ON THE NUTRITION-STATURE HYPOTHESIS

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ABSTRACT

Social scientists who study stature have advanced markedly different hypotheses concerning the relationship between income, nutrition and stature. Economic historians hypothesize that households in the nineteenth century substituted away from carbohydrates and fiber and towards protein and fat as their incomes rose. Anthropometric historians assert that the same gains in stature can be explained by increased nutrient intake without any nutritional substitution. I test these hypotheses using the 1888 Cost of Living Survey. I fail to reject the hypothesis that the income elasticity of fiber is greater than or equal to the income elasticities of protein, fat, or sugar-- contrary to the nutritional substitution posited by economic historians. A food modified Engel curve reveals that the shares of carbohydrates, fat and sugar in the diet vary with household income, but the shares of protein and fiber do not. I do find, however, that the share of protein from animal sources increases with household income. In looking at the diet calorically, I reject the hypothesis of income elasticity equality between cereal calories and meat calories, and also between cereal calories and dairy calories. I also find that the diets of late nineteenth century industrial workers were surprisingly balanced by modern standards.

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I. Introduction

For more than two decades economic historians and development economists have included stature, the final adult height achieved, in their analysis of living standards. There are several justifications for analyzing stature, with the strongest being that stature is a net measure of living conditions and reflects changes in living conditions over the long run better than other aggregate measures. Steckel (1995), in a review of the literature, schematically outlines the relationships surrounding stature. First, there are socioeconomic determinants (income, food prices, inequality, etc.) that act on proximate determinants (diet, maintenance requirements, etc.) which then act on stature. In that same schematic, stature itself has functional consequences (mortality, morbidity, human capital formation, etc.) that act on the socioeconomic determinants of stature. Although Steckel's schematic is a feedback loop, most of the empirical work in the anthropometric literature concentrates either on the relationship between stature and its socioeconomic and proximate determinants or the relationship between stature and its functional consequences. In this paper I am concerned with the relationship between one socioeconomic determinant, income, and one proximate determinant, diet.

As outlined by Steckel (1995), the general hypothesis is that higher incomes lead to better investments in health, disease control, and nutrition, and these in turn produce taller stature for those who are better off economically. One problem, however, is that the theory underlying the relationship between the socioeconomic and proximate determinants of stature remains ambiguous. It is difficult to identify a single factor's relative importance among other factors that influence stature and physiological well-being more generally. In particular, the relationship between income and nutrition has not been empirically validated—there are competing theories that produce the same result. While economists see gains in stature coming from substitution in the nutritional content of the diet as income increases, anthropometric historians see the same gains in stature coming without any nutritional substitution as income increases, although anthropometricians and economic historians both assert that diets will increase in size as incomes grow. In this paper I test the validity of these two competing hypotheses about the relationship between income and dietary nutrition by looking at the macronutrient content of the diet.[1]

Economists have paid special attention to the role of changing diet quality, where households moved from cheap carbohydrates to more expensive protein and fat, in explaining

[1] Macronutrients in this paper are taken to mean carbohydrates, fat, protein, fiber, and sugar.

gains in stature over time, and this idea has been advanced explicitly and implicitly in the economics literature. The theory that nutritional content of the diet changed over time as incomes grew is a key component in much of the anthropometric literature as analyzed and discussed by economists. Fogel (1994a) asserts that as income increased in the late nineteenth century the diets of workers shifted "from grains and food with high fiber content to sugar and meats. These dietary changes raised the proportion of ingested energy that can be metabolized" (p. 24). This statement asserts that households will increase their consumption of proteins and sugars more than their consumption of fiber and grains as their incomes increase, and Fogel provides some evidence that this type of dietary change has occurred over time using nutritional balance sheets. Fogel (2004) goes on to assert that this change in the diet played a large role in economic growth, accounting for approximately half of all economic growth since the Industrial Revolution. Implicit in this conception of the nutrition-stature hypothesis, which we can term the economic nutrition-stature hypothesis, is the notion that consumers are able to achieve their true nutritional desires as their incomes increase and that these changes facilitate gains in stature.

While economists assert that the nutritional content of the diet is likely to change as income increases, anthropometric historians have asserted that households simply consumed more of the same nutrients, and in the same proportion, as their incomes grew. The anthropometric historian concept of nutritional stability, which can be called the anthropometric nutrition-stature hypothesis, asserts that the composition of the diet stayed the same as income increased, although the size of the diet did increase. Riley (2001) notes that the same outcome, increased stature, that economic historians believe is achieved through substitution in the nutritional content of the diet may be attained by simply consuming more of the same foods. He argues that both processes produce the same result in terms of workers consuming better diets as workers would naturally consume larger amounts of protein and fat as their diets increased, but they would remain in the same proportion in the total diet.

The economic nutrition-stature hypothesis can be tested by looking both at income and expenditure elasticities of carbohydrates, protein, fat, fiber, and sugar and by looking at whether the share of protein, fat, carbohydrates, fiber, and sugar in the diet change as total household expenditure increases. If economists are correct, then the income elasticities of protein and sugar will be greater than the income elasticity of fiber. Also, when mapping out the shares of the diet in each macronutrient group against total expenditure one should see a shift towards protein and sugar, and a movement away from fiber. If the anthropometric nutrition-stature hypothesis holds, the income elasticities of fiber, sugar and protein should be similar, and the shares of each in the diet would remain constant when mapped against total household expenditure. This is not a rejection of the underlying economic theory that food is a normal good, but it would be a rejection of a particular specification of that theory, namely that consumers had greater demand for protein and sugar than they had for fiber.

In this paper I use the 1888 Cost of Living Survey to obtain precise and robust estimates of the nutritional content of the diets of American and British industrial households in the late nineteenth century. One of the unique features of these data, that is particularly relevant to the study here, is that we can control for many of the socioeconomic determinants of stature, allowing us to identify the relationship between income and nutrition. Using these data, I fail to reject the hypothesis that the income and expenditure elasticities of fiber are greater than or equal to the income and expenditure elasticities of protein, fat, or sugar-- contrary to what has been posited by the economic nutrition-stature hypothesis. Using a food modified Engel curve, I find the shares of carbohydrates, fat and sugar in the diet vary somewhat with total household income, but the shares of protein and fiber do not. In general, non-parametric results reveal that overall changes in the shares of the diet are not very large, which I take as further evidence that substitution between macronutrient groups is mild at best.

This does not decisively prove that economists are incorrect about nutritional substitution in the diet, although the evidence suggests they may have been incorrect about the type of substitution. One of the problems with the two hypotheses stated above is that they concentrate explicitly on the nutritional content of the diet in terms of macronutrients. Consumers explicitly purchase food in its various forms (e.g. fish, rice, apples), and only implicitly purchase macronutrients. This is even truer in the nineteenth century, when the science of nutrition was in its infancy. I therefore test the hypothesis that the income and expenditure elasticities of food group calories (e.g. meat calories, cereal calories, dairy calories, etc) are equal. If Fogel's conception is correct, the elasticities of cereal calories will be significantly different from those of meat calories and dairy calories. In looking at the caloric composition of the diet, I find that the economic conception of the nutrition stature hypothesis is correct for food groupings. In particular, I reject the hypothesis of income and expenditure elasticity equality between cereal calories and meat calories, and also between cereal calories and dairy calories.

In short, the economic nutrition-stature hypothesis is correct about food but incorrect about nutrition, and the anthropometric nutrition-stature hypothesis is correct about nutrition and incorrect about food. We can reconcile these two divergent results by noting that nutrition and food groups may not be highly correlated with one another. The elasticity estimates produced in this paper imply that while meat may be a good proxy for protein, cereals are not a good proxy for carbohydrates. Also, it does not appear that dairy is a good proxy for fat, or that fruits and vegetables are a good proxy for fiber. The problem may be that hypotheses about the relationship between income and nutrition tend to conflate food groups and macronutrient groups. For example, economic historians have taken high demand for meat as high demand for protein without taking into account the fact that protein comes in many forms, and that increased demand for meat may be at the expense of other protein types. While high demand for meat will put more animal protein in the diet, it may be at the expense of non-animal protein, and the total share of protein in the diet may not increase as much as expected.

In general, the findings here allow us to craft a new economic nutrition stature hypothesis which is grounded in empirical observation. Namely, the new nutrition stature hypothesis asserts that there was marked substitution in the diet in the late nineteenth century, but it was for food groups, and not necessarily for nutrient groups. In particular, there was high demand for meats and dairy, and therefore a greater share of protein and fat came from animals as income increased. While the overall nutritional shares of the diet remained largely unchanged over the range of industrial incomes, the sources of those nutrients changed from being plant to animal based as income increased, and this fact becomes an important piece of the theory of technophysio evolution that has been advanced by economic historians.[2]

The rest of the paper proceeds as follows. Section II highlights the prominent themes surrounding the two nutrition-stature hypotheses. Section III discusses the data, describes how this work is able to identify the relationship between income and diet, and presents the methodology, highlighting the food modified Engel curves that have not, to my knowledge, been estimated previously in the literature. Section IV presents the results of the analysis, and Section V concludes with a statement of the new nutrition stature hypothesis and a discussion of the policy implications of the results presented here.

[2] For an introduction see Fogel (2004), and for a formal statement see Fogel and Costa (1997).

II. Anthropometric History and Theory

Stature is one of the key outputs of a process described by the term "technophysio evolution" that was popularized by Fogel and Costa (1997). Technophysio evolution refers to the process technological improvements and improvements in human physiology that have occurred since the beginning of the industrial revolution. In short, the theory posits that improvements in technology allow improvements in human physiology, and these physiological improvements lead to further technological gains. One important contribution of the theory is that it distinguishes between changes in human physiology and changes in physiological output.

