1

The Space and Strategy of Demographic Growth

1 Humans and Animals

Throughout human history population has been synonymous with prosperity, stability, and security. A valley or plain teeming with houses, farms, and villages has always been a sign of well-being. Travelling from Verona to Vicenza, Goethe remarked with pleasure: "One sees a continuous range of foothills... dotted with villages, castles and isolated houses... we drove on a wide, straight and well-kept road through fertile fields... The road is much used and by every sort of person."[1] The effects of a long history of good government were evident, much as in the ordered Sienese fourteenth-century landscapes of the Lorenzetti brothers. Similarly, Cortés was unable to restrain his enthusiasm when he gazed over the valley of Mexico and saw the lagoons bordered by villages and trafficked by canoes, the great city, and the market (in a square more than double the size of the entire city of Salamanca) that "accommodated every day more than sixty thousand individuals who bought and sold every imaginable sort of merchandise."[2]

This should come as no surprise. A densely populated region is implicit proof of a stable social order, of nonprecarious human relations, and of well-utilized natural resources. Only a large population can mobilize the human resources necessary to build houses, cities, roads, bridges, ports, and canals. If anything, it is abandonment and desertion rather than abundant population that has historically dismayed the traveler.

Population, then, might be seen as a crude index of prosperity. The 1 million inhabitants of the Paleolithic Age, the 10 million of the Neolithic, the 100 million of the Bronze, the 1 billion of the Industrial Revolution, or the 10 billion that we shall doubtless attain in the course of the coming century, certainly represent more than simple demographic growth. Even these few figures tell us that demographic growth has not been uniform over time. Periods of expansion have alternated with others of stagnation and even decline; and the interpretation of these, even for relatively recent historical periods, is not an easy task. We must answer questions that are as straightforward in appearance as they are complex in substance: Why are we 6 billion today and not more or less, say 100 billion or 100 million? Why has demographic growth, from prehistoric times to the present, followed a particular path rather than any of numerous other possibilities? These questions are difficult but worth considering, since the numerical progress of population has been, if not dictated, at least constrained by many forces and obstacles which have determined the general direction of that path. To begin with, we can categorize these forces and obstacles as biological and environmental. The former are linked to the laws of mortality and reproduction which determine the rate of demographic growth; the latter determine the resistance which these laws encounter and further regulate the rate of growth. Moreover, biological and environmental factors affect one another reciprocally and so are not independent of one another.

Every living collectivity develops particular strategies of survival and reproduction which translate into potential and effective growth rates of varying velocity. A brief analysis of these strategies will serve as the best introduction to consideration of the specific case of the human species. Biologists have identified two large categories of vital strategies, called *r* and *K*, which actually represent simplifications of a continuum.[3] Insects, fish, and some small mammals practice an *r*-strategy: these organisms live in generally unstable environments and take advantage of favorable periods (annually or seasonally) to reproduce prolifically, even though the probability of offspring survival is small. It is just because of this environmental instability, however, that they must depend upon large numbers, because "life is a lottery and it makes sense simply to buy many tickets."[4] *r*-strategy organisms go through many violent cycles with phases of rapid increase and decrease.

A much different strategy is that practiced by *K*-type organisms – mammals, particularly medium and large size, and some birds – who colonize relatively stable environments, albeit populated with competitors, predators, and parasites. *K*-strategy organisms are forced by selective and environmental pressure to compete for survival, which in turn requires considerable investment of time and energy for the raising of offspring. This investment is only possible if the number of offspring is small.

r and *K* strategies characterize two well-differentiated groups of organisms (figure 1.1). The first are suited to small animals having a short life span, minimal intervals between generations, brief gestation periods, short intervals between births, and large litters. *K* strategies, on the other hand, are associated with larger animals, long life spans, long intervals between generations and between births, and single births.

