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SECOND THOUGHTS ON THE EUROPEAN ESCAPE FROM HUNGER: FAMINES, PRICE ELASTICITIES, ENTITLEMENTS, CHRONIC MALNUTRITION, AND MORTALITY RATES

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ABSTRACT

The six principal findings of this paper are as follows: (1) Crisis mortality accounted for less than 5 percent of total mortality in England prior to 1800 and the elimination of crisis mortality accounted for just 15 percent of the decline in total mortality between the eighteenth and nineteenth centuries. (2) The use of variations in wheat prices to measure variations in the food supply has led to gross overestimates of the variability of the food supply. (3) The famines that plagued England between 1500 and 1800 were man-made, the consequence of failures in the system of food distribution related to an extremely inelastic demand for food inventories, rather than to natural calamities or inadequate technology. (4) It was not only within the power of government to eliminate famines but in fact the food distribution policies of James I and Charles I succeeded in reducing the variability of annual wheat prices by over 70 percent. (5) A change in the government policy could not have eliminated chronic malnutrition. Elimination of chronic malnutrition required technological changes that permitted the per capita consumption of food to increase by about 50 percent. (6) Improvements in average nutritional status appear to explain nearly all of the decline in mortality rates in England, France, and Sweden between 1775-1875 but only about half of the mortality decline since 1875.

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> Most of the people in the world are poor, so if we knew the economics of being poor we would know much of the economics that really matters.
>
> T.W. Schultz (1980)

During the late 1960s a wide concensus emerged among social and economic histories regarding the causes of the decline in the high European death rates that prevailed at the beginning of the early modern era. The high average mortality rates of the years preceding the vital revolution were attributed to periodic mortality crises which raised "normal" mortality rates by 50 to 100 percent or more. It was the elimination of these peaks rather than the lowering of the plateau of mortality in "normal" years that was principally responsible for the much lower mortality rates that prevailed at the end of the nineteenth century (Helleiner 1967, p. 85; Wrigley 1969, p. 165; Flinn 1970, p. 45). These crises, it was held, were precipitated either by acute harvest failures or by epidemics (Flinn 1970, p. 45). Some scholars argued that even if the diseases were not nutritionally sensitive, famines played a major role because epidemics were spread by the beggars who swarmed from one place to another in search of food (Meuvret 1965, pp. 510-511). Whatever the differences on this issue, it was widely agreed that many of the mortality crises were due to starvation brought on by harvest failure (Wrigley 1969, pp. 66, 165-169; Flinn 1970, pp. 45-48; Flinn 1974).

A mechanism by which a harvest failure was transformed into a mortality crisis was proposed by Hoskins in two influential papers published in the 1960s (1964, 1968). Noting that it was possible to identify harvest failures by looking at the deviations in grain prices from their normal level, Hoskins computed the annual deviations of wheat prices from a 31-year moving average of these prices. Normal harvests were defined as those with prices that were within plus or minus 10 percent of the trend. He found that over the 280 years from 1480 to 1759 good harvests (prices 10 percent or more below trends) were about 50 percent more frequent than deficient harvests (prices 10 percent or more above trend). His most important finding, however, was that good and bad harvests (as shown by prices) ran in sequences, so there were frequently three or four bad years in a row. These sequences, he argued, were not due primarily to weather cycles but to the low yield-to-seed ratios, which he put at about 4 or 5 for wheat at the beginning of the sixteenth century. Thus, one bad harvest tended to generate another because starving farmers consumed their reserve for seeds. The consequence of several bad harvests in a row was a mortality crisis. Numerous studies published during the 1960s and 1970s of localities in Britain, France, and other parts of the Continent confirmed that famines brought on by harvest failures were a major factor in mortality crises that plagued Europe through the end of the eighteenth and into the early part of the nineteenth centuries (Goubert 1960, 1968, 1970; Drake 1962, 1968; Appleby 1973, 1978; Flinn *et al* 1978; Rogers 1975; Meuvret 1965; Gooder 1972; Post 1977, 1984; LeBrun 1971).

The interpretation of the European escape from hunger and high death rates embodied in this train of research was brought into question with the publication of *The Population History of England, 1541-1871: A Reconstruction* by E.A. Wrigley and R.S. Schofield (1981). Using data from 404 parish registers widely distributed throughout England, these scholars and their associates constructed monthly and annual estimates of the English population over a 331 year period, as well as monthly and annual estimates of the national birth rates, mortality rates, and nuptuality rates. Although important issues have been raised about various assumptions employed in the analytical procedures that transformed the information on baptisms and burials contained in the Anglican registers into national estimates of birth rates and death rates, it is widely agreed that the reconstruction was carried out with meticulous care, and that the various adjustments for deficiencies in the record were judicious. Whatever the shortcomings of the reconstructions, the new time series produced by Wrigley and Schofield have become the foundation for all further research into the demographic history of England (Flinn 1982; Lindert 1983).

In addition to presenting their basic time series and describing the complex procedures employed to produce them, Wrigley and Schofield also began the processes of relating these demographic rates to underlying economic and social phenomena. They determined that both fertility rates and marriage rates were strongly correlated with measures of real wages and the cost of living, but that mortality rates were not.[1] A chapter of the book contributed by Lee (1981) reported a statistically significant but weak relationship between short-term variations in death rates and in wheat prices, but Lee, as well as Wrigley and Schofield, concluded that short-run variations in English mortality were "overwhelmingly determined" by factors other than the food supply (Schofield 1983, p. 282). In so far as the long-term trend in mortality was concerned, Wrigley and Schofield reported that they were unable to find even a weak statistical correlation between mortality rates and the food supply (Wrigley and Schofield 1981, pp. 325-326).

Since the findings of Wrigley, Schofield, and Lee appear to be so sharply in conflict with the train of research that has linked the escape from high mortality rates to the escape from hunger, it is tempting to declare that one of the research trains must be wrong, and to choose sides. I believe that such a conclusion is not only premature but very likely wrong. The aim of this paper is to reconsider the older line of research in the light of the findings of Wrigley, Schofield, and Lee in order to see where they are compatible and where the evidence tilts toward one or the other side.

The six principal findings of this paper are as follows: (1) Crisis mortality accounted for less than 5 percent of total mortality in England prior to 1800 and the elimination of crisis mortality accounted for just 15 percent of the decline in total mortality between the eighteenth and nineteenth centuries. Consequently, regardless of how large a share of crisis mortality is attributed to famines, famines only accounted for a small share of total mortality prior to 1800. (2) The use of variations in wheat prices to measure variations in the food supply has led to gross overestimates of the variability of the food supply. (3) The famines that plagued England between 1500 and 1800 were man-made, the consequence of failures in the system of food distribution related to an extremely inelastic demand for food inventories, rather than to natural calamities or inadequate technology. (4) It was not only within the power of government to eliminate famines but in fact the food distribution policies of James I and Charles I succeeded in reducing the variability of annual wheat prices by over 70 percent. (5) Although proper governmental policy could have eliminated famines prior to 1800, the government policy could not have eliminated chronic malnutrition. Elimination of chronic malnutrition required advances in agricultural and related technologies that permitted the per capita consumption of food to increase by about 50 percent. (6) Improvements in average nutritional status (as indicated by stature and body mass indexes) appear to explain nearly all of the decline in mortality rates in England, France, and Sweden between 18-IV (the fourth quarter of the eighteenth century) and 19-III but only about half of the mortality decline between 19-III and 20-III.

1. The New Findings on Mortality Crises

One of the most important aspects of the The Population History is the new light it sheds on mortality crises over the 331 years it covers. Wrigley and Schofield are the first scholars who have had a sample of parishes large enough in number and wide enough in geographic coverage to permit an estimate of the national impact of mortality crises on the annual crude death rates in early modern England. Following established procedures they measure mortality crises as deviations from a 25-year moving average, and define a crisis year as one with an annual cdr that is more than 10 percent above trend. That criterion yielded 45 crisis years, a bit less than 14 percent of the years in their study (p. 333). They also computed national crisis months (months with monthly death rates at least 25 percent above trend), and found that 94 years contained at least one crisis month (pp. 338-339). Their analysis confirmed many of the findings of scholars working with less complete data. The year 1558/9, for example, emerged as by far the worst year for mortality in the entire period. They also found that the most severe mortality crises were concentrated during 1544-1658, although there was a lethal recurrence during the late 1720s.

Perhaps the most important aspect of the new time series on mortality, however, is that these data drastically diminish the role of crisis mortality as an explanation for the high mortality rates that generally prevailed between 1541 and 1800. This conclusion emerges from two tables in The Population History, which together provide the data needed to compute the crisis component of total mortality. The results of the computation are presented in Table 1 by quarter centuries (or fractions thereof) as well as by centuries (or fractions thereof). In no quarter century did crisis mortality account for as much as 10 percent of the total mortality. Even after crisis mortality is factored out, the "normal" mortality remains above 25 per thousand for the 16th, 17th, and 18th centuries. Indeed, the "normal" mortality rate of the 18th century was as high as the total mortality rate of each of the two preceding centuries, despite their many crises. Consequently, the escape from high mortality rates was not due primarily to the elimination of crises, as many have previously argued, but to the reduction in so-called normal mortality levels. Nearly three-quarters of the decline of mortality between 1726-50 and 1851-71, despite the relatively high level of crisis mortality at the beginning of this period and its negligible level at the end of it, was due to the reduction of "normal" mortality.

It follows that even if every national mortality crisis identified by Wrigley and Schofield was the result of a famine, the elimination of periodic famines cannot be the principal explanation for the secular decline in mortality. This is not to deny that famines in particular localities at particular times produced great increases in local mortality rates.[2] Too much evidence of local disasters induced by food shortages has accumulated to rule out such phenomenon. However, in light of the Wrigley and Schofield data it now seems clear that, dramatic as they were, mortality crises

Table 1
The Impact of Crisis Mortality
On the Average Crude Death Rate,
1541-1871

Period	1 Crude death rate per thousand person years	2 Crisis mortality per thousand person years	3 Crude death rate after factoring out crisis mortality (per thousand)	4 Crisis mortality as percentage of average mortality mortality	5 Crisis mortality as percentage of "premature" mortality
			By Quarter Centuries		
1. 1541-50	30.33	2.25	28.08	7.42	9.64
2. 1551-75	28.28	2.35	25.93	8.31	11.04
3. 1576-1600	24.21	1.22	22.99	5.04	7.09
4. 1601-25	24.61	2.05	22.56	8.33	11.64
5. 1626-50	26.36	0.99	25.37	3.76	5.11
6. 1651-75	28.07	1.58	26.49	5.63	7.50
7. 1676-1700	30.29	1.66	28.63	5.48	7.13
8. 1701-25	27.79	0.06	27.73	0.22	0.29
9. 1726-50	30.57	2.34	28.23	6.40	9.93
10. 1751-75	27.28	0.40	26.88	1.47	1.97
11. 1776-1800	26.85	0.55	26.30	2.05	2.77
12. 1801-25	25.40	0.15	25.25	0.59	0.82
13. 1826-50	22.58	0.13	22.45	0.58	0.83
14. 1851-71	22.42	0.13	22.29	0.58	0.84
			By Centuries		
15. 1541-1600	26.93	1.87	25.06	6.92	9.38
16. 1601-1700	27.33	1.57	25.76	5.74	7.72
17. 1701-1800	28.12	0.83	27.29	2.95	3.93
18. 1801-1871	23.53	0.14	23.39	0.59	0.85

Notes to Table 1

Lines 1-14. Column 1. Each entry is the average of the quinquennial rates for the period given in Wrigley and Schofield 1981, pp. 528-529. Column 2. Each entry is the difference between the corresponding entries in columns 1 and 3. Column 3. Wrigley and Schofield 1981, p. 333 give the cdr (D_{cc}) for each of the 45 years they identify as a crisis year, as well as the percentage deviation of the crisis cdr from a 25-year moving average, which is taken to be the normal cdr for that year. Hence by dividing 1 plus the percentage deviation into the crisis cdr it is possible to obtain the "normal" cdr for the crisis year (D_{nc}). It is also possible to solve the following equation for the normal cdr in a non-crisis year (D_{nn})

$$D = \theta D_{cc} + (1 - \theta)D_{nn},$$

where D is the average cdr for the time period (as shown in column 1) and θ is the share of crisis years during the time period. The average cdr with the crisis mortality factored out (D_n) is then given by

$$D_n = \theta D_{nc} + (1 - \theta)D_{nn}.$$

The entries in column 3 are the values of D_n. Column 4. Each entry is 1 minus the ratio of the column 3 entry to the column 1 entry.

Lines 15-18. Columns 1 and 3. The entries for each period are averages of the corresponding figures for the subperiods in lines 1-14, weighted by the number of years in the subperiods. Column 2. Each entry is the difference between the corresponding entries in columns 1 and 3. Column 4. Each entry is 1 minus the ratio of the column 3 entry to the column 1 entry.

Column 5. "Premature" mortality is defined as the crude death rate of a given period minus the English death rate of 1980 standardized for the English age structure of 1701-1705 (see Fogel 1986a, Table 1).

whether caused by famines or not, were too scattered in time and space to have been the principal factor in the secular mortality decline after 1540. It is still possible that mortality crises were a much larger part of total mortality before 1541 than they were afterward, both because of differences in the nature of the prevailing diseases in the two periods and because food supplies were probably more inadequate in medieval times.