Fogel and Costa see both thermodynamic growth (where humans have more calories/energy available for work) and physiological growth (where humans are better able to convert calorie intake to work through, for example, disease reduction) as important parts of the economic growth story. While the canonical literature has stressed the channel through which technological change acted on physiological change (in particular, where agricultural improvements led to greater calorie availability), Fogel and Costa stress that physiology feeds back into technological gain.[3] Nutrition, then, plays a role in both thermodynamic efficiency and physiological efficiency. Measuring thermodynamic efficiency is simply a matter of measuring output, but measuring physiological changes is more difficult. While the physiological changes are sometimes deduced from mortality and morbidity data, stature has been the most consistently used measure of physiological change.

In the literature height has been treated a measure of the stock of health and as a measure of net nutrition. Height data is more readily available than data for other measures of well-being for historical populations. Following Steckel's (1986) initial investigations into the heights of American slaves, economic historians began looking at anthropometric standards of living. The consensus is that human populations have been achieving generally taller statures for the past 300 years or so, although there have been periods where height declined for a few decades.[4] These studies have covered the globe in the search for anthropometric records, although there are a few important studies that can actually link the anthropometrics to demographic outcomes.

[3] Thinking that human physiology plays a large role in economic growth has led to the relatively new term, physiological capital.
[4] Steckel (2001) finds a similar pattern of height gains and subsequent losses in the pre-industrial era, but in modern populations the gains far outweigh the losses, and humans are now, on average, taller than they have ever been.

Both Costa and Fogel, for example, have made use of the records of Civil War veterans to investigate the links between stature and mortality, which in Steckel's schematic are functional consequences of stature. Costa (2002) has found that height was a strong predictor of later life morbidity and mortality. In particular she finds that sixty percent of the mortality decline between 1915 and 1988 can be explained by changing human physiology using the records of Civil War Veterans. Costa (1993) found the same trends in other data for Civil War Veterans, and in general this work strengthens the case that height is a predictor of mortality in historical populations. Fogel (1998) highlights the fact that average stature, usually taken from military records, follows the same time trend as life expectancy at age 10, further establishing the relationship that stature has with other measures of well-being. The growth or shrinking of a population is now taken as evidence of improving or deteriorating living conditions.

Fogel (1994a, 1994b) has noted, however, that the transmission of improved health and height over time may have a lag. Women who were malnourished as children or who are overworked while pregnant may not be large enough to carry a sufficiently large fetus, and the mechanism through which economic growth improves health can be delayed by several generations as a result. In a sense, this is a restatement of Barker's (1992) hypothesis that inutero insults to health cannot be overcome with better living conditions later in life. Steckel (1986) has noted that dietary improvements, even those after early childhood, could act to overcome this transmission failure, particularly when metabolized calories (e.g. meats) are added to the diet in sufficient amounts. In particular, he finds that American slaves, who are very small as young children grow to be as tall or taller than free whites in the North. In some ways, then, Steckel's work implies that height may not be the type of physiological outcome that conforms to Barker's hypothesis.

Many of Steckel's proximate and socioeconomic determinants have been taken as the dominant players in stature trends. Komlos (1987, 1998) has speculated that diets worsened over the period of industrialization as agricultural production could not keep up with demand, although there has been no general agreement on the issue. It has also been argued that urban dwellers were unhealthy due to both increased expenditures on essential non-food items and the relatively high cost of food in cities. Recently, Haines, Craig, and Weiss (2003) have argued that environment and disease played the dominant role in the antebellum decline in stature in the United States, although deteriorating diets also had an effect.

Despite areas of broad agreement in the literature, there are many open questions and puzzles in anthropometric history. Fogel, et. al. (1983) find that gains in height and nutrition were uneven in Western Europe and the United States from 1700 to 1900, and they remain unsure as to why the marked variance existed despite the similar economic growth patterns of the nations involved. A'Hearn (2003) finds that despite their backwards economic position, Northern Italians were as tall as their European contemporaries. Riley (1994) argues that the link between height and mortality, important to the theory of technophysio evolution, is tenuous. He analyses a group of British men in 1865 and finds that although they are shorter and thinner than men today they are no more at risk of death than taller and thicker men.

There is an expanding literature in development economics that uses height data to discuss well-being. Strauss and Thomas (1995) investigate the links between wages and heights in developing countries today. They report that height and BMI are positively correlated with wages in the Brazilian population, and this is much stronger evidence that increased nutrition (in the long run) can act to increase productivity. While Berhman and Doelalikar (1987) and Subramanian and Deaton (1996) debate whether policies that grow income will have any nutritional effect on poor people, most development economists believe that there is a positive relationship between income and nutrition, although the identification of the relationship is difficult because of the feedback between nutrition and income. Strauss and Thomas (1998) later review the literature and place height within the realm of health and human capital. They present estimates of the rate of growth of mean height by birth cohort in developing nations in the second half of the twentieth century, and find them similar to the early twentieth century height trends found in the United States. In their analyses they lean heavily on the work of economic historians and others who have made "a compelling case for linking aggregate movements in adult height to long-run changes in standards of living, including income, mortality, and possibly morbidity" (p.768). It is somewhat troubling, however, that they do not acknowledge the problems with and puzzles in the anthropometric literature.

III. Data and Methodology

A. Data and Diets

In this paper I am able to overcome many of the problems in other anthropometric studies by concentrating on the relationship between one socioeconomic determinant, income, and one proximate determinant, diet. Using a cross section of industrial households in the late nineteenth century I am able to control for nearly all of the socioeconomic determinants but income. Since income is, arguably, the only relevant variable allowed to vary freely I can identify the impact that income has on the diet. In this way, I am able to offer a test of the economic nutrition-stature hypothesis in a historical population at a time when heights were increasing. Such a test is powerful in that it allows us to properly identify and rank the influences that socioeconomic and proximate determinants may have on stature.

The data analyzed in this paper comes from the "Cost of Living of Industrial Workers in the United States and Europe 1888-1890" survey (henceforth 1888CEX) published by the United States Department of Labor. The study was conducted under the direction of Carroll D. Wright, then the U.S. Commissioner of Labor, who at the time was given the task of empirically analyzing American industrial living standards relative to that of European industrial workers. The 1888CEX data set contains a sample of more than 8,500 families working in iron, steel, coal, textile, and glass industries in both Western Europe and the United States. There are 6,809 households in the survey from the United States, which come from more than 20 states. The European sub-sample of households comes from Germany, Switzerland, Belgium, Great Britain, and France, although the vast majority, 1,024, come from Great Britain.[5]

One of the chief criticisms of the anthropometric literature is that it is does not allow us to identify or rank single factors in terms of their importance. There are, it is argued, a number of reasonable explanations for the trends in height that we see, and explanations usually identify a number of possible factors, the ranking of which is deduced from logical argument or fragmentary evidence. Steckel's (1995) review of the literature finds a number of possible factors that influence stature. The criticism is not that there are several factors, but that it has been nearly impossible to identify the impact of any single factor on changes in stature over time. Such a situation is inevitable, however, since anthropometric evidence is usually time

[5] See Logan (2004) for more on the 1888CEX.

series evidence, and several factors may be involved at any given time.[6] Steckel lists nine socioeconomic determinants and five proximate determinants that may, at one time or another, be the dominant force behind a given height trend. The socioeconomic factors are public health, disease environment, technology, labor organization, food prices, inequality, personal hygiene, cultural values, and income. The proximate determinants are diet, genetics, maintenance, disease, and work intensity.

The timing of the survey is particularly important in terms of identifying the relationship between income and diet. Fogel (1998), Steckel (1991) and others have shown that by 1880 gains in height were once again seen for men in the United States. This gives us a firm basis to insist that the "traditional" links between income, diet, and height were in effect at the time the survey was taken. In using a cross section at a point in time I am able to control for inequality, technology, and food prices, which will be fixed at any point in time. Additionally, including the geographic location of the household acts as a way to control for food prices in the market, since the state is the smallest area of geographic detail in the 1888CEX. Including the industrial occupation of the household head allows us to use it as a proxy for labor organization, which will also be fixed at a point in time. The geographic location of the household can be used as a quasi-control for public health and disease environment. This is advantageous since it is usually difficult to control for the disease environment in the height literature since it may change over time or interact with technology and public health, as the theory of technophysio evolution suggests. The other socioeconomic determinants, personal hygiene and cultural values, cannot be captured in any econometric model and almost surely vary from household to household.

The 1888CEX survey contains annual expenditure on twenty-two food items.[7] These expenditures can be converted to nutrients using the report "Retail Prices and Wages: A Report by Mr. Aldrich" (1892). In the American sample, I took the annual average price of each food item as given in the Aldrich report for the twelve months from June, 1889 to May, 1890. I then divide the annual expenditure on each food item by the annual quantity price estimate for that food item in the household's state. For the British sample I divide the expenditure by the June, 1889 prices that are given in the Aldrich report. Lastly, I use a standard nutrition conversion

[6] Steckel (2004) has recently used synthetic longitudinal data to overcome many of these identification problems.
[7] In particular, bread, coffee, milk, eggs, cheese, sugar, potatoes, poultry, rice, butter, pork, beef, meat, lard, molasses, tea, condiments, flour and meal, vegetables, fruit, fish, and "other foods" are the categories I which food expenditure is enumerated.

table to convert the estimates of food quantity to their grams of fat, fiber, sugar, protein, and carbohydrates, which are the nutrient groups of interest in this analysis, and to their caloric values as well (Nutribase 2001).

A word on the validity of the nutritional conversion is warranted. While it is true that foodstuffs in the distant past bear little resemblance to their current form, by the late nineteenth century food production was largely a regulated and standardized industry in the United States, and products were broadly similar to their twentieth century counterparts, particularly for dietary staples. As Law (2003) has shown, by the end of the nineteenth century nearly every state in the United States had passed legislation regulating food and dairy products in order to standardize food production and to ensure quality thresholds were met. These laws also ensured that foods were not adulterated and that there was truth in advertising for food products. What this tells us is that in the food products consumed in the late nineteenth century were standardized in such a way that the nutritional conversions can be applied since foods were largely what they were represented to be and adulteration was rare. Furthermore, the standardization of food production gives us confidence that the nutritional conversions here reasonably reflect the true nutritional content.