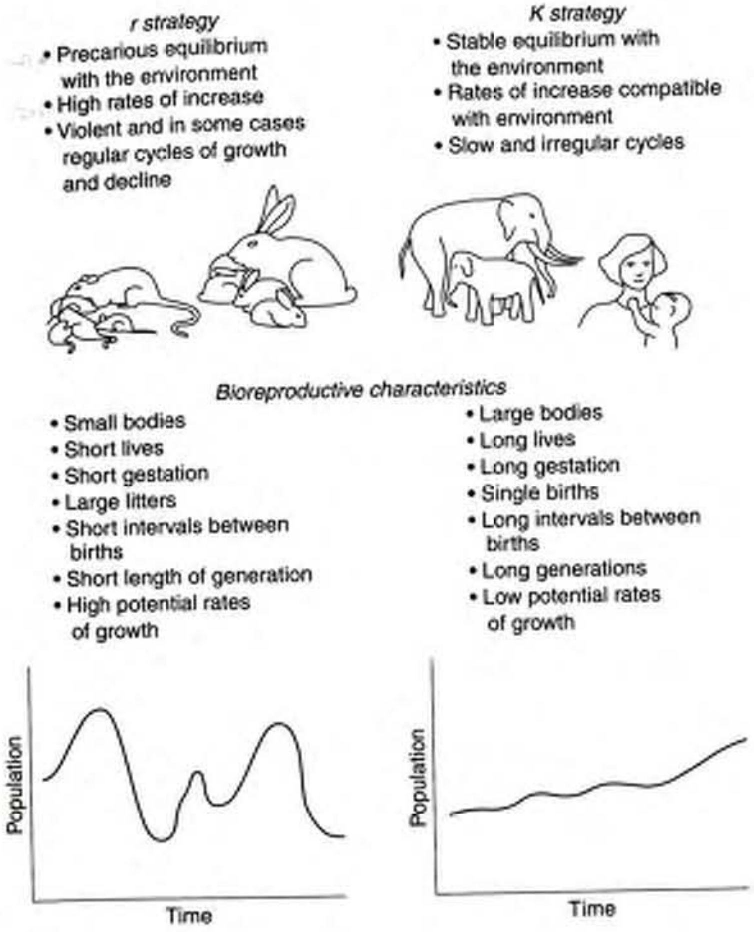


Figure 1.1 *r* strategy and *K* strategy

Figure 1.2 records the relation between body size (length) and the interval between successive generations for a wide array of living organisms: as the first increases so does the second. It can also be demonstrated that the rate of growth of various species (limiting ourselves to mammals) varies more or less inversely with the length of generation and so with body size.[5] At an admittedly macroscopic level of generalization, the lower potential for demographic growth of the larger animals can be linked to their lower vulnerability to environmental fluctuations and this too is related to their larger body size. Because their life is

