons of rural birth gained an advantage of 0.8 inches by the time of the Revolution, and this gap continued down to the time of the Civil War.[8] There were also significant shifts over time in the relationship between occupations and stature. From only minor discrepancies in final heights between farmers and other occupational groups during the colonial period, significant differences had emerged by the time of the Civil War. Blue collar recruits are nearly 0.8 inches shorter than farmers, after adjusting for urban/rural and nativity status. In all four time periods, the cross-sectional regressions yielded statistically significant coefficients on region of birth, race, and migratory experience.

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[8]Among the native born serving during the French and Indian War, there is no evidence of a statistically significant relationship between urban birth or residence and stature. In the Revolutionary sample, the results are sensitive to the age group over which the regressions are estimated. If the regression is estimated over recruits aged 24-35, the urban birth coefficient is not significantly (in a statistical sense) different from zero. The urban residence (for native born) coefficient is -0.9 and of marginal statistical significance ($t = 1.71$). If one estimates the equation over recruits aged 24-45, the urban birth coefficient is significant at the 90% level, and the urban residence coefficient remains of marginal statistical significance. The negative coefficient on a native birth in an urban area only becomes statistically significant and robust in the 1815-20 sample, when it is -0.5 with a t-statistic of -4.12.

Because ex-slaves in the Union army were geographically concentrated, the sample already in hand is large enough to experiment with cross-sectional analysis at the county level. The analysis of final heights was performed on a sample of 913 ex-slaves who were between ages 12 and 17 at the time of the 1850 census. On average, ex-slaves were about an inch shorter than native-born whites. Moreover, slaves from the deep-South states that specialized in cotton and rice were shorter than those from border states engaged in tobacco and general farming. These state differentials appear to be explained by the positive correlation of height with per capita corn production,[9] a negative correlation with the median size of the slave plantation, and a negative correlation with urbanization.

In the case of the London boys there is much information on their socio-economic characteristics before they entered the Marine Society[10] which may be relevant in explaining variations in heights, but analysis of this information is retarded by the limited range of differences in the occupational categories, by variations in the minimum height standard, and by the rapid pace of change. Two characteristics which do appear as significant determinants of height so far are addresses outside of London (which are associated with taller boys) and the designation "destitute" (which is associated with shortness).

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[9] Since corn was mainly a feed crop, corn per capita may be viewed as a proxy for meat per capita.

[10] The Marine Society, the source of the height data on the London boys, was a charitable organization which took in indigent or otherwise poor boys and prepared them for careers in the merchant marine or the Royal Navy.

## 3.4 The Influence of Height on Social and Economic Behavior

One of the bodies of data recently analysed bears on the impact of height on the productivity of manual laborers. Some commanders of the Union Army treated runaway slaves as contraband of war, and so, in addition to recording some of the usual information found in muster rolls, they also included information on the value of the slaves. One such contraband list, discovered in records for Mississippi, has recently been analyzed.[11] The mean height of the 523 adult males in this sample was 67.4 inches, with a standard deviation of 2.8 inches--almost identical with the corresponding figures for Mississippi recruits obtained in the main sample of black companies (see line 2 of Table 1).[12]

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[11] These records were discovered by Armstead Robinson. The estimates of value appear to have been made by bona-fide slave appraisers.

[12] The contraband sample is exceptional not only because of the information on value, but also because it is a rare instance, for the early and mid-nineteenth century, when data are available for both height and weight. The Mississippi slaves had a mean weight of 2.3 pounds per inch of height, when measured at mean height. Corresponding figures for samples of adults aged 30-34 are 2.2 pounds per inch for whites in the Union Army, 2.3 pounds per inch for white registrants in World War II, and 2.3 pounds per inch for black registrants in World War II. These weight-for-height figures indicate that Mississippi slaves were slightly heavier, for given stature, than the whites in the Union Army, but about the same as registrants for selective service in World War II. The Union Army figure was computed by fitting a linear regression to the data in Gould, pp.426-428; the World War II figures are from Karpinos, p.32.

Regression analysis revealed that the value of slaves was positively associated with both height and weight. A slave of average weight for his height who was one standard deviation taller than the mean height was worth 7.7 percent more than a slave who was one standard deviation shorter than the mean height. Some part of this increment in value may be due to the fact that tall slaves were, on average, stronger, healthier, and capable of more intense labor than short slaves. But two other factors, which could not be entered into the regression because of the absence of information on them in the contraband sample, are probably also reflected in the differential in value associated with stature. It is probable that healthy slaves had a longer life expectation than unhealthy ones. It is also possible that slaves in the more highly skilled jobs were taller than those engaged in field work. Thus the increase in productivity implied by the height differential in value could have taken several forms: one is greater intensity of labor per day at a given task and for a fixed expectation of life and labor; a second is unchanged intensity of daily labor at a given task with an increased expectation of life and labor; a third is unchanged intensity of daily labor and life expectation, but employment in occupations requiring greater skill than ordinary field work.

Analysis of the data in the Trinidad sample (see item 10 of Table 1) bears on these possibilities. Height was a factor in the selection of slaves for particular occupations in Trinidad. Among adult males craftsmen were on average a half inch taller, and drivers (the foremen of field gangs) were an inch taller than fieldhands, while domestics were an inch shorter than fieldhands. Since slaves were not usually chosen for craft occupations until their twenties, and since regression analysis revealed no relationship between the occupation of the parents and the height of the children, it appears that the final height of children was not affected by their position, but that owners or overseers used height as a criterion for determining which slaves would be assigned to particular occupations.

Perhaps the most important result to emerge from the study of the Trinidad data thus far is that death did not choose slaves at random. Short slaves at every age during the life cycle were more likely to die than tall slaves. After standardizing for age, the annual death rate for the shortest quintile of males (47 per 1000) over a twenty month period extending from 1813 to 1815 was more than twice as great as that of the tallest quintile of males (21 per thousand). Among females the standarized death rates for the lowest and highest quintiles of height were 43 and 29 per thousand, which suggests that female death rates were less sensitive to nutritional circumstances than were males. One implication of this finding is that the combination of the exceedingly high death rates in Trinidad and the large impact of height on the probability of dying makes the observed height-by-age profile rise more rapidly than would have been so in a less severe environment in which a larger proportion of short slaves would have survived to adult ages. Alternative simulations suggest that a 50 percent reduction in the death rate with other factors held constant, might have reduced the observed final heights of males by about an inch.

## 4. Some Economic and Demographic Issues Raised by the Preliminary Findings

The apparent downward shift in the U.S. height profile for the native-born whites during the last several decades of the antebellum era does not imply that the profile of every subpopulation declined. The decline might have been heavily concentrated within the urban population. The rate of urbanization accelerated sharply after 1820, and conditions of life in the larger cities apparently deteriorated. There is evidence in several northeastern cities of an upward trend in the mortality rates (Yasuba). On the other hand, the decline might have been a consequence of an increased flow of immigrants; experiments on animals indicate that malnutrition in one generation effects the size of subsequent generations (Chandra). The patterns observed in the height-by-age data are consistent with evidence that the period between 1820 and 1860 was marked by an increase in the inequality of the income distribution, with the heights and wages of common laborers falling relative to those of other groups (Lindert and Williamson).