In this paper I work with the three major macronutrient food groups—protein, fat, and carbohydrates. Among the class of carbohydrates, this paper further considers two types of carbohydrates, sugars and fiber, which play very important roles in their own right. Since the nutrition-stature hypotheses discussed earlier involve each of these nutrients in some way, their similar and differing roles in human development and physiology are of particular interest.

Protein is the nutrient most responsible for human growth and the maintenance of muscle, hormones, and antibodies. Protein is the primary source of nitrogen for the human body, and protein is essential because it contains amino acids, which are found in every cell of the human body and are the building blocks protein. Roughly half of the twenty-two amino acids needed for normal functioning (including growth and development) are not made by the body and must be supplied by food sources. Protein not only helps in the construction and maintenance of muscle and tissue, but also makes up the compounds that form the body's chemical reactions, including the flow of blood and the management of blood glucose levels. It also helps the body maintain its acid/base balance. Although our bodies are able to use protein for energy, they prefer to use fat and carbohydrates for that purpose since amino acids carry out functions that carbohydrates and fat cannot.

Fat is necessary for the maintenance of skin and hair, although in high amounts it does much more harm to a body than good. Most of the fat that humans consume is in the form of triglycerides, and only small amounts come from cholesterol or waxes. In general, humans consume fat from either animal sources, which are high in saturated fat, or from vegetable sources, which are high in unsaturated fat. Fat aids in the absorption of key vitamins such as A, D, and E. Fat also acts to deposit itself around organs in the body with the aim of protecting them. Diets lacking in certain types of fat will lead to problems with kidneys and blood disorders. Many important bodily functions, such as the onset of menarche, require the body to be above some fat threshold.

Carbohydrates provide the fuel for the human body. They are the major source of metabolic energy. In particular, carbohydrates serve as a component involved in the transportation of energy throughout the body. They also play a key role in the construction of organs and the nervous system. They even help to define a person's blood type. Two types of carbohydrates, fiber and sugar, are analyzed separately here.

Sugars are the simpler carbohydrates (glucose, fructose, etc.). Sugars are comprised of monosaccharides (simple sugars), disaccharides (two simple sugars combined), and polyols (which are sugar based alcohols). Sugars are the main energy sources of carbohydrates. Sugars taken in by humans are converted to glucose, and the more complex the sugar the more enzymes (which come from proteins) needed to break the sugar down to its simpler form. Some parts of the body, including the brain, only use glucose as an energy source since they do not use fats as an energy source.

Fiber is also a carbohydrate, and is the portion of plant material that cannot be digested. For this reason, diets high in fiber are not likely to be favored over those that are more diverse in nutrients, as diets high in fiber will not be nutritious. Even though humans do not digest fiber, it performs many important functions in the body. One important function of fiber is that it maintains the intestinal track by increasing the mass in the intestine. Some fibers ferment in the large intestine, and this is how fiber promotes a feeling of fullness and helps with overall digestive health by regulating the intestinal track, and in this way diets lacking in fiber will usually result in intestinal and digestive problems that may make it difficult to absorb nutrients (Nutribase 2001).

B. Empirical Strategy

I estimate the nutritional elasticities discussed herein with the log linear equation $\ln\left(\frac{g_i}{n}\right) = \alpha_i + \beta_i \ln\left(\frac{x}{n}\right) + \varepsilon_i$ where β is the elasticity, *x* is household income, and *g* is the macronutrient, and *n* is the household size. To test the elasticity hypotheses, I regress the log of per capita grams of protein, fiber, and sugar (respectively) on the log of per capita income and separately on the log of per capita expenditure. Using robust estimates of the standard errors, I test the hypothesis that the elasticity coefficients from the regressions are equal to one another for the protein, fiber, and sugar income and expenditure elasticities. I also include the log of family size, shares of the household in five year age categories, dummy variables for the industry that employs the head of the household, and dummy variables for the state of residence in the American sample. The same procedure was used for food group calorie elasticities, where the dependent variable is the log of the per capita food group calories (e.g. meat calories, cereal calories, etc.).

In looking at the shares of the diet devoted to particular macronutrient groups I use a food modified Engel curve that has not, to my knowledge, been presented previously in the literature. I modify the traditional Engel curve by regressing the fraction of the diet devoted to particular nutrients on household income, household size and household demographics. The modified Engel curve estimates changes in the macronutrient distribution of the diet to household expenditure, household size, and the share of the household devoted to particular age categories. To test the shares of the diet hypotheses I regress the nutritional shares of the total diet (e.g. share of protein), as opposed to the total budget, on the log of per capita income and expenditure, respectively. For each macronutrient share of the diet, *w*, I estimate

$$\frac{g_i}{d} \equiv w_i = \alpha_i + \beta_i \ln\left(\frac{x}{n}\right) + \varphi_i \left[\ln\left(\frac{x}{n}\right)\right]^2 + \sum_{k=1}^{K-1} \vartheta_{ik}\left(\frac{n_k}{n}\right) + \Theta Z_i + \varepsilon_i$$

Where g is either the grams of fat, protein, sugar, fiber, or carbohydrates, d is total nutrients grams available to the household, n is the size of the family, x is total expenditure, k is 5-year age categories (e.g. 5-9, 15-19, etc.), and Z is a vector that contains industry and state dummy variables. As Deaton (1997) explains, "the transformation of expenditures to budget shares and of total outlay to its logarithm induces an approximate normality in the joint density of the transformed variables, so that the regression function is approximately normal" (p. 231). Diet shares and the log of household expenditure exhibit a similar type of normality. Note that, in congruence with the Engel function, prices do not enter here as they are assumed constant and would collapse into the intercept. The hypothesis is that the coefficients of the income and expenditure terms are equal to zero.

I also estimate the modified Engel curve non-parametrically with locally linear regression. Locally linear regression is a non-parametric technique that does not impose the restrictive assumption of global linearity of the regression model. I preform a linear local regression of the share of the diet in the respective nutrient group on the natural log of per capita expenditure (lnPCE) with a smoothing parameter of .2. Locally linear regressions are weighted regressions where the weights are equal to

$$\omega_i = \left[1 - \left(\frac{|x_i - x_j|}{\max_i |x_i - x_j|}\right)^3\right]^3$$

This weighted regression is only run for the 20% of observations that are closest to x_j, which in this case is logged per capita expenditure.

The local linear regression works under weaker assumptions than the general OLS function, as a line within a small neighborhood of x will closely approximate nearly any well-behaved function. The strength of this approach is that one only invokes the idea of a Taylor series approximation to a function, which in small neighborhoods will be a line.[8] I further investigate the hypothesis by fitting the shares through the non-parametric techniques discussed above to further validate the stability or instability of the shares of the diet.

[8] Technically, there will be very little difference, in a small neighborhood, between a Taylor series approximation of degree n and a first degree approximation (which is a line).

IV. Empirical Results

A. Elasticities of Nutrients

As discussed earlier, economic historians have asserted that households substituted away from fiber and towards sugar and protein as their incomes grew. If this is true, then the income and expenditure elasticities of fiber should be less than the income and expenditure elasticities of protein and sugar. I find, however, that I cannot reject the hypothesis that the income and expenditure elasticities of fiber are greater than or equal to the income and expenditure elasticities of protein and sugar. I also find that I cannot reject the hypothesis that the income and expenditure elasticities of fiber are equal to the income and expenditure elasticities of protein and sugar.

Table 1, which presents nutrient income elasticity estimates, shows that the estimated income elasticity of fiber is greater than the estimated income elasticities of sugar and fat, and protein for the American households.[9] Indeed, I am unable to reject the hypothesis that the income elasticity of fiber is greater than or equal to the income elasticities of fat, protein, and sugar for the American industrial households. Also, I cannot reject the hypothesis that the income elasticity of fiber is equal to the income elasticities of protein and sugar. That fiber has the largest income elasticity of all the nutrients is surprising considering the role that protein plays in the anthropometric literature, both for economic historians and development economists.

For the British households, the income elasticity of fiber is greater than that of sugar and only slightly lower than the income elasticity of protein, a difference which is not statistically significant. For the British data, I am unable to reject the hypothesis that the income elasticity of fiber is greater than the income elasticity of protein and sugar. Furthermore, I fail to reject the hypothesis that the income elasticity of fiber is equal to the income elasticities of protein and sugar. The results of Table 1 do not support the contention that households in the late nineteenth century substituted away from fiber and towards protein and sugar as income increased. The income elasticities show similar levels of demand responsiveness between protein, fiber and sugar. At best, these results support the argument that households had approximately uniform demand for all nutrients except non-sugar, non-fiber carbohydrates.

[9] In this paper, the significance level used for all test is .001.

Carbohydrates, however, appear to occupy a unique position here. It has long been established that demand for carbohydrates is less than demand for other nutrients since carbohydrates are so cheap and plentiful. Table 1 does show that carbohydrates have the lowest income elasticities of all the macronutrients considered here. This result does conform to what has been found in other dietary studies in the developing world today. These results suggest that the demand for non-fiber, non-sugar carbohydrates must be particularly low, since carbohydrates as defined in these regressions include both fiber and sugar, and their separate elasticities are much higher than the income elasticity of total carbohydrates.

The nutrient expenditure elasticities reported in Table 2 mirror those of the income elasticities. As with the income elasticities, I fail to reject the hypothesis that the expenditure elasticity of fiber is greater than or equal to the expenditure elasticities of protein and sugar. I also fail to reject the hypothesis that the expenditure elasticity of fiber is equal to the expenditure elasticities of protein and sugar. This holds for both the American and British estimates of the macronutrient expenditure elasticities. As with the income elasticities, it does not appear that households had low demand for fiber relative to protein and sugar, although there was lower demand for carbohydrates. The theory of nutritional substitution laid out by economic historians is not empirically supported in Tables 1 and 2.