2. Measuring the Variability of the Food Supply

The Population History does not provide the same challenge to previous thought on the scope of subsistence crises as it does on the question of mortality crises. Indeed, the periods which Wrigley and Schofield identified as the major subsistence crises (p. 321) generally coincide with those identified by Hoskins (1964, figure facing p. 29; 1968, figure facing p. 15). That outcome is not surprising since the procedures used in the identification and measurement of subsistence crises by Wrigley, Schofield, and Lee are quite similar to those of Hoskins. Wrigley and Schofield used annual deviations in an index of real wages from a 25-year trend to identify subsistence crises. Because of the procedure for smoothing the wage series, as they pointed out, nearly all the variability in the index came from the price deflator which was dominated by grains (broadly defined). Lee, like Hoskins, relied on wheat prices alone, on the grounds that the price of wheat was so highly correlated with other food prices that wheat was "a good proxy for food prices in general" (Lee 1981, p. 357).

The tradition of judging the shortfall in the food supply by price is an ancient one dating back at least to Gregory King, who first formalized the systematic relationship between the yield of a harvest and the subsequent price of the grain. Called "King's Law," his schema (see Table 2) has been employed as an estimate of the elasticity of demand for wheat.

Table 2

A Comparison between King's Law
and a Constant Elasticity of
Demand Equation
(1 = normal price and yield)

King's Law		$Q = 1.00P^{-0.403}$	
Q	P	Q	P
1.0	1.0	1.00	1.0
0.9	1.3	0.90	1.3
0.8	1.8	0.79	1.8
0.7	2.6	0.68	2.6
0.6	3.8	0.58	3.8
0.5	5.5	0.50	5.5

Source: Slicher von Bath (1963, pp. 118-119) presents King's Law and compares it with those of Jevons and Bouniatian.

Later economists, such as Jevons and Bouniatian, formulated quite similar laws in equations (Slicher von Bath 1963, pp. 118-119). All three laws are closely approximated by constant elasticity demand curves with ε ranging between 0.403 and 0.422. As Table 2 shows, the equation

$$(1) \qquad Q = 1.00P^{-0.403}$$

gives a very close fit to King's Law in the specified range of prices.[3] It seems quite reasonable, therefore, to use the deviation in price to infer the deviation in the yield of a harvest from its normal level, as numerous analysts have done ever since King's time.

When King's Law is combined with the proposition that the yield-to-seed ratios of wheat was about 4--that one-quarter of the crop was needed for seeds--the interpretation of harvest failures developed from price series by Hoskins and numerous other scholars during the past three decades follows immediately. Wheat prices 50 percent above normal imply a harvest that is 15 percent below normal, a situation presumed to have put heavy pressure on farmers to dip into their seed reserve. With two such years in a row, even if farmers succeeded in maintaining the normal proportion of the crop for seed reserves, consumption in the second year would be cut to more than a third--pushing the average food intake of the lower classes to perhaps 1,340 calories per equivalent adult or less per day.[4] How devastating then must have been years such as 1555 and 1556 when a 50 percent deviation of the price of wheat above normal was followed by a 105 percent deviation above normal--suggesting a decline of lower-class consumption to the neighborhood of 1,180 calories.[5] The problem is that the implied level of caloric consumption in 1556 is too low to be believable, since it is well below the requirement for basal metabolism. We know from both controlled semistarvation experiments and from actual conditions in underdeveloped countries today that even levels of 1300-1500 calories produce PEM serious enough to incapacitate a large proportion of the population and also leads to so many cases of kwashiorkor that death rates increase significantly among those affected (Scrimshaw 1987; DeMaeyer 1976; Mellor and Gavian 1987; Kumar 1987; For. Aff. Comm. 1985). A population forced to consume less than basal metabolism for a whole year would have produced noticeable increases in mortality. Yet the Wrigley and Schofield time series, while confirming Hoskins's finding that 1555 and 1556 were years of extreme dearth, report that the mortality rates during these two years averaged about 10 percent below normal (p. 321). Indeed, after searching for a correlation between extreme annual deviations in prices and in mortality rates, Wrigley and Schofield concluded that no significant simultaneous relationship existed (pp. 325-326), although there was evidence of a weak lagged relationship.

This puzzle is not necessarily without a solution. One possibility is that government intervention prevented a subsistence crisis from turning into a mortality crisis. Some questions about the role of the government will be explored in section 4. Another possibility is that defects in the Wrigley and Schofield estimates of mortality may explain the anomalous results. Yet their ingenious procedures for correcting the undercount of deaths, if less than perfect, seems to have produced a series quite adequate for the particular analysis they have undertaken. The problem, I believe, lies not so much in the data but in a series of implicit assumptions that have gradually crept into the analysis of the data, assumptions made so often that they hardened into an unquestioned procedure. It was only with the discovery of the Wrigley-Schofield-Lee paradox that the need to reconsider the analytical procedures became evident.

The crux of the problem is with the application of King's Law which, as has been indicated, is well described by a simple demand equation of the form

$$(2) \qquad Q = P^{-\varepsilon}.$$

When P (price) and Q (quantity) are measured as deviations from trend, equation (2) becomes

$$(3) \qquad \overset{*}{Q} = -\varepsilon\overset{*}{P},$$

where an asterisk over a variable indicates percentage deviations from trend, and ε is the elasticity of demand. Equation (3), which is the definition of that elasticity, is thus a simple linear equation in which the value of the coefficient of the right-hand variable is given by

$$(4) \qquad \varepsilon = \frac{\sigma_q}{\sigma_p} r_{pq} = -\frac{\overset{*}{Q}}{\overset{*}{P}}$$

where σ_q is the S.D. of $\overset{*}{Q}$, σ_p is the S.D. of $\overset{*}{P}$, and r_{pq} is the correlation coefficient between $\overset{*}{Q}$ and $\overset{*}{P}$. It follows that the value of ε will be greatest when r_{pq} is assumed to equal 1, which is the assumption generally made in the application of King's Law. Since this assumption is not at issue in the analysis that follows, and because a value of r_{pq} less then one would strengthen my argument, I will assume $r_{pq}=1$ in the balance of the discussion.

It follows from equation (4) that one can estimate an elasticity for wheat by obtaining estimates of σ_p and σ_q. The estimate of σ_p for wheat is readily available from the wheat prices used by Lee and is about 0.22 for the period 1540-1840 (Lee 1981, p. 374). The value of σ_q (measured as a deviation from trend), computed for the first 30 years for which data on the physical yield of wheat in England are available (1884-1913), is 0.040.[6] Assuming, as a first approximation, that the climatic factors affecting the variability of yield were similar between the seventeenth century and the end of the nineteenth, the preceding figures imply that the demand elasticity for wheat was 0.183 (0.0402 ÷ 0.220), which is more than 50 percent below the elasticity of the demand for wheat implied by King's Law, or at least by the way that it has been interpreted.

The problem with some previous interpretations of King's Law is that investigators implicitly assumed that carryover stocks of wheat from the previous harvests were zero. This assumption was an unintended but necessary consequence of treating the deviations from normal annual yields (column 1 of Table 2) as the total supply--as when I used the series in columns 1 and 2 of that table to estimate equation (1). However, the annual supply is not just the harvest in a given year, but the harvest plus the carryover stock from previous years. Davenant (1699, p. 82) estimated that in normal times carryover stocks varied between four and five months (i.e. between 33 and 42 percent of a normal crop). Consequently, when estimating the demand curve, the proper quantity is not Q but Q' or Q'' (see Table 3). When those series are substituted for Q, the estimated values of ε are given by equations (2.1) and (2.2):

(2.1) $Q' = 1.00P^{-0.248}$ (when carryovers are five months)

(2.2) $Q'' = 1.00P^{-0.272}$ (when carryovers are four months).

Thus when one corrects for the neglect of carryover stocks, King's Law implies an elasticity of demand that is not only between 33 and 38 percent below the level often presumed, but a good deal closer to the estimate obtain by using the S.D. of deviations of physical yields from trend at the end of the nineteenth century.

Before pursuing the implications of this finding, one other implicit assumption needs to be made explicit. That assumption stems from the

Table 3

The Effect of Allowing for Carryover Stocks in the Supply of Wheat at the End of the New Harvest

1 Deviation from normal yield of current harvest Q_j	2 Price	3 Deviation from normal supply if carryover is 5 months Q	4 Deviation from normal supply if carryover is 4 months Q
1.0	1.0	1.00	1.00
0.9	1.3	0.93	0.92
0.8	1.8	0.86	0.85
0.7	2.6	0.79	0.78
0.6	3.8	0.72	0.70
0.5	5.5	0.65	0.62

<u>Note</u>: Columns 1 and 2 are from Table 2. Columns 3 and 4 entries are computed from

$$Q_j^{\,i} = \theta I + (1 - \theta)Q_j$$

where I is the carryover inventory which is assumed to be constant for each value of Q_j (taken from column 1), and θ is the share of carryover inventories after the close of a normal harvest (θ = 0.294 with 5-month carryovers and 0.250 with 4-month carryovers).

neglect of grains fed to livestock as a reserve for human consumption. Although feeding off of grasses, clover, vetches, turnips, lentils, other meadow crops, and hay provided the bulk of animal feed, Davenant (1699, p. 71-72) estimated that about 12 percent of annual grain production was normally fed to livestock. In other words, human consumption of grains (see Table 4) normally constituted only about 45 percent of the available supply at the close of a harvest. Even if we add the 17.6 percent reserved for seeds, there was still normally a reserve of 37.9 percent (carryover plus feed) that could serve as a buffer before a deficient harvest required a restriction of human consumption or encroachment on the seed reserve.

It follows from equation (3) that not even a 100 percent deviation of wheat price above trend, which occurred only once in the entire period examined by Hoskins or Lee, implied a physical shortfall of wheat (standing here for a typical grain) so large as to eliminate carryover stocks, let alone the combination of carryover stocks and animal feed. Even the worst pair of years identified by Hoskins (1555 and 1556) would still have left more than 10 percent of the normal carryover inventory as a buffer without encroaching on feed, seed, or human consumption in either year.[7]

The point of the preceding exercise is that even for a single grain, and even assuming a low yield-to-seed ratio, the physical shortfall in the worst pair of years was not so great as to require a general encroachment on seeds in order to maintain human consumption, although such encroachments undoubtedly occurred in some localities in some years, especially among the poorer farmers. This is not to say the high prices did not cause sharp reductions in consumption, especially among the lower classes, or to deny the existence of famines. I mean only to call into question the proposition

Table 4

The Normal Distribution of the Supply of Grain (New Crop Plus Carryover Inventories) at the Close of Harvest (in Percent)

1.	Carryover stocks	29.4
2.	Animal feed	8.5
3.	Seed for the next crop	17.6
4.	Human consumption	44.5

Sources: Lines 1 and 2: Davenant 1699, pp. 71-74, 82. Line 3: Hoskins 1968, pp. 25-26.

that nationwide subsistence crises after 1541 were the consequence of natural disasters.

Indeed, even the preceding discussion overemphasizes the part played by natural factors since I have until now accepted the common assumption that because wheat prices were highly correlated with other food prices, wheat prices alone are an acceptable proxy for an index of all food prices. However, when one is attempting to infer the variability of the quantity of food from the variability in wheat prices the critical question is not the strength of the correlation but the size of the elasticity between these two variables. Since the elasticity (α) of all food prices with respect to wheat prices is given by

$$(5) \qquad \frac{\overset{*}{P}_f}{\overset{*}{P}_w} = \alpha = \frac{\sigma_f}{\sigma_w} r_{fw}$$

it follows that if α is less than one, σ_f (the S.D. of deviations around the trend in food prices) will be less than σ_w (the S.D. of deviations around the trend in wheat prices). As it turns out, the estimated value of α is 0.346, (and $\bar{R}^2$ is 0.61) over the years 1540-1738, so that use of wheat prices, and their conversion within the context of King's Law into a measure of supply, greatly exaggerates the variability of the food supply during the early modern era (see the Appendix).

If the deviations around trend in the food supply (σ_{fq}) are to be estimated from the deviations in wheat prices, what we need to know is the elasticity of the food supply with respect to wheat prices (ε_{fw}) rather than the King's Law which, even when properly interpreted, gives only the elasticity of the quantity of wheat demanded with respect to wheat price. Unfortunately the time series needed to estimate σ_{fq} (the S.D. of deviations in the annual quantity of the food supply) for England is not yet available even for recent times, but it is possible to estimate σ_{gq} (the S.D. of deviations from trend in an index of all grain yields) after 1884. With this change the desired elasticity ε_{fw} can be estimated from equation (6)

$$(6) \qquad \varepsilon_{fw} = \frac{\sigma_{gq}}{\sigma_w} r_{gq.w}$$

(where σ_w is the S.D. of deviations from trend on wheat prices). If we assume $r_{gq.w} = 1$, only σ_{gq} needs to be estimated, since as indicated earlier $\sigma_w = 0.220$. When σ_{gq} is estimated from data over the period 1884-1913 it turns out to be 0.0300, which puts ε_{fw} at 0.136.

This provisional estimate of ε_{fw} implies that even the largest deviation of wheat prices above trend in Hoskins's entire 280-year period (or Wrigley and Schofield's 331-year period) involved a manageable shortfall in the supply of food. Although carryover stocks were diminished, more than two-thirds of the normal amount -- more than a three months supply -- remained over and above all claims for feed, seed, and human consumption.

