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1 *Our changing bodies: 300 years of technophysio evolution*

This book is based on the belief that changes in the size, shape, and capability of the human body since the beginning of the eighteenth century both reflect and illuminate economic and demographic change over those three centuries. Such change has been immense. To take the United Kingdom as an example, its population has risen from under 5.5 million in 1700 to over 61 million today; life expectation at birth has risen from about 38 years to 75 years for males and 80 years for women; and gross domestic product per capita has risen in real terms from £1,643 to £20,790 (Wrigley 2004). Despite the setback in the world economy at the time of writing, similar changes have occurred in every other country of the developed world and are now occurring in almost every country in the world as a whole. At the same time, humans have become much taller and heavier and now experience lives which are much healthier, as well as longer, than ever before in human history.

It is only recently that the full potential of linking these apparently disparate aspects of the human experience has been realized by historians, economists, human biologists, and demographers. It was a matter of common observation during the eighteenth and nineteenth centuries that men and women from the richer groups within a given society – be it France, Britain, Belgium, or the United States – tended to be taller and heavier than those from poorer backgrounds, to suffer less from chronic and debilitating diseases, to live as long or longer and to be capable of harder and more sustained work. But the elucidation of the exact mechanisms which led to these observations – and their generalization to wider changes within economies and societies – has been a task of the late twentieth and early twenty-first centuries which is not yet complete. This book surveys the current state of knowledge of these matters, discusses some of the evidential and statistical problems which have been encountered, and suggests further lines of enquiry.

In one sense, the thesis of this book is very simple. It is, in brief, that the health and nutrition of one generation contributes, through mothers

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and through infant and childhood experience, to the strength, health, and longevity of the next generation; at the same time, increased health and longevity enable the members of that next generation to work harder and longer and to create the resources which can then, in their turn, be used to assist the next, and succeeding, generations to prosper. But this relatively simple statement conceals great complexity and also requires simultaneous attention to many different aspects of human experience which have normally been considered separately by different groups of human, social, and natural scientists. Even the terms used in the simple statement above are problematic. How do we define and measure "health" or "nutrition?" What is "one generation?" Does increased longevity contribute to greater productivity or does it, as is sometimes argued, impose great costs on society through higher costs of healthcare and pensions for an ageing population?

It will be particularly surprising to many people that this book chooses to place at the center of its enquiries into these matters the size and shape of the human body. How tall or heavy, pretty or ugly, each person grows up to be is often a matter of intense interest to them and to their friends and families, but it is not widely known how much can be gleaned, from statistics arising from the measurements of groups of people, about the societies and economies from which they came, even if they lived in periods before the existence of written documents (Steckel and Rose 2002). Nor is it generally known that historians and economists are able, by linking together the many apparently disparate documents which exist from more recent periods about the bodies of men and women, to describe and analyze social and economic change, often in great detail and not only over time but over space.

There is a further feature of this book which needs to be emphasized. Like much interdisciplinary or multi-disciplinary enquiry, it seeks to link phenomena and findings of previous studies which are simultaneously obvious or taken for granted by some and a revelation to others. It is, for example, a commonplace among human biologists that improved nutrition will lead rapidly to taller, stronger and heavier children; but it comes as a surprise to some historians that humans have grown significantly taller and heavier over recent decades and that this is more likely to have been the result of improved nutrition than of evolution or of the effects of migration in changing the composition of populations. It is equally surprising to many economists that the mean height of a group within a population can be used to measure changes to

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the standard of living, since they conceive of that term as being exclusively about monetary income and expenditure. Finally, it comes as a surprise to many human biologists, used to the concept of the "secular trend" in height, that historical studies show that growth in average height has been uneven and sometimes actually reversed.

There is, however, one matter that is common to all disciplines and, indeed, to all living beings: the conversion of energy into work. Human beings, from conception to death, take in energy in the form of food and warmth and expend it in body maintenance, growth, exercise, and work – both physical and intellectual. Greater inputs of energy allow men and women to work longer but also more intensively. In addition, for much of human history, intellectual work has resulted in the invention and innovation of tools which enable men and women to convert their energy more efficiently into outputs, both physical and intellectual. These tools have enabled men and women to transcend the limitations of their own individual physical capacity for work and thus, over centuries, have expanded their productivity – their lifetime output – to an enormous degree. Much of that expanded productivity has occurred during the past three centuries and the subjects of this study – centered around the size and shape of the human body – are the linkages and interactions which have made it possible. Much of the evidence for this – growth in childhood, mortality, adult living standards, labor productivity, food, or manufacturing output – has hitherto been studied as discrete topics; the ambition of this book is to link them.

1.1 A schema: technophysio evolution

There are dangers, but also benefits, in simplification and the use of analogy. Put very simply, this book will – on the basis of studies within many different disciplines – attempt to justify the use of the following schema:

1. The nutritional status of a generation – shown by the size and shape of their bodies – determines how long that generation will live and how much work its members will be able to do.
2. The work of a generation, measured both in hours, days, and weeks of work and in work intensity, when combined with the available technology, determines the output of that generation in terms of goods and services.

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3. The output of a generation is partly determined by its inheritance from past generations; it also determines its standard of living and affects its distribution of income and wealth, together with the investment it makes in technology.
4. The standard of living of a generation determines, through its fertility and the distribution of income and wealth, the nutritional status of the next generation.
5. And so on *ad infinitum*.

It might perhaps be prudent to replace the word "determines" in each of these statements by the word "influences" or "partially determines." The former word is probably too strong, the latter two probably too weak. An alternative form of caution, beloved by economists, is to append the words *ceteris paribus* – others things being equal. The schema is certainly not put forward as a deterministic model; there are, in its workings, many historical contingencies and also many uncertainties. This book seeks to make use of the voluminous literature on these topics to assign some magnitudes, at the least, to the effects of one variable on another.

Economists will recognize this schema as a simplified form of endogenous growth theory, in which technology develops partly through investment in human capital in the form of health and education (see, for example, Mankiw, Romer, and Weil 1992; López-Casasnovas, Rivera, and Currais 2005).[1] Like such models, the schema focuses attention on the central or salient features which need to be measured and related one to the other – nutritional status, morbidity, mortality, technology, output, productivity, standard of living, investment, fertility, distribution of income and wealth. It differs from contemporary growth theory, appropriately for a work which has its genesis in economic history, in emphasizing long period change and, in particular, in its focus on the concept of "generation," which has defied attempts at precise definition but still remains useful as an heuristic device; there is no such thing as a single generation of a society, since generations overlap in very confusing ways, but it remains useful to think of the

[1] Such models have not yet fully integrated changes in health. As Morand (2005, p. 251) puts it: "additional theoretical work is needed to incorporate other mechanisms into a unified model of the long-term interaction between economic growth, population health and longevity, and that further empirical work is also needed to test the hypothesis generated by these models."

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transmission of health and wealth within society in a way analogous to similar transmission within a family, where the term "generation" can more easily, though still with some difficulty, be defined.

Whatever the problems of definition, there is no doubt that from 1700 to 2000, over the course of some 12–15 human generations, all the features of this schema have been transformed in ways never seen before in human history. In the process, humankind has gained equally unprecedented control over its environment – even if it has sometimes misused that control – through the invention and application of new forms of technology. One sign of that control is that, in most if not quite all parts of the world, the size, shape, and longevity of the human body have changed more substantially, and much more rapidly, during the past three centuries than over many previous millennia. There were, of course, evolutionary changes to our bodies during those past millennia, but the change that has occurred in recent times is of a different character. It has come about, within a timescale which is minutely short by the standards of Darwinian evolution, through the application of technology, in particular to food production and distribution and to the development of means of combating disease. Fogel and Costa have named this process "technophysio evolution," linking technological with physiological change and using the word evolution – by analogy with Darwinian evolution – to emphasize the magnitude and speed of the changes that have occurred (Fogel and Costa 1997; Fogel 2004b).

As Jones has explained in his best-selling attempt to "update" Darwin's *Origin of Species*, modern evolutionary theory rests on the two fundamental principles of variation and selection. Variation in sexual populations occurs because of recombination and mutation, while evolution occurs because some of these variations will prove more or less beneficial in the environments within which they find themselves. However, although the incidence of such variations may be quite high, the pace of evolutionary change is nevertheless slow. This is because most variations are, in themselves, of limited value and need to be maintained for several generations before acquiring a "fixed character" (Jones 2000; Ridley 2004, pp. 87–89, 590–611).

The theory of "technophysio evolution" differs from conventional theories of biological evolution because it emphasizes the extent to which human beings have a unique capacity to shape their own environments; it differs also because of the rapidity of the changes which it describes. As Fogel and Costa explained in 1997: "the theory of

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technophysio evolution rests on the proposition that, during the last three hundred years, particularly during the last century, humans have gained an unprecedented degree of control over their environment – a degree of control so great that it sets them apart not only from all other species, but also from all previous generations of *homo sapiens*" (Fogel and Costa 1997). This "unprecedented degree of control" has led to dramatic improvements in the "physiological capital" of human beings and in their life expectancy.

The theory of technophysio evolution also draws on recent research into the relationships between early-life health and health at older ages. Although the ideas which lie behind this research are not new, they have become increasingly influential in recent work as a result of the work of Barker and others, who have drawn attention to the fetal origins of adult disease (Barker 1992; Barker 1998). This has encouraged a large number of researchers to adopt a "life-course" approach to the study of human longevity (e.g., Ben-Shlomo and Kuh 2002).