One feature of Tables 1and 2 that should be stressed is that these results help to establish plausible estimates of macronutrient income elasticities for industrial families in the late nineteenth century. As the tables show, demand for all nutrients is strong, which we should expect from the narrative evidence from the late nineteenth century which tells us that industrial families were malnourished.[10] While the pattern of elasticities does not conform to the pattern of nutritional substitution described in economic nutrition-stature hypothesis, they do support the contention that industrial households in the late nineteenth century had high demand for macronutrients. Another interesting feature of Tables 1 and 2 is that fat, in particular, appears to be in great demand for both American and British households. Fogel (1994a) has stressed the role of fat in diets in historical populations, but most work continues to give the primary role to protein. High demand for fat may have implications for the energy requirements of industrial work in the late nineteenth century. The high income and expenditure elasticity estimates for fat

[10] See Oddy (1990), Streightoff (1911), Byington (1910), and Chapin (1909) for more on the nutritional well-being of industrial families at the time.

suggest that fat should be discussed more often in the anthropometric literature, and its role in physiological changes through the nineteenth century.

B. Parametric and Non-Parametric Diet Shares: The Modified Engel Curve

If the hypotheses advanced by economic historians are correct then the share of the diet devoted to fiber will decrease with income while the shares of protein and sugar in the diet will increase with income. By fitting food modified Engel curves I am able to see how responsive the shares of the diet are to changes in household income and expenditure. The food modified Engel curves allow me to control for the fact that food becomes a smaller portion of the total budget as income and expenditure increase (Engel's Law) and that families with higher incomes tend to consume more food than lower income families.

I find that the shares of carbohydrates, fat and sugar in the diet vary with household income, but the shares of protein and fiber do not. Also, the non-parametric estimates of diet shares show the diets of these workers to be surprisingly consistent regardless of income and remarkably balanced nutritionally. In particular, the shares of the diet devoted to each macronutrient do not appear to change much and are very close to what the United States Department of Agriculture (USDA) recommends for 2,000 and 2,500 calorie diets today. Once again, the economic nutrition stature hypothesis fails to hold for the nutrient shares of the diet.

Table 3 presents results of the modified nutrient-income Engel curve. Fat, carbohydrates, and sugar appear to behave in the expected manner. The shares of sugar and fat in the diet increase with income, and their income coefficients are statistically significant and economically large. The share of carbohydrates decreases with income. Also, the sign on the squared income coefficient is the opposite of that of the income term for carbohydrates, fat, and sugar, and for all three regressions they are significantly different from zero. The shares of protein and fiber, however, are not responsive to changes in income and neither their income nor the squared income coefficients are statistically different from zero.

What is most striking here is that the failure to reject the null hypothesis that the income coefficient is equal to zero is not due to less precise estimates of the standard errors in the fiber and protein modified Engel regressions. Protein and fiber have the most precise standard errors, and this further establishes the lack of protein or fiber variation with household income. The income coefficient estimates themselves are very close to zero, much closer than any of the other income coefficient estimates, and that is why I fail to reject the hypothesis of no income effect for the shares of fiber and protein in the diet. The shares of the diet devoted to protein and fiber are simply not responsive to changes in income.

Results for the British households are similar to those of the American sample, with sugar and fat increasing with income and carbohydrates decreasing with income. Once again, the carbohydrate, fat, and sugar regressions have statistically significant income and squared income coefficients. Also, the coefficients of income and squared income in the fiber and protein regressions are not statistically different from zero. The failure to reject the zero slope hypothesis is not a statistical artifact—both protein and fiber have some of the smallest standard errors, it is the coefficients themselves which are close to zero. The failure of the diet shares to move strongly with respect to income in either direction for fiber and protein is surprising as this implies that the share of protein in the diet did not vary with income.

The modified expenditure-nutrient Engel curve the results are troubling for the economic nutrition-stature hypothesis as well. In Table 4 the expenditure coefficient of the protein share regression is negative and the expenditure coefficient of the fiber regression is positive, although neither coefficient estimate is statistically different from zero. Also, neither protein nor fiber's squared expenditure coefficients are statistically different from zero. Fat, sugar, and carbohydrates do behave in the same way as in Table 3, with statistically significant expenditure and squared expenditure coefficients. The British expenditure-Engel estimates mirror those of the American expenditure estimates, with neither the expenditure nor squared expenditure-Engel coefficients in the protein and fiber regressions statistically different from zero. As with the income nutrient Engel curves, Table 4 shows that the fat, carbohydrate, and sugar regressions do have expenditure and squared expenditure coefficients that are statistically different from zero.[11]

Using the locally linear regression procedure discussed in section III, I fit the shares of the diet by per capita expenditure, which allows us to see the predicted share of the diet in each of the macronutrient food groups as functions of expenditure. These results, since they are fit with locally linear regressions, are not appropriate to test hypotheses, but they do give us an idea of what the shares of the diet look like when mapped out against per capita expenditure and act

[11] Even though these coefficients are statistically different from zero, the estimates are small enough such that, over the range of PCI and PCE, the changes in the diet shares are very small.

as a graphical description of the regressions in Table 4. Also, these functions will reveal if linear regressions of the type preformed in Tables 3 and 4 are appropriate. If the function is not quadratic then the regression model used would be incorrect. As a check for consistency, it is true that the sum of the three primary macronutrient food group shares (carbohydrates, fat, and protein) sum to 100% at each level of per capita expenditure (PCE).

Figures 1 and 2 show that the shares of the diet are remarkably flat when laid out against per capita expenditure. Also, the shares appear to be quadratic functions of expenditure, and the case for OLS model in Tables 3 and 4 is strengthened by the figures. What is surprising, however, is that the predicted shares are very similar to what the USDA recommends for 2,000 and 2,500 calorie diets today. In the USDA's dietary recommendation approximately 15% of the nutrients should come from fat, 67% from non-fiber carbohydrates, 6% from fiber, and 12% from protein. As both Figures 1 and 2 show, the diets of these nineteenth century industrial households are very close to USDA recommendations. On average, these late nineteenth century households had diets that were 68% non-fiber carbohydrates, 15% protein, 5% fiber, and 12% fat. Considering how monotonous historical diets are believed to have been, they conform quite well to what health officials have advised. Indeed, these historical diets are much closer to USDA recommendations than what the Centers for Disease Control found for American diets today (Wright, et. al. 2003). If it is true that nutrient variation is slight, then it is interesting to discover that the diets were, in percentage terms, nutritionally balanced. This suggest that nutritionally rich diets would be achieved by eating "more of the same" as income increased, and in fact the large scale dietary substitution described in the economic nutrition-stature hypothesis may be unwarranted.[12]

C. Solving the Protein Puzzle

The most surprising finding thus far is the relative lack of dietary movement with respect to protein. Given the strong role that protein plays in the anthropometric literature one would expect large protein increases in the diet as income increased. The problem, however, is that the analysis so far has not distinguished between the type of protein in the diet. This becomes important because not all proteins are equal.

[12] This would, naturally, depend on whether one was willing to accept the USDA's recommendation as signifying an adequate diet.

Complete proteins are proteins that allow for normal growth and development and reproduction. Most food protein contains a combination of proteins that would make them complete in combination, but this is not universally true. Furthermore, this does not mean that all combinations of protein rich foods will solve the problem of protein deficiency. For example, combinations of grains are more often than not inferior to milk as a source of protein because one would have to consume such a large amount of grains to get the same protein content present in milk. Also, red meats and poultry supply iron, vitamin B, and zinc, and these are usually found in very small amounts in plant based proteins. More importantly, animal protein also contains membrane fusion proteins (MFP) factors that aid in the absorption of iron and zinc from plant sources. By absorbing iron humans avoid anemia and the fatigue associated with it, and zinc helps the body to heal and aids the immune system in staving off infection.

Given this special role in human physiology, it would seem that meat-based protein should play a significant role in physiological efficiency. Diets rich in animal protein not only provide protein, but they help the body absorb key micronutrients that allow humans to avoid fatigue and strengthen the immune system. Since this type of physiological feedback exists, then the share of protein coming from animal sources should increase with income.

Table 5 shows this to be the case. For American households moving from bottom to top decile in income and expenditure results in a 3% increase in the percentage of protein in the diet that is animal based. In Great Britain the share of protein that is animal-based increases by 6% as one moves from the bottom to top income deciles. These percent changes are larger than the changes of meat as a percentage of the diet calorically. Table 6 shows the results of a protein modified Engel curve, inc which the dependent variable is the share of protein that is comes from meat sources. In the regression of Table 6 both the income and expenditure terms are large and significant. This tells us that although protein as a share of the diet does not appear to change with respect to income, the composition of that protein does vary with income. More importantly, this change in the composition of protein has important implications for human physiology. As humans consume more meat-based protein they are better able to absorb key micronutrients that aid in their ability to work and to become more productive, and excess energy can then be used for improving the physiological structure (through taller stature, increased lung capacity, etc.). In this sense, physiological efficiency can be achieved by consuming more meat-based protein as that will increase both the amount of work (through iron, which will prevent anemia) and the ability to do more work (by staving off infection through greater zinc absorption). This implies that greater output can be achieved for the same input of animal protein than for the same amount of plant protein.

D. Caloric Food Group Elasticities

If the economic statement of the nutrition stature hypothesis is correct then the income and expenditure elasticities of meat calories (which are high in protein) and dairy calories (which are high in fat) will be greater than those of cereal calories (which are high in fiber and carbohydrates in general). Table 7 shows the estimates of the income elasticity of food group calories. I reject the hypothesis that the income elasticity of meat calories is less than or equal to the income elasticity of cereal calories. I also reject the hypothesis that the income elasticity of dairy calories is less than or equal to that of cereal calories. That I reject the hypothesis of income elasticity equality between fruit and vegetable calories and cereal calories, while noting the macronutrient elasticities reported above, may suggest that dietary fiber moves from being cereal based to being fruit and vegetable based as incomes increase. Much of this increase could be due to potatoes, which are grouped as vegetables here. The rejection of these hypotheses suggests that the economic nutrition stature hypothesis is correct-- if we look at food group demand elasticities.