3. Famines Amid Surpluses: A Suggested Mechanism

Consequently, there does not appear to have been a single year after c.1500 in which the aggregate supply of food was too low to avoid a subsistence crisis. These crises were man-made rather than natural disasters, and clearly avoidable within the technology of the age, as Davenant (1699, pp. 78-88) and other contemporary men of affairs pointed out. Famines amid surpluses remain a phenomenon even today, as Amartya Sen (1981) recently emphasized, not only because foods on a world scale are ample enough to prevent famines but because famines have broken out in certain underdeveloped nations despite good harvests. These famines were caused not by natural disasters but by dramatic redistributions of "entitlements" to grain. The events which promoted the redistributions of entitlements were sharp rises in the price of grain relative to wages or other types of income received by the lower classes. In the "great Bengal famine" of 1943, for example, the exchange rate between wages and foodgrains declined by 86 percent, despite an "exceptionally high" supply of grain. In this case the rise in grain prices had nothing to do with the bountifulness of the harvest, but was driven by forces outside of the agricultural sector. The Bengal famine, Sen points out, was a "boom famine" caused by "powerful inflationary pressures" unleashed by a rapid expansion of public expenditures (pp. 66, 75).

The relevance of the entitlement approach to the interpretation of the social and economic history of the early modern era does not depend on the source of the rise in grain prices that triggers the redistribution of entitlements. It is the similarity in the structural characteristics of traditional societies of the past and of low-income countries today that makes the entitlement approach pertinent (Tilly 1983; Hufton 1983; Appleby 1979a; Post 1976; Flinn 1974). At the root of these structural similarities is the highly unequal distribution of wealth and the overarching importance of land as a source of wealth. These twin characteristics lead directly to two other structural features: First, they cause the price elasticity of the total demand for grains to be quite low. Second, they drive a large wedge between the grain demand elasticities of the upper and the lower classes, with the elasticity of the lowest classes having a value that may be 10 or 20 times as large as the elasticity of the class of great land magnates. It is these large class differences in demand elasticities (caused by social organization) rather than wide year-to-year swings in harvest yields (caused by variations in weather or other natural phenomena) that were the source of the periodic subsistence crises that afflicted late medieval and early modern England and the Continent.

The balance of this section sets forth a mechanism that may have produced a world with famines amid surpluses that were more than adequate to have prevented the famines. I have endeavored to make the model that follows conform as closely as possible to the known facts of English society during the early modern era. The appendix describes my procedures for estimating the key parameters and the sources for these estimates. It also gives the derivations of equations (7)-(11).

Equation (7) is a convenient starting point for the estimation of the relevant elasticities.

(7) $\varepsilon_i = [\theta(1 - \varepsilon_t) - \beta_i]\psi_i - \bar{\varepsilon}_i$

where

ε_i = the price elasticity of the demand for grain

ψ_i = the income elasticity of the demand for grain

$\bar{\varepsilon}_i$ = the income-adjusted price elasticity of the demand for grain

β_i = the share of grain in total consumption expenditures

θ_i = the share of income arising from the ownership of grain

ε_t = price elasticity of the total aggregate demand for grain (see equation 10)

i = a subscript designating the *i*th class

Equation (7) states that the price elasticity of demand for grains of a given class depends not only on $\bar{\varepsilon}_i$ (the income-adjusted price elasticity, which is often referred to as the "substitution" elasticity) but also on the relative magnitude of $(1 - \varepsilon_t)\theta$ (which is the elasticity of nominal income with respect to the price of grain) and of β_i. It follows from equation (7) that wealthy landlords would have a much more inelastic demand for grain (because the share of their income arising from ownership of grain-producing lands equaled or exceeded the share of their income that was spent on the consumption of grains--i.e. because ($[1 - \varepsilon_t]\theta_i \geq \beta_i$) than landless laborers (for whom $\theta_i = 0$ and β_i is large).

Table 5 divides the English population at the middle of the Wrigley-Schofield-Lee period (c.1700) into four categories or classes that correspond roughly to the aristocracy and gentry, the yeomanry, artisans and petty shopkeepers, and common laborers (including the unemployed). Out servants working in the households of the upper classes are included with these classes, since their masters provided the food that they consumed. In other words, the population embraced by the landlords (class 1 in Table 5) includes not only the landlords and their immediate families but all of their retainers, high and low. The category titled "farmers and lesser landlords" also includes such other owners of food inventories as bakers, brewers, innkeepers, and grain merchants. In other words, the categories are defined so that virtually all inventories are owned by the two top classes and virtually none by the two bottom ones. Table 5 also presents my estimates of the share of the English population represented by each of the classes, the normal share of each class in the annual consumption of grain (ϕ_i), and of $\theta_i(1 - \varepsilon_t)$, β_i, ψ_i, and ε_i (see the Appendix for sources and procedures). The values of ϕ_i shown in column 2 imply that landlords consumed nearly two-thirds more, and yeomen consumed about a sixth more, grain per capita than the national average (much of it as ale and spirits), that shopkeepers and craftsmen consumed the national average, and that common laborers and paupers consumed about three-quarters of the national average. These values of ϕ_i imply that the average caloric intake of the poor was at about the mean level of Ghana or Chad today (World

Table 5

Estimates of the "Normal" Shares in Foodgrain Consumption and of the "Normal" Price Elasticities of the Demand for Foodgrains by Socioeconomic Class in England c. 1700

Class of Household Head	1 Share in population	2 Normal share in consumption of the foodgrains	3 Share of grain in total expenditure of a class	4 Elasticity of nominal income with respect to the price of grain	5 Income elasticity	6 Income-adjusted price elasticity	7 Price elasticity
		ϕ_i	β_i	$\theta_i(1 - \varepsilon_t)$	ψ_i	$\bar{\varepsilon}_i$	ε_i
1. Landlords (including servants & retainers)	0.11	0.18	0.15	0.23	0.10	0.02	0.01
2. Farmers & lesser landlords (including servants)	0.34	0.39	0.15	0.35	0.19	0.05	0.01
3. Shopkeepers, minor professionals and craftsmen (including servants)	0.11	0.11	0.35	0.00	0.36	0.19	0.32
4. Laborers and the unemployed (not including servants covered in lines 1, 2, & 3)	0.44	0.33	0.70	0.00	0.92	0.41	1.05

Source: See Appendix.

Bank 1984), while the landlords were at about the level of U.S. farmers c.1850 (Fogel and Engerman 1974).

One important implication of Table 5 is that although laborers were about 44 percent of the population, they only accounted for 33 percent of the normal consumption of foodgrains. Another implication of Table 5 is that the effect of a rise in grain prices on elasticities was quite different for different classes (see columns 6 and 7). In the case of landlords and farmers (classes 1 and 2) the rise in prices had two effects: as owners of surpluses, the rise in prices increased their income, while as consumers it reduced their income. Since the producer's effect is stronger than the consumer's effect, the income component of the price elasticity $[\{(1 - \varepsilon_t)\theta - \beta\}\psi]$ is negative and so offsets the income-adjusted elasticity $(\bar{\varepsilon})$, making the price elasticities of these two classes quite close to zero. In the case of laborers, however, only the consumption effect operated. In this case the income component of the price elasticity augments $\bar{\varepsilon}$. Although $\bar{\varepsilon}$ is already relatively high, the total price elasticity (ε) is more than twice as high.

The values set forth in Table 5 make it possible to estimate the aggregate elasticity of the foodgrain demand for grains (ε_c), by making use of the relationship set forth in equation (8):

$$(8) \qquad \varepsilon_c = \phi_1\varepsilon_1 + \phi_2\varepsilon_2 + \phi_3\varepsilon_3 + \phi_4\varepsilon_4.$$

Substituting the appropriate values of ϕ_i and ε_i into equation (8) yields

$$(9) \qquad \varepsilon_c = (0.18)(0.01) + (0.39)(0.01) + (0.11)(0.32) + (0.33)(1.05) = 0.387.$$

Thus, the estimates of class elasticities in Table 5 imply that the elasticity of the aggregate foodgrain demand was below 0.5, even though common laborers and paupers, who accounted for nearly half the population had an elasticity in excess of one. However, as equation (8) indicates, it is shares in consumption rather than in population that determine the value of ε_c. If it were the population shares that mattered, ε_c would be nearly 30 percent larger than the indicated size.

Although ε_c is the price elasticity of the aggregate foodgrain demand, it is not the price elasticity of aggregate demand for all grain, which is given by equation (10):

$$(10) \qquad \varepsilon_t = \delta\varepsilon_s + (1-\delta)\varepsilon_c$$

where

ε_s = the price elasticity of demand for grains used as seed, feed, and carryover inventories

δ = the share of the total supply used as seed, feed, and carryover inventories.

Since about 55 percent of the supply of grains were reserved for carryover, seed and feed, the estimation of ε_s is critical. If ε_s were 0, ε_t would be only 0.174. There is much commentary in the literature which suggests that that was the case.[8] There was, for example, virtually no long-term variation in the amount of wheat seed planted per acre, which appears to have stood at about 2.5 bushels from the fourteenth century to the nineteenth (Wrigley 1987, p. 85; Hoskins 1968, pp. 27-28). During the Irish famine it was noted that many farmers starved to death while holding on to the stocks of potatoes and grains they had set aside to pay their rents (Flinn 1981, p. 50). Farmers were apparently loath to dip into grain set aside for animal feed.[9] It is not possible with the data currently at hand to estimate ε_s directly, but it is possible to estimate ε_t, and then to solve for equation (10) for ε_s. Using the estimate of σ_{gp} (the S.D. of deviations in grain prices around trend) for the period 1540-1738, and of σ_{gq} for 1884-1913, ε_t can be estimated from equation (11),

$$(11) \qquad \varepsilon_t = \frac{\sigma_{gq}}{\sigma_{gp}} r_{gq.gp} ,$$

again assuming $r_{gq.gp} = 1$. The resulting value of ε_t is 0.178, which tends to confirm the belief that during the early modern era the elasticity of the demand for stocks held in reserve to insure feed, seed, and rental payments, and other contingencies was close to zero.[10]

An important implication of the model set forth in this section is that a relatively small decline in the supply of grain could have produced a sharp rise in prices. Because of the highly inelastic demand for inventories virtually all of the adjustment in entitlements would have taken place among consumers. As Table 6 shows, even a shortfall of supply as small as 5 percent, triggers significant shifts in the shares of grain consumed by different classes. In the case of landlords, the rise in their share partially offsets the decline in output so that their per capita consumption rises slightly. In the case of laborers, however, the decline in their share reinforces the decline in output so that their per capita consumption is down by 32 percent. It is worth noting that although output declines by 5 percent, aggregate foodgrain consumption declines by 11 percent. Because the demand for grain reserves for feed, seed, and rentals is so inelastic, virtually the entire shortfall is borne by foodgrain consumption.

The sharp decline in consumption of the laboring class (when $Q_s = 0.95$) is due to the combination of its high elasticity of demand ($\varepsilon_4 = 1.05$) and the sharp rise in price (P goes to 1.49). It should be noted that about a third of the indicated price rise is due not directly to a decline in Q_s from 1 to 0.95, but to the decline in the value of ε_t as the price

Table 6

The Consequence of Shifting "Entitlement" Exchange Ratios on the Share of Each Class in the Reduced Crop and on the Per Capita Consumption of Each Class

Case where $Q_s = 0.95$

	Normal share of each class in foodgrain crop $Q_d = Q_s = 1$ $P = 1$ $\varepsilon_t = 0.178$	Share of each class in reduced output of foodgrain at market-clearing price	Percentage decline of each class from normal per capita consumption of foodgrains
	(1)	(2)	(3)
1. Landlords (including servants & retainers)	0.18	0.202	0.4
2. Farmers & lesser landlords (including servants)	0.39	0.438	0.4
3. Shopkeepers, minor professionals, & craftsmen (including servants)	0.11	0.110	12.0
4. Laborers & the unemployed (not including servants listed under 1, 2, & 3)	0.33	0.250	28.1

Source: See Appendix.

increases. If ε_t had remained constant, the decline in Q_s would have led to a 33 percent increase in prices instead of a 49 percent increase. In other words, one of the effects of the shifting distribution of entitlements is to reduce ε_t, both because ε_c declines and because δ increases. It follows that an initial rise in prices tends to feed on itself, even in the absence of speculative hoarding, by increasing the share of grain entitlements held by classes with a highly inelastic demand.

4. The Long Struggle to Repair the System of Food Distribution

Reductions in the national supply of grain by as much as 5 percent were rare events during the early modern era, occurring about once a century. However, deficits of 4 percent in the grain supply were more frequent, occurring about once a generation. When such events occurred, their impact was devastating on laborers and the unemployed, among whom the subsistence crisis was largely confined. Such great events, which reduced a normally poor diet to starvation levels, were social disasters. Whatever their impact on mortality, they could not be ignored by either local or national authorities.