Some of the concepts used in discussion of technophysio evolution and in the schema which will be elucidated below – such as mortality, fertility, income, or wealth – are familiar, if not always free from problems. Two, however, are less familiar or less well defined but nevertheless so important in summing up the changes that have occurred that they demand special attention at this stage: the standard of living and nutritional status.

1.2 The "standard of living" and "nutritional status"

In 1848 Thomas Babington Macaulay (later Lord Macaulay) devoted the third chapter of *The History of England* to a description of the state of England in 1685 (Macaulay 1848, pp. 209–320). Although this chapter is described by the author of the *Oxford Companion to English Literature* as "superficial and discredited" (Drabble 1985, p. 599), Macaulay displays in it a clear sense of the change in living conditions of the population which had occurred, and would occur, the difficulty of measuring such changes in human welfare, and the need to take account in any historical narrative of many different aspects of those conditions and of the distribution of the rewards of economic growth. As he concluded (Macaulay 1848, pp. 320–321):

It is now the fashion to place the golden age of England in times when noblemen were destitute of comforts the want of which would be intolerable

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to a modern footman, when farmers and shopkeepers breakfasted on loaves the very sight of which would raise a riot in a modern workhouse, when men died faster in the purest country air than they now die in the most pestilential lanes of our towns, and when men died faster in the lanes of our towns than they now die on the coast of Guiana. We too shall, in our turn, be outstripped, and in our turn be envied. It may well be, in the twentieth century, that the peasant of Dorsetshire may think himself miserably paid with fifteen shillings a week; that the carpenter at Greenwich may receive ten shillings a day; that labouring men may be as little used to dine without meat as they now are to eat rye bread; that sanitary police and medical discoveries may have added several more years to the average length of human life; that numerous comforts and luxuries which are now unknown, or confined to a few, may be within the reach of every diligent and thrifty working man. And yet it may then be the mode to assert that the increase of wealth and the progress of science have benefited the few at the expense of the many, and to talk of the reign of Queen Victoria as the time when England was truly merry England, when all classes were bound together by brotherly sympathy, when the rich did not grind the faces of the poor, and when the poor did not envy the splendour of the rich.

Macaulay encapsulates, in this passage, the difficulty of measuring what was later to be called the "standard of living" of a population. He was writing at a time when many observers were concerned at the "condition of England" under the impact of industrialization and urbanization and when Marx and Engels had just begun to mount their challenge to emergent industrial capitalism. In the process, they were to challenge also Macaulay's presupposition, which became known as the Whig interpretation of history, one of continual progress toward a better society.

During the twentieth century, historians and economists focused their discussion of living standards on the measurement of wages, adjusted for changes in the cost of living. The wages of different groups of workers were aggregated and compared with movements in the prices of "baskets of goods" representing their consumption expenditure. This had the merit of simplicity and reasonable precision, particularly if the nature of the occupations whose wages were being measured had not changed significantly. The principal drawbacks of the method were that – being based entirely on monetary income – it could not incorporate such issues as changes to the length of human life, that it did not adequately reflect the advent of new "comforts and luxuries," that it was difficult to incorporate new occupations, and that it was always difficult to ensure that the whole, or even a majority, of the population was considered.

These deficiencies did not prevent the resultant measures of real wages being used as evidence in what has rightly been called "the most sustained single controversy in British economic history" (Mathias 1975, p. vii).[2] The controversy was essentially begun by Engels in *The Condition of the Working Class in 1844*, first published in Germany in 1845. During the course of the next hundred years, British economic historians became divided between the "optimists," who believed that economic growth during and after the Industrial Revolution had benefited the working classes at the time, and the "pessimists," who believed by contrast that industrialization had led to declining living standards or, worse, to the "immiseration" of the English proletariat. The controversy was so long lasting – it is, indeed, still in progress – for two main reasons. First, there was no general agreement on a definition of the "standard of living" and, second, measures of changes to real wages were ambiguous. As Von Tunzelmann put it at one stage of the debate, after examining several series of wages and prices, "the patterns of real wages … range anywhere from an increase of 150 percent between 1750 and 1850 down to no increase at all" (1979, p. 48). While the later work of Feinstein (1998) has achieved general acceptance as to the course of changes to real wages, argument still remains on the scope of measures of living standards and the quality of life. This topic is discussed in more detail in Chapter 4 below, where account is also taken of recent contributions to the debate from Clark (2007) and Allen (2009).

In the middle of the twentieth century, living standards came to be defined by economists, even more narrowly than before, in terms of income per capita, in other words the total annual measured income of an economy divided by the number in the population. The measurement of national income, primarily due to the work of Simon Kuznets, represented an enormous step forward in the ability of economists to describe and analyze economic growth and to compare that growth over time and space. It also provided, in the shape of the calculation of real income or real gross domestic product per capita, a means of comparing the average living standards of the population of a particular

[2] Oddly, as Engerman (1997) points out, a similar controversy did not take place in Germany, France, or the United States.

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country either with those of another country or with those of the past. It did not, however, remove the drawbacks of the previous calculations of real wages, in particular their exclusive concentration on monetary income. Thus, as has often been pointed out, it ignored the contribution of unpaid employment such as housework or gardening, did not value leisure time, could not incorporate improvements in the quality of goods and services unless they were reflected in prices, could not take account of changes in health and mortality, and, in general, did not measure changes to the "quality of life."[3] Nor could it reflect, without the addition of other statistics, changes in the distribution of income (both within and between households) in order to test, as Macaulay put it, whether increasing national income had "benefited the few at the expense of the many."[4]

In recent years, these problems with the use of national income analysis in the description of changes in the standard of living have been addressed in two entirely separate ways. First, a number of economists have followed Nordhaus and Tobin (1972) and Usher (1980) in seeking to make adjustments to measured income per capita so as to reflect elements of life which are not included within conventional measures of income per capita. The major such adjustments have been for non-paid work such as housework and gardening and for leisure. In similar vein, Williamson (1981; 1982) attempted to value changes to the quality of life, including morbidity and mortality, with particular reference to the growing cities of the United Kingdom in the nineteenth century. These adjustments, each dependent on a series of debatable assumptions, share the characteristic that – when put into practice – they are quite large, thus throwing further doubt on the value of the underlying calculation of income per head when making temporal and spatial comparisons.[5] The second approach has relied on the insights of Sen (see, for example, 1999) and in particular on his stress

[3] Economists such as Kuznets and Abramowitz, who devised and refined the methods of measuring the national accounts, were of course fully aware of these omissions and deficiencies and discussed them in a number of papers and books. The problem lies, however, in the use to which simple measures of GDP and other variables have been put in cross-national and temporal comparisons.

[4] In recent years, economists have paid increasing attention to the question of whether economic growth increases happiness and of how happiness can be best measured; see, for example, Layard 2006 and Bok 2010.

[5] For a very thoughtful and comprehensive account of the relationship between national income analysis and economic welfare, see Offer 2003.

on "capabilities" as the true definition of living standards. Rather than using a measure which stresses income and the command over resources which it gives at one point of time, he regards a greater standard of living as being given by an improved capability to live a rewarding and fulfilling life. Part of this is, of course, "freedom from want," and therefore in measures based on these insights, such as the Human Development Index (HDI) developed by the United Nations, income per head forms one input into the index, the others being the average expectation of life and the average literacy of the population or country being measured. This concept has been further developed by the addition, in some formulations, of measures of political and civil freedom, again because they are seen as conferring a capacity or capability (Dasgupta and Weale 1992). It is natural that the HDI, and these other formulations based upon it, produce somewhat different rankings of nations in terms of living standards from the simpler criterion of income per capita. This has the virtue of drawing attention to particular features of societies, such as the expectation of life in the United States, which is low compared to other nations with similar, or even smaller, incomes per capita.[6]

Income per capita – whether adjusted or not – reflects the output of an economy, and the command over resources which this gives to its citizens, at one point in time. The HDI, or any measure based on the concept of capability, is intended to reflect the capacity or potential of the economy and society and thus in a sense its future as well as its present.[7] The difference is not as large as it might seem, since income per capita also reflects the potential for using resources in the future, but the emphasis of the HDI is on the long term, of income per capita on the short term. Both, of course, reflect the past in the sense that income and capabilities today are both determined and constrained by their development over past decades or centuries.

For these and other reasons, it seems unnecessary or misleading to express a generalized preference for one type of measure over another. Each is designed to measure a particular feature, or set of features, of

[6] For an application of the Human Development Index to historical data for Europe, see Crafts (1997). The Human Development Index and similar indices are, of course, sensitive to the chosen, and inevitably arbitrary, weighting of the different components of the index.

[7] For a slightly different formulation, see Harris, Gálvez, and Machado 2009.

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society and economy; what is important is that the measure should be appropriate to the question that is being asked. The search for an "ideal" measure of living standards is, in that sense, a search for a chimera; there are, instead, several different measures, each with their own virtues, implications, and correlates. The measures may, or may not, conflict in any given historical circumstance but conflict carries with it as much information as agreement.