The question that remains is whether we can safely take these food groups as substitutes for the macronutrient elasticities. If so, then the results presented here pose a serious problem in that they have both confirmed and rejected the economic nutrition stature hypothesis. By comparing the food group calorie elasticities to their macronutrient proxies we can determine whether or not the assumption holds. All foods are made up of a combination of macronutrients. Demand for a food, then, should be a weighted function of its contents. This can be represented by $\xi_j = \sum_i \alpha_{ij} \beta_i$ where i is an index of macronutrients, β is the macronutrient demand elasticity, and α is the weight that food j has for macronutrient i. If a food elasticity is a good proxy for a macronutrient elasticity then α is close to 1 for some i and close to zero for all other i.

I find that, more often than not, foods are very bad proxies for macronutrients. The income elasticity of dairy calories, which are usually high in fat, is greater than the income elasticity of fat and I reject the hypothesis that the two are equal to one another. Similarly, the income elasticity of fruit and vegetable calories, which will be high in fiber, is greater than the income elasticity of fiber, and I reject the hypothesis of equal income elasticities for the two. Similarly, carbohydrates and cereals are not good proxies for one another either. Indeed, Table 7 shows the income elasticity of cereals to be lower than the income elasticity of carbohydrates, and I reject the hypothesis that the two are equal to one another. Meat, however, appears to be a good proxy for protein. The income elasticity of meat calories is very close to the income elasticity of protein, and I am unable to reject the hypothesis that the two are equal to one another. The same is true for oil, fat, and sugar calories, which have an income elasticity close to that of sugar, and I am unable to reject the hypothesis of income elasticity equality between the two. The trends in the relation between food group and macronutrient elasticities, however, do not appear to hold in general for the British households, but this is most likely due to smaller sample size and larger standard errors in the British sample.

Table 7's British food income elasticities largely agree with the American results. The income elasticities of meat and dairy calories are greater than that of cereal calories and these results also confirm the economic nutrition stature hypothesis for food groups. Table 8, which shows the expenditure elasticity results for the American and British samples, mirror those of the income elasticities, with the expenditure elasticities of meat calories and those of dairy calories being greater than those of cereal calories. Also, Table 8 shows that the expenditure elasticities of fruit and vegetable calories are greater than the expenditure elasticity of cereal calories. Indeed, Table 8 confirms that the expenditure elasticities of cereal calories is significantly lower than all of the other food group elasticities. Broadly, food group elasticities appear to behave in the way that the economic statement of the nutrition stature hypothesis has predicted.

V. Conclusion

This paper has empirically tested, with historical cross section evidence, hypotheses about the relationship between income and the diet in late nineteenth century industrial populations. These are the populations that gave rise to the second cycle of gains in physiological capital in the United States and Western Europe in the late nineteenth and early twentieth centuries. The household survey cross section allowed us to control for many of the other socioeconomic determinants of stature so that only income was allowed to vary. In this way, we were able to meter out the effect of income on the diet in a way that is not possible with time series or panel data. Also, by using a food modified Engel curve we were able to investigate how the proportions of the diet devoted to different macronutrient groups changed with income.

In general, we found that the economic nutrition stature hypothesis did not apply to macronutrients, but did hold for food groups, and that the anthropometric nutrition stature hypothesis did not apply to food groups, but did hold for macronutrients. In particular, the demand elasticities for fiber were not statistically different from the demand elasticities for protein and sugar. Furthermore, the share of the diet devoted to each macronutrient did not appear to vary much with households income. An important caveat, however, is that protein became more animal based as incomes increased, and this plays a large role in physiological efficiency. Lastly, we found that the demand elasticities for meat and dairy calories were much greater than the demand elasticities for cereal calories.

The empirical evidence presented here allows us to specify a new economic nutrition-stature hypothesis. Households in the nineteenth century did substitute among different food groups, preferring dairy and meat to oils and cereals as their incomes increased. This type of food substitution, however, did not result in diets that were markedly different nutritionally, but these diets were different physiologically as diets rich in animal products improve human development and growth by allowing people to better absorb nutrients. What this implies is that some nutrients, in particular fat and protein, went from being plant-based to animal-based as incomes increased. It also appears that non-sugar, non-fiber carbohydrates lost out in the substitution that took place, and that all of the other nutrient groups remained in fairly constant proportions in the diet. These types of substitutions both explain the gains in stature over time and agree with the macronutrient and food-group elasticities presented here.

A possible reason for the failure of the economic nutrition-stature hypothesis could be due to the fact that nutrition groups are not closely associated with food groups. Indeed, we saw that most groups were poor substitutes for their supposed macronutrient proxy. As Riley (1994) has shown, even goods that would be classified as fiber or cereals can have a fairly large proportion of protein. For example, wheat flour is 17% protein, and wheat flour would certainly not be considered meat when classified as a food group. In short, these results hint at the distinction between food groups and nutrient groups, and the problems inherent in posing hypotheses about one with information on the other.

Another conclusion from this work is that industrial households in the late nineteenth century had surprisingly balanced diets. This is surprising given the small stature and inferred poor living standards at the time. In looking at the shares of the diet devoted to macronutrient groups, I find that the diets are balanced enough that marked substitution in the diet would not be warranted. While this finding does not speak directly to the issue of malnutrition, since it most likely does not contain the poorest industrial households, there is enough variation in income to justify the conclusions reached here about the diet as a function of income and the overall nutritional status of industrial households. That this work finds the diets of stunted people to be nutritionally balanced is surprising, and further microeconomic work on historical diets should be performed to see if the results presented here hold for other historical populations.

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Table 1

Income Elasticity of Nutrients Estimates -- Constant Elasticity Functional Form, 1888 Cost Of Living Survey

	American Sample					British Sample				
	I	II	III	IV	V	VI	VII	VIII	IX	X
	Protein	Carb	Fat	Fiber	Sugar	Protein	Carb	Fat	Fiber	Sugar
Intercept	6.20911	8.66866	6.2851	3.61898	7.18291	3.951	7.07876	3.0034	1.54224	5.8994
	(.09784)	(.10589)	(.18508)	(.21133)	(.17687)	(.29055)	(.32526)	(.40412)	(.90151)	(.48305)
lnPCI	0.39898	0.27369	0.39504	0.40246	0.34158	0.64963	0.44756	0.70884	0.64498	0.5091
	(.00849)	(.00918)	(.01605)	(.01836)	(.01536)	(.02835)	(.03173)	(.03943)	(.08795)	(.04713)
lnFamSize	-0.10766	-0.11679	-0.07837	-0.01699	-0.16453	-0.07006	0.07832	-0.13015	0.11359	0.00002
	(.01038)	(.01124)	(.01964)	(.02244)	(.01878)	(.03685)	(.04125)	(.05125)	(.11319)	(.06065)
Share 0-4*	-0.3278	-0.41084	-0.32329	-0.37244	-0.32974	-0.12275	-0.38166	0.02379	-0.44545	-0.30357
	(.02256)	(.02442)	(.04268)	(.04880)	(.04084)	(.08074)	(.09038)	(.11230)	(.24909)	(.13347)
Share 5-9*	-0.26971	-0.21196	-0.32489	-0.31174	-0.20223	-0.08415	-0.35474	0.08411	-0.47067	-0.24316
	(.02598)	(.02812)	(.04914)	(.05620)	(.04703)	(.08602)	(.09629)	(.11964)	(.26481)	(.14189)
Share 10-14*	-0.20369	-0.10738	-0.36689	-0.15908	-0.09037	0.05563	-0.13892	0.15272	-0.38939	-0.0511
	(.02822)	(.03054)	(.05338)	(.06098)	(.05103)	(.09550)	(.10690)	(.13282)	(.29427)	(.15768)
Share 15-19*	-0.01832	0.04811	-0.05197	0.03413	0.00054	0.00307	-0.07065	0.08867	0.00893	-0.06241
	(.02764)	(.02992)	(.05229)	(.06001)	(.05021)	(.08964)	(.10035)	(.12468)	(.27593)	(.14785)
Share 20-24*	0.04184	0.05849	0.09984	0.10136	0.03193	0.07968	0.04094	0.16047	-0.1352	-0.02095
	(.01969)	(.02131)	(.03724)	(.04287)	(.03588)	(.05554)	(.06217)	(.07725)	(.17087)	(.09156)
R-Square	0.6438	0.4571	0.4516	0.3878	0.3644	0.6065	0.4522	0.4749	0.185	0.3109
N	6809	6809	6809	6697	6698	1024	1024	1024	1014	1014

Coefficient estimates on lnPCI are income elasticity estimates of the respective nutrient group.

Heteroskedasticty-consistent standard errors are listed under coefficient estimates in parentheses.

Regressions also include dummy variables for geography and industry (there are no geographic variables for the British Sample).

* Share x-y is the share (proportion) of the number of people in the household who are aged x to y.