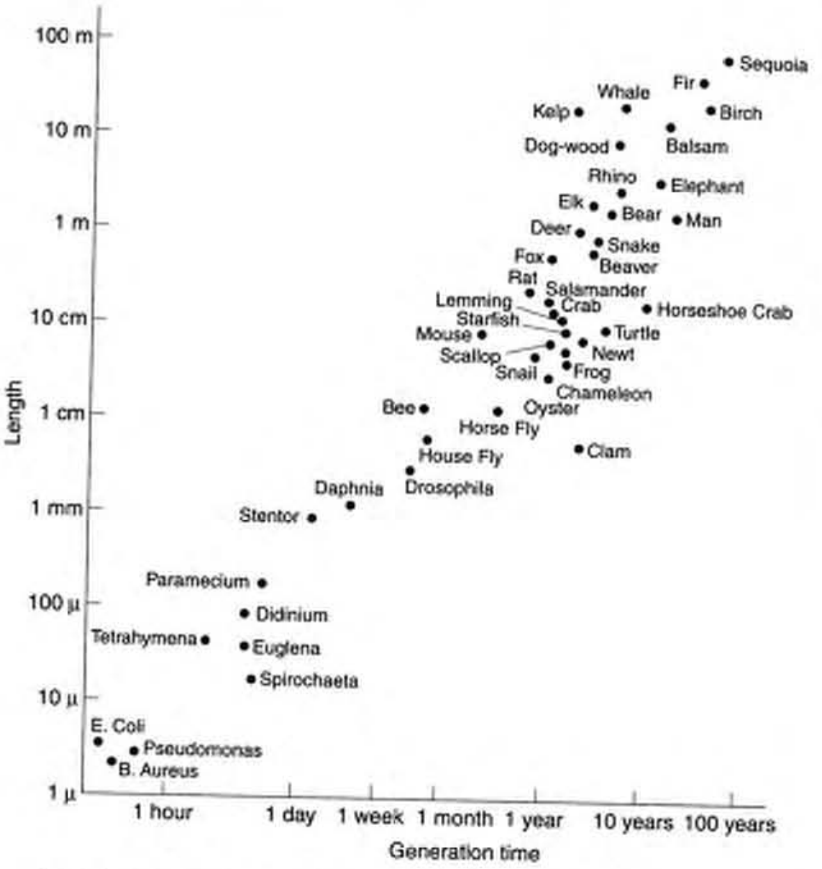


Figure 1.2 The length of an organism at the time of reproduction in relation to the generation time, plotted on a logarithmic scale

Source: J. T. Bonner, *Size and Cycle: an Essay on the Structure of Biology* (Princeton University Press, Princeton, 1965), p. 17.

not a lottery and their chances of survival are better, the larger animals do not need to entrust the perpetuation of the species to high levels of reproduction. The latter, in fact, would detract from those investments of protection and care required to ensure the offspring's reduced vulnerability and keep mortality low.

These ideas have been well known at least since the time of Darwin and Wallace, founders of the theory of natural selection. Nonetheless, they provide a useful introduction to discussion of the factors of human increase. Our species obviously practices a *K* strategy, in that it has successfully controlled the fluctuating environment and invests heavily in the raising of its young.

Two principles will be particularly helpful for the purpose of confronting the arguments of the following pages. The first concerns the relation between population and environment; this should be understood broadly to include all the factors – physical environment, climate, availability of food, and so on – that determine survival. The second concerns the relation between reproduction and mortality insofar as the latter is a function of parental investment, which in turn relates inversely to reproductive intensity.

2 Divide and Multiply

Many animal species are subject to rapid and violent cycles which increase or decrease their numbers by factors of 100, 1,000, 10,000, or even more in a brief period. The 4-year cycle of the Scandinavian lemming is well known, as are those of the Canadian predators (10 years) and many infesting insects of temperate woods and forests (4 to 12 years). In Australia, "in certain years the introduced domestic mouse multiplies enormously. The mice swarm in crops and haystacks, and literal bucketfuls can be caught in a single night. Hawks, owls and cats flourish at their expense . . . but all these enemies have little effect in reducing the numbers. As a rule the plague ends rather suddenly. A few dead mice are found on the ground and the numbers dwindle rapidly to, or below, normal."[6] Other species maintain an equilibrium. Gilbert White observed two centuries ago that eight pairs of swallows flew round the belfry of the church in the village of Selborne, just as is the case today.[7] There are, then, both populations in rapid growth or decline and populations that are more or less stable.

The human species varies relatively slowly in time. Nonetheless, as we shall see below, long cycles of growth do alternate with others of decline, and the latter have even led to extinction for certain groups. For example, the population of Mesoamerica was reduced to a fraction of its original size (one-fifth, one-tenth?) during the century that followed the Spanish conquest (initiated at the beginning of the sixteenth century), while that of the conquering Spaniards grew by half. Other populations have disappeared entirely or almost entirely – the population of Santo Domingo after the landing of Columbus or that of Tasmania following contact with the first explorers and settlers – while at the same time others nearby have continued to increase and prosper. In more recent times, the population of England and Wales multiplied sixfold between 1750 and 1900, while that of France in the same period increased by barely 50 percent. According to probable projections, the population of the Democratic Republic of Congo will have increased tenfold between 1950 and 2030, while in the meantime that of Italy by a mere 10 percent.