The concept known to human biologists as "nutritional status," which is at the center of this book, can therefore easily take its place within the set of possible measures of living standards. Nutritional status, usually measured by the physical growth of infants, children, and young people, has to be clearly distinguished from nutrition, which is the amount and nature of energy ingested in the form of food and drink. Nutritional status is a net measure; it represents the energy which has been used for growth once the demands of body maintenance, resistance to disease, play, and work have been satisfied. If nutritional status is inadequate, a child or young person will not grow, either not at all or less than he or she would do under more favorable circumstances. This inadequacy results normally either from lack of food or warmth or the effects of disease – which act in tandem in so much of the developing world even today – but growth can also be affected if the child is expected to undertake significant manual work or even if it is deprived of love and psychological support. Inadequate growth will result in children and adults who are stunted – short compared with some recognized standard – or wasted – light by comparison with some such standard; it can also affect children in less obvious ways, affecting their intelligence or mental capacity. But the primary evidence of nutritional status lies in our bodies and particularly in our height and weight.

Poor nutritional status and its effects can be most clearly seen in the developing world, where human biologists and development economists have intensively studied it and its correlates. The results of studies of malnutrition are unambiguous. Dasgupta (1993, pp. 12–13) sums them up:

> The general effects of persistent undernourishment and infections vary widely, but they all result in an impaired life. In expectant mothers it affects the growth of the foetus, and therefore its health status (e.g., weight) at birth. It affects . . . the lactation performance of nursing mothers . . . causes fatigue and lowers resistance to infections . . . causes muscle wastage and growth retardation, and thus future capability . . . increases morbidity and

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> vulnerability to infections … affect[s] brain growth and development … influences mental capacities through damage to the nervous system … reducing the energy that children have available for learning … [A]mong adults [it] diminishes their muscular strength, their capacity to do physical work, and their protection against a wide range of infectious diseases … it brings marked psychological changes … [and diminished] life expectancy.

The converse is in each case true for children and adults born and brought up in more favorable circumstances. Nutritional status thus sums up the resources – monetary and other – available to the growing child and the use that is made of them. It particularly reflects the environment of the child over a relatively short period of time; although humans continue to grow in stature for nearly 20 years after birth and in weight for many years thereafter, it is in the fetal stage and in early infancy – and later in adolescence – that growth is particularly responsive to energy inputs and demands.

However, as the quotation from Dasgupta implies, nutritional status is influenced by events that occur long before the birth of a child and persist long after, in fact until its death even in old age many years later. Indeed, through the effect of the nutritional status of a mother upon her child, the influence may be felt through yet further generations. The same conclusion has been reached, in a different way, by human biologists studying the fetal origins of adult disease (see, for example, Barker 1992; Barker 1998). In these senses, therefore, the measure of nutritional status is analogous to measures of capability. It sums up both the historical influences on parents and children and the capacity of that population to live, thrive, and contribute to economy and society.

A number of factors exert different impacts at different stages of life. It seems likely, for example, that maternal nutrition has an effect on the nutritional status of a fetus, affecting both birth weight and the potential for growth of the child after birth. Diet and disease – and possibly demands for work – then also affect that growth, particularly at phases – infancy, early childhood, and adolescence – when normal growth would otherwise be most rapid. Finally, after growth in height has ceased, nutrition, work, and disease continue to affect weight and productivity.

Paradoxically, the very far-reaching and multiple causes and consequences of changes in measured nutritional status diminish its usefulness in explaining the causes of changes to the standard of living of a population or socioeconomic group. It is frustrating to historians and economists that it is rarely possible to ascribe a single cause to a movement in the average height of a population or even to date it very precisely.[8] Of course, few indicators of living standards – even life expectancy or literacy, which can be very precisely measured – are really free from such problems. Even movements in income per capita arise as the outcome of a multiplicity of causes operating throughout the economy, many of which are difficult to discern.

To some economists, nutritional status – measured for example by heights – suffers as a measure of living standards because height is not normally seen as an object of desire or something that can be bought.[9] In economic jargon, height is not an argument in a utility function.[10] People do not normally or consciously sacrifice current expenditure so that their children can be taller. This is certainly not an overwhelming argument against the use of nutritional status as a measure of living standards, since it can be made with equal force against other measures such as life expectancy and, even more obviously, civil and political freedom. In addition, parents certainly do desire health and growth for

[8] These difficulties are compounded by difficulties in measuring height and its correlates in the past, or even in the present. Schultz (2005, p. 279), for example, draws attention to problems of measurement error in contemporary studies in the developing world: "The major complexity posed by health, which is less of a problem with education, is that the indicators that represent health are multifaceted and are not always adequately justified by their correspondence with mortality, morbidity and the quality of life. Many of these health indicators may represent proxies for human capital, consuming current social resources and yielding increased potential over the life cycle of cohorts. These indicators are a mixture of exogenous measurement error and genetic components, on the one hand, and an endogenous (or human capital) component. This distinction is perhaps most evident in the case of adult height, which has been emphasized here. In all of these studies of height, community health services and the socioeconomic characteristics of parents account for only 2–10 percent of the variation in the population, and much of the unexplained variation in height is undoubtedly due to genotypic variation across individuals and survey measurement errors." How much worse are the problems faced by historians.

[9] This is not entirely true, as can be seen from the immense efforts and expense undertaken by some parents of particularly short children to lengthen their children by persuading surgeons to break their leg bones and then to stretch their legs as they heal.

[10] Or, as Engerman (1997, p. 39) puts it more precisely: "While we might believe that individuals maximize utility, not measured income, life expectation, food consumption or height, it is not clear how to determine what enters into different individual utility functions."

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their children and are prepared to make sacrifices of income to attain this. Recently, indeed, some economists have seen the force of these arguments and have accepted that increased height, among other attributes, can be seen as one aspect of the accumulation of human capital. As Schultz (2003, p. 331) puts it:

> Schooling, height, weight-for-height and migration are attributes of workers associated with their current productivity. These forms of worker heterogeneity are to some degree reproducible: schooling and migration are created by well-described processes, whereas height and weight-for-height are formed by the biological process of human growth … These worker attributes are viewed here as indicators of human capital because they can be augmented by social or private investments, but they also vary across individuals because of genetic and environmental factors that are not controlled by the individual, family or society.

Some economists have sought to counter objections to the use of anthropometric indicators as an indicator of the standard of living, which essentially come down to the non-monetized nature of such indicators as height and weight, by referring to “the biological standard of living” rather than “nutritional status” (Komlos and Baten 1998; Komlos and Cuff 1998). This is a distinction without a difference and serves merely to confuse. The problem in fact arises not from the inappropriateness of the term “nutritional status” but from the restricted definition of “standard of living” adopted by economists. As Eric Hobsbawm (1963, p. 131) once observed in a contribution to the standard of living debate, “men do not live by bread alone”; it is simply foolish to exclude from consideration matters which clearly contribute to welfare, such as health, longevity, and quality of life.

Standard of living, quality of life, nutritional status are, therefore, all different but intimately related concepts which are useful in measuring human welfare, either over time or between nations or political and social groups at one point of time. Other aspects of the schema presented above – such as mortality, morbidity, or productivity – may in practice be more relevant to, or more affected by, one method of describing welfare than another and it is important to choose the most appropriate method in any given circumstance. Historical analysis is rarely tidy, since one is dealing with the complexities of societies and economies which are undergoing constant change, so the most that one can hope for is clarity in any particular argument.

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1.3 Understanding technophysio evolution

The schema set out earlier in this chapter describes the interconnections between different aspects of economy and society which have made technophysio evolution possible. To be useful, however, the schema has to be fleshed out, first in general terms and in relation to the condition of the economy at the start of the eighteenth century. This is done in the remainder of this chapter. Chapters 2 and 3 deal with the technical aspects of a number of measurement issues, especially the need to think in terms of distributions rather than means. Then the concept of technophysio evolution is explored through studies of the process in Britain (Chapter 4), Europe (Chapter 5), and North America (Chapter 6) since the beginning of the eighteenth century.

The first, and crucial, proposition is that:

1. The nutritional status of a generation – shown by the size and shape of their bodies – determines how long that generation will live and how much work its members will be able to do.

The concept of nutritional status has been explained in the last section. But what was not explained there was how nutritional status determines the size and shape of bodies and what are its short-, medium-, and long-term consequences for health and productivity. Nor have the consequences of considering these issues within the framework of a generation been considered.

Human beings require energy to maintain their bodies, to grow and engage in activity such as work and play. While a child is in the womb, this energy is supplied by the mother and is a call upon her energy resources; if she is malnourished – lacking sufficient energy inputs for growth, body maintenance, and the tasks which she needs to perform – then the fetus will be deprived and will not grow as well as it could under better circumstances. The most obvious – but certainly not the only – manifestation of this deprivation will be low weight at birth. This in itself affects the chances of the child surviving through infancy and childhood, but there is also increasing evidence to support the so-called Barker hypothesis, that the poor nutritional status of a fetus can pre-dispose that person to develop a number of diseases in adulthood. This pre-disposition is distinct from any effects of genetic disorders which may be passed on from mother to child; it reflects, instead, the environment of the mother while she is childbearing and, indeed, her own nutritional status since childhood.