The two cycles in height discovered for U.S. slaves probably have somewhat different explanations. Since the coastwise manifests did not distinguish between foreign- and native-born slaves, and given the three-inch differential between the height of U.S. slaves of African-born slaves in Trinidad indicated by the data, an increase from 15 to 30 percent in the proportion of the African-born slaves listed in the manifests could account for about three-quarters of the first decline in slave heights. Since the years between the end of the Revolution and the close of the international slave trade witnessed a sharp increase in slave imports, such an explanation is plausible. Some part of the second height decline (of slaves born in the late 1830s and the 1840s) might be due to ethnic mix, but it is unlikely that the share so attributed could exceed one-quarter of the estimated decline. The Trinidad data indicate that first generation of native-born males in non-sugar production were about 1.5 inches taller than the African-born males, which suggests that about half the height gap was made up in one generation. Moreover, it is probable that close to half of the persons descended from Africans imported into the U.S. between

1783 and 1808 and born between 1835 and 1845 were not children but grandchildren or great-grandchildren of Africans. It seems likely, therefore, that most of the second decline was due to a rise in the intensity of labor, a decline in meat consumption, a rise in morbidity (cf. Steckel 1979b), or some combination of these factors.

The changing levels of nutrition and health over time implied by the height data have substantial implications for the study of the U.S. mortality experience. The evidently high level of nutrition in America at the time of the Revolution may well provide a partial explanation of the high fertility rates and low mortality rates, relative to Europe, which characterized the early U.S. demographic experience.[13] As the consumption of food is a major component of the standard of living in such preindustrial societies, the advantage in height also provides strong evidence of the superior material

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[13] Recent summaries of evidence bearing on the link between nutrition, fecundity (reproductive capacity) and fertility (actual reproduction) are Bongaarts (1980) and Menkin, Trussell and Watkins (1981). Both papers stress that moderate chronic malnutrition has only "a minor effect on fecundity" and that the effect on fertility "is very small." However, famine and severe chronic malnutrition can substantially reduce fertility. It is not clear how much of the reduction associated with famine and severe chronic malnutrition is due to a decline in fecundity (although amenorrhea and reduction in sperm motility and longevity are involved) and how much is due to such indirect factors as loss of libido, increased separation of spouses (because of search for work or food) and, especially for societies during the eighteenth and nineteenth centuries, because of increases in deaths which lead to a premature ending of childbearing or to increased birth intervals (because widowhood reduces sexual intercourse).

conditions enjoyed by the average American during the period. However, despite the close correlation between changes in heights and in mortality over the period 1730-1865 (see N.B.E.R.), a substantial portion of the pre-1850 decline in national mortality rates appears to be explained by other factors besides changes in nutrition. The late eighteenth and early nineteenth centuries were characterized by the narrowing of interregional differences in mortality rates between New England and the South. Crude mortality rates in Massachusetts appear to have remained in the 15 to 25 per thousand range throughout this period, while the rates for whites in the South declined from about 50 per thousand to about 25 per thousand (Vinovskis, Fogel et al). The higher mean final height found for the South than for the North during this period tends to dispel the notion that the southern mortality rates were linked to lower levels of nutrition in that area. It now seems more likely that superior nutritional circumstances may have operated to close the gap between regional death rates by counteracting factors that tended to increase mortality in the South (disease pool, climate, etc.). Fragmentary evidence suggests that southerners were heavy consumers of meat in the late colonial and early national eras (cf. Sokoloff and Villaflor 1972; L. C. Gray).[14]

Nevertheless, it is possible that some part of the height advantage of the South was due to the "Trinidad effect." Although death rates were far less severe in the South between 1750 and 1860 than in Trinidad c.1813, the higher probability of death for shorter persons would have tended to inflate southern

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[14] In 1901, the earliest year for which systematic surveys of food consumption by region are available, the per capita consumption of beef and pork was about 4 percent greater in the South than in the North. The food survey is from U.S. Bureau of Labor, pp. 647-648. The North is an average of the NA and NC regions and the South is an average of the SA and SC regions, using the regional populations as weights.

heights relative to northern heights, over and above the direct nutritional effect. Consequently there not only appears to be a direct nutritional effect but (holding nutrition constant) a mortality effect, and an interaction effect. The magnitudes of these separate effects are yet to be determined.[15]

We are currently preparing to study the relationship between mortality and nutrition in the United States (or height as an index of nutrition) more directly. Utilizing genealogical and military data from the eighteenth and nineteenth centuries, we are beginning to link estimated mortality rates at a county level with mean final heights for the geographic regions. We will also, as previously indicated, introduce measures of nutritional status into production functions for both the agricultural and manufacturing sectors. The results may not be unambiguous, since the intensification of labor that enhanced productivity and accompanied the growth of the manufacturing sector could have led to an increase in the per capita energy output relative to the consumption of calories and nutrients among adolescent laborers, and this may have produced a decline in stature.

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15 The "Trinidad effect" might also have contributed to the decline in white heights after the mid-1820s shown in Figure 2, since persons from the earlier birth cohorts who survived to be mustered into the Union army would be taller than those from later birth cohorts, even if the mean height of each cohort at a specified age (such as 30) was the same. Given the prevailing mortality schedules, however, and the age span involved (25-45), the "Trinidad effect" could account for only about one-tenth of the drop after the mid-1820s shown in Figure 2, and it could not explain the preceding rise in heights.

It cannot be assumed, therefore, that a decrease in the final heights of native-born whites after 1825 necessarily implies a reduction in per capita food consumption. It might seem unlikely that the stature of whites, who were free and experienced most of their growth by age 20, would be much influenced by changes in labor organization. During the nineteenth century, however, especially before 1850, boys commonly entered the labor force before age 16 and the peak of their adolescent growth spurt generally was not reached until age 16. Consequently, a decline in height could have resulted because there was an increase in the per capita energy output of these young workers without a corresponding increase in the per capita consumption of calories and nutrients. British invesigations of child labor in factories during the nineteenth century tend to support this hypothesis. Children of a given socioeconomic class who worked in factories were substantially shorter at each age than children of the same class who were not so employed (Great Britain 1833; British Association).

Still, it is possible that the food consumption of the urban laboring classes did decline between 1825 and 1860. This possibility cannot be ruled out either because of the slight downward trend in food prices or because of the upward trend in some of the currently available indexes of real wages. Part of the problem with the wage indexes, as previously noted, is that the series on money wages may confound urban with rural wage rates and is not adequately standardized for locational and occupational mix. Another part of the problem is that the current measures of consumer prices do not include data on the cost of shelter, which may have accounted for a quarter or more of the total expenditures of urban laborers during this period. There is considerable evidence that the rapid growth of the urban population between 1820 and 1860 led to severe shortages in urban housing, and hence probably to a sharp rise in the price of shelter. The decline in the availability of wood and the shift from wood to coal as a fuel source may also have contributed to the rising cost of shelter. Consequently, it is entirely possible that an index of consumer prices that included the cost of shelter would show that the real wages of urban laborers declined between 1825 and 1860. Moreover, if the income and price elasticities of the demand for shelter by urban laborers (at the relatively meager incomes of the time) were sufficiently low, sharp rises in the cost of shelter could have led to decreases in the amount of food consumed, particularly in the consumption of such relatively expensive foods as meats and fish, even in the face of constant or declining food prices.