Table 2

Expenditure Elasticity of Nutrients Estimates -- Constant Elasticity Functional Form, 1888 Cost of Living Survey

	American Sample					British Sample				
	I	II	III	IV	V	VI	VII	VIII	IX	X
	Protein	Carb	Fat	Fiber	Sugar	Protein	Carb	Fat	Fiber	Sugar
Intercept	3.65176	6.8105	3.34572	0.92298	4.79517	2.32904	6.0327	0.98314	-0.0978	4.26357
	(.10594)	(.12272)	(.21664)	(.25184)	(.21015)	(.32771)	(.37610)	(.45710)	(1.05062)	(.55638)
lnPCE	0.64957	0.45542	0.68169	0.66611	0.57478	0.81481	0.55421	0.91416	0.81203	0.67511
	(.00960)	(.01112)	(.01963)	(.02284)	(.01906)	(.03230)	(.03707)	(.04505)	(.10356)	(.05484)
lnFamSize	0.01355	-0.02887	0.06035	0.10946	-0.05271	0.01668	0.13647	-0.02988	0.20073	0.0765
	(.00967)	(.01120)	(.01977)	(.02291)	(.01912)	(.03609)	(.04142)	(.05034)	(.11443)	(.06060)
Share 0-4*	-0.27604	-0.37061	-0.25349	-0.31534	-0.27674	-0.09082	-0.36682	0.08376	-0.41293	-0.24353
	(.01999)	(.02316)	(.04088)	(.04740)	(.03956)	(.07767)	(.08914)	(.10834)	(.24716)	(.13089)
Share 5-9*	-0.23258	-0.18211	-0.27094	-0.26928	-0.16186	-0.08291	-0.35989	0.10655	-0.4703	-0.21439
	(.02301)	(.02666)	(.04705)	(.05458)	(.04554)	(.08250)	(.09468)	(.11507)	(.26195)	(.13872)
Share 10-14*	-0.20604	-0.10639	-0.35899	-0.15908	-0.08792	0.01862	-0.16956	0.13039	-0.42799	-0.05667
	(.02501)	(.02897)	(.05115)	(.05925)	(.04944)	(.09140)	(.10489)	(.12748)	(.29039)	(.15378)
Share 15-19*	-0.07476	0.00748	-0.11534	-0.09315	-0.05117	0.02786	-0.05393	0.11698	0.03349	-0.04129
	(.02462)	(.02853)	(.05035)	(.05860)	(.04889)	(.08657)	(.09935)	(.12075)	(.27497)	(.14562)
Share 20-24*	-0.02666	0.01029	0.02725	0.02923	-0.03052	0.0635	0.0297	0.14315	-0.15194	-0.03349
	(.01755)	(.02033)	(.03589)	(.04190)	(.03496)	(.05362)	(.06154)	(.07479)	(.17020)	(.09013)
R-Square	0.7181	0.5078	0.4929	0.418	0.3992	0.6331	0.4632	0.5076	0.1909	0.3318
N	6809	6809	6809	6697	6698	1024	1024	1024	1014	1014

Coefficient estimates on lnPCE are expenditure elasticity estimates of the respective nutrient group.
Heteroskedasticty-consistent standard errors are listed under coefficient estimates in parentheses.
Regressions also include dummy variables for geography and industry (there are no geographic variables for the British Sample).
* Share x-y is the share (proportion) of the number of people in the household who are aged x to y.

Table 3

Nutrient Income Modified Engel Curve Estimates-- 1888 Cost of Living Survey

	American Sample					British Sample				
	I	II	III	IV	V	VI	VII	VIII	IX	X
	ProtShare	CarbShare	FatShare	FiberShare	SuagrShare	ProtShare	CarbShare	FatShare	FiberShare	SugarShare
Intercept	0.01551	1.62806	-0.64358	0.04948	-0.61542	-0.79288	2.95203	-1.15915	0.09094	-2.95007
	(.08156)	(.15746)	(.12288)	(.03129)	(.25290)	(.32251)	(.54105)	(.32449)	(.19040)	(.87911)
lnPCI	0.0205	-0.18431	0.16381	-0.00902	0.19062	0.18999	-0.44846	0.25846	-0.01784	0.68399
	(.01701)	(.03284)	(.02563)	(.00653)	(.05274)	(.06913)	(.11597)	(.06955)	(.04081)	(.18843)
(lnPCI)^2	-0.00035	0.00833	-0.00798	0.00056	-0.01004	-0.00899	0.0218	-0.01281	0.00114	-0.03559
	(.00089)	(.00172)	(.00134)	(.00034)	(.00276)	(.00371)	(.00622)	(.00373)	(.00219)	(.01010)
lnFamSize	0.00061	-0.0273	0.00212	0.00213	-0.01392	-0.01638	0.03657	-0.02018	0.00089	0.01006
	(.00120)	(.00231)	(.00180)	(.00046)	(.00371)	(.00399)	(.00670)	(.00402)	(.00236)	(.01088)
Share 0-4*	0.00895	-0.01497	0.00602	0.00014	0.00399	0.02439	-0.05777	0.03338	0.00775	0.03082
	(.00260)	(.00503)	(.00392)	(.00099)	(.00808)	(.00876)	(.01469)	(.00881)	(.00517)	(.02387)
Share 5-9*	-0.00471	0.01597	-0.01125	-0.00153	0.01234	0.02726	-0.06478	0.03752	-0.00581	0.0203
	(.00300)	(.00579)	(.00452)	(.00115)	(.00929)	(.00932)	(.01563)	(.00938)	(.00550)	(.02540)
Share 10-14*	-0.00775	0.03402	-0.02627	-0.00146	0.01506	0.01805	-0.0443	0.02625	-0.00386	0.02569
	(.00325)	(.00628)	(.00490)	(.00125)	(.01009)	(.01036)	(.01738)	(.01042)	(.00611)	(.02823)
Share 15-19*	-0.00687	0.01753	-0.01066	-0.00075	-0.01713	0.00463	-0.01445	0.00982	-0.00109	-0.03003
	(.00320)	(.00617)	(.00482)	(.00123)	(.00991)	(.00974)	(.01633)	(.00979)	(.00575)	(.02654)
Share 20-24*	-0.00268	-0.00271	0.00539	0.00157	-0.00733	0.00167	-0.01051	0.00884	-0.00232	0.00964
	(.00227)	(.00439)	(.00342)	(.00087)	(.00704)	(.00602)	(.01010)	(.00606)	(.00355)	(.01641)
R-Square	0.2012	0.315	0.3351	0.2233	0.2122	0.4104	0.379	0.2215	0.0843	0.1523
N	6809	6809	6809	6809	6809	1024	1024	1024	1024	1024

Heteroskedasticty-consistent standard errors are listed under coefficient estimates in parentheses.
Regressions also include dummy variables for geography and industry (there are no geographic variables for the British Sample).
* Share x-y is the share (proportion) of the number of people in the household who are aged x to y.

Table 4

Nutrient Expenditure Modified Engel Curve Estimates-- 1888 Cost of Living Survey

	American Sample					British Sample				
	I	II	III	IV	V	VI	VII	VIII	IX	X
	ProtShare	CarbShare	FatShare	FiberShare	SuagrShare	ProtShare	CarbShare	FatShare	FiberShare	SugarShare
Intercept	0.10837	1.90733	-1.0157	0.08964	-1.12052	-0.88464	3.38715	-1.50251	0.15164	-4.56467
	(.10630)	(.20452)	(.16018)	(.04100)	(.33118)	(.38864)	(.64915)	(.38963)	(.23027)	(1.05810)
lnPCE	-0.00677	-0.22507	0.223184	-0.01822	0.30618	0.2048	-0.53257	0.32777	-0.03278	1.03083
	(.02234)	(.04298)	(.03366)	(.00862)	(.06960)	(.08443)	(.14102)	(.08464)	(.05002)	(.22986)
(lnPCE)^2	0.00144	0.00967	-0.01111	0.00109	-0.01653	-0.00956	0.02588	-0.01632	0.00203	-0.05422
	(.00118)	(.00226)	(.00177)	(.00045)	(.00366)	(.00458)	(.00765)	(.00459)	(.00271)	(.01247)
lnFamSize	0.00387	-0.01101	0.00715	0.00239	-0.01654	-0.01363	0.03135	-0.01771	0.00153	0.01182
	(.00125)	(.00240)	(.00188)	(.00048)	(.00389)	(.00404)	(.00675)	(.00405)	(.00239)	(.01100)
Share 0-4*	0.01	-0.01875	0.00875	0.00015	0.00092	0.02575	-0.06143	0.03569	0.00152	0.03379
	(.00258)	(.00497)	(.00389)	(.00099)	(.00804)	(.00871)	(.01455)	(.00873)	(.00516)	(.02371)
Share 5-9*	-0.00433	0.01367	-0.00934	-0.00158	0.00942	0.02745	-0.06621	0.03876	-0.00537	0.02287
	(.00297)	(.00571)	(.00447)	(.00114)	(.00924)	(.00942)	(.01540)	(.00924)	(.00546)	(.02511)
Share 10-14*	-0.00832	0.03422	-0.0259	-0.00158	0.01324	0.01729	-0.04382	0.02653	-0.00368	0.02711
	(.00323)	(.00621)	(.00486)	(.00124)	(.01005)	(.01023)	(.01708)	(.01025)	(.00606)	(.02784)
Share 15-19*	-0.0081	0.02071	-0.01261	-0.00085	-0.01614	0.00526	-0.01504	0.00978	-0.00075	-0.03325
	(.00318)	(.00612)	(.00479)	(.00123)	(.00991)	(.00971)	(.01623)	(.00974)	(.00576)	(.02645)
Share 20-24*	-0.00482	0.00081	0.00402	0.00126	-0.00525	0.00114	-0.00944	0.00829	-0.00237	0.00856
	(.00226)	(.00436)	(.00341)	(.00087)	(.00705)	(.00599)	(.01001)	(.00601)	(.00355)	(.01632)
R-Square	0.2101	0.3271	0.3423	0.2238	0.2134	0.4155	0.3897	0.2337	0.0857	0.1617
N	6809	6809	6809	6809	6809	1024	1024	1024	1024	1024

Heteroskedasticty-consistent standard errors are listed under coefficient estimates in parentheses.
Regressions also include dummy variables for geography and industry (there are no geographic variables for the British Sample).
* Share x-y is the share (proportion) of the number of people in the household who are aged x to y.