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The first measurable characteristic of nutritional status is birth weight. Birth weights were not routinely recorded until the nineteenth century (Ward 1993). There is, however, little doubt that average birth weight in 1700 was very low, by modern standards, as can be inferred from stillbirth and neonatal mortality rates.[11] As Wrigley puts it (2004, p. 73): "Analyses of the proximate determinants of stillbirth rates consistently show that by far the most important single factor is birth weight. Low birth weight babies, especially at full term, are subject to very much higher perinatal mortality rates than those close to the optimum weight, usually taken to be in the range 3500–3900 grams. The stillbirth rate at an average birth weight of 2500 grams (the conventional point for defining low birth weight) is between ten and thirty times higher than the rate at an average of 3500 grams." In England at the end of the seventeenth century, the stillbirth rate was "probably between 100 and 125 per 1000 (total births)" though it was to fall, over the next 150 years or so, to 40–50 per 1,000 total births (Wrigley 2004, p. 71).[12] Neonatal mortality also fell from 203 per 1,000 in 1710–1719 to 140 per 1,000 in 1830–1837. The perinatal mortality rate (stillbirths plus neonatal mortality) is extremely strong evidence of the poor nutritional status of much of the population, in all European countries, at the start of the eighteenth century. Indeed, although the English statistics appear horrifying to modern eyes, Wrigley *et al.* (1997, p. 217) point out that: "infant mortality in England was never high by the standards of many pre-industrial communities, or indeed by comparison with those widely prevalent in Europe in the nineteenth century."

Provided that the child survives birth and its immediate aftermath, its energy needs in infancy and childhood are for body maintenance, activity, and growth. Growth charts, now routinely used by pediatricians and others, show clearly the two peaks of rapid growth in a well-nourished child; the first is immediately after birth, the second the so-called "growth spurt" at the advent of adolescence. Such charts

[11] Stillbirths are deaths of the fetus in the womb. Neonatal mortality is the mortality of infants in the first month of their lives. Perinatal mortality is mortality that occurs at or around birth. Infant mortality is death which occurs in the first year of life.

[12] Woods (2009) has recently argued that the fall was less, from a figure close to 60 deaths per 1,000 births at the start of the eighteenth century, although still substantial. He is also skeptical of the strength of the link between stillbirths and maternal nutrition.

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also show the cessation of growth, which occurs nowadays and in developed countries in late teenage years (Eveleth and Tanner 1976; Tanner 1978). Malnutrition disturbs these patterns; it diminishes and retards the growth process, as there is insufficient energy intake to cope with the demands of body maintenance and growth, even if – as will often happen – activity is also diminished. Although it is possible for the body to recover from a short period of malnutrition – and even, through the phenomenon known as catch-up growth, to recover to the size and shape that it would have had – prolonged malnutrition leads to both stunting and wasting.[13] One sign of this is that the growth process itself continues for longer than under more favorable circumstances. But normally, despite this, the malnourished child or young adult will be both shorter and lighter than a child with more abundant energy supplies.

Stunting and wasting can also occur through the existence of other demands on the body's energy supplies. In particular, if the child has to combat disease or if he or she has to work from an early age, then energy which would otherwise be available for growth will have to be used for these purposes. This accounts for the phenomenon, seen both in the developing world today and in historical evidence, of young people and adults from upper social classes, where it is unlikely that there was any shortage of food, who are nevertheless stunted and wasted compared to their peers in more favorable environments.

There is essentially no evidence about the height and weight of children in the early eighteenth century in Britain, the rest of Europe, or North America. However, Floud, Wachter, and Gregory (1990) studied the records of the Marine Society of London, which took boys from the slums of London and found them berths on the ships of the Royal and merchant navies. The earliest measurements are of boys born in 1755, at a time when the evidence of mortality statistics suggests that there may have been a small improvement in conditions of life since the start of the century. Despite this, "The boys of the Marine Society were extraordinarily short, particularly in the eighteenth century. Thirteen-

[13] Such effects can be observed today; even periods of economic dislocation, short of what would normally be seen as famine conditions, can affect child growth. See, for example, Dangour *et al.* (2003), who report that in the 1990s in Kazakhstan the growth of 4-year-old boys ceased, while the average height of successive cohorts of girls actually fell, probably as the result of decisions on the distribution of food within the household.

year-olds born in 1753–1780 average 51.4 in (130.6 cm), a full 10 inches (25.4 cm) less than the children of London measured by Tanner and others in the 1960s" (Floud, Wachter, and Gregory 1990, p. 165). The nearest equivalent, in the modern world, is the children of Papua New Guinea (Eveleth and Tanner 1976).

It is clear, from these data, that some groups of children in England, and presumably in other countries, in the early eighteenth century were severely stunted and – although we have no direct evidence of weight – wasted. It must also be remembered that these children were those who had survived the high perinatal and infant mortality rates reported earlier. Other data for England also suggest that young people from the highest social groups, where presumably there were no income constraints on diet, were still much shorter than similar groups today, even if they were also much taller than their less fortunate contemporaries recruited by the Marine Society. Floud, Wachter, and Gregory report that boys recruited, in their early teenage years, to the Royal Military Academy at Sandhurst and drawn "from a narrow segment at the top of the British class and income distribution" (1990, p. 174) nevertheless had a mean height below the 25th centile of the modern British height standard (1990, p. 179, Fig. 4.10). It seems likely that the growth of these children was retarded by the disease environment in which they had been brought up.

Although growth in height – and the demands on energy inputs for this purpose – ceases in early adulthood, nutritional status remains a useful concept even if it is no longer demonstrated by height. In fact, height still remains a useful indicator, because the physical capacity of the body – in terms of strength and resistance to disease – remains affected by the stunting that has occurred; it was for this reason that British army recruiters, in the eighteenth and nineteenth centuries, rejected short applicants wishing to join the army (Floud, Wachter, and Gregory 1990, pp. 30–83). If, and this is the most normal circumstance throughout much of the world, deprivation and malnutrition in childhood and adolescence are succeeded by more deprivation and continued malnutrition in adulthood, then nutritional status will still be inadequate and the body will not have sufficient energy for body maintenance and work. The most obvious sign of this will be continued wasting, together with an enhanced susceptibility to infectious diseases. While this is a general phenomenon, caused by bodily weakness, malnutrition appears to produce enhanced susceptibility to a number of life-threatening diseases. In addition, there is increasing evidence, for example from studies of Union Army veterans, that deprivation in childhood will increase the chances of suffering from chronic and disabling diseases. For whatever reason, the capacity to work will be limited.

Evidence drawn from the heights of military recruits supports the view that large sections of the populations of the eighteenth century were severely malnourished. For the United Kingdom, Floud, Wachter, and Gregory estimate (1990, pp. 140–149, Table 4.1) that the average height of recruits aged 18 or 19 and born in the late 1740s or early 1750s was less than 64 inches (162.5 cm), although young men of that age were still growing and final heights were probably 2 inches (5 cm) greater. The earliest estimates for French army recruits aged 20 in 1804 suggest that their average height was 163.5 cm (Weir 1997, p. 191 and see Chapter 5 below). White, native-born recruits, born in the first half of the eighteenth century, to North American armies were significantly taller, at about 172 cm tall on average, but nevertheless much shorter than current standards (Costa and Steckel 1997, p. 51). In all three countries, military recruits were drawn from the working classes, but it is nevertheless notable that these British heights are 6 inches (15 cm) less than the modern standard for the whole population. Once again, it has to be remembered that these were survivors from a regime of high perinatal, infant, and child mortality.

Even if malnutrition in childhood is followed by improved economic circumstances in later life, so that there is then no lack of energy for current work and other activity, the earlier deprivation can have long-term consequences. Although this theory is still unproven, it is suggested (Osmani and Sen 2003) that the "western diseases" which now afflict South Asia – in particular coronary heart disease and diabetes – together with the obesity which is now a feature of all developed countries, arise from a rapid increase in consumption among people who were previously malnourished.[14] Although there was little apparent increase in the body mass index in many developed countries during the nineteenth and most

[14] Cameron (2003, p. 41) suggests that this phenomenon can also be seen in South Africa: Children who are "born small and then grow quickly are at an increased risk of obesity and risk factors for type II diabetes. This increased risk is probably due to post-natal exposure to high fat, low fibre, high-energy diets resulting from economic and consequent nutritional transition."

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of the twentieth centuries, it is possible that this phenomenon of early deprivation succeeded by later abundance could be one of the causes of the high incidence of coronary heart disease in, for example, Britain and the United States in the second half of the twentieth century although other causes of death have different relationships with nutritional status.[15]

In past centuries, however, the more typical pattern was one of deprivation both in childhood and in adulthood. In such circumstances, it seems likely that poor nutritional status has a direct effect on labor productivity. This was taken for granted in past centuries, as shown by the imposition of minimum heights for recruitment to armies. Officers and recruiters assumed that a taller soldier would be a fitter soldier, better able to withstand the rigors of military life. This indirect evidence of the link between nutritional status – as measured by height – and health is paralleled by direct evidence from modern studies of the relationship between height and wages. These demonstrate, as Dasgupta puts it, that "the link between nutritional status, physical work capacity, endurance and physical productivity is an established fact" (1997, p. 19) and that "a person's physical work capacity is determined by his entire nutritional history" (1997, p. 20).

Modern studies assume that, if employers are prepared to pay higher wages to taller men, they must be doing so because those taller men are more productive. Strauss and Thomas (1998) report estimates of the relationship between height and hourly wages in the United States and in urban Brazil, while observing that similar relationships have been observed in "a wide range of countries across the world" (1998, p. 799).