In the English case, we have been able to make a comparison between a series on heights and a widely used series on real wages for London artisans. Although Von Tunzelmann has demonstrated that nation-wide indexes of real wages are unreliable because of the implicit shifts in the weights brought about by the splicing together of diverse series, there is still the question of whether indexes for particular localities and classes of labor are reliable. Also at issue is the assumption that trends in the real wages of artisans mirror those of common laborers. Tucker's series on the real wage of London artisans benefits from the restriction of its geographic scope to one locality. When one compares the mean height of boys aged 14-16 from families of common laborers in the London area, over the years between 1775 and 1865, with Tucker's series, a certain degree of conformity is evident (see Figure 3). The heights of the boys will reflect their cumulative nutritional experience over their lifetimes, and especially the experience of the years immediately preceding and during the growth spurt. Accordingly, the height series is related to the wage series lagged five years, although longer lags (10 and 13 years) provide similar results.[16]

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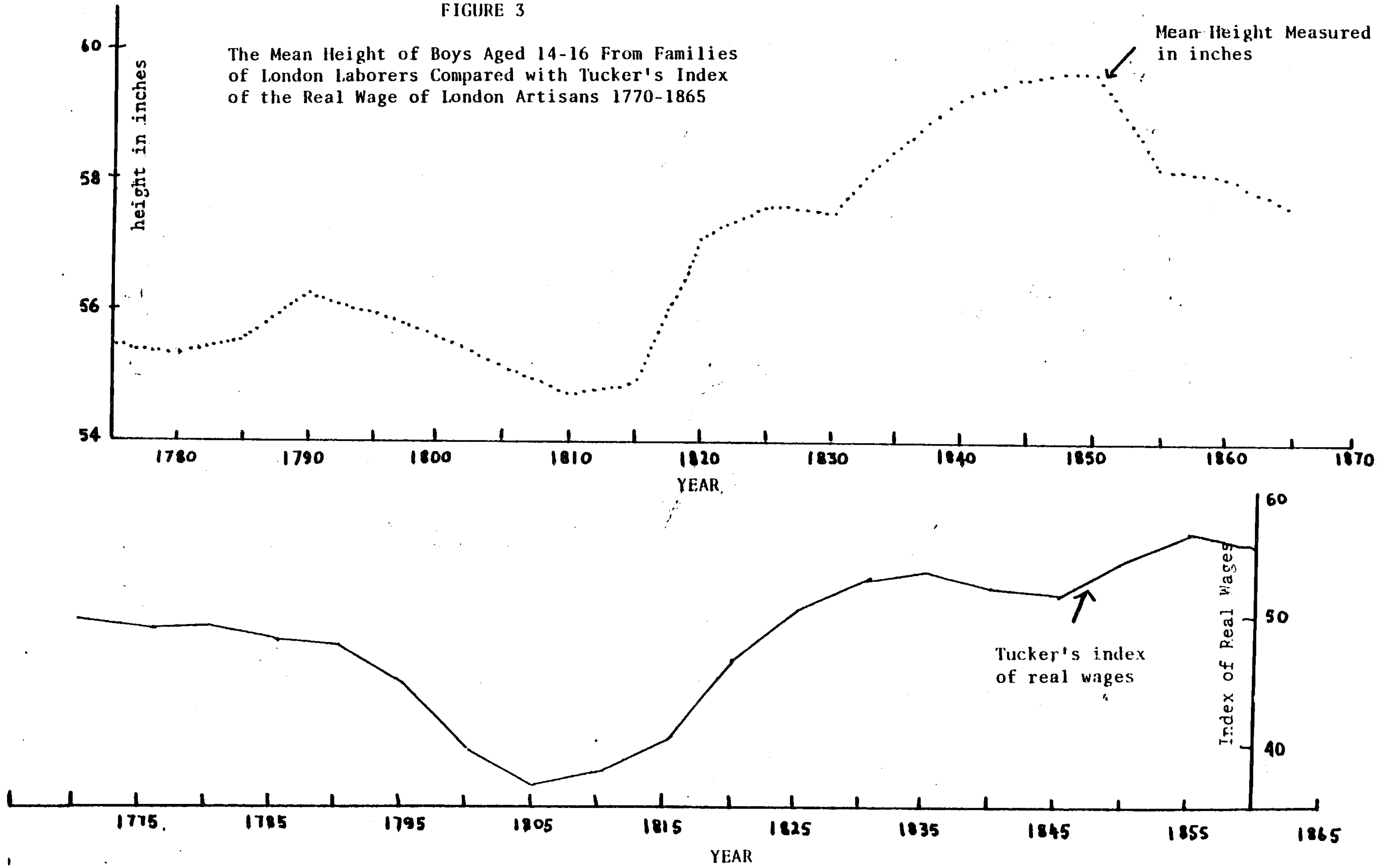
[16]Each observation is an average of 10 years centered at the indicated date.

FIGURE 3

The Mean Height of Boys Aged 14-16 From Families of London Laborers Compared with Tucker's Index of the Real Wage of London Artisans 1770-1865



The two series generally move together during both rising and declining phases, except for the last two decades. The results suggest that for most of the century, the real wages of artisans and of the poorest sections of the London working class tended to move together in London. On the other hand, the elasticity of height with respect to Tucker's wage index is not constant, and the preliminary regression analysis of the relationship between the height of boys in the Marine Society and the occupations of their parents suggests that the difference in height by occupational strata within the laboring classes changed over time. These findings raise the possibility of a changing relationship between the wages of common laborers and of artisans even prior to 1840, and illustrates the problem of generalizing from the experience of one group of a population (or the average) to those of other groups.