These few examples should suffice to demonstrate at what different rates the human species can grow even in similar situations (France and England) and over long periods. It should also be clear that here lies the heart of demography as a science: to measure growth, analyze mechanisms, and understand causes.

Population growth (whether positive or negative, rapid or slow) can be described by a simple calculation. In any interval of time a population (P) varies numerically as a result of renewal or arrivals (births B and immigration I) and elimination or departures (deaths D and emigration E). Leaving aside migration (considering the population "closed," as is that of the entire planet), the change in population dP in any interval of time t – by convention and for convenience demographers use years – is given by the following:

$$dP = B - D,$$

and so the rate of growth r (where $r = dP/P$) will be equal to the difference between the birth rate b (where $b = B/P$) and the death rate d (where $d = D/P$):

$$r = dP/P = b - d$$

The range of variation of the birth and death rates is fairly wide. Minimum values are 5 to 10 per thousand (possible today with mortality and fertility under control) and a maximum 40 to 50 per thousand. As mortality and fertility are not independent, it is unlikely that opposite extremes should coexist. Over long periods growth rates vary in practice between −1 and 3 percent per year.

For most of human history fertility and mortality must have remained in virtual equilibrium, as the rate of population growth was very low. If we accept the estimates of 252 million for the world population at the beginning of the present era (0 AD) and 771 million in 1750 (table 1.2), at the beginning of the Industrial Revolution, then we can calculate the average annual growth rate for the period as 0.06 percent. If we imagine that mortality averaged 40 per thousand, then fertility must have been 40.6 per thousand, just 1.5 percent greater than mortality. The past 30 years have witnessed a much different situation, as fertility has exceeded mortality by 200 percent.

Fertility and mortality rates are numerical calculations with little in the way of conceptual content, and as such are not well adapted to the description of the phenomena of reproduction and survival on which demographic growth depends.

3 Jacopo Bichi and Domenica Del Buono, Jean Guyon and Mathurine Robin

Jacopo Bichi was a humble sharecropper from Fiesole (near Florence).[8] On November 12, 1667 he wed Domenica Del Buono. Their marriage, although soon ended by the death of Jacopo, nonetheless produced three children: Andrea, Filippo, and Maria Maddalena. The latter died when only a few months old, but Andrea and Filippo survived and married. In a sense, Jacopo and Domenica paid off their demographic debt: the care received from their parents, and their own resistance and luck succeeded in bringing them to reproductive age. They in turn bore and raised two children who also arrived at the same stage of maturity (reproductive age and marriage) and who, in a sense, replaced them exactly in the generational chain of life. Continuing the story of this family, Andrea married Caterina Fossi, and together they had four children, two of whom wed. Andrea and Caterina also paid their debt. Such was not the case for Filippo, who married Maddalena Cari. Maddalena died shortly afterward, having borne a daughter who in turn died at a young age. The two surviving sons of Andrea constitute the third generation: Giovan Battista married Caterina Angiola and had six children, all but one of whom died before marrying. Jacopo married Rosa, who bore eight children, four of whom married. Let us stop here and summarize the results of these five weddings (and ten spouses):

Two couples (Jacopo and Domenica, Andrea and Caterina) paid their debt, each couple bringing two children to matrimony.

One couple (Jacopo and Rosa) paid their debt with interest, as the two of them produced four wedded offspring.

One couple (Giovan Battista and Caterina Angiola) finished partially in debt in spite of the fact that they produced six children; only one wed.

One couple (Filippo and Maddalena) was completely insolvent, as no offspring survived to marry.