> There is a powerful association between height and wages in Brazil. Taller men earn more: a 1 percent increase in height is associated with an almost 8 percent increase in wages. While this dwarfs the magnitude of the correlation in the United States, even taller American men earn higher wages. This ranking probably reflects differences in the extent of poor nutrition in the two countries as well as differences in the nature of work that is commonplace in each society, since manual labor – and thus reliance on physical strength – is far more important in Brazil. (1998, p. 772)

[15] As Waaler (1984) originally demonstrated, the relationship between height or BMI and later disease differs between diseases. The same point is made by Davey Smith *et al.* (2000) who show that there is a negative association between height and certain causes of premature death, such as prostate cancer, lymphoma, and colorectal cancer.

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Strauss and Thomas show that this relationship holds even for those with no education, with a 1 percent increase in height being associated with a 4 percent increase in wages within that group. In other words, height is not simply a proxy for education, although taller and healthier children may also have greater access to, and derive greater benefit from, education. Similarly, Schultz (2002, p. 351) shows that, after controlling for schooling, post-schooling experience, and residence:

> Height is significantly positively associated with the log hourly wage for men and women aged 25–54 in Ghana during 1987–1989, aged 25–54 in Brazil in 1989, and among youth aged 20–28 in the United States during 1989–1993. Ethnic-language or race groups are controlled by dummies and the effect of height is derived from deviations from the ethnic/race group mean, as proposed by Francis Galton … An additional centimeter in adult height is significantly associated with a 1.5% higher wage for men and a 1.7% higher wage for women in Ghana; 1.4% and 1.7% higher wages in Brazil, respectively; and 0.45 and 0.31 % higher wages in the United States. The percentage increase in wages associated with height in the United States is less than one-third of that in the two lower–income countries, and this may be due to diminishing returns to nutrition/health associated with height in the United States than in Ghana and Brazil.

In a more recent survey, Schultz (2005, p. 277) concludes that "an additional centimeter of height is associated with a gain in wage rates of roughly 5–10 percent."

In addition, in modern urban Brazil, Strauss and Thomas show that nutritional status also affects labor force participation. "It is clear that shorter men not only earn less, they are also less likely to be working. Over 10 percent of men who are 154 cm tall were not working at the date of the survey, but among those who are about 167 cm tall, the fraction is only 5 percent."

It is not only height, as an indicator of nutritional status, which is associated with wage and labor force participation. Strauss and Thomas show that there are equivalent relationships with Body Mass Index (BMI), which to some extent reflects current nutritional status, as opposed to height which reflects nutritional status during childhood.[16] The difference between the United States and Brazil persists.

[16] The Body Mass Index is defined as the ratio of weight in kilograms to height in meters squared. It is therefore a measure of weight standardized for height.

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> The magnitude of the differences in wages across the BMI distribution in the United States is dwarfed by the magnitude in Brazil, where the shape is also quite different. Among men whose BMI is less than 27, wages rise dramatically (in Brazil) as BMI increases, particularly for those above 22. Wages are essentially unrelated to BMI for the 13 percent of men whose BMI is above 27. (Strauss and Thomas 1998, p. 774)

Once again, the association persists even for those with no education, perhaps because "elevated BMI is associated with greater physical strength, which is of value for manual labor." In summary, the evidence reported by Strauss and Thomas – even if it is based on cross-sectional data – suggests that, particularly in less developed economies where manual labor is relatively important, improved nutritional status leads to higher labor productivity.[17] Very low levels of BMI have also been found to be associated with poor health and difficulty in performing physical labor (Kimhi 2003).

In addition, it seems likely that poor nutrition affects labor productivity because it diminishes cognitive ability and the capacity to undertake and to benefit from education. Behrman, Alderman, and Hoddinott (2004) sum up the modern evidence on childhood ability:

> Poorly nourished children tend to start school later, progress through school less rapidly, have lower schooling attainment and perform less well on cognitive achievement tests when older, including into adulthood. These associations appear to reflect significant and substantial effects in poor populations even when statistical methods are used to control for the behavioural determinants of pre-school malnutrition. In productivity terms, the magnitudes of these effects are likely to be substantial, easily exceeding the effects of height on productivity even if the indirect effect of height on wages mediated by the relationship between height and schooling is included. (Behrman, Alderman, and Hoddinott 2004, pp. 372–373)

More broadly, severe malnutrition leads to "deficits in cognitive development … Malnourished children score more poorly on tests of cognitive function, have poorer psychomotor development and fine motor skills, have lower activity levels, interact less frequently in their environments and fail to acquire skills at normal rates" (2004, pp. 368–369).

[17] It may therefore be expected that the relationship between height and earnings will diminish over time in a typical country which is undergoing economic development.

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Such relationships between nutritional status and cognitive ability do not exist only in very malnourished populations. Richards *et al.* (2001, p. 199) use the 1946 British birth cohort to show that:

> Birth weight was significantly and positively associated with cognitive ability at age 8 … between the lowest and highest birthweight categories after sex, father's social class, mother's education and birth order was controlled for. This association was evident across the normal birthweight range (>2.5 kg) and so was not accounted for exclusively by low birth weight. The association was also observed at ages 11, 15, and 26, and weakly at age 43, although these associations were dependent on the association at age 8. Birth weight was also associated with education, with those of higher birth weight more likely to have achieved higher qualifications, and this effect was accounted for partly by cognitive function at age 8.

Case and Paxson (2008, p. 503) put the argument clearly, after surveying a range of evidence: "the height premium in earnings is largely due to the positive association between height and cognitive ability, and it is cognitive ability rather than height that is rewarded in the labor market." Similarly, some modern evidence suggests that the connection between early health and cognitive ability persists throughout life. As Case and Paxson (2009, p. 104) put it: "We find evidence that the burden of disease in early life – measured using either mortality rates by cause or the overall infant mortality rate – is significantly associated with performance on cognitive tests in old age."

On the basis of all this evidence from the modern world, it seems highly likely that populations in the past, with high levels of malnutrition, suffered from low productivity not simply because of diminished physical strength but also because of diminished cognitive ability or intelligence. The relative contribution of these two potential causes of low productivity may be impossible to determine, but they are likely to have reinforced each other.

This is such a potentially contentious statement – particularly when applied to differences in stature between and within modern populations – that the argument needs to be spelled out. It is assumed that all human populations have equal potential which will be fulfilled under conditions of optimal nutritional status – even if that state has possibly never been achieved. (As always, there will in every population be a range of ability around the mean.) For the reasons just discussed, poorer than optimal nutritional status will lead to stunting and wasting and to

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diminished cognitive ability among infants and children. Education and training can enhance capability, even among malnourished populations, but poor educational opportunities – typical of so much of the world – will exacerbate or at least fail to mitigate earlier disadvantage. Thus a combination of environmental circumstances are likely to lead to the observation that – on average – more stunted and wasted populations will have lower cognitive ability than less stunted and wasted populations. This will affect the relative productivity of those populations.

Nutritional status, finally, affects the time of death. This is both because malnutrition in old age can affect the body's ability to combat disease, but also because of the evidence of such studies as those by Barker (1998) and Waaler (1984) that very early life experiences, of the kind which lead to stunting and wasting, influence expectation of life. Even the deprivation experienced by disadvantaged sections of developed nations today, mild though it is by historical standards, has very large effects on expectation of life. As just one example among many, Kuh *et al.* (2002, p. 1080) utilize the 1946 British birth cohort to examine the mortality experience of men and women who have lived, throughout their lives, in a welfare state in one of the richest countries in the world. They find, nevertheless, that:

> Estimates from a model including father's social class and adult social class and their non-significant interaction indicate that those in manual households in childhood and young adulthood have almost a threefold increase in mortality compared with those in non-manual households at each time. Study members who experienced upward social mobility or downward social mobility had intermediate rates. The contrast using home ownership was even more noticeable; those from manual origins who did not own their home as young adults had an almost fivefold increase in mortality compared with those from non-manual origins who became owner occupiers. When smoking was included in the model, the effects weakened slightly but remained significant.

Such a modern British cohort has a life expectation of over 70 years. The average expectation of life at birth of men and women born in England at the end of the seventeenth century was about 38 years. This was, in fact, a substantial improvement on the situation only 20 years earlier, since Wrigley estimates that the birth cohort of 1681–1685 had an expectation of life of only 31.27 years (2004, p. 64, Table 3.1). This

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improvement continued during the eighteenth century, but much more slowly and with substantial fluctuations – for example to a figure of only 25.34 for those born in 1721–1731 – through the eighteenth century. During that century, perinatal mortality and maternal mortality both improved substantially – Wrigley (2004, p. 83) describes it as a "remarkable" change in which "the period immediately before birth, birth itself and the period immediately after birth became radically less dangerous to both mother and child" – and there was significant change in infant but not in child mortality. Adult mortality as a whole greatly improved (Wrigley 2004, p. 80).

The demographers' symbol for expectation of life at birth, e_0, is not as illuminating in historical periods as it is today, because of the very high levels of mortality in early life. Provided a man or woman survived this early mortality, his or her average age at death was substantially higher, although in the 1680s in England men or women who had reached the age of 25 lived on average for only another 28 years; this improved to at least 38 years by the end of the eighteenth century (Wrigley 2004, p. 80). However, this does not imply that there was no connection between early life conditions and later life mortality; on the contrary, the experience of the survivors of early life mortality continued to affect their health, productivity, and life chances until their deaths. The increase in life expectancy, therefore, tells us something about the experience of those men and women during their infancy and childhood.