Nor were they. In England during the Tudor and Stuart eras, containing the damage caused by grain shortages was a primary objective of the state. Famines were viewed not only as natural and economic disasters, but political ones as well (Everitt 1967, p. 575). The basic strategy of the Crown was to leave the grain market to its own devices during times of plenty, except to guard against abuses of weights and measures and to foil plots to corner markets. Even these measures provoked hostility from provincial justices and traders who resented the attempts of the central government to usurp local rights. As a result of their pressure the Long Parliament passed legislation which made it impossible for a uniform system of weights and measures to be established until the nineteenth century (Everitt 1967, pp. 578-579).

In years of grain shortage, however, the state overrode the complaints of traders, merchants, brewers, bakers, and other processors. In 1587 and in subsequent years of dearth, the Privy Council issued a "Book of Orders" which instructed local magistrates to determine the grain inventories of all farmers, factors, maltsters, and bakers; to force holders of inventories to supply their grain to artificers and laborers at relatively low prices; to suppress unnecessary taverns and unnecessary expenditures of corn in manufacturing; and to prevent all export abroad and limit transportation at home (Everitt 1967, p. 581).

It was, of course, easier to issue such orders than to enforce them. Despite the specter of popular upheaval that spurred the authorities, they found it difficult to gain control of inventories or to curb the rise of prices. Despite the attempts of magistrates, corn continued to be exported abroad or sold to brewers. Innkeepers who had contracted for their supplies before the harvest insisted on the enforcement of their contracts. When maltsters complied with suppression orders they often found themselves prosecuted by customers who had sent barley to them to be malted. Caught in the middle, many tradesmen and processors were driven to poverty by regulations intended to prevent it. The procedure enraged farmers and tradesmen who were subject to the inquisitional searches of bailiffs and constables, often for no better reason than the testimony of a common informer (Everitt 1967, pp. 583-585).

Because of the resistance of landlords, farmers, merchants, maltsters, and other owners of stock, it has been argued that government efforts to gain control of grain surpluses and to reduce the volatility of prices were a failure. Some hold that the paternalistic restrictions of the government were actually counterproductive, since the effort to uncover hidden stocks of grain served to promote alarm and pushed prices up. Instead of promoting greater efficiency in the market, these restrictions thwarted the activities of middlemen, whose function was balancing demand and supply by moving grain from places in which it was abundant to those in which it was scarce (Gras 1915, pp. 236-246; Everitt, 1967, pp. 581-585). Others believe that Tudor-Stuart paternalism actually worked. Although it might have taken a while before the scheme to ration grain on behalf of the poor became effective, numerous instances can be cited during the reigns of James I and Charles I in which concealed grain was brought to market and sold to the poor at reduced prices (Everitt 1967, pp. 585-586; Lipson 1971, III, pp. 444-453; Supple 1959, pp. 244-245).

Evidence bearing on this debate can be obtained by relating the variance in deviations of wheat prices from trend to the dominant policies of government in particular periods. For this purpose I have defined four periods. The first is 1541-1599, which represents the years before the paternalistic apparatus for controlling grain supplies during dearth was in place or became effective. Although precedents for the intervention of the Privy Council during a subsistence crisis may be found during the reign of Henry VIII, it was not until the end of the third decade of Elizabeth's reign that a potentially effective system was spelled out. The Book of Orders, published in 1587, listed 33 measures aimed at giving the authorities enough control over the supply to permit the sale of grain for consumption directly to laborers at moderate prices. It set forth a mechanism at the local level for enforcing the regulations, assigned specific roles to sheriffs, justices of the peace, and mayors, and it called for special juries of the leaders in each community to oversee the search for surplus stocks (Gras 1915, pp. 236-240; Lipson 1971, III, pp. 442-445).

Devising a minute system of regulations and making it work are two separate matters, especially since the local justices, who were the lynch-pin of the system, were lukewarm to the policy. The system did not become effective until the Privy Council provided the zeal and the administrative pressure required to mobilize local authorities. The turning point came in 1597, with the passage of a series of new laws aimed at alleviating poverty, laws framed in response to three years of turbulence set off by a combination of a depression and of severe dearth. Fearing spontaneous insurrections, the Privy Council not only promoted the new legislation but sought to enforce vigorously its Book of Orders. Beginning about 1600 the Council brought increasingly heavy pressure to bear on the local authorities. Proclamations were much the same as they had been but the orders were more detailed and the followup more systematic. Local authorities responded. In some cities and towns public granaries were established so that stores would be available to sell grain to the poor below market price; the making of malt was regulated by quotas; and searches for surpluses were more thorough. By 1631 the sale of grain to the poor below market prices had become widespread (Leonard 1965, pp. 184-199; Jordan 1959, pp. 83-108, 126-133; Lipson 1971, III, pp. 444-453; Supple 1964, pp. 244-246, 251-253).

The paternalistic system began to unravel with the Civil War. The heavy-handed intervention of the Privy Council with local authorities in order to relieve poverty was, indeed, one of the grievances of the opposition to Charles I. Although the victory of Parliament over the King enabled those who sought free markets and the protection of property to have their way, the paternalistic system did not collapse at once. The same inertia at the local level that made it so difficult for Elizabeth and the early Stuarts to effect their reforms, now operated in the opposite direction. Although the landholders and merchants who dominated Parliament developed a legislative program aimed at unshackling farmers, producers, and merchants from the restraints that had been imposed on them, local authorities continued to prosecute those who sought to profit from dearth at the expense of the poor. However, as Parliament implemented its new program, local authorities veered in the new direction and the paternalistic apparatus atrophied (Chartres 1985).

The motivation for the switch in government policy has been debated by historians but not resolved. Some investigators believe that after the Civil War landowning classes, unrestrained by the bureaucratic paternalism of the Tudors and early Stuarts, lifted restrictions on producers and merchants and placed a tariff on imports as acts of self-aggrandizement. That process was, in this view, abetted by a grateful William III who supported export bounties on grain as one of his favors to the class that put him in power (Barnes 1930; Rose 1961; Lipson 1971, II). Others, noting that the principal economic problem after the Restoration was economic stagnation and unemployment, believe that new measures were aimed at stimulating a depressed agriculture, promoting the reclamation of the fens and other waste lands, improving the system of marketing and transportation, and promoting industry. According to this view, it was not so much the landlords but the ordinary tenant farmers who would have been impoverished by outworn policies that continued to drive prices down. In the face of an agricultural depression that gripped not only England, but the Continent, the key issue was the encouragement of agricultural diversification and the

greater efficiency in the market, these restrictions thwarted the activities industrial production of agricultural products, including beer and spirits (Everitt 1967, p. 586; Lipson 1971, II; Abel 1980; Thirsk 1985; Chartres 1985).

Whatever the motivation for the switch in policy, it was the abandonment of the Tudor-Stuart program of food relief, not natural disasters or the technological backwardness of agriculture, that subjected England to periodic famines for two extra centuries. That conclusion is implied by Table 7, which shows that during the period from 1600 to 1640, when government relief efforts were at their apogee, the variance of wheat prices around trend declined to less than a third of the level of the preceding era. That large a drop cannot be explained plausibly by chance variations in weather, since the F-value is statistically significant at the 0.0001 level.[11] Nor is it likely that the sharp rise in the variance of wheat prices during the last six decades of the seventeenth century was the result of chance variations in weather.[12]

In the absence of government action to reduce prices during grain shortages, workers took to the streets and price-fixing riots became a standard feature of the eighteenth century. During the early decade of the eighteenth century the government sought to cope with such outbreaks by enforcing vagrancy and settlement laws and by force (Lipson 1971, III, pp. 457-467; Rose 1961). During the late 1750s, however, after food riots of unprecedented scope and intensity, proposals for the government to intervene vigorously in the grain market (to return to the Tudor-Stuart policies), including proposals to reestablish public granaries reemerged. As the battle over these questions ebbed and flowed during the next half century, the government, at the local and the national levels, gradually shifted toward more vigorous intervention in the grain market. However, it

Table 7

Analysis of the Variance in the Deviations of Wheat Prices from Trend During Four Periods Between 1541 and 1745

	Period	Dates	S^2 (measured as percentage deviations from trend)
1.	The years preceding paternalist regulation or during which the machinery for regulation was being put in place	1541-1599	935
2.	The apogee of regulation	1600-1640	277
3.	The dismantling of the regulatory machinery	1641-1699	625
4.	The dominance of government policies aimed at promoting agricultural growth and diversification by raising prices and developing markets	1700-1745	633

Source: Wheat prices are from Hoskins 1964, 1968 was not until the nineteenth century that the government control over stocks became adequate to reduce the variance in wheat prices to the level that prevailed at the apogee of Tudor-Stuart paternalism. By the middle of the nineteenth century, famines had been conquered, not because the weather had shifted, or because of improvements in technology, but because government policy (at least with respect to its own people[13]) had unalterably shifted back to the ideas and practices of commonweal that had prevailed during 1600-1640 (Barnes 1930, pp. 31-45; Post 1977).[14]

5. Chronic Malnutrition and the Secular Decline in Mortality

Had the political will been present, a system of public relief adequate to deal with grain crises could have been in place long before the nineteenth century, so much of the famine-related mortality, and much related suffering short of death between 1640 and 1815, could have been avoided. However, as Table 1 shows, even complete success in the struggle to eliminate famines would have left the level of mortality in "normal" times shockingly high. Indeed, Table 1 undoubtedly exaggerates the extent of famine mortality since the available evidence suggests that in the English case less than 10 percent of all crisis mortality between 1541 and 1871 was due to famines (Fogel 1986a, pp. 494-495).

Although the possibility that famines might have had only a small impact on aggregate mortality had been anticipated (Lebrun 1971; Flinn 1974; Flinn 1981), Wrigley and Schofield provided the data needed to measure the national impact. By demonstrating that famines and famine mortality are a secondary issue in the escape from the high aggregate mortality of the early modern era, they have indirectly pushed to the top of research agendas the issue of chronic malnutrition and its relationship to the secular decline in mortality. It is clear that the new questions cannot be addressed by relating annual deviations of mortality (around trend) to annual deviations of supplies of food (from their trend). What is now at issue is how the trend in malnutrition might be related to the trend in mortality and how to identify the factors that determined each of these secular trends.

The new problems require new data and new analytical procedures. In this connection one must come to grips with the thorny issue of the distinction between diet (which represents gross nutrition) and malnutrition (which represents net nutrition: the nutrients available to sustain physical development). I will not dwell on this distinction here (which is set forth in Floud, 1987) but will only emphasize that when I mean gross nutrition I will use the term diet, and that such other terms as "malnutrition," "undernutrition," "net nutrition," and "nutritional status" are meant to designate the balance between the nutrient intake (diet) and the claims on that intake.

Malnutrition can be caused either by an inadequate diet or by claims on that diet (including work and disease) so great as to produce widespread malnutrition despite a nutrient intake that in other circumstances might be deemed adequate. There can be little doubt that the high disease rates prevalent during the early modern era would have caused malnutrition even with extraordinary diets, that is with diets high in calories, proteins and most other critical nutrients. I believe that the United States during 1820-1880 is a case in point (see Fogel 1986a and 1988a). However, recent research indicates that for many European nations prior to the middle of the nineteenth century, the national production of food was at such low levels that the lower classes were bound to have been malnourished under any conceivable circumstance, and that the high disease rates of the period were not merely a cause of malnutrition but undoubtedly, to a considerable degree, a consequence of exceedingly poor diets.

Recently developed biomedical techniques, when integrated with several standard economic techniques, make it possible to probe deeply into the extent and the demographic consequences of chronic malnutrition during the eighteenth and nineteenth centuries. The biomedical techniques include improved approaches to the estimation of survival levels of caloric consumption and of the caloric requirements of various types of labor; epidemiological studies of the connection between stature and the risk of both mortality and chronic diseases; and epidemiological studies of the connection between body mass indexes (BMI) and the risk of mortality. The economic techniques include various methods of characterizing size distributions of income and of calories, as well as methods of relating measures of nutrition to measures of income and productivity.

Energy Cost Accounting: The Cases of Britain and France During the Last Quarter of the Eighteenth Century

In developed countries today, and even more so in the less developed nations of both the past and the present, the basal metabolic rate (BMR) is the principal component of the total energy requirement. For adult males age 20-39 living in moderate climates, BMR normally ranges between 1,350 and 2,000 depending on height and weight (FAO/WHO/UNU 1985, 71-72; Davidson et al. 1979, 19-25; Quenouille et al. 1951) and for reasonably well-fed persons normally represents somewhere in the range of 45 to 65 percent of total calorie requirements (FAO/WHO/UNU 1985, 71-77). Since the BMR does not allow for the energy required to eat and digest food, nor for essential hygiene, an individual cannot survive on the calories needed for basal metabolism. The energy required for these additional essential activities over a period of 24 hours is estimated at 0.27 of BMR or 0.4 of BMR during waking hours. In other words, a survival diet is 1.27 BMR. Such a diet, it should be emphasized, contains no allowance for the energy required to earn a living, prepare food, or any movements beyond those connected with eating and essential hygiene. It is not sufficient to maintain long-term health but represents the short-term maintenance level "of totally inactive dependent people" (FAO/WHO/UNU 1985, 73). Energy requirements beyond maintenance depend primarily on how individuals spend their time beyond sleeping, eating, and essential hygiene. In order to standardize for the age and sex distribution of a population, it is convenient to convert the per capita consumption of calories into consumption per equivalent adult male aged 20-39 (which is referred to as a consuming unit).