In three generations, five couples (ten spouses) produced nine wedded children in all. In biological terms, ten breeders brought nine offspring to the reproductive phase, a 10 percent decline which, if repeated for an extended period, would lead to the family's extinction.

A population, however, is made up of many families and many histories, each different from the others. In this same period, and applying the same logic, six couples of the Patriarchi family married off 15 children, while five Palagi couples did so with 10. The Patriarchi paid with interest, while the Palagi just fulfilled their obligation. The combination of these individual experiences, whether the balance is positive, negative, or even, determines the growth, decline, or stagnation of a population in the long run.

In 1608 Québec was founded and the French inhabitation of the Saint Lawrence Valley, virtually abandoned by the Iroquois, had begun.[9] During the following century, approximately 15,000 immigrants arrived in these virgin lands from Normandy, from the area around Paris, and from central western France. Two-thirds of these returned to France after stays of varying lengths. The current population of 6 million French Canadians descends, for the most part, from those 5,000 immigrants who remained, as subsequent immigration contributed little to population growth. Thanks to a genealogico-demographic reconstruction carried out by a group of Canadian scholars, a considerable amount of information relating to demographic events is known about this population. For example, two pioneers, Jean Guyon and Mathurine Robin, had 2,150 descendants by 1730. Naturally, subsequent generations, including wives and husbands from other genealogical lines, contributed to this figure, which in and of itself has little demographic significance. On the other hand, the fate of another pioneer, the famous explorer Samuel de Champlain, was very different, and he left no descendants at all. The extraordinary Canadian material also provides measures of significant demographic interest. For example, the 905 pioneers (men and women) who were born in France, migrated to Canada before 1660, and both married and died in Canada produced on average 4.2 married offspring (figure 1.3), a level of fertility which corresponds to a doubling of the original population in a single generation (from two spouses, four married children). The exceptionally high reproductive capacity of the settlers of French Canada was the result of an extraordinary combination of circumstances: the physical selection of the immigrants, their high fertility and low mortality, ample available space, low density, and the absence of epidemics.

We have unknowingly touched the heart of the mechanisms of population growth. As we have seen, a population grows (or declines or remains stationary) from one generation to the next if those who gain access to reproduction (here defined by the act of marriage) are in turn successful in bringing a larger (or smaller or equal) number of individuals to marriage. The end result, whatever it might be, is basically determined by two factors: the number of children each individual, or each couple, succeeds in producing – due to biological capability, desire, age at marriage, length of cohabitation, and other factors – and the intensity of mortality from birth until the end of the reproductive period. A familiarity with these mechanisms, which I shall discuss in the following section, is essential for understanding the factors of demographic change.

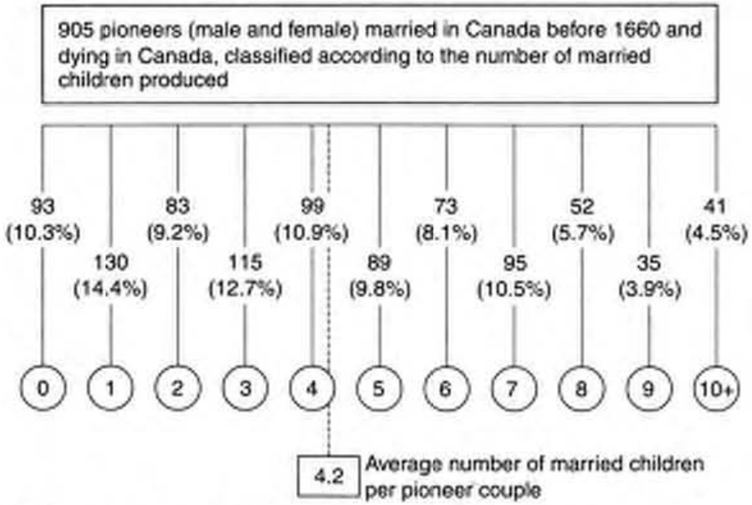


Figure 1.3 Growth of the French Canadian population (seventeenth century): pioneers and their children