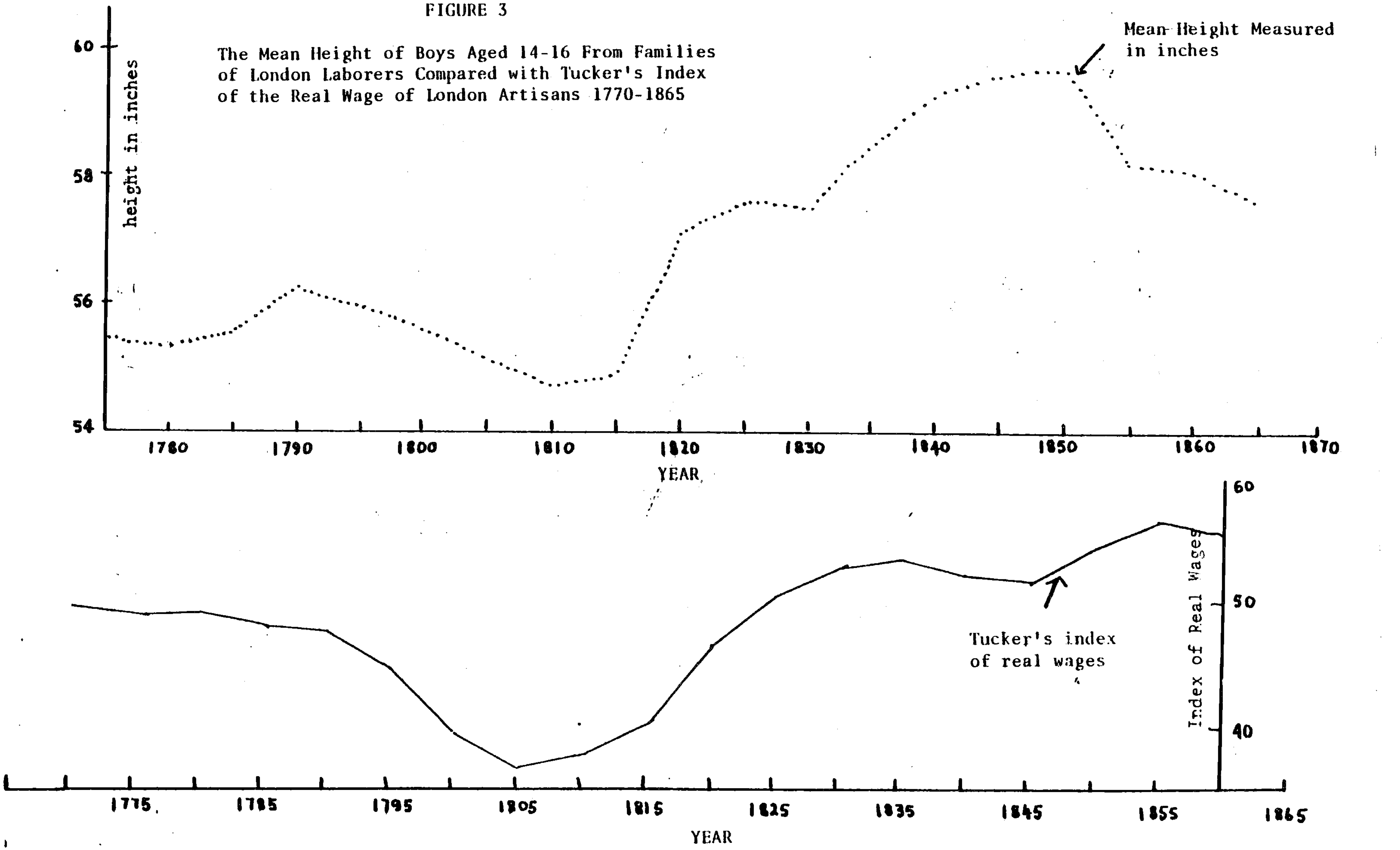



FIGURE 3

The Mean Height of Boys Aged 14-16 From Families of London Laborers Compared with Tucker's Index of the Real Wage of London Artisans 1770-1865

Figure A.1

Estimates of Heights of Males Ages 8 – 18
U.S. Slaves, Trinidad Slaves, Massachusetts Whites and British Whites, Nineteenth Century