It is this insight – drawn from the epidemiological work of Barker and, more broadly, from the experience of a number of longitudinal studies – that leads to a reframing of economic and social history in terms of the histories of successive generations. Demographers are familiar, of course, with one of the stock tools of their trade, the life table, which sets out the demographic experience of a cohort. But life tables have normally been seen as descriptive rather than explanatory and, more important, economic and social historians have not utilized them in describing or analyzing the experience of groups of people. By contrast, most historical statistics are presented as annual snapshots, even if it is accepted that they are the outcome of dynamic processes. This is not the only way to depict reality.

The evidence which has been presented briefly above, about the long-term effects of nutritional status, the impact of nutritional status on labor productivity and labor-force participation, and the relationship between early life experience on mortality, suggests an alternative approach. This

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is to amalgamate evidence on health, longevity, and work effort so as to consider the potential output of successive generations.

The experience of England during the "long" eighteenth century from 1681 to 1841 is particularly interesting because of the unusually rapid increase in population which occurred. In the period as a whole, "the English population almost trebled in size, from 5.1 to 14.9 million" (Wrigley 2004, p. 65), but this was the product of extremely slow growth, of about 0.2 percent per annum, from 1681 to 1741, followed by very rapid growth, of 1.01 percent per annum, for the period from 1741 to 1841. Wrigley and Schofield argue that the main reason for this increase was changes in fertility, although changes in mortality – such as the reductions in perinatal and maternal mortality, and in stillbirths (described above) – were significant; this view of the process, though disputed by some, now represents the consensus. Whatever the balance of causes between fertility (including nuptiality) and mortality, it is clear that the English population of the early eighteenth century – malnourished as it was – was experiencing startling and probably unprecedented change, in which far more people came to live far longer than in the immediate past.

Despite the dramatic demographic events of the period, it has become the consensus among economic historians that economic growth, in the sense of the growth of real output per capita, was very slow indeed. Indeed, in a recent survey, Mokyr concludes that "little if any real per capita growth can be discerned in Britain before 1830 … As a macro-economic phenomenon, then, the Industrial Revolution in its 'classical years', 1760–1830, stands today diminished and weakened" (2004, pp. 1–2).

On the other hand, if one employs – as is done in Chapters 4, 5, and 6 below – evidence on food inputs, nutritional status, mortality, and their correlates to examine the growth in output of successive generations in the eighteenth and nineteenth centuries, it is clear that it was considerable. Further research is needed, unfortunately, to be more precise about the change in output from generation to generation, but it is clear that the extent of technophysio evolution, and hence of rising productivity, in the eighteenth and early nineteenth century was considerable and perhaps greater than is implied by the conventional measures of per capita income or output.

It is possible to give an illustration of the potential benefits of exploring the historical evidence of changes in height and combining it with

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Table 1.1 ***Mean height of military recruits by birth cohort, 1745–1749 and 1800–1804 (cm)***

Age	Birth 1745–49	Birth 1800–04	% change	Absolute change (cm)
18	160.76	166.34	3.47	5.58
19	161.37	167.69	3.92	6.32
20	161.29	168.48	4.46	7.19
21	162.97	169.11	3.77	6.14
22	166.14	169.62	2.09	3.48
23	167.34	170.31	1.77	2.97
24–29	165.66	169.57	2.36	3.91
Mean change			3.12	5.08

modern evidence of the relationship of wages to productivity. Unfortunately, it is impossible to estimate the height of the English population in 1700, since the earliest reliable estimates from military records date only from recruits born in the first half of the 1740s (Floud, Wachter, and Gregory 1990, Table 4.1). At that time, however, average heights were as shown in Table 1.1, which also reports heights of cohorts born in 1800.[18]

While the percentage changes in heights appear small, they are large by historical standards. In addition, one can apply the modern evidence, compiled by Schultz and others (Schultz 2005) to illustrate their potential impact. The comparison is particularly apposite because the heights of British military recruits in the middle of the eighteenth century were considerably less than those of the male workers in West Africa and Brazil studied by Schultz (though more comparable to those from Vietnam). However, by the end of the eighteenth century, the absolute levels of heights in the historical and modern samples were very

[18] Komlos (1993a; 1993b; 2004) has thrown doubt on the height estimates by Floud, Wachter, and Gregory (1990) for the later eighteenth century. He uses an alternative statistical technique, which involves discarding a larger proportion of observations, to conclude that English heights fell at the end of the eighteenth century, and attributes this to a Malthusian crisis. Floud, Wachter, and Gregory (1993) defend their estimates. See Chapter 2 for further discussion of this issue.

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similar.[19] Even if, as is sometimes postulated, there are diminishing returns to nutritional improvements, it is unlikely that they can have operated at such low absolute height levels. Recall that Schultz concluded that an additional one centimeter of height was associated, in modern cross-sections, with an increase of wages of 5–10 percent. If, and they are two very large caveats indeed, such relationships between height and wages exist also over time and if wages are an accurate reflection of productivity, then Table 1.1 suggests that increases in height in the second half of the eighteenth century could have been associated with large increases in productivity.

Modern evidence can also be used to assess the implications of other features of change in the eighteenth century. Expectation of life at age 25 is estimated, for example, to have increased by 10 years. This compares well with the estimate by Barro and Sala-i-Martin that "a 13 year increase in life expectancy raises the annual growth rate by 1.4 percent" (Morland 2005, p. 243). All this evidence accords with the view that, during the eighteenth century, the economy was experiencing extensive rather than intensive growth; in other words, the overall output was growing through demographic, agricultural, and behavioral changes – the last in the sense of changes to the number of hours worked, although it is debatable whether working hours increased quite as dramatically as some authors have been inclined to suggest (cf. Voth 2000, p. 123; Voth 2001; and Chapter 2 below).

The period is clearly one of the substantial accumulation of human capital. This occurred through extensions in the average working life – increasing the return on educational and other infrastructure investment and allowing accumulated experience to be applied to economic activity – and through increases in health and stature arising from improved nutritional status, indicating improvements in cognitive ability. It is possible to speculate, as Mokyr has done from a different direction (1990; 2004), that it is this accumulation of human capital that allows for the subsequent achievements of the Industrial Revolution of the nineteenth century.

To sum up, work output in the past was limited by the amount of energy available for it, by the physical and intellectual capacity or

[19] The heights of male 25–29 year olds (Schultz 2005, p. 276, Table 10.3) were, for Ghana in 1987–1989, 169.46 cm; for Côte d'Ivoire in 1985–1987, 170.11 cm; for Brazil in 1989, 168.90 cm; and for Vietnam in 1992–1993, 162.10 cm.

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inheritance of members of a generation, by the effects of disease during life, and by limited lifespans. All these are closely related to and, in past ages, limited by nutritional status. This implies, in its turn, that the work effort of past generations was limited by the food supply – interacting with the disease environment and sources of income – available to each and every member of that generation, both during infancy, childhood, and adolescence, and as an adult. This constraint was at its most obvious at times of famine, when climatic conditions or problems of distribution limited the supply of food and increased the impact of disease; it used to be thought that "mortality crises" caused by famine had significant demographic effects and, in some cases, they did. But far more pervasive and insidious was the simple fact that large sections of the population were permanently malnourished and therefore permanently unable to work to what would have been, in other more favorable circumstances, their full capacity. Food, in other words, must be seen not simply as an item of consumption, but as a fuel for future work effort, one which, in past centuries, was often inadequate. The food supply is therefore, for all kinds of reasons, crucial to the concept of technophysio evolution and is considered at more length below.

2. The work of a generation, measured both in hours, days, and weeks of work and in work intensity, when combined with the available technology, determines the output of that generation in terms of goods and services.

The work output of human beings does not spring simply from their physical and mental effort or from the food intake that makes this effort possible; it is crucially assisted by technology, the product of their, and previous generations', ingenuity and investment. This relationship forms the second proposition in the schema of technophysio evolution.

This proposition is much more familiar than the first, but still not entirely self-evident. Three aspects in particular deserve further discussion: the relationship between supply and demand; the definition of "the available technology"; the definition of "output." All have a long history of discussion by economists and historians, which needs to be rehearsed briefly for a wider audience.

First, the second proposition implies that output is determined by the supply of work effort and technology, rather than, in the short run, by the demand for goods and services in the economy. This often seems questionable in a world which is used to economic cycles of "boom and

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bust" and to the manipulation by governments of public expenditure and interest rates in an effort to maintain economic stability. A great deal of economic analysis, most famously by John Maynard Keynes in relation to the slump of the 1930s, has been devoted to the inadequacy in such circumstances of aggregate demand and the measures that can be taken to stimulate demand in order to produce economic growth. Fluctuations in demand clearly do affect the short- and medium-term behavior of an economy and, in so doing, produce significant periods of misery or depression, characterized by unemployment and waste of resources, as well as other periods of prosperity and full employment.

However, the focus of this book, and of this second proposition of technophysio evolution, is on the long term and, in such an analysis, it is appropriate to focus on the long-term capacity of the economy, which is constrained by supply-side factors such as the number of people, their ability to work, and the equipment which they have available. The first proposition, discussed above, suggested that nutritional status is a major constraint on the work of a generation throughout its life, and even further through the effects on future generations. Neither the nutritional status of a generation, nor the technology with which it works, can change rapidly and the focus, in discussion of such factors, is properly on the long term.