Table 5

Percentage of Protein Coming from Meat Sources, 1888 Cost of Living Survey

United States Sample

Share by Income			Share by Expenditure		
Mean	Bottom 10% PCI	Top 10% PCI	Mean	Bottom 10% PCE	Top 10% PCE
49.78%	47.69%	51.57%	49.78%	47.43%	50.91%

Great Britain Sample

Share by Income			Share by Expenditure		
Mean	Bottom 10% PCI	Top 10% PCI	Mean	Bottom 10% PCE	Top 10% PCE
49.85%	43.97%	49.68%	49.86%	44.30%	50.47%

Table 6

Animal Based Protein Modified Engel Curve, 1888 Cost of Living Survey

	US I	GB II	US III	GB IV
Intercept	-0.95947	-5.7131	-1.8627	-8.0250
	(.32231)	(1.284)	(.42214)	(1.54358)
lnPCI	0.31844	1.3062		
	(.06721)	(.27522)		
(lnPCI)^2	-0.01608	-0.0681		
	(.00351)	(.01475)		
lnPCE			0.5106	1.8001
			(.08871)	(.33532)
(lnPCE)^2			-0.0263	-0.0946
			(.00467)	(.01820)
lnFamSize	0.00128	-0.0376	0.0024	-0.0340
	(.00473)	(.0159)	(.00495)	(.01604)
Share 0-4*	-0.02665	0.0455	-0.0285	0.0536
	(.01029)	(.03487)	(.01025)	(.03460)
Share 5-9*	-0.01792	0.0812	-0.0202	0.0876
	(.01184)	(.0371)	(.01178)	(.03662)
Share 10-14*	-0.03288	0.0649	-0.0351	0.0697
	(.01286)	(.04123)	(.01281)	(.04062)
Share 15-19*	-0.03661	0.0087	-0.0374	0.0043
	(.01263)	(.03876)	(.01264)	(.03858)
Share 20-24*	-0.01403	0.0559	-0.0133	0.0544
	(.00898)	(.02397)	(.00899)	(.02380)
N	6809	1024	6809	1024
R-Square	0.1799	0.1455	0.1809	0.157
Industry Dummies?	Yes	Yes	Yes	Yes
State Dummies?	Yes	No*	Yes	No*

*Note: Geographic detail is not available for the British sample
Share x-y is the share proportion of the household who are aged x to y.
Each column is a separate OLS regression where the animal (meat based) share of protein was the dependent variable.

Table 7

Income Elasticity of Food Group Calorie Estimates -- 1888 Cost of Living Survey

	American Sample					British Sample				
	I	II	III	IV	V	VI	VII	VIII	IX	X
	Dairy	FV	OFS	Meat	Cereals	Dairy	FV	OFS	Meat	Cereals
Intercept	5.60861	3.62948	8.93883	7.4138	9.98851	4.76122	3.93618	8.26092	4.52918	9.54598
	(.23613)	(.26404)	(.15823)	(.15684)	(.14141)	(.35640)	(.57198)	(.38056)	(.35395)	(.47995)
lnPCI	0.59895	0.59184	0.32738	0.44308	0.20429	0.71026	0.50388	0.39611	0.724	0.27757
	(.02052)	(.02292)	(.01375)	(.01362)	(.01229)	(.03479)	(.05582)	(.03715)	(.03454)	(.04683)
lnFamSize	-0.15631	-0.06827	-0.19065	-0.07483	-0.02316	-0.09286	0.05961	0.02104	-0.17156	0.11076
	(.02481)	(.02784)	(.01675)	(.01664)	(.01501)	(.04472)	(.07187)	(.04830)	(.04455)	(.06026)
Share 0-4*	-0.0684	-0.1392	-0.32906	-0.38137	-0.53463	0.01137	-0.43856	-0.43462	-0.05687	-0.65131
	(.05387)	(.06052)	(.03642)	(.03620)	(.03263)	(.09836)	(.15810)	(.10560)	(.9785)	(.13261)
Share 5-9*	-0.12768	-0.25068	-0.19062	-0.35575	-0.25751	0.11763	-0.3035	-0.37429	0.13611	-0.599
	(.06225)	(.06968)	(.04197)	(.04171)	(.03761)	(.10475)	(.16780)	(.11246)	(.10438)	(.14098)
Share 10-14*	-0.18286	-0.00655	-0.08331	-0.31889	-0.16095	0.12697	-0.20911	-0.20956	0.1217	-0.38934
	(.06741)	(.07537)	(.04555)	(.04525)	(.04079)	(.11615)	(.18658)	(.12472)	(.11574)	(.15667)
Share 15-19*	-0.02724	-0.10586	0.01566	-0.07099	0.13435	0.0344	-0.08282	-0.10726	0.08534	-0.0162
	(.06625)	(.07423)	(.04473)	(.04446)	(.04014)	(.10899)	(.17489)	(.11681)	(.10854)	(.14690)
Share 20-24*	-0.02799	-0.0057	0.0757	0.03784	0.08925	0.12706	-0.18183	0.00345	0.14406	-0.01504
	(.04740)	(.05320)	(.03201)	(.03180)	(.02868)	(.06745)	(.10923)	(.07225)	(.06717)	(.09097)
R-Square	0.5685	0.4522	0.3644	0.5379	0.289	0.5483	0.2662	0.4259	0.6022	0.2505
N	6506	6564	6660	6700	6691	1011	1006	1006	1016	1014

Coefficient estimates on lnPCI are income elasticity estimates of the respective food group.
OFS is Oils, Fats, and Sugars; FV is Fruits and Vegetables
Heteroskedasticty-consistent standard errors are listed under coefficient estimates in parentheses.
Regressions also include dummy variables for geography and industry (there are no geographic variables for the British Sample).
* Share x-y is the share (proportion) of the number of people in the household who are aged x to y.

Table 8

Expenditure Elasticity of Food Group Calorie Estimates -- American Sample of 1888 Cost of Living Survey

	American Sample					British Sample				
	I	II	III	IV	V	VI	VII	VIII	IX	X
	Dairy	FV	OFS	Meat	Cereals	Dairy	FV	OFS	Meat	Cereals
Intercept	2.43224	1.32501	6.57832	4.20304	8.25623	2.86945	2.94487	7.0485	2.4882	8.91161
	(.27850)	(.32078)	(.18639)	(.17925)	(.16897)	(.40355)	(.66898)	(.43974)	(.39680)	(.56050)
lnPCE	0.9129	0.82204	0.55782	0.75633	0.37253	0.90285	0.60543	0.51923	0.93151	0.3423
	(.02527)	(.02907)	(.01691)	(.01626)	(.01533)	(.03980)	(.06596)	(.04337)	(.03912)	(.05525)
lnFamSize	-0.0057	0.0408	-0.08062	0.07543	0.05764	0.0047	0.12099	0.07925	-0.06918	0.14665
	(.02521)	(.02891)	(.01693)	(.01630)	(.01537)	(.04387)	(.07284)	(.04834)	(.04332)	(.06105)
Share 0-4*	-0.02034	-0.13326	-0.27354	-0.30819	-0.48891	0.05419	-0.44543	-0.39462	-0.00009	-0.6445
	(.05208)	(.05973)	(.03505)	(.03373)	(.03180)	(.09472)	(.15716)	(.10378)	(.09341)	(.13186)
Share 5-9*	-0.1033	-0.25815	-0.14856	-0.29884	-0.22034	0.12598	-0.32759	-0.35732	0.15356	-0.6048
	(.06012)	(.06877)	(.04035)	(.03885)	(.03663)	(.10059)	(.16640)	(.11018)	(.09933)	(.13975)
Share 10-14*	-0.20678	-0.04945	-0.07832	-0.3127	-0.15171	0.08979	-0.26107	-0.2185	0.09308	-0.41116
	(.06517)	(.07442)	(.04383)	(.04217)	(.03975)	(.11125)	(.18458)	(.12189)	(.10988)	(.15492)
Share 15-19*	-0.10014	-0.15982	-0.06428	-0.14191	0.09791	0.03167	-0.06522	-0.09117	0.11425	-0.006
	(.06439)	(.07365)	(.04325)	(.04164)	(.03932)	(.10542)	(.17470)	(.11529)	(.10404)	(.14669)
Share 20-24*	-0.12392	-0.09383	0.01505	0.04466	0.0485	0.10933	-0.19466	-0.00552	0.12573	-0.02238
	(.04610)	(.05284)	(.03098)	(.02981)	(.02811)	(.06522)	(.10907)	(.07129)	(.06436)	(.09080)
R-Square	0.5936	0.4621	0.4074	0.5959	0.3199	0.5776	0.268	0.4409	0.6346	0.2528
N	6506	6464	6660	6700	6691	1011	1006	1006	1016	1014

Coefficient estimates on lnPCE are expenditure elasticity estimates of the respective food group.
OFS is Oils, Fats, and Sugars; FV is Fruits and Vegetables
Heteroskedasticty-consistent standard errors are listed under coefficient estimates in parentheses.
Regressions also include dummy variables for geography and industry (there are no geographic variables for the British Sample).
* Share x-y is the share (proportion) of the number of people in the household who are aged x to y.