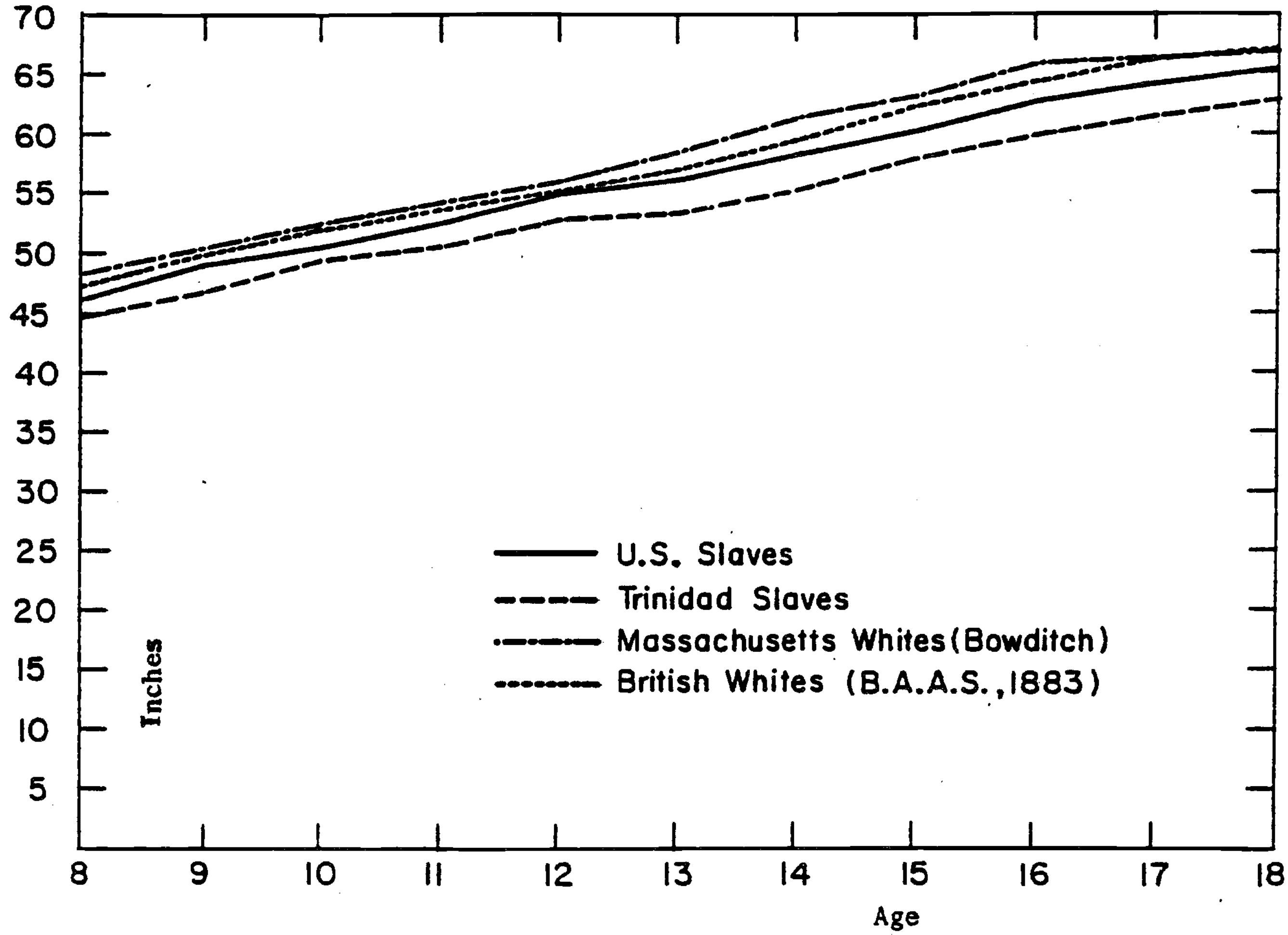
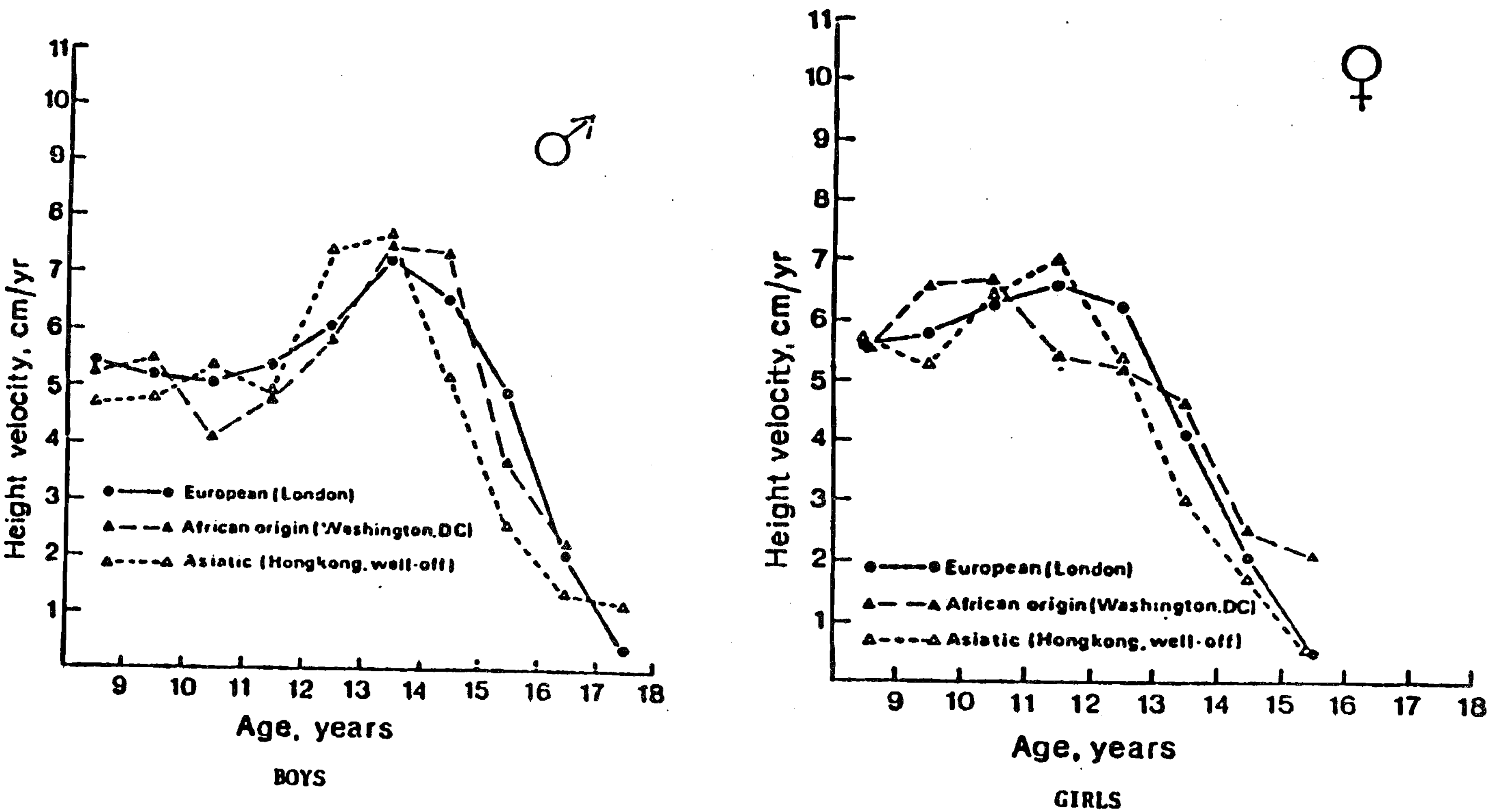


Figure A.2

PROFILES OF HEIGHT VELOCITIES DERIVED FROM CROSS SECTIONS FOR THREE CONTEMPORARY POPULATIONS




SOURCE: Tanner and Eveleth

but the British study reported that children employed in factories were shorter and lighter at each age than those that were not, and Quetelet suggested that the distribution of heights at each age was described by the normal curve. Various studies between 1829 and 1875 showed variation in the age at which growth of stature terminated, and associated this variation with socioeconomic factors (Villermé; Quetelet, Dunant, Gould, Champouillon, Baxter).

The existence of the adolescent height and weight spurts was noted by Roberts and more completely described by Bowditch in the late 1870s. Boas in 1892 and 1930, and then Davenport, Shuttleworth (1937, 1939), and Tanner (1962) demonstrated that both in cross-sectional and longitudinal growth studies the standard deviation of height at each age rose during the adolescent spurt, reached a maximum at the peak of the spurt, and then declined. Boas (1892) and Tanner (1959) also noticed that, although the distribution of height at each age was approximately normal before and after the growth spurt, it was slightly right-skewed as growth accelerated and slightly left-skewed as it decelerated. During the past half century there have been numerous investigations of the relationships between such measures of maturity as the height spurt, skeletal age, age of menarche, dental age, and muscle growth (Shuttleworth; Stoltz and Stoltz; Tanner 1962; Frisch and Revelle; Frisch 1974 and 1975; Tanner, Whitehouse, Marubini, and Resele).

5.2. Secular Growth

Students of human growth during the nineteenth century debated the question of secular shifts in the height-by-age profile but did not necessarily presume that these shifts were upward. There was concern both in England and on the continent with the possibility that stature might have declined (Boudin; British Association; Floud 1978). Beginning in the late 1920s, and continuing at an accelerating pace down to the end of the 1960s, various investigators called attention to evidence suggesting that substantial upward shifts in the height-by-age profile had occurred over the 50 to 100 years following the third quarter of the nineteenth century (H. Gray; Boas 1935; Kiil; Morant; Boyne and Letich; Hathaway and Foard; Tanner 1966; Ljung, Bergsten-Brucefors and Lindgren; Greulich 1976; van Wieringen; Gandevia).

While these studies have established a world-wide pattern in industrialized countries during the past 100 years toward earlier maturation and greater final heights, several important questions remain open. One is whether the secular trend in heights has been (more or less) monotonic or cyclical. Some studies indicate that while famines, epidemics, wars, and severe business cycles have briefly interrupted or briefly reversed the pattern of secular growth (Tanner 1962; Udjus; van Wieringen), such episodes did not fundamentally alter the generally upward thrust of secular growth. On the other hand, Trotter and Glesser, using measurements of white and black cadavers, found evidence suggesting that the long-term pattern of change in U.S. stature might have been cyclical, with substantial periods of no-growth or decline. Another question is when the secular growth trend began. Norwegian military data stretching back to 1740 indicate little change in conscript heights prior to 1830 and only about a half-inch increase over the next 50 years (Kiil), but a sample of Swedish military data indicates that adult Swedish heights increased between 1720 and 1760, stabilized for about 3 decades, and then increased again after 1790 (Sandberg and Steckel). Dutch data suggest that from about 1860 to about 1900 secular growth was experienced mainly by conscripts from lower classes but that after 1900 conscripts from upper classes were drawn into the process (van Wieringen).