A possible source of confusion, in this connection, is that the symptoms of a deficiency of aggregate demand and of constraints of supply can, in certain circumstances, be the same. Many observers in the sixteenth and seventeenth centuries discussed what was later to be called unemployment, drawing attention to the number of beggars or those dependent on poor relief. They pointed also to what they regarded as the laziness of the laboring classes, prone to extend the weekend by taking "Saint Monday" off from work or seizing other excuses to reduce their working week; this occurred despite apparently low wages which might have encouraged the seeking of work whenever and wherever it could be found. This phenomenon, later called underemployment, has been explained in terms of poor organization of the economy, for example in an inability to deal with the effects of climate on the distribution of goods, but also as simple distaste for work or, in economic jargon, a "high leisure preference." Voth (2000) documents the extension of working hours in the eighteenth century and the demise of "Saint Monday" and indeed most religious holidays, ascribing the change principally to the desire of the working population to expand

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their money incomes in response to the increasing availability of durable consumption goods.[20]

However, it is also possible that unemployment and underemployment in the period was, at least in part, the result of constraints on the ability of the population to work, because of poor nutritional status and the ravages of infectious and chronic disease. The stunting and wasting of the population – described in the previous section – indicates that many people, particularly at the lower end of the income distribution, would simply have been incapable of sustained manual labor for all or a large part of a day. They would not have died, but they would have been able to work only for limited periods. This would have reduced even further an already low wage and, in its turn, limited food consumption to serve as fuel for further work effort.

Strauss and Thomas (1998) throw doubt on the existence of this phenomenon, sometimes known as that of the "efficiency wage," in the modern underdeveloped world, although this is disputed by Dasgupta (1997). In addition, cyclical unemployment, caused by demand deficiency, can still be superimposed on long-term underemployment; the condition of the working classes can be further worsened, on relatively rare occasions, by famines or plagues, but these have relatively short-term effects. What is really constraining and determining the long-term growth of the economy is the underlying supply of people and the work that, limited or enabled by their nutritional status, they are able to do.

The second feature of the second proposition is that it places considerable emphasis on "the available technology" without explaining what that is and how it has become available. The latter question will be taken up shortly in discussing the third proposition. Here, it is necessary to explain that by "the available technology" is meant the entire apparatus of the economy which helps to translate human brain and muscle power into work and then into goods and services. "Technology" in modern parlance is often associated with complex machines, but the word is being used here with much wider connotations, ranging from simple hand tools to complex astronomical instruments and incorporating the buildings, such as watermills or iron-foundries, in which the tools were used and in which work took place. To introduce another

[20] An earlier, but still highly influential, treatment of these topics is that of E. P. Thompson (Thompson 1967).

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piece of terminology, the technology available to a society is made up of a series of techniques applied to the production of different goods and services.

It is important not to underestimate the technology available to Britain, Europe, and North America in the first half of the eighteenth century. Recent research has documented the impressive growth of a wide range of capital and consumer goods – buildings, clothing, footwear, pottery, glass, agricultural machinery, transport infrastructure, etc. – which became available in the eighteenth century, much of it associated with new production methods. In addition, the development over several centuries of an extensive network of world trade gave access, on the part of each of these economies, to technologies of production in many other parts of the world; the fashion among the upper classes of eighteenth-century Europe for "chinoiserie" is just one example of the way in which this global network altered consumption patterns and gave access to a new technology.

Technology is not, of course, evenly spread across an economy. Tools and machinery replaced or assisted human effort in some activities earlier than in others, so that in any economy there is a co-existence between highly labor-intensive activities – such as teaching – and highly capital-intensive activities – such as power generation. This was true in the early eighteenth century, as it is today, but what characterized the economy of that period was the low level, compared to today, of labor productivity – output per head or per worker employed – even when making use of the best available techniques of production. In addition, as described above, recent research suggests that, in Britain at any rate, the overall – though not necessarily the sectoral – growth of labor productivity was low, if not non-existent, for much of the eighteenth century.

The third feature of the second proposition which requires discussion is the definition of the word "output." As was described briefly in examining the concepts of nutritional status and standard of living, the success and utility of the development of national income analysis has had one unfortunate consequence in limiting the concept of output to matters which are the subject of monetized transactions. This is particularly problematic in a world such as that of the eighteenth century, in which much output in the form of, for example, food from gardens or home-made clothing, was produced within the household. It should, therefore, be included within the definition of output, if only because it contributed to the overall food supply and thus to the nutritional status of the population.

So too must the provision of services. Economists have been emphasizing for over two centuries, at least since the time of Adam Smith, that there is no distinction in principle between the production of food, such as a tonne of wheat, the production of manufactured goods, such as a car, or the production of a service, such as an accountant completing a tax return. All three represent the product of work effort and the available technology and all are done because someone is prepared to pay for them. It is therefore entirely meaningless for politicians to say, as they sometimes do – unconsciously harking back to the mercantilist theories which preceded Adam Smith – that our economy is "dependent" on the production and sale overseas of manufactures and that the sale of brainpower by teachers or lawyers is somehow inferior. Services must be included within the definition of output, both today and in an economy such as that of the early eighteenth century in which domestic and personal service, both within and outside the household, was so important a form of economic activity. Services were certainly not as important a component of work activity at the beginning of the eighteenth century as they were later to become. In all the economies considered in this book, the leading role in 1700 was taken by agriculture, although "Britain already had a relatively large proportion of people in non-agricultural activities, both full-time artisans and part-time in cottage industries" (Mokyr 2004, p. 17). The proportion of the population engaged in agriculture probably fell from 74 percent in 1500 to only 45 percent in 1750, a level among the lowest in Europe (Allen 2004, p. 116).

3. The output of a generation is partly determined by its inheritance from past generations; it also determines its standard of living and its distribution of income and wealth, together with the investment it makes in technology.

The implication of propositions one and two, combined with evidence about the state of the economies of Britain, Europe, and North America in the early eighteenth century, is that the standard of living of the population was low and constrained by its nutritional status, even with the application to production of an increasing range of techniques. A further implication is that low output levels constrained the investment that could be made in more techniques, so as to enhance output for current and future generations.

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It is important to refer again, at this point, to the salience of the distribution of income and wealth across the different members of a given population. In much of the preceding discussion, this has been ignored in the interests of simplicity, although reference was made to the fact that nutritional status was particularly poor – to the point that it constrained work – among those at the bottom of the income distribution. Apart from this, the discussion has considered the total output of a generation and, on occasion, output per head – total output divided by numbers in the population.

In reality, however, societies at the beginning of the eighteenth century were highly unequal in very many ways, to the point that a simple average – such as income per head – can be seriously misleading as a way of describing the society, unless it is accompanied by information on distribution around the average – such as the distribution of income and wealth. Thus these societies were characterized, to take a simple example, by a very small number of the very wealthy, a larger number of the "middling classes," and a very large number of the poor and working classes. This was such an important feature of these societies, to those who lived in them, that the distribution of income was the subject of perhaps the first example of social science investigation, Gregory King's enumeration of the population of England in 1688 (King 1696 [1973], pp. 48–49). Although there is no similar contemporary description of other European societies, it is likely that they were at least as unequal as British society in the early years of the eighteenth century, although the society of North America may have been somewhat more equal (see Chapters 2 and 3 below). There was thus an enormous difference between the income of an aristocrat and an agricultural laborer, a difference which we know from later evidence to have been reflected in their nutritional status, the size and shape of their bodies.

Floud, Wachter, and Gregory (1990) document, for example, the wide variation in height by social class; while the most dramatic differences were found between young boys recruited to the Royal Military Academy at Sandhurst and those from the London slums recruited by the Marine Society, clear and marked gradients in height existed by social class and even within working-class occupations.

Substantial parts of the generations which lived in the early eighteenth century were living essentially from hand to mouth, with incomes which constrained physical growth in their children and limited their own ability to undertake normal physical activity, let alone sustained work.

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Such people – constituting a large fraction of the population – had no surplus, in fact a deficit, of income above immediate consumption needs. Moreover, it is likely that there were significant inequalities in consumption by gender and age within the family. By contrast, a small part of these generations had far more income, derived in many cases from inherited wealth, than they could conceivably require for immediate needs, whether for food or other items of consumption. This inequality becomes particularly important in determining how these societies transformed themselves – through the processes of economic growth and technophysio evolution – into the developed societies of today.[21]

Economic growth requires the creation of a surplus, above immediate needs for consumption and renewal – such as seed to be used for next year's planting – which can be invested in new techniques which will then help the society to raise its productivity. The relationship between investment, technological change, and the genesis of sustained economic growth is, to say the least, a complex one which has enthralled and puzzled many generations of economists. It has been very difficult, despite many studies of the process of technological change, to prove that there is a clear and quantifiable relationship between investment and innovation – in the sense of the adoption of a new technique – let alone with its invention. This is partly because these studies have shown most invention and innovation to be continuous and incremental, best described in the phrase "learning by doing," rather than the occasion of a single inventor shouting "eureka."

Despite these difficulties, it would be perverse to conclude that the economic growth which occurred during the eighteenth century in all three of the geographical areas considered in this book – very slow though it was – did not, at least by the end of the century, have something to do with what has been described as the "wave of gadgets" known to economic historians as the Industrial Revolution. Even in North America, where growth may have been equally due to an increase in knowledge about how to make use of the abundant land resources of the country, the introduction of new crops like cotton was intimately bound up with their use in the developing textile industries of Europe. In all these cases, the economic growth that was ultimately – over two centuries – to provide for the "escape from hunger" owed something to

[21] Dasgupta (1997) proposes a mechanism by which malnutrition leads to inequality.