Historical estimates of mean caloric consumption per capita have been derived from several sources, including national food balance sheets and household consumption surveys. The various problems attendant upon using these sources have been described elsewhere (see Fogel 1988b). Despite their limitations, Toutain's (1971) time series of food consumption in France and the household surveys of English food consumption toward the end of the eighteenth century (Shammas 1984) indicate that in each of these countries a majority of the population was malnourished (Fogel 1988b).

Toutain (1971), on the basis of a national food balance sheet, has estimated that the per capita consumption of calories in France was 1,753 during 1781-1790 and 1,846 during 1803-1812. Converted into calories per consuming unit (equivalent adult male), the figures become about 2,290 and 2,410 calories. Data in the household budget studies recently re-examined by economic historians indicate that English daily consumption during 1785-1795 averaged about 2,700 calories per consuming unit (Fogel 1988b; cf. Shammas 1984).

One way of assessing these two estimates is by considering their distributional implications. As has been noted elsewhere, all of the known distributions of the average daily consumption of calories for populations are not only reasonably well described by the lognormal distribution but have coefficients of variation that lie between 0.2 and 0.4 -- a narrow range that is determined at the top end by the human capacity to use energy and the distribution of body builds, and at the bottom end by the requirement for basal metabolism and the prevailing death rate (Fogel 1988b). Consideration of available evidence on mortality rates (Bougeois-Pichat 1965; Weir 1984) and the findings of Goubert (1960, 1973), Bernard (1969), Hufton (1974), Kaplan (1976), and others on the condition of the lower classes in France during the late ancien régime rule out either 0.2 or 0.4 as plausible estimates of the coefficient of variation and suggest that 0.3 is the best approximation in the light of current knowledge.[15]

Table 8 displays the caloric distribution for England and France implied by the available evidence. Several points about these distributions that lend support to Toutain's estimate for the French and the estimates derived for the English from the budget studies are worth noting. First, the average levels are not out of keeping with recent experiences in the less developed nations. Low as it is, Toutain's estimate of French supply of calories is above the average supply of calories in 1965 estimated for such nations as Pakistan, Rwanda, and Algeria, and only slightly less (39 calories) than that of Indonesia. The English estimate is above that for 30

Table 8
A Comparison of the Probable French and English Distributions of the Daily Consumption of Kcals per Consuming Unit Toward the End of the Eighteenth Century

	A France c. 1785 $\bar{X}$ = 2,290 ($s/\bar{X}$) = 0.3		B England c. 1790 $\bar{X}$ = 2,700 ($s/\bar{X}$) = 0.3	
Decile (1)	Daily kcal consumption (2)	Cumulative % (3)	Daily kcal consumption (4)	Cumulative % (5)
1. Highest	3,672	100	4,329	100
2. Ninth	2,981	84	3,514	84
3. Eighth	2,676	71	3,155	71
4. Seventh	2,457	59	2,897	59
5. Sixth	2,276	48	2,684	48
6. Fifth	2,114	38	2,492	38
7. Fourth	1,958	29	2,309	29
8. Third	1,798	21	2,120	21
9. Second	1,614	13	1,903	13
10. First	1,310	6	1,545	6

Sources and procedures: See Fogel 1988b, esp. tables 4 and 5 and note 6.

less developed nations in 1965, including China, Bolivia, the Philippines, and Honduras, and only slightly below (37 calories) India (World Bank 1987).

Second, the distributional implications of the two estimates are consistent with both qualitative and quantitative descriptions of the diets of various social classes (Hufton 1974, 1983; Goubert 1973; L. Tilly 1971; C. Tilly 1975; Frijhoff and Julia 1979; Blum 1978; Cole and Postgate 1938; Rose 1971; Drummand and Wilbraham 1958; Pullar 1970; Wilson 1973; Burnett 1979; Mennell 1985). For example, Bernard's study (1975) of marriage contracts made in the Gévaudan during the third quarter of the eighteenth century revealed that the average ration provided for parents in complete pensions contained about 1,674 calories. Since the average age of a male parent at the marriage of his first surviving child was about 59, the preceeding figure implies a diet of about 2,146 calories per consuming unit (Fogel 1988b). That figure falls at the 47th centile of the estimated French distribution (Table 8, distribution A), which is quite consistent with the class of peasants described by Bernard.

The two estimates are also consistent with the death rates of each nation. The crude death rate in France c. 1790 was about 36.1 per thousand while the figure for England c. 1790 was about 26.7 (Weir 1984; Wrigley and Schofield 1981). It is plausible that much of the difference was due to the larger proportion of French than English who were literally starving (Scrimshaw 1987). The French distribution of calories implies that 2.48 percent of the population had caloric consumption below basal metabolism, most of them presumably concentrated at very young and at old ages. Table 8 implies that proportion of the English below basal metabolism was 0.66 percent. If a quarter of these starving individuals died each year (see Fogel 1988b), they would account for about a fifth (6.6 per 1000) of the

French crude death rate, but only about a sixteenth of the English rate (1.7 per 1000) and for about half of the gap between the crude death rates of the two nations.[16]

What, then, are the principal provisional findings about caloric consumption at the end of the eighteenth century in France and England? One is the exceedingly low level of food production, especially in France, at the start of the Industrial Revolution. Another is the exceeding low level of work capacity permitted by the food supply, even after allowing for the reduced requirements for maintenance because of small stature and reduced body mass (cf. Freudenberger and Cummins 1976). In France the bottom 10 percent of the labor force lacked the energy for regular work and the next 10 percent had enough energy for less than 3 hours of light work daily (0.52 hours of heavy work). Although the English situation was somewhat better, the bottom 3 percent of its labor force lacked the energy for any work, but the balance of the bottom 20 percent had enough energy for about 6 hours of light work (1.09 hours of heavy work) each day.[17]

That the English ultra poor were better off than the French ultra poor was partly due to the greater productivity of English agriculture (as measured by the per capita production of calories). However, the distribution of income was so unequal in England, that had it not been for the English system of poor relief, the proportion of the English that starved would have been nearly as great as that of the French. In response to the bread riots of the eighteenth century, English authorities substantially expanded the system of poor relief. Between 1750 and 1801, poor relief increased at a real rate of 2.3 percent per annum, which was nearly three times as fast as the growth of either G.N.P. or the pauper class (Crafts 1985, p. 45; M. Rose 1971, pp. 40-41; Marshall 1968, p. 26;

Mitchell and Deane 1962, p. 469). Consequently, by c. 1790 relief payments to the ultra poor had become substantial, more than doubling the income of households in the lowest decile of the English income distribution. In pre-revolutionary France, on the other hand, the average annual relief provided to the ultra poor could purchase daily only about one ounce of bread per person (Fogel 1988b, n. 17 and 18). The responsiveness of the British government to the bread riots of the poor (Barnes 1930; R. Rose 1961; Marshall 1968), not only kept the English death rate from soaring but may have spared Britain from a revolution of the French type.

The Implications of Stature and Body Mass Indexes for the Explanation of Secular Trends in Morbidity and Mortality

The available data on stature and on body mass tend to confirm the basic results of the analysis based on energy cost accounting: Chronic malnutrition was widespread in Europe during the eighteenth and nineteenth centuries. Recent advances in biomedical knowledge make it possible to use anthropometric data for the eighteenth and nineteenth centuries to study secular trends in European nutrition, health, and risks of mortality. Extensive clinical and epidemiological studies over the past two decades have shown that height at given ages, weight at given ages, and weight-for-height (a body mass index) are effective predictors of the risk of morbidity and mortality. Until recently most of the studies have focused on children under 5, using one or more of the anthropometric indicators at these ages to assess risks of morbidity and mortality in early childhood and it was at these ages that the relevance of anthropometric measures was established most firmly (Sommer and Lowenstein 1975; Chen, Chowdhury, and Huffman 1980; Billewicz and McGregor 1982; Kielmann et al. 1983; Martorell 1985). During the last few years, however, a considerable body of evidence has accumulated suggesting that height at maturity is also an important predictor of the probability of dying and of developing chronic diseases at middle and late ages (Marmot, Shipley, and Rose 1984; Waaler 1984; Fogel et al. 1986). Body mass indexes have similar predictive properties (Heywood 1983; Waaler 1984; Martorell 1985).

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

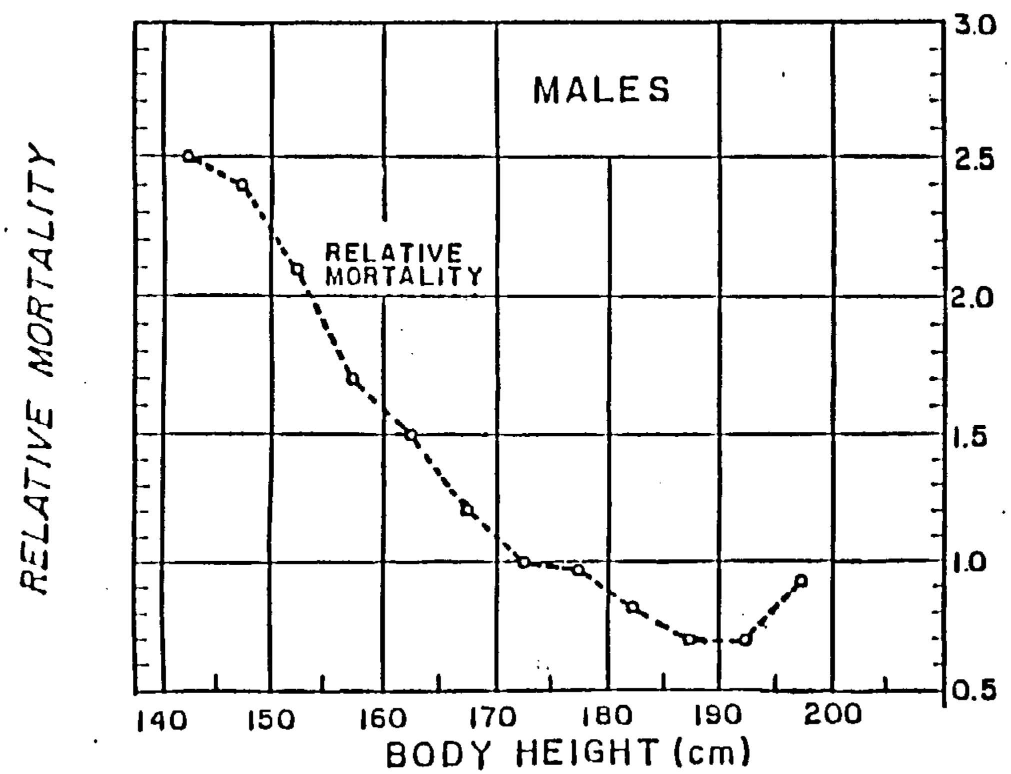
The predictive power of height and body mass indexes with respect to morbidity and mortality are indicated by Figures 1 and 2. Part A of Figure 1 reproduces a diagram by Waaler (1984). It shows that short Norwegian men aged 40-59 at risk between 1963 and 1979 were much more likely to die than

Figure 1

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

PART A

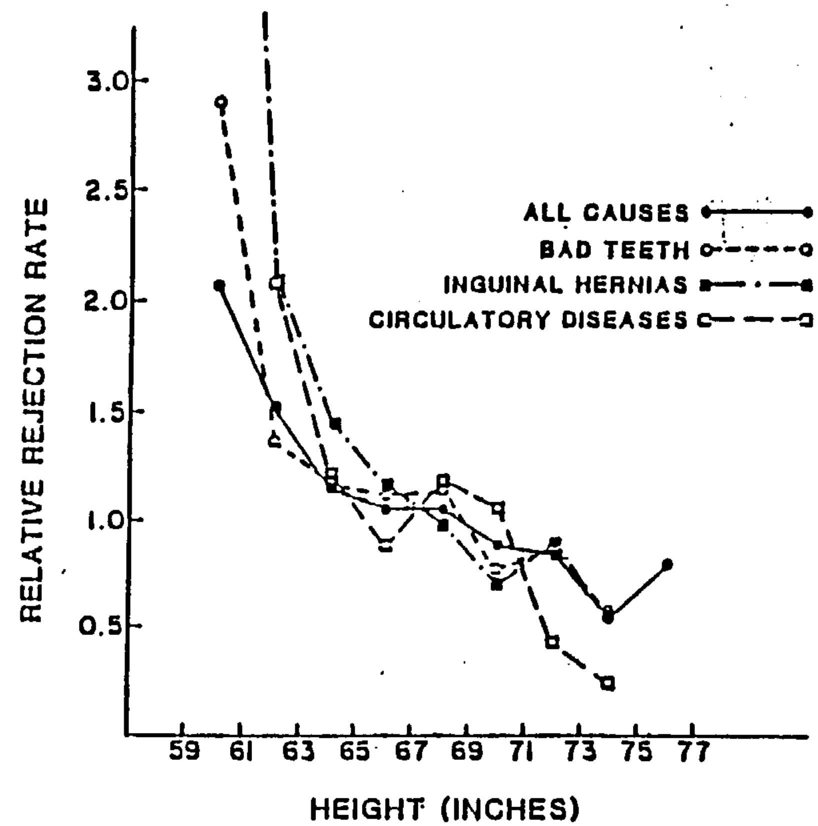
Relative mortality rates among Norwegian men aged 40-59, between 1963 and 1979