5.3 Socioeconomic and Other Factors Influencing the Pattern of Growth

Observational studies of human populations and laboratory experiments with monkeys have demonstrated the impact of nutrition on the shape and position of the height-by-age profile (see Tanner 1962, Eveleth and Tanner, Tanner 1978, and the sources cited in these). The height profiles of well-fed males (females) in a given population are higher at all ages than of poorly-fed males (females) from the same populations. Moderate chronic malnutrition will delay the growth spurt and extend the growing period but will have only a small effect on terminal heights. Severe chronic malnutrition leads to permanent and substantial stunting. Severe but brief episodes of malnutrition, as in wartime famines, delay growth but are generally followed by rapid recovery and do not affect final height. Laboratory experiments on monkeys indicate that growth is affected by both caloric and protein deficiencies but that the effects of protein deficiencies on growth may be more severe than caloric deficiences alone. (Fleagle, Samonds and Hegsted; Elias and Samonds). Minor diseases have little effect on the growth profiles of well-nourished children but may have transient effects on the profiles of poorly-nourished children. Major diseases, as with severe brief famines, delay growth, but recovery leads to catching-up and, with the exception of disorders of the growth process itself, do not cause permanent stunting.

Twentieth-century studies show that urban residents have more rapid tempos of growth than rural ones and achieve greater final heights (Eveleth and Tanner; Tanner 1978). Quetlet found the same effect among the French in the 1830s but Roberts reported that in Great Britain in the 1870s rural boys aged 8 to 13 were 1.5 to 3.0 centimeters taller than urban boys. It thus appears that there may have been significant changes over time and place in the effects of particular socioeconomic variables on the tempo of growth.[17]

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[17] In many more developed nations, height differences by occupation are narrower today than in the nineteenth century, but Sweden is the only nation so far in which they have disappeared (Tanner 1981).

There are differences in the height profiles by race, both in tempo and final heights, but the relative importance of genetic and environmental factors is still a matter of dispute (Greulich 1958, 1975; Eveleth and Tanner). Well-fed Nigerians have growth profiles quite similar to Europeans. Well-fed U.S. whites and blacks have the same final heights but blacks exhibit a more rapid tempo of growth, with earlier peaking of the adolescent growth spurt and earlier menarche than whites. Asians from high socioeconomic classes generally have a more rapid tempo of growth than Europeans or U.S. whites, but have lower final heights. In recent years the difference in final heights between Japan and Europeans or Americans has diminished.

Both tempo and final heights are correlated with occupation, although in twentieth-century U.S. and European populations the differences in final heights appear to be relatively small. Tempo also appears to be affected by birth order and number of sibs. Other factors affecting the height profile include psychosocial stress (apparently operating through the rate of hormone secretion); and climate, which may, over evolutionary time, have affected body proportions, but which appears to have little effect on tempo or final heights. The rate of growth appears to vary over the seasons of the year.

## 6. Appendix B

## Statistical Issues

Much of our work during the past four years has been devoted to assessing the quality of the data in the samples listed in Table 1 (pp. 10-11) and in working out procedures for the detection and correction of biases that might distort our estimates of secular trends in height. Many of these problems relate to the fact that the oldest and most numerous bodies of information were collected by military organizations. Use of military data raises questions about the extent to which soldiers and sailors were representative of the underlying populations from which they were drawn. The problem is different in volunteer armies and 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, there is the question of the extent to which applicants are self-screened. In conscript armies virtually every male in the eligible age, including those who offer substitutes or are otherwise excused, are examined and measured.

Our procedures for the detection and correction of bias turn on a combination of theoretical considerations, empirical information, and simulation techniques. Much of the power of these techniques turns on the fact that the distribution of final heights is well described by a normal distribution. The standard deviation of this distribution is rather tightly bounded for European, North American, and Afro-American populations. Regardless of the ethnicity or the socioeconomic conditions of the population, the standard deviations appear to fall in the range of $2.6 \pm 0.6$ inches.[18] The distribution of height

[18] This is the case in large samples of complete populations. Of course for smaller samples, the range of the standard deviation is larger. For further evidence, see Kemsley, Karpinos, U.S.D.H.E.W., and the sources cited in them.

at each age during growing years is not normal, but is nearly so. Moreover, the standard deviation of height follows a pattern during the adolescent growth spurt that is quite similar to the velocity profile. It rises as the growth spurt approaches, reaches a peak at the peak of the growth spurt, and then declines back to the level just before the onset of the spurt.

6.1. Sample-Selection Biases

Use of military records to measure secular trends in height poses a variety of sample-selection biases. The most important of these is the problem of left-tail truncation which is characteristic of both the U.S. and British armies during peacetime. Truncation and other censoring problems are discussed in section 6.3. Here we consider two other questions: the self-selection bias of volunteers; and whether persons rejected for reasons other than height are nevertheless shorter than those accepted.

There is clearly evidence of self-selection bias in volunteer armies. Persons of foreign birth and from cities are overrepresented. Native-born individuals living in rural areas are underrepresented. Similarly, artisans and non-farm laborers are overrepresented while farmers and those in white collar occupations 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 aggregate heights. Necessary weights are available from the federal censuses and other sources. Of course, much of the interest turns on secular trends in the heights of particular groups which, even if underrepresented, are nevertheless present in sufficient numbers to permit analysis.

There is, of course, the issue of whether volunteers in particular subgroups (eg., blue-collar urban laborers aged 20-25) are representative of the class from which they are drawn. Our approach to this question is to compare the characteristics of the volunteers in the peacetime army with individuals of the same subgroups in wartime armies subject to conscription (World War II), or in which a very high proportion of those of military age were examined (the Civil War), or in scientifically designed random samples (the U.S.D.H.E.W. sample of 1960-1962). Most of our work to date has focused on the Civil War records of the Union army. The Civil War involved a larger proportion of persons of military age than any other war in American history. Thus about 95 percent of white males aged 18-25 in the Union states were examined; and about 75 percent of the examinees were inducted.[19] The results of our investigation so far indicate that with respect to height volunteers from particular subgroups are representative of the subgroups from which they are drawn, although we are still at an early stage of this investigation. If subsequent research should indicate biases so far undetected, that work will also provide the desired correction factors.

There is still the question of whether persons actually inducted into the army, but rejected for reasons other than height, were shorter than those accepted. The World War II data analysed by Karpinos show that 41 percent of all those called for examination were rejected and that rejectees were an average of 0.22 inches shorter than those inducted. Consequently, the failure to take account of rejectees would bias the estimated mean final height of the overall population upward by 0.09 inches. While a bias of this magnitude is statistically significant because of the large sample size, it is too small to have a significant effect on most of the points at issue in this study. The data presented by Baxter indicate that the bias arising from the non-measurement of persons rejected because of disease in the Union army introduces

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[19] Estimated from data in Gould, Baxter, and U.S. Provost-Marshall-General.

an upward bias in the estimated final height of the overall population of 0.03 inches. Although we are planning to draw a sample of rejectees from the Union army records (see Table 1, item 4) to further analyze their characteristics, the expense of corresponding samples for other military organizations does not now seem warranted.