4 Reproduction and Survival

The growth potential of a population may be expressed as the function of two measures, whose significance should be intuitive: (1) the number of births, or children, per woman, and (2) life expectancy at birth. These are synthetic measures of, respectively, reproduction and survival. The first describes the average number of children produced by a generation of women during the course of their reproductive lives and in the hypothetical absence of mortality.[10] Below we shall consider the biological, social and cultural factors which determine the level of this measure. The second, life expectancy at birth, describes the average duration of life (or average number of years lived) for a generation of newborns and is a function of the force of mortality at the various ages, mortality which in turn is determined by the species' biological characteristics and relationship with the surrounding environment. In the primarily rural societies of past centuries, which lacked modern birth control and effective medical knowledge, both of these measures might vary considerably. The number of children per woman ranged from less than five to more than eight (though today, in some Western societies characterized by high levels of birth control, it has declined below one), and life expectancy at birth ranged from 20 to 40 years (today it is approaching 80 in some countries).

The number of children per woman depends, as has been said, on biological and social factors which determine: (1) the frequency of births during a woman's fecund period, and (2) the portion of the fecund period – between puberty and menopause – effectively utilized for reproduction.[11]

The frequency of births

This is an inverse function of the interval between births. Given the condition of natural fertility – a term used by demographers to describe those premodern societies which did not practice intentional contraception for the purpose of controlling either the number of births or their timing – the interval between births may be divided into four parts:

1. A period of infertility after every birth, as ovulation does not recommence for a couple of months. However, this anovulatory period, during which it is impossible to conceive, increases with the duration of breast-feeding, which is often continued until the second, and in some cases even third, year of the child's life. The duration of breast-feeding, however, varies considerably from one culture to another, so much so that the minimum and maximum limits for the infertility period fall between 3 and 24 months.
2. The waiting time, which consists of the average number of months that pass between the resumption of normal ovulation and conception. It is possible that some women, either for accidental or natural reasons, may conceive during the first ovulatory cycle, while others, even given regular sexual relations, may not do so for many cycles. We can take five and ten months as our upper and lower limits.
3. The average length of pregnancy, which as everyone knows is about nine months.
4. Fetal mortality. About one out of every five recognized pregnancies does not come to term because of miscarriage. According to the few studies available, this seems to be a frequency which does not vary much from population to population. After a miscarriage, a new conception can take place after the normal waiting period (five to ten months). As only one in five conceptions contributes to this component of the birth interval, the average addition is one to two months.

Summing the minimum and maximum values of 1, 2, 3, and 4, we find that the interval between births ranges from 18 to 45 months (or approximately 1.5 to 3.5 years), but, as a combination either of maxima or minima is improbable, this interval usually falls between two and three years. The above analysis holds true for a population characterized by uncontrolled, natural fertility. Of course, if birth control is introduced the reproductive life span without children may be expanded at will.

The fecund period used for reproduction

The factors that determine the age of access to reproduction, or the establishment of a stable union for the purpose of reproduction (marriage), are primarily cultural, while those that determine the age at which the reproductive period ends are primarily biological.

1. The age at marriage may vary between a minimum close to the age of puberty – let us say 15 years – and a maximum which in many European societies has exceeded 25.
2. The age at the end of the fecund period may be as high as 50, but on average is much lower. We can take as a good indicator the average age of mothers at the birth of the last child in populations that do not practice birth control. This figure is fairly stable and varies between 38 and 41.

We can say then – again combining minima and maxima and rounding – that the average length of a union for reproductive purposes, barring death or divorce, may vary between 15 and 25 years.