Figure 1
Diet Shares by Per Capita Expenditure -- American Sample of 1888CEX

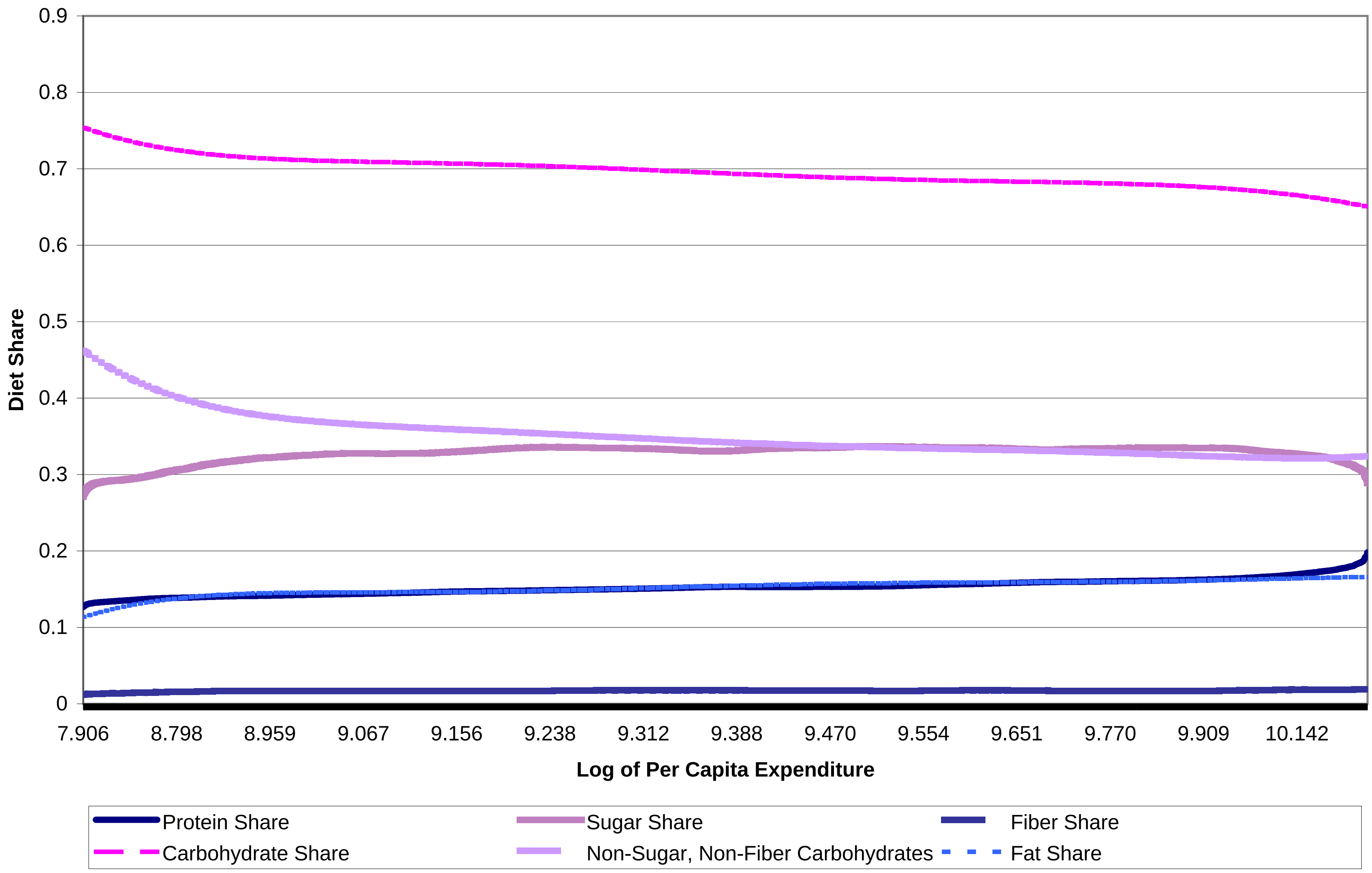
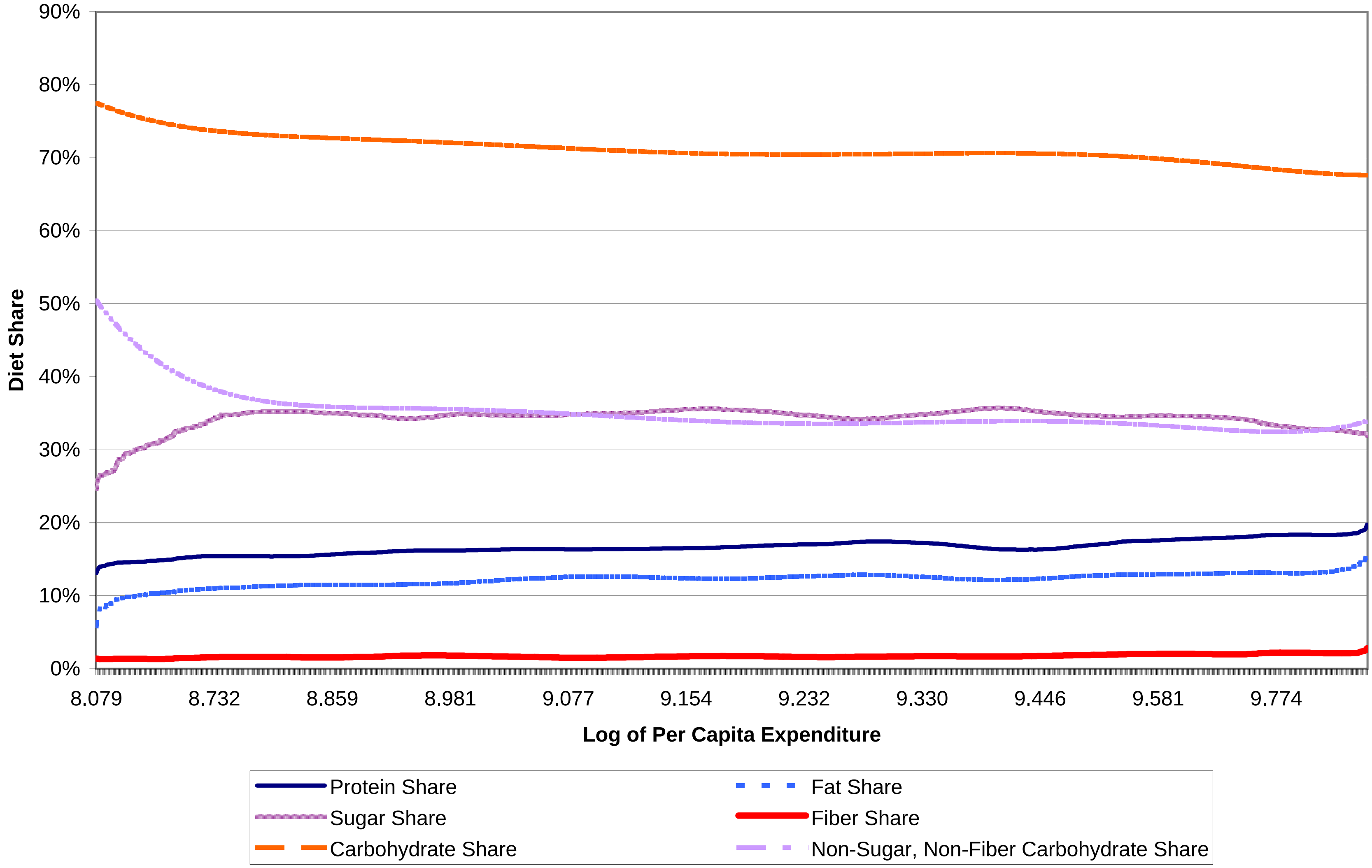


Figure 2
Diet Shares by Per Capita Expenditure -- British Sample of 1888CEX



Appendix

The macronutrient elasticities and the modified Engel Curve are intimately related. To see this, consider the macronutrient elasticity β (in this case the fat elasticity) which is estimated in the regression

(1) $$\ln\left(\frac{FatGrams_i}{n_i}\right) = \alpha + \beta \ln\left(\frac{x_i}{n_i}\right) + \varepsilon_i$$

Where n is the household size and x is total income. It is easy to show that

(2) $$FatGrams_i = e^{\alpha} e^{\beta \ln(x_i)} e^{(1-\beta)\ln(n_i)} e^{\varepsilon_i}$$

Note that total grams in the diet has the same relationship as fat grams, with an elasticity of Ψ, such that

(3) $$TotalGrams_i = e^{\phi} e^{\Psi \ln(x_i)} e^{(1-\Psi)\ln(n_i)} e^{\upsilon_i}$$

Keeping in mind that the modified Engel curve, in the simplest case, takes the form

(4) $$\left(\frac{FatGrams_i}{TotalGrams_i}\right) = \Delta + \theta \ln\left(\frac{x_i}{n_i}\right) + \nu_i$$

where Δ is a constant and ν is the error term. If we substitute equations 2 and 3 into the modified Engel we find

(5) $$e^{\alpha - \phi} x_i^{\beta - \Psi} n_i^{\Psi - \beta} e^{\varepsilon_i - \upsilon_i} = \Delta + \theta \ln\left(\frac{x_i}{n_i}\right) + \nu_i$$

The relationship between the modified Engel curve income coefficient, θ, and the dietary demand elasticities, β and Ψ, follows from equation 5. Note that Ψ is the same for each of the macronutrient modified Engel curves, such that the weighted average of β is equal to Ψ. The demand elasticity for the total diet must be a weighted average of the demand elasticities of the components of that diet. Taking the expectation of equation 5, and then differentiating with respect to income (x) gives the following relationship.

$$e^{\alpha-\phi}(\beta - \Psi)x_i^{\beta-\Psi} n_i^{\Psi-\beta+1} = \theta \tag{6}$$

Keeping in mind that, empirically, x>1, n$\geq$1, 0<β<1, and 0<Ψ<1, the exponent on n will always be greater than zero and term $n_i^{\Psi-\beta+1}$ will therefore always be greater than 1. Also, since x>1 the sign of the left hand side of equation 6 is determined by β-Ψ. There are, then, three cases to consider. When β>Ψ (case 1) the growth of the nutrient in the diet is faster than the growth of the diet in general, and therefore its share of the grows as well, meaning that θ>0. When β=Ψ (case 2) the growth of the nutrient is equal to the growth of the diet, meaning that it does not increase or decrease in its share of the diet, so θ=0. When β<Ψ (case 3) the growth of the nutrient in the diet is slower than the growth of the diet in general, and therefore its share decreases, meaning that θ<0. What this means is that the sign of θ tells us how the nutrient's demand elasticity is related to the overall demand elasticity of the diet.

This interpretation of θ holds only in the linear case of the modified Engel curve, however. If, as in the paper, we include a squared log per capita income term in equation 4 the derivative in (6) would become

$$e^{\alpha-\phi}(\beta - \Psi)x_i^{\beta-\Psi} n_i^{\Psi-\beta+1} = \theta + 2\delta \ln\left(\frac{x_i}{n_i}\right) \tag{7}$$

Where δ is the coefficient of the squared income term in the modified Engel curve. In this case we can specify the relationship between θ and δ in the three cases. When β>Ψ (case 1), θ>2δln(x/n). When β=Ψ (case 2), θ=2δln(x/n). When β<Ψ (case 3), θ<2δln(x/n). These inequalities, however, do not constrain sign of the coefficients in the way the linear case had. The sign of the left hand side of (7) does still tell us about the size of the nutrient elasticity in relation to the overall diet elasticity, however, and it is in this way that the relationship is conceptually the same as in the linear case.