## 6.2. Measurement Biases

These are a series of issues regarding the reliability of measures pertaining to the height-by-age schedule. Some pertain to the accuracy of the age information, some to the accuracy of the height information. Issues regarding age include age-heaping, whether ages are reported to the nearest birthday or the last birthday, and whether ages were arbitrarily assigned on the basis of height. Issues regarding height include heaping on even heights, whether heights were rounded to the nearest inch (or fraction of an inch) rather than to the last full inch (or fraction), 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. While such heaping will add perturbation to the height-velocity profile, it usually will not affect the determination of the age at which the profile peaks. A more serious issue arises in the case of the coastwise manifests, 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 passed (cf. section 5.1 above). That pattern is present in the manifests (Trussell and Steckel).

Heaping on even inches is evident even when the measurement is conducted by qualified personnel (as in the U.S.D.H.E.W. sample of 1960-1962). In military organizations with minimum height requirements, there is further evidence of heaping at the inch just above the cutoff. Simulation models inicate that even-number heaping does not introduce systematic bias. Although it may affect the accuracy of estimates of mean height, even with large amounts of heaping (in the range of 15 to 30 percent) the error will be in the neighborhood of a tenth of an inch. With respect to rounding, from the earliest date for which military records are available, the standard order was to round to the nearest inch or fraction. 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 (Karpinos). There is no reason to assume that this tendency has changed over time. Our 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 any case, the magnitude of this error will not seriously distort secular trends, nor should it significantly affect the cross-sectional analysis of the relationship between height and economic or demographic factors.

In the case of the coastwise manifests and the colonial muster rolls (items 6 and 7 of Table 1) the question arises as to whether individuals were measured with or without shoes. To resolve this question, we have turned to data on recruits into the Union army or the regular army where individuals are known to have been measured without shoes. The Gould report contains a sample of black recruits born in the slave states who were aged 25 and over (N=13,653). The mean height in this sample, 67.2 inches, is virtually identical with the mean height (67.1 inches) computed for the same category in the coastwise manifests. Similarly, recruits into the regular U.S army born between 1771 and 1790 averaged 68.3 inches (N=611), which exceeds the mean height in the Revolutionary sample by 0.1 inches. When the collection of data from the regular army is extended back to 1790, the test can be repeated not merely with birth cohorts adjacent to those in the Revolutionary army but with cohorts that overlap those of the Revolutionary army.[20]

### 6.3. Methods of Estimating Mean Height from Truncated Distributions

For many of our files, the possibility of obtaining useful information from the height-by-age data depends on solving the problem of selection bias due to truncation or shortfall in the height distribution, particularly for lower heights. Various distortions of the true underlying distribution of heights in the population contributing soldiers and sailors are to be expected in military height distributions, including heaping on whole or even numbers of inches, oversampling in the center of the distribution, and sometimes undersampling of high heights. While some distortions are apparent in all our bodies of data, the problem of undersampling of small heights is particulary acute for the regular armed forces of Britain and the United States. These organizations set minimum height limits at different times, varying with military needs, sometimes shifting frequently, and sometimes ranging as high as 67 inches. 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% of the small heights in the underlying distribution may be missing. Such undersampling could vitiate the information content of the data, unless reliable statistical procedures are employed to correct for the problem.

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[20]The Baxter sample was limited to military units where men were measured without shoes. Baxter (pp.14-15) conjectured that the recruits in some of the units in the Gould sample were measured with shoes. However, for the ages shown in Table 2 above, the Baxter and Gould samples yield mean heights that differ from each other by less than a tenth of an inch. This finding indicates that the proportion of the men in the Union army that may have been measured with shoes was too small to affect the analysis.

An important aspect of the project has been the development of statistical estimators that perform reliably in the presence of undersampling of small heights. These estimators must also cope with the other distortions that we suspect in the observed distributions. The multiple distortions make our problem more complicated than most undersampling problems treated in the statistical literature (cf., e.g., Cohen 1950, Harter and Moore 1966, Poirier 1978), although some ideas in the literature may be capable of extension. Our problem occurs at two levels. The first is the estimation of average height of an underlying distribution for men old enough to attain their terminal heights. A gaussian distribution for terminal heights is well-established for contemporary data and consistent with preliminary examination of our files, and the assumption of normality for the underlying distribution puts our problem into a well-defined parametric framework. There is also 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 spurts.

Our two principal methods for correcting left-tail censoring, the quantile bend method (QQ) and the maximum likelihood method (RSMLE) are described in Wachter and in Wachter and Trussell. The extension of the RSMLE method to regression analysis is reported in Trussell and Wachter. These methods have been tested extensively both by Monte Carlo techniques and by simulation techniques on actual distributions of heights. The tests have shown that both methods are generally reliable.

One of the tests, for example, was performed on a sample of the heights of London school children for 1965. The data consist of complete (i.e. non-truncated) distributions at each age during the growth spurt. Sample sizes varied from

801 to 2,493; the absolute value of the coefficient of skewness ($\gamma_1$) varied from 0.031 to -0.201. Our procedure was to use our estimators to estimate the true mean of the distribution under conditions of increasing truncation. The truncation was allowed to range from 0 to 80 percent of the distribution (truncating from the lower end). The particular point at issue was whether techniques devised to cope with truncation of normal distributions would be reliable on distributions of height at growing ages, which are positively skewed during the rising portion of the growth spurt and negatively skewed during the declining portion. This effect was first discovered by Boas in 1892, but it was documented by Tanner using London County Council data for 1955. The degree of skewing is statistically significant but small enough so that the distribution is treated as normal in the estimation of the centiles that demarcate the bounds for normal adolescent development. Nevertheless, it was necessary to determine whether even such moderate skewing would mislead our estimators in situations in which such skewing is combined with truncation, as is the case in the Marine Society data which were used in Figure 3.

The estimators achieved nearly perfect results before truncation, demonstrating that skewing was too small to require the abandonment of the normal approximation in this case (a conclusion previously reached by Tanner, Whitehouse, and Takaishi). The estimators generally continued to behave quite well even with truncation of up to 50 percent of the original distribution. The RSMLE estimator performed very well with both continuous and grouped data. Up to a 50 percent level of truncation it consistently produced estimates close to the true mean, although there was a tendency to over-correct, i.e., to produce estimates below the true mean. The accuracy of the RSMLE estimator decreased with truncation above the modal value. The QQ estimator was generally correct even with truncation above 50 percent, although in one instance it was thrown off for reasons we are still investigating. In this instance, however, the RSMLE continued to do well.