SOURCE: WAALER 1984

PART B

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



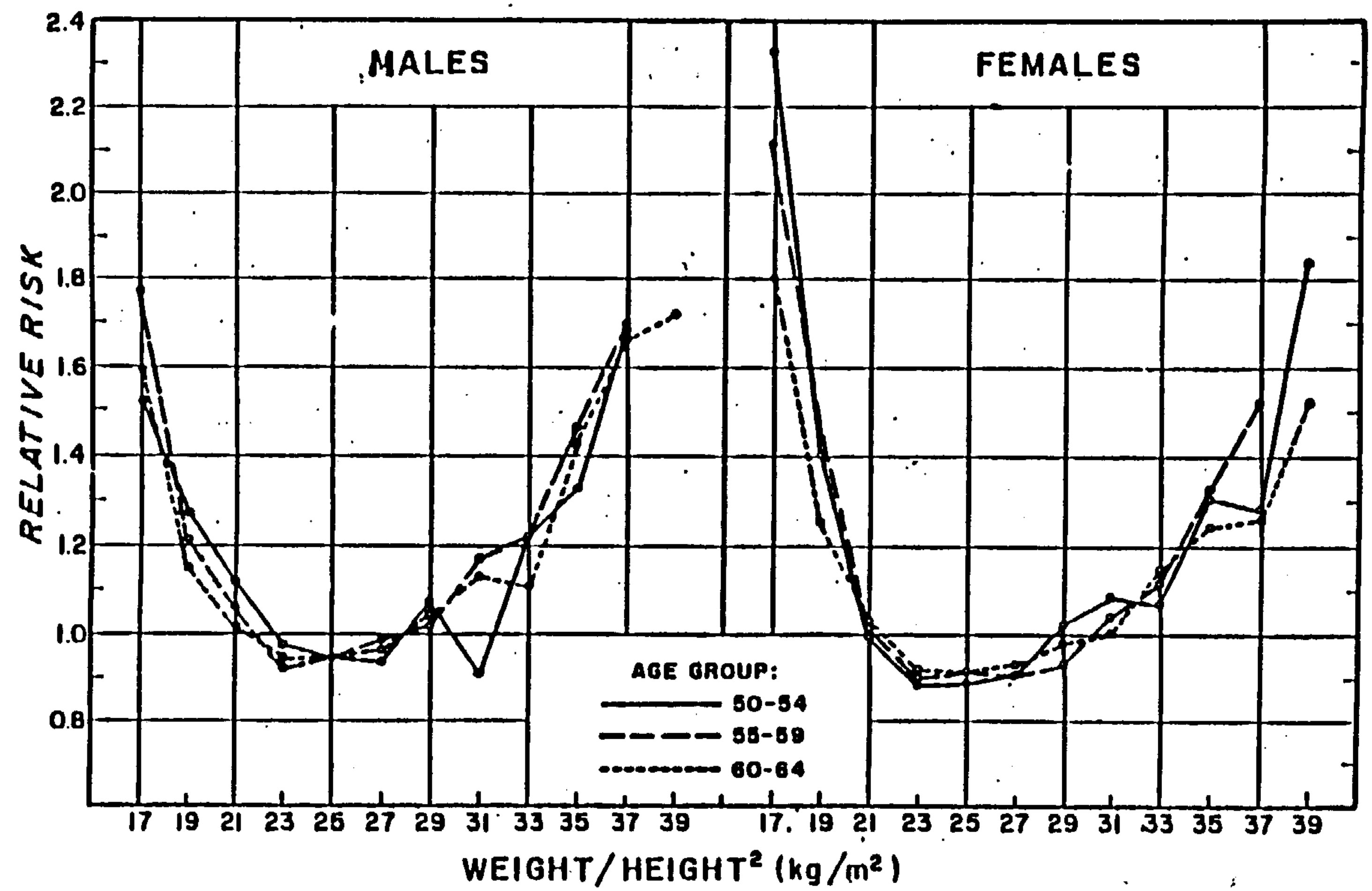
SOURCE: FOGEL ET AL., 1986

tall men. Indeed, the risk of mortality for men with heights of 165 cm (65.0 inches) was on average 71 percent greater than that of men who measure 182.5 cm (71.9 inches). Part B shows that height is also an important predictor of the relative likelihood that men aged 23-49 would be rejected from the Union Army during 1861-1865 because of chronic diseases. Despite significant differences in mean heights, ethnicities, environmental circumstances, the array and severity of diseases, and time, the functional relationship between height and relative risk are strikingly similar. Both the Norwegian curve and the U.S. all-causes curve have relative risks that reach a minimum of between 0.6 and 0.7 at a height of about 187.5 cm. Both reach a relative risk of about 2 at about 152.5 cm. The similarity of the two risk curves in Figure 2, despite the differences in conditions and attendant circumstances, suggests that the relative risk of morbidity and mortality depends not on the deviation of height from the current mean, but from an ideal mean: the mean associated with full genetic potential.[18]

Waaler (1984) has also studied the relationship in Norway between a BMI and the risk of death in a sample of 1.7 million individuals. Curves summarizing his findings are shown in Figure 2 for both men and women. Although the observed values of the BMI (kg/m^2) ranged between 17 and 39, over 80 percent of the males over age 40 had BMI's within the range 21-29. Within the range 21-29, the curve is relatively flat, with the relative risk of mortality hovering close to 1.0. However, at BMI's of less than 21 and over 29, the risk of death rises quite sharply as the BMI moves away from its mean value.[19] It will be noticed that the BMI curves are much more symmetrical than the height curves in Figure 1, which indicates that high BMI's are as risky as low ones.

Figure 2

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



SOURCE: WAALER 1984

Not only do adult height and the BMI measure different aspects of nutritional status, but they are uncorrelated in cross sections, both within populations and over them (Benn 1971; Billewicz, Kemsley, and Thomson 1962; Waaler 1984; Fogel et al. 1986). The absence of such a correlation is explained by two important aspects of the biology of nutrition. Not only is stunting due to malnutrition during developmental ages, but it appears that most stunting occurs under age 3, after which even badly stunted children generally move along a given height centile, that is, develop without incurring further height deficits (Tanner 1982; Billewicz and MacGregor 1982; Martorell 1985). Second, no matter how badly stunted an adult might be, it is still possible to have an optimum (or good) weight for that height. Thus, for example, a Norwegian male stunted by two inches during his developmental ages could still have had a normal risk if his BMI was about 26.

The fact that even badly stunted populations may have quite normal BMIs reflects the capacity of human beings to adapt their behavior to the limitations of their food supply. Adaptation takes place in at least three dimensions. Small people have lower basal metabolism, because less energy is needed to maintain body temperature and sustain the function of vital organs. Small people need less food and hence, require less energy to consume their food and for vital hygiene. The third aspect of adaptation comes in the curtailment of work and discretionary activity. If a small (56 kg) man confines himself to a few hours of light work each day, he could remain in energy balance and maintain his BMI at a satisfactory level with as little as 2,000 or 2,100 kcals. However, a larger man (79 kg) engaged in heavy work for 8 hours per day would require about 4,030 kcals to maintain his energy balance at a BMI of 24 (FAO/WHO/UNU 1985).

The fact that a stunted individual is in energy balance at a good BMI does not imply that he or she is not at greater risk than a person not stunted, but only that the demands on their energy intake leaves them in energy balance at a satisfactory level -- without causing them to consume tissue in order to sustain their energy output. As Figure 3 shows, there is an optimum weight for a 160 cm male, a weight which makes his relative mortality risk a minimum. At a weight of 65 kg (BMI = 25.4), the risk of a 160 cm man is about 35 percent less than that of a similarly stunted male of just 45 kg (BMI = 17.6). On the other hand, even at his optimum weight, a 160 cm male is at about 50 percent greater risk than a 175 cm male of optimum mass (74 kg and BMI = 24.1).

What implications do these new analytical tools have for the interpretation of secular trends in nutritional status and mortality? Table 9 compares the final heights of seven populations for which final heights have been estimated during the period 1750-1875. They are all severely stunted by modern standards (see line 6 of Table 9). The French cohort of 18-IV is the most stunted, measuring only 160.5 cm (63.2 inches). The two next shortest cohorts are those of Norway for 18-III and Hungary for 18-IV, which measured 163.9 cm (64.5 inches). Britain and Sweden were the tallest populations between 1775 and 1875, although by the end of the period, Norway nearly matched the leaders.

France may have experienced the most rapid early growth rate of any nation shown in Table 9, with stature increasing by 1.24 cm per decade between 18-IV and 19-II. However, French heights declined slightly over the next quarter century and hovered between 165.3 and 166.7 until the turn of the twentieth century (Floud 1983a). British heights also increased quite rapidly (0.76 cm per decade) and for a longer period than the French. The

Table 9

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

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

Sources: Fogel 1988b, Table 7.

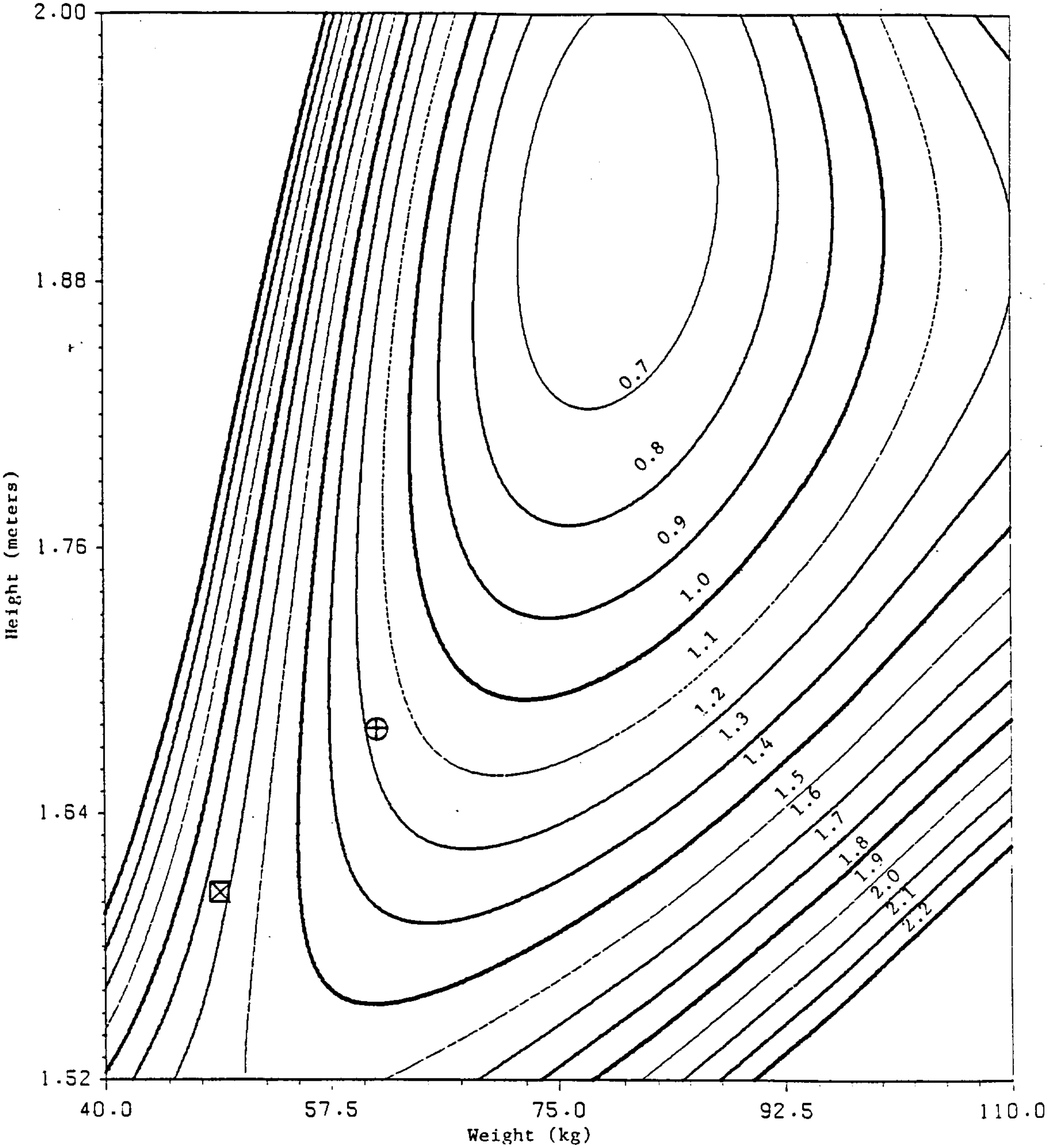
increase over the first 75 years (18-III to 19-II) was 5.7 cm, more than three-fifths of the total increase in British heights between 18-III and the current generation of adults. However, British heights like those of the French, declined slightly with the cohort of 19-III and also remained on a plateau for about half a century (Floud, Gregory, and Wachter 1988). Swedish heights appear to have declined during the last half of the eighteenth century but then rose sharply beginning with the second quarter of the nineteenth century, initiating the marked secular increases in Swedish heights that have continued down to the present day.

Indeed over the last century the three Scandinavian countries (shown in Table 9) and the Netherlands (Chamla 1983) have had the most vigorous and sustained increases in stature in the Western World, outpacing Britain and the United States (Fogel 1986a). Hungary's growth pattern differs from that of all the other European nations (Komlos 1987). Its cohort of 18-III was taller than that of Sweden, but then Hungarian heights declined sharply for half a century and, despite a turnabout in the nineteenth century, remains one of the shortest populations in Europe. Its mean height today is below the level achieved by the British cohort of 19-II.