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the possession by a small fraction of the population of resources which could be invested in technological improvement (Mokyr 1990). We have not tried to defend the inequality of these societies, such as that of pre-Revolutionary France, or the consequent immiseration of much of their population – from an ethical perspective, so the statement that it also provided the capacity to invest is not a signal of approval; it is simply a judgment on the means by which, in the particular historical circumstances, economic growth was achieved.

At the same time, there is increasing evidence that – even during the so-called classical period of the English Industrial Revolution after 1750 – changes in technology proceeded mainly through very small improvements to existing techniques, rather than from major or path-breaking inventions. By definition, these improvements did not require, individually, significant investment funds. As Bruland puts it (2004, p. 146): "innovation was a broad process, pervasively embedded in many industries, even those that were essentially matters of hand technology." There was, she suggests, a "general social propensity to innovate." It seems unlikely that this suddenly sprang into life in 1750 and likely, therefore, that English society of the early eighteenth century was already benefiting, in terms of increased efficiency and improved living standards, from a general willingness to try out new ideas. Where this came from, in contrast to the situation in other economies at the time, is a much more difficult issue to resolve.

4. The standard of living of a generation determines, through its fertility and the distribution of income and wealth, the nutritional status of the next generation.

The fourth proposition follows on from all that has gone before, but adds a new factor in drawing attention to the importance of fertility. Decisions by men and women, about marriage (or in modern times, cohabitation) and about the number of children they will have, affect the distribution of resources within the family and, potentially, the nutritional status of the children. These decisions are not taken in a vacuum; instead, the collective behavior of a generation, in its marriage and fertility patterns as in many other ways, reflects a series of decisions in response partly to economic circumstances and opportunities. One such influence is their current and expected standard of living, which will itself depend on the overall standard of living and on the prevailing distribution of income and wealth.

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There is now a consensus that the primary determinant of population growth in England in the eighteenth century was changing fertility, although changes in mortality were by no means unimportant; Wrigley (2004, pp. 68–69) estimates that fertility change was responsible for about 64 percent of the increase in the intrinsic growth rate of the population between 1666 and 1841. Careful analysis through family reconstitution suggests that fertility rose through a combination of an increase in the fertility rates of both married and unmarried women, earlier marriage, and a reduction in the proportion of women who remained unmarried (Wrigley 1998; Wrigley 2004, p. 69). Particularly notable was an increase in illegitimacy and prenuptial conceptions. Together, fertility trends – and particularly the first marriage rate – in England follow what is thought to have been the upward trend in real wages, presumably because improving economic circumstances encouraged marriage and childbearing.

Despite the evidence of changing marriage age and thus the response in fertility behavior to economic circumstance, it is obvious that poverty and malnutrition do not stop people from having children or from seeking to care for them as well as possible. However, it is equally obvious that poor and malnourished adults will find it difficult to care for their children, that the resources of the family will be spread more thinly, and that the children will therefore have a larger than average chance of themselves being malnourished.

In addition, as was argued above, there is direct evidence that the well-being of a mother affects the life chances of a child. This occurs partly through the likelihood that a wasted and stunted mother will have a child of low birth weight; such a mother is likely to have a small pelvis, associated either with low birth weight or, in extreme cases, difficulties during the birth. Such children will have a lesser chance of survival in infancy; in addition, through the longer-term influences of deprivation in the fetal period they will suffer from an increased chance of developing life-threatening or chronic diseases in adult life. As Osmani and Sen (2003) point out, this situation is exacerbated, in the modern world, by gender inequality, in which female children and women suffer discrimination in the distribution of food and other resources within the family. This leads to maternal undernutrition, then to low birth weight and to poor health and increased mortality in the later life of the children. While this is a particular feature of South Asia today, demonstrated for example in the lowest average birth weights, it is likely to have been a much more widespread feature of societies in the past.

The mechanisms by which the standard of living of one generation affects the standard of living and nutritional status of the next generation are therefore clear. But in fact the process is one which lasts over several generations. Wasting and stunting in a mother are likely to have arisen partially from her own deprivation before and after birth and, therefore, to have been influenced by the nutritional status and standard of living of her own mother. It is therefore in no way fanciful to see the influence of the health and welfare of grandparents in the bodies of their grandchildren and the effect may be even longer lasting. As Horrell, Humphries, and Voth (2001, p. 352) conclude from their reanalysis of data about recruits to the Marine Society in London in the eighteenth century:

> Analysis of this sample provides evidence that deprivation in childhood conditioned human capital acquisition, with ongoing adverse effects on labor market opportunities, which confined the child to low-paid, low-status jobs. But perhaps the effects go further; their disadvantaged labor market position implies that when these fatherless boys in turn become parents their children would be at a disadvantage in the acquisition of skilled, better–paid jobs. Regression analysis reveals that, when other factors are controlled for, the nearest relative's qualification level often has a significant effect on a boy's height with higher qualification levels feeding into greater height attainment. Again this demonstrates the impact of parental attainment on human capital acquisition and provides further evidence of the intergenerational transmission of disadvantage.

Deprivation and disadvantage can arise from biological, economic, or cultural factors or, in most cases, from the interaction of all three. Sometimes, indeed, different factors may work in different directions. Such processes may account for a phenomenon of child growth which has been observed on a number of occasions; it can take several generations of prosperity before a community throws off its history of deprivation. The most graphic illustration of this phenomenon can be found in the Japanese-American and Italian-American populations of the modern United States. In these communities, it is commonly at least two generations before the young people take on the bodily characteristics of the host population. They have clearly not been constrained by any genetic factor, since the time period of two or three generations

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during which they do attain the size or shape of the host community is far too short for any genetic modification. But it is therefore puzzling that the transformation – in these cases of several centimeters of average height – does not occur more rapidly. One possible social or cultural explanation lies in diet or other attributes of care, which persist within the immigrant community and take some time to change. An alternative, or complementary, biological explanation is that there is a limit to the amount of change that can take place between generations, presumably because the nutritional status and standard of living of one generation constrains the change that can take place within the next generation (Osmani and Sen 2003). An alternative biological mechanism is proposed by Cole (2003) who believes that there is a physiological limit on the amount of growth in a given generation. However, if this is so, it is becoming clear that the constraint does not apply to weight gain, since the intergenerational increase in weight among South Asian populations is now very considerable and rapid and is leading to a serious problem of obesity in the younger generations.[22]

5. And so on *ad infinitum*

The five propositions which make up the schema of technophysio evolution are essentially circular, a never-ending process of influence from one generation to the next, and the next, and the next. Even if the logic and evidence which supports these propositions – and they are

[22] The problem is not confined to South Asia. Ulijaszek (2003) shows that mean BMI of women in the Cook Islands rose from 27.2 in 1952 to 28.9 in 1966 to 33.8 in 1996 (pp. 128–129). Similarly, Smith *et al.* (2003) find in a study of children of Mayan origin in the United States that: "Immigration from low-income countries to the US generally increases immigrants' nutritional intake, access to health care and clean water, but it also introduces some unhealthy lifestyle patterns, such as diets dense in energy, especially fat, and little regular physical activity" (p. 146). Maya-American children are 10.2 cm taller than their Guatemalan counterparts and this difference is not due to genetic change nor selective migration, about 60 percent of the height gain being due to leg length (p. 149). Maya children have more stunting, but less overweight and obesity; Maya-Americans, by contrast, are likely to be overweight compared to white children. But children of parents who had not assimilated, shown by speaking Spanish, were less likely to be overweight, which suggests that those who had assimilated were at higher risk. "If we use language as an indicator of assimilation, then this result is consistent with the hypothesis that a bicultural assimilation path generally results in healthier children. It also suggests the greater assimilation to American culture may place immigrant children at risk of weight problems" (p. 159). See also Popkin and Udry 1998.

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admittedly controversial – is accepted, there are two major caveats which must be made at this stage and then explored throughout the remainder of the book.

The first is that, since the schema is designedly circular, only historical circumstances can determine where on the circle any process of change begins. In the formulation above, changes to the size and shape of the body as indicators of nutritional status are given pride of place, but the circle could equally easily be formulated to begin with proposition two, or three, or four. In this sense, the schema does not answer the question: "where did it all begin?" or even "which feature is most important at any one period?" All that it can do is to point to a dynamic system, in which both positive and negative feedback is possible and in which both have almost certainly occurred within the past three hundred years.

The second caveat is that the schema, designedly, does not attempt at this stage to estimate quantitatively the influence of one factor within it on another. This gap will trouble most economists, used to estimating elasticities; they want to know, not just that nutritional status affects the ability to work, but how much work effort changes in response to a 1 percent increase in height. In very similar vein, historians want to know how much of the decline in mortality in the late nineteenth century can be explained by improvements in nutritional status, how much by declines in the virulence of infectious disease, how much by investment in the infrastructure of public health such as drains and clean water supplies.

The remainder of this book will attempt both to flesh out and to diminish the force of these caveats, by providing historical evidence of the changes which are described as technophysio evolution and the factors which have influenced those changes. Where it is possible to answer questions about elasticities or the respective influence of one or other factor, they will be answered. But it should always be remembered that this book is extremely ambitious in seeking to encompass so many different aspects of history, economics, demography, and human biology – all normally treated separately – and that it is almost inevitable that the arguments will fail to satisfy all or some adherents of those disciplines.

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