6.4 The "basketball" problem

It has been argued that one cannot assume, merely from the fact that a military distribution appears to be closely approximated by a normal or truncated (censored) normal distribution, that the mean of the distribution may be taken as a reasonable estimate of the mean final height of males in civilian life. The issue raised here goes beyond biases of the type already considered. Persons rejected for reasons other than height, as we have seen, are only slightly shorter than those accepted (less than a tenth of an inch in the Civil War case); and the self-selection biases served to favor particular socioeconomic subgroups rather than to distort the height distributions of these subgroups.

What is at issue in the "basketball" problem is the possibility that the sampling criteria of the military organizations might produce distributions of height which, while they are normal, have a much higher mean height than that of the general population of adult males. In this connection, it is argued that one cannot use the normality of a given distribution as evidence of its representativeness. It is further suggested that if procedures such as those that we have developed were applied to the height distribution of players in the National Basketball Association, we would discover that this distribution was also normal, so that careless application of our procedures could lead to the erroneous conclusion that the mean height of American males was 78 inches.

Clearly, one cannot use the mere normality of a military distribution as evidence that it represents the overall adult civilian distribution-- among other reasons, because the height distribution of each of the major socioeconomic subgroups in the population is also normal, although their means are significantly different.[21] The power of the QQ plots lies in what they tell us about height distributions that depart from normality. The distortions in such distributions are clues which, when carefully analysed, suggest the nature of the selection or self-selection criteria that produced the distortions.

The usefulness of our procedures is well-illustrated by applying them to the distribution of heights in the National Basketball Association. Figure B.1 shows the QQ plot for the N.B.A. If the distribution of heights was normal, the plot should form a straight line, with the mean of the distribution given by the intersection of the plot with the zero ordinate. As can be seen in Part A of Figure B.1, the plot of the N.B.A. distribution is quite irregular, unlike the Civil War distribution of heights in Part C. Upon inspection, it appears that the N.B.A. distribution might actually consist of at least two, and possibly three, straight-line segments. In other words, the plot in Part A suggests that the N.B.A. distribution of heights might actually be the result of a composite of three normal distributions. Indeed, when separate distributions are computed for guards, centers, and forwards, we obtain 3 single-peaked distributions that appear to be censored normals, with means at 74.4, 80.2 and 83.4 inches (see Part B of Figure B.1). Thus it appears that the managers of teams

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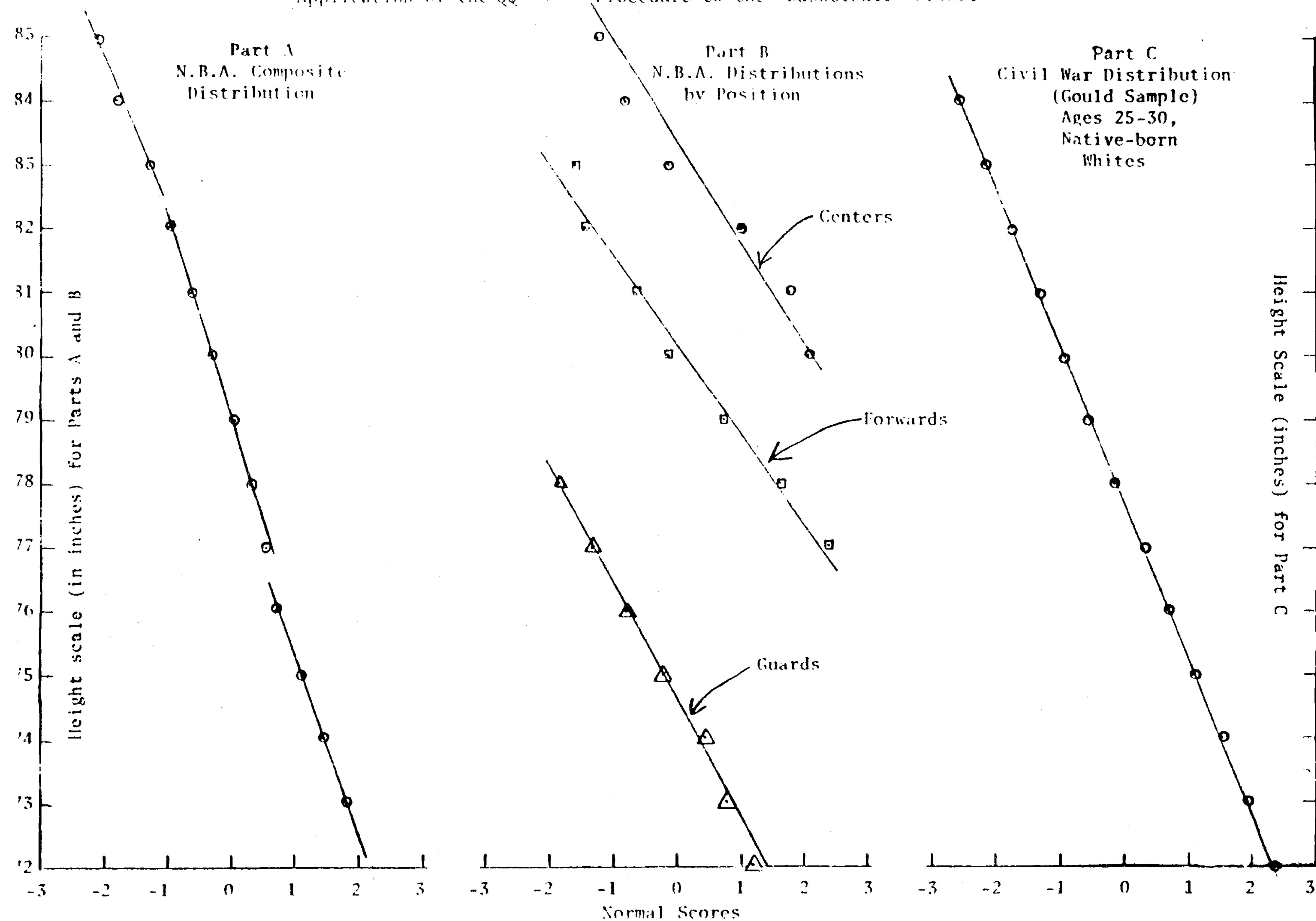
[21] Theoretically, if the heights of each of the subgroups of a population are normally distributed, but have different means, the overall population cannot be normally distributed and have the same standard deviation as the sub-populations. Nevertheless, the normal distribution gives a good fit to the overall distribution in such data sets as the Union army, as well as to each of the major subgroups, and the standard deviations are generally quite similar.

Figure B.1

Application of the QQ - Procedure to the "Basketball" Problem



in the N.B.A. have target heights for each position. Target heights will yield normal distributions even if the underlying population from which the sample is being drawn is highly skewed (as is the extreme right-hand tail of the distribution of adult heights).

It follows that when working with military data one should take into account the sampling strategy of particular military units. In the case of the U.S. army, official orders that established the standard for recruiting in different units have been published. In the British case, the standards are described in unpublished orders. The most common procedure was to have a minimum height requirement, which shifted up or down, depending on the demand for, and supply of, recruits. Some units, such as the cavalry and the navy, had both minimum and maximu requirements. Only a few parade companies had target heights.

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