Data on body mass indexes for France and Great Britain during the late eighteenth and most of the nineteenth centuries are much more patchy than those on stature. Consequently attempts to compare British and French BMIs during this period are necessarily conjectural. It appears that c. 1790 the average English BMI for males about age 30 was between 21 and 22, which is about 10 percent below current levels. The corresponding figure for French males c. 1785 may only have been about 19, which is about 20 percent below current levels (Fogel 1988b). The conjectural nature of these figures makes the attempt to go from the anthropometric data to

Figure 3

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



Note: ⊠ = the possible location of adult French males aged 25-34 c. 1785 on the iso-mortality map

⊕ = the possible location of comparable English males c. 1790

All risks are measured relative to the average risk of mortality (calculated over all heights and weights) among Norwegian males aged 50-64.

Source: Fogel 1988b.

differential mortality rates more illustrative than substantive. However, Figure 4 indicates the apparent location of French and English males of 18-IV on the iso-mortality map generated from Waaler's data. These points imply that the French mortality rate should have been about 40 percent higher than that of the English, which is quite close to the estimated ratio of mortality rates for the two countries.[20] In other words, the available data suggest that in 18-IV both France and Great Britain were characterized by the same mortality risk surface (i.e. the same mortality regimen) and that differences in their average mortality rates are explained largely by differences in their distributions of height and weight-for-height.

This result raises the question as to how much of the decline in European mortality rate since 18-IV can be explained merely by increases in vtature and BMIs, that is, merely by movements along an unchanging mortality risk surface. For the three countries for which even patchy data are available -- England, France, and Sweden -- it appears that nearly all of the decline in mortality between 18-IV and 19-III was due to movements along the Waaler mortality surface, since the estimated changes in height and BMI appear to explain virtually the entire decline in mortality during this three-quarters of a century. However, movements along the Waaler surface appear to explain only about 50 to 60 percent of the decline in mortality rates after 1875. After 1875 increases in longevity involved factors other than those that exercise their influence through stature and body mass. In other words, there appear to have been substantial shifts in the Waaler surface between 19-III and 20-III (Fogel 1988b).

Notes

[*]This paper stems from research connected with the project on "Secular Trends in Nutrition, Labor Welfare, and Labor Productivity," which is jointly sponsored by the National Bureau of Economic Research and the Center for Population Economics of the University of Chicago. The findings reported here were supported by grants from the Walgreen Foundation and the University of Chicago. I am especially indebted to E.A. Wrigley who called to my attention a number of the key issues discussed below, and whose criticisms of my early work on these issues pushed my research in new directions. I have also benefitted from the comments of George Alter, Jere Berhman, R. Floud, Patrick Gallway, John Komlos, A. Osmani, James Riley, and Armatya Sen on an earlier draft and from the discussion at the Conference on Poverty, Undernutrition, and Living Standards.

[1]Thirsk (1983) doubts that the real wage series employed by Wrigley and Schofield is adequate to sustain the analysis that has been based on them, calling particular attention to the failure of the index to reflect the changes in the diet over the period in question. Flinn (1982) and Lindert (1983) question the adjustments made by Wrigley and Schofield for the undercount of vital events. They also question the finding that fertility, operating through age at first marriage, rather than a decline in mortality was the principal factor in the acceleration of population growth at the end of the eighteenth and the beginning of the nineteenth century. Flinn also argues that lags of two generations between the real wage series and the population series throws the validity of the causal mechanism favored by Wrigley and Schofield (delay of marriage) into doubt. Weir (1984)

questions their reliance on a Malthusian model in both their interpretation of the French and the English data. He also finds that it was lower total marital fertility rather than higher ages at first marriage that made the cbr of the English lower than that of France during the middle and late eighteenth century.

[2]The analysis of Wrigley and Schofield is cast in terms of crude death rates rather than in age-standardized rates because the counts of vital events in their 404 parishes do not give the specific ages at which these events occurred. Consequently they were not able to examine the effects of famines on the age structure of mortality.

[3]In a constant elasticity demand equation of the form

$$Q = DP^{-\varepsilon},$$

D represents all of the variables that might cause the intercept of demand curve to shift (income, prices of substitutes, prices complements). The implicit assumption of those who have used King's Law is that both D and ε are constant. When all variables are standardized on 1, D = 1. It should also be kept in mind that in applications of King's Law, wheat is generally used as a proxy for grain or for food. Since applications of King's Law generally do not take account of the possibility that ε shifted during periods of dearth, I have worked within the framework of that tradition in this section because my aim here is to reveal issues that do not turn on a shifting demand curve. In section 3, below, an adjustment is made for a shifting elasticity. However, in both sections it is assumed that the aggregate demand curve is relatively fixed and that year to year fluctuations in price are due primarily to shifts in a perfectly inelastic short-run supply curve from one harvest to another. See the Appendix for a further discussion of these points.

[4]The figure on caloric consumption is derived by applying $(1.5^{-0.403})^2$ to the average caloric consumption of the three lowest deciles of the English distribution in Table 8.

[5]The figure is derived in the same way as in note 4, except that the factor is $(1.5^{-0.403})(2.05^{-0.403})$.

[6]The implicit assumption in the literature is that acres planted remained constant and that net imports were zero, so that all of the yearly variation in the quantity of grain was due to variation in yields. In order to avoid complicating the argument further than need be, I have accepted these assumptions. The effect of the assumptions is to bias the result against the point I am making since the root MSE around the trend of total production and around the trend of total production plus imports were below the root MSE around the trend of yields during 1884-1913.

[7]I do not mean to suggest that farmers actually dipped deeply into carryover inventories or into feed stores when grain prices rose. Indeed, as I shall argue below, they were quite unwilling to do so. Nevertheless those inventories were more than adequate to cover the food needs of the destitute without encroaching on reserves for seeds.

[8]The suggestion that ε_s is close to zero may appear to conflict with the discussion on p. 16, above, which indicated that carryover inventories were more than adequate to feed the destitute without impinging on seed reserves. However, the fact that carryover inventories were adequate to

feed the destitute does not mean that the owners of the inventories were willing to release them at prevailing prices, let alone at normal prices.

[9]We do not yet know what made the feed demand for grain so inelastic. However, it may be that feedgrains were used primarily for work animals and that farmers believed that skimping on feedgrains would weaken the horses and oxen on whose wellbeing the next year's crop would depend.

[10]See the Appendix for the sources and procedures in estimating σ_{gq} and σ_{gp}. Is it valid to use data for 1884-1913 to estimate the variability of per acre yields in the eighteenth century in view of the marked advances in agricultural technology after 1700? That point needs to be pursued and it may be possible to estimate the average variance in annual per acre yields for the eighteenth century from data in estate records. The earliest aggregate time series are for the United States which began its system of crop reporting shortly after the Civil War. These data suggest that although the technological advances produced large increases in the average yield per acre, they had little effect on the coefficient of variation. For example, the mean wheat yield in the U.S. during 1961-1970 was more than twice the figure for 1871-1880. However, the coefficients of variation for the two time periods were virtually identical (computed from U.S. Bureau of the Census 1975, pp. 510-511). Despite irrigation, crop spraying, etc., the principal factors which affect variations around trend (rainfall, sunshine, temperature, etc.) do not seem, even today, to have yielded much to science.

In Fogel 1986a, p. 489, I argued that ε_s was only moderately inelastic, despite the fact that English agricultural historians have implicitly or explicitly maintained that the seed and feed elasticities of demand were quite low (Hoskins 1964, 1968; Everitt 1967). The same point was vigorously argued by E.A. Wrigley in an exchange of letters that we had in 1985. I nevertheless put these views aside on the ground that the estimates of production functions indicated that the output elasticity of seeds was in the neighborhood of 0.1 (Griliches 1963). Furthermore, experiments by plant biologists early in the twentieth century also indicate that the elasticity of output with respect to seeds was in the same neighborhood as that obtained from econometric analysis (Johnson and Brooks 1983, pp. 154-61; Montgomery 1912; Dobben 1966). That finding together with the empirical estimate of the elasticity of substitution between inputs in agriculture led me to conclude that 0.6 was an appropriate value for ε_s (Allen 1967; Griliches 1967; Nerlove 1967; Brown 1966).

I now consider my earlier argument a good example of a bad way to make use of theory and of the pitfalls of argument by analogy. However, it was only after I estimated ε_t from data on yields for the period 1884-1913 that I reconsidered my earlier judgement and more closely examined the evidence that Wrigley called to my attention. The weight of that evidence supports Wrigley's position, and so poses a problem to economists who would normally expect farmers, given enough time, to shift their practice in a cost-minimizing direction. Since seven centuries surely ought to have been enough time, how does one explain the failure to change practice? One could always resolve the problem by invoking the lack of information (after all it was not until the twentieth century that plant breeders discovered the low seed elasticity of output) and cultural lag. And those answers might well be correct. It is also possible that high ratios of seed per acre reduced the variance of yields more than they increased the means, and that farmers were so risk averse that such a policy made economic sense. Russian farmers today use higher levels of seed per acre than makes sense, if one neglects attitudes toward risk and other aspects of culture (Johnson and Brooks 1983, pp. 154-161).

[11]The result of the F test would not have changed if equation (11) had been used to obtain the implied values of σ_{gq} (assuming $\varepsilon_t = 0.178$), since $(0.178)^2$ would appear in both the numerator and the denominator of the F statistic and hence cancel out.

[12]The F-values for $\frac{S_3^2}{S_2^2}$ and $\frac{S_4^2}{S_2^2}$ are significant at the 0.004 level.

[13]The Irish famine makes this qualification necessary. As Mokyr (1985, p. 292) has emphasized, if Ireland had been considered an integral part of the British community, the British government might have felt compelled to intervene much more vigorously than it actually did.

[14]In this connection it is worth noting that famines came to an end early in the nineteenth century, not only in England where per capita consumption of calories appears to have reached levels by 18-IV that are comparable to modern day India, but also in countries such as France where average caloric consumption was 15 to 20 percent lower. This issue is discussed more fully in the next section of the paper.

15. The main conclusions summarized in this section are robust to any value of the coefficient of variation in the range 0.3 ± 0.1.

16. This discussion only takes account of the incidence of mortality among those in each country whose consumption of calories was below basel metabolism. However, there were many other individuals who were at

increased risk of death because they were malnourished, even though the degree of malnourishment was less extreme. See pp. 50-54 and n. 20.

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

18. For a further discussion of this possibility see Fogel 1988b. It is important to keep in mind that the denominator of the relative risk curve is the average mortality rate computed over all heights. Consequently the curve will shift as the overall mortality shifts. What appear to be stable over a wide range of mortality regimens are the height-specific relative rates.

19. As with height, these curves have the average mortality rate, calculated over all BMI's, in the denominator. Compare the discussion in note 18. The body mass index used here, weight in kilograms and height measured in meters squared (kg/m^2), is referred to as the Quetolet index. Epidemiologists use height-squared rather than height in the denominator because that transformation reduces the correlation between height and the BMI to close to zero in cross section.

20. The English cdr for 11 years centered on 1790 is 26.7 and 1.40 times that number is 37.3, which is close to the French cdr derived from Weir's data for the 11 years centered on 1790.

Appendix

This appendix deals with the assumptions, mathematical derivations, estimation procedures, and sources of data for the analysis and estimates presented in sections 2 and 3 of this paper. For the assumptions, mathematical derivations, and estimation procedures reported in section 5 see Fogel (1988b).

The two principal implicit assumptions that underlie the analysis in sections 2 and 3 are traditional in the literature on the pricing of English grain during the early modern era (here taken to be 1500-1750), and are consistent with the available evidence. The first of these assumptions is that the average price each year was established under conditions of a completely inelastic aggregate short-run supply curve. The second assumption is that year-to-year changes in price were due to fluctuations in this short-run supply from one harvest to another around a fixed (or relatively fixed) aggregate demand curve.

The assumption that the demand curve was relatively fixed rests on the flat trend in income and in the relative prices of complements and substitutes for foodgrains (broadly defined), and in the stability of tastes (Mitchell and Deane 1962, p. 468; Drummond and Wilbraham 1958; Coleman 1977, ch. 3; Grigg 1982; Holderness 1976; Shammas 1983; Wrigley and Schofield 1981).[1] The assumption that the short-run supply curve of grain was completely inelastic rests (1): on the observation that once the harvest was concluded, the production of grain could not be increased until the next crop was planted and harvested, and (2): on the fact that the price wedge between England and the Continent was such that net imports of grain were generally negative even during years of dearth. In the few years when net imports were positive, they were about one percent of annual consumption (Gras 1915; Barnes 1930; Shumpeter 1960; Mitchell and Deane 1962).[2]

When the aggregate short run supply curve is perfectly inelastic, the usual problems of simultaneity disappear, and the estimate of the elasticity of aggregate demand curve can be obtained by regressing price directly on quantity. However, the usual econometric issues of simultaneity remain if one wishes to explain the distribution of the fixed supply between the holders and non-holders of grain inventories (cf. Fogel and Engerman 1974, II, pp. 56-58). That task is not undertaken in section 2. When it is undertaken in section 3, the key parameters are not estimated by the econometric procedures since neither the time-series nor cross-sectional data needed for such estimation are available.

A third important implicit assumption for the analysis presented in section 2 is that the distribution of arable land among crops did not vary from year to year but remain fixed by conventions that changed slowly over time. Consequently, all the short-run variation in output from one year to the next in grain crops has traditionally been presumed to have been due to variations in per acre yields rather than to variations in the number of acres sown (Wrigley 1987; cf. Slicher von Bath 1963; Hoskins 1964, 1968; Abel 1980; Appleby 1978; Grigg 1982).

The Derivation of Equation 7

The demand curve for the i^{th} class of consumers for a good (Q), when income is measured in real terms, may be written as:

$$(7.1) \qquad Q_i = \left(\frac{Y_i}{P^{\beta_i} P_m^{1-\beta}}\right)^{\psi_i} P_m^{\varepsilon_{mi}} P^{-\bar{\varepsilon}_i}$$

where Q = the quantity of grain

P = the price of Q

P_m = the price of all other goods, Q_m

Y = nominal income

β = the share of Q in consumption expenditures

$1-\beta$ = the share of all other goods in consumption expenditures

ψ = the income elasticity of the demand for Q

ε_m = the cross-elasticity of the demand for Q with respect to P_m

$\bar{\varepsilon}$ = the own-price elasticity of the income-adjusted demand for Q

i = a subscript referring to the i^{th} class of consumers

Differentiating (7.1) totally and rearranging terms yields

$$(7.2) \quad \overset{*}{Q}_i = \psi_i \overset{*}{Y}_i + [\varepsilon_{mi} - \psi_i(1-\beta_i)]\overset{*}{P}_m - (\psi_i\beta_i + \bar{\varepsilon}_i)\overset{*}{P}.$$

Since by assumption Q_m is the numeraire, $\overset{*}{P}_m = 0$ and equation (7.2) reduces to

$$(7.3) \qquad \overset{*}{Q}_i = \psi_i \overset{*}{Y}_i - (\psi_i\beta_i + \bar{\varepsilon}_i)\overset{*}{P}.$$

Now, by definition,

$$(7.4) \qquad Y_i = PQ_i + P_m Q_{mi}.$$

Differentiating (7.4) totally yields

$$(7.5) \qquad \overset{*}{Y}_i = \theta_i(\overset{*}{P} + \overset{*}{Q}_i) + (1 - \theta_i)(\overset{*}{P}_m + \overset{*}{Q}_{mi}),$$

where θ_i is the share of PQ_i in Y_i. Since Q_m is the numeraire and $\overset{*}{Q}_m = 0$ by assumption, equation (7.5) reduces to

$$(7.6) \qquad \overset{*}{Y}_i = \theta_i(\overset{*}{P} + \overset{*}{Q}_i)$$

If it is also assumed that all classes which own farm land suffer or benefit from random fluctuations in yields proportionately,

$$(7.7) \qquad \overset{*}{Q}_i = -\varepsilon_t \overset{*}{P},$$

so that equation (7.6) reduces to

$$(7.8) \qquad \overset{*}{Y}_i = (1 - \varepsilon_t)\theta_i \overset{*}{P},$$

where ε_t is the aggregate price elasticity of demand over all classes of consumers of grain (see equation 10). Substituting equation (7.8) into equation (7.3) and rearranging terms yields

$$(7.9) \qquad \overset{*}{Q}_i = \{\psi_i[\theta_i(1-\varepsilon_t) - \beta_i] - \bar{\varepsilon}_i\}\overset{*}{P}.$$

Hence, the price elasticity of demand for the i^{th} class of consumers (ε_i) is the coefficient of $\overset{*}{P}$ in equation (7.9), or

$$(7.10) \qquad \varepsilon_i = [\theta_i(1-\varepsilon_t) - \beta_i]\psi_i - \bar{\varepsilon}_i,$$

which is the same as equation (7).

<u>The Derivation of Equations 8 and 10</u>

The derivation of equation (8) follows directly from the identity

$$(8.1) \qquad Q_c = Q_1 + Q_2 + Q_3 + Q_4 = \sum_{q=1}^{4} Q_i,$$

where Q_c = the aggregate demand for foodgrain

Q_1, Q_2, Q_3, Q_4 = demand for foodgrains of each of the four classes defined in Table 5.

Differentiating (8.1) totally yields

$$(8.2) \qquad \overset{*}{Q}_c = \sum_{i=1}^{4} \phi_i \overset{*}{Q}_i,$$

where ϕ_i = the share of Q_i in Q_c. Substituting $-\varepsilon_i \overset{*}{P}$ for $\overset{*}{Q}_i$ in equation (8.2) yields

$$(8.3) \qquad \overset{*}{Q}_c = -\overset{*}{P} \sum_{i=1}^{4} \phi_i \varepsilon_i .$$

Hence, by definition, we have

$$(8.4) \qquad \varepsilon_c = \sum_{i=1}^{4} \phi_i \varepsilon_i = \phi_1 \varepsilon_1 + \phi_2 \varepsilon_2 + \phi_3 \varepsilon_3 + \phi_4 \varepsilon_4 ,$$

which is the same as equation (8).

The derivation of equation (10) is symmetrical to the derivation for equation (8), except that the initial identity is

$$(10.1) \qquad Q_t = Q_c + Q_s$$

where Q_t = the aggregate quantity demanded for grain for all uses

Q_s = the quantity demanded for grain used as seed, feed, and carryover inventories.

<u>The Sources for the Estimation of Parameters in Equations 4,5,6, and 11</u>

The estimate for σ_q was taken from the RMSE of a linear regression of annual wheat yields on time. The RMSE of yields rather than of wheat production or wheat production plus net imports was used because of the assumption in the literature that the distribution of arable land across crops remained fixed from year to year by conventions that changed only very slowly over time (cf. p. 62 above). The RMSE around the yield regression is greater than those around the production or around the annual production plus net imports. The data on wheat yields for the period 1884-1913 are from Mitchell and Deane 1962, pp. 92-93. The RMSE around quadratic trends were lower than those around the linear trends.

The estimates of α were based on two time series of prices that were spliced at the overlap to provide a continuous series for the period 1540-1738. The series for 1540-1649 are from Bowden 1967, pp. 814-870, and the series for 1640-1749 are from Bowden 1985, pp. 827-902. "Grains" was defined to include wheat, barley, oats, rye, and peas and beans. "Food" was defined to include the preceding crops plus livestock and animal products. The grain price index and the food price index were constructed by giving equal weight to the prices of each of the commodities. The reasons for choosing equal weights are discussed by Bowden 1967, p. 870. Plausible alternative weighting schemes (such as those indicated in Phelps Brown and Hopkins 1956, Thirsk 1983, Shammas 1983 and 1988, and Komlos 1988) tend to reduce both α and σ_{gp} because the prices of livestock and of animal products are less variable than those of grains. The data on crop yields and total output are reported in Mitchell and Deane 1962, pp. 92-93 and in the sources cited there.

The standard deviation of prices from trend during 1540-1738 were computed around a 25 year moving average in which the trend value of the price was standardized at 1. A similar procedure was followed in computing the standard deviation around a moving average of the real wage series developed by Wrigley and Schofield (1981, pp. 638-644) from the series of Phelps Brown and Hopkins as well as around the original price series. The estimates of the standard deviation around trend from these series over 1541-1871 were quite close to those computed from the Bowden all-food series for 1540-1738. Use of an 11-year moving average instead of a 25-year moving average also had negligible effects on the estimates of the standard deviation around trend in the several series.

<u>The Sources for the Parameter Estimates in Table 5</u>

<u>Column 1</u>. The population shares are based on King's table (Laslett 1984), except that out servants were divided among the top three classes on the assumption that there were an average of 5 out servants for each household of a landlord ("landlords" include the gentry down through "Persons in the Law"), an average of 0.44 out servants for each farm and lesser landlord household (a category which includes households of freeholders and ordinary clergy in addition to farmers), and an average of 0.24 out servants for each household in the category of shopkeepers, minor professionals and craftsmen (including military officers). The remainder of the households in King's table, which comprise the fourth class of Table 5, are presumed to hire no out servants. The analysis temming from Table 5 is not particularly sensitive to reasonable alternative definitions of classes or of other distributions of out servants nor to re-estimates of King's table, such as that proposed by Lindert and Williamson (1982), since such redistribution would have little effect on the inequality of the caloric distribution by income or social class.

<u>Column 2</u>. The shares of the 4 classes are based on the assumption that the English distribution of calories was lognormal with $\bar{X}$ = 2,700 kcal per equivalent adult and $s/\bar{X}$ = 0.3 (see Table 8 above). The means of the 4 classes are obtained from

$$(A.1) \qquad Z_{mi} = \frac{N_i}{(2\pi)^{0.5}} \int_{Z_i}^{Z_{i+j}} Ze^{-0.5Z^2} dZ$$

$$(A.2) \qquad \bar{X}_i = e^{Z_{mi}\sigma+\mu}$$

where Z_{mi} = the Z scores of the mean of the i^{th} class

Z_{j+i} and Z_i = the Z scores of the upper and lower bounds of the interval for the i^{th} class

$\bar{X}_i$ = the mean of the i^{th} interval in the lognormal distribution

N_i = the reciprocal of the area between Z_i and Z_{i+j}.

For a further discussion of this procedure see Fogel 1988b.

Column 3. The shares of grain in the expenditure of the four classes is based on the following assumptions:

Class	1 Share of food in total expenditures	2 Share of grain in food expenditures	3 Col. 1 x Col. 2 (rounded to nearest twentieth)
1	0.30	0.50	0.15
2	0.40	0.40	0.15
3	0.60	0.60	0.35
4	0.80	0.90	0.70

Values in column 3 were rounded to the nearest twentieth. These estimates are rough approximations based on data in Stigler 1954; Crafts 1980; Shammas 1983 and 1984; Phelps Brown and Hopkins 1956; cf. Thirsk 1983. The share of grain and of food in total expenditures for landlords may seem high, but it should be kept in mind that the majority of the persons in their households were from the lower class and that bread and beer or ale were the main components of their ration (cf. Dyer 1983).

Column 4. Estimates of King (1973, 52-55) and Davenant (1699, pp. 71-74) indicate that foodgrains accounted for about 43 percent of value added in agriculture c. 1700 and animal products about 30 percent (cf. Chartres

1985, pp. 443-448; O'Brien and Keyder 1978, 44; Deane and Cole 1969, p. 156). The remaining 28 percent were accounted for by feed crops, other crops (e.g. flax, hemp), timber, and firewood. It is likely, however, that non-grain products, particularly animal products, represented a larger share of the agricultural income of wealthy landholders (class 1) than of farmers and lesser landlords (class 2). I have assumed that $1-\varepsilon_t = 0.82$, that class 1 had claims upon or produced about one quarter of annual grain output, and that the remaining three quarters belonged to class 2.

Column 5. The income elasticity for grains for class 4 was estimated directly by Shammas (1984, p. 259) from the Edens and Davies surveys of c. 1790. Her figure (0.92) is quite close to the elasticity of grain (rice) derived from Timmer's equation for contemporary Indonesia (Timmer, Falcon, and Peason 1983, p. 59). For classes 2 and 3 I used Timmer's equation, and the income per household relatives for classes 2 and 3 computed from King's table (Laslett 1984), with the per household income of class 4 standardized at 100. Since the relative average income of class 1 was far beyond the range of observations on which Timmer's equation was computed, I arbitrarily assumed that the value of ψ for class 1 was one half of that for class 2.

Column 6. Timmer's procedure (Timmer, Falcon, and Pearson 1983, p. 59) was followed, employing the income relatives computed from King's table, as indicated in the note to column 5. For the reason indicated in the previous note, and Timmer's finding that the $\bar{\varepsilon}$ declines more rapidly than ψ with income, I arbitrarily assumed that $\bar{\varepsilon}$ for class 1 was 0.02.

Notes to Appendix

[1]Wrigley and Schofield (1981, p. 420) present a 25-year moving average of a real-wage index, which they use as a proxy for the trend in real annual per capita income. The average rate of increase in that index between c. 1551 and c. 1751 is about 0.06 percent per annum. However during that period the index trends downward for about 73 years beginning c. 1562 and then upward for a longer period beginning c. 1635. The average annual rate of decrease in the index between 1562 and 1635 is about -0.26 percent, while the average rate of increase between 1635 and 1750 is about 0.25 percent.

[2]Annual net exports or imports of grain were converted into a percentage of total annual grain consumption on the assumptions that grains provided 80 percent of caloric intake and that the average daily per capita consumption of all foods yielded about 2,100 calories. The total annual calories obtained from grains in a given year were estimated by multiplying the population of a given year by 2,100 x 0.8 x 365. Net exports of grain were converted to calories on the assumption that 29 percent of the weight of grain was lost in processing (either milling or using grain to produce beer) so that the flour equivalent of a bushel of wheat was about 44 pounds and that each pound of equivalent wheat flour provided 1584 kcals (Mitchell and Deane 1962, p. 86; McCance and Widdowson 1967). Estimates of the average annual net exports of grain are also provided by Bairoch 1978, p. 459; Coleman 1977, p. 121; and Deane and Cole 1969, p. 65; cf. Chartres 1985, pp. 448-454.

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