Simplifying still more, we can estimate what the minimum and maximum levels of procreation might be in hypothetical populations not subject to mortality. To obtain the minimum we combine the minimum reproductive period (15 years) with the maximum birth interval (3.5 years).

$$\frac{\text{15-year reproductive period}}{\text{3.5-year birth interval}} = 4.3 \text{ children}$$

To obtain the maximum level we instead combine the maximum reproductive period (25 years) with the minimum birth interval (1.5 years):

$$\frac{\text{25-year reproductive period}}{\text{1.5-year birth interval}} = 16.7 \text{ children}$$

These combinations of extremes (especially the latter) are of course impossible, as the various components are not independent from one another. The repeated childbearing which follows early marriage, for example, can create pathological conditions which lower fecundability or else lead to an early decline in sexual activity and so increase the birth interval. In stable historical situations, average levels of under five or over eight children per woman are rare.

The number of children per woman depends primarily upon the age at marriage (the principal factor determining the length of the reproductive period) and the duration of breast-feeding (the principal component determining the birth interval). Figure 1.4, borrowed from the Bongaarts and Menken article on which this discussion is based, shows how the average number of children per woman can vary as a result of the variation (between maximum and minimum values) of each component. We take as a standard seven children, obtained by combining average values of the various components. As one component varies the others remain fixed.[12]

In figure 1.5 the above model is applied to several historical (and theoretical) examples. In addition to the biological maximum (1), there is: a possible maximum (2) resulting from a combination of early marriage (at age 18) and short birth intervals (due to early weaning); a possible minimum in the absence of birth control (6) resulting from late marriage (at age 25) and prolonged breast-feeding; three intermediate levels (3), (4), and (5); and finally, examples of medium and very high levels of birth control, (7) and (8), yielding respectively three and one children. These examples should not be considered to represent a chronological or evolutionary sequence, as almost all can be found in populations living in the same historical periods (except for the last two, characterized by strongly controlled fertility, which can only be found in modern populations).

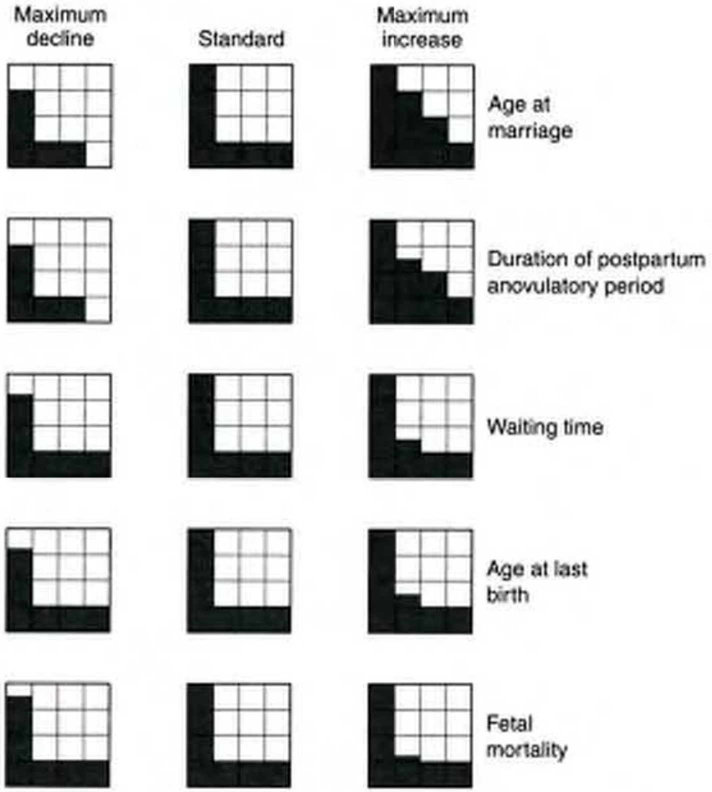


Figure 1.4 Effect on the average number of children per woman of maximum variations of the components of fertility above and below the standard (1 square = 1 birth)

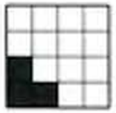
Children per woman (*TFR*)		Reproductive space utilized	Characteristics	Populations	Historical example (populations)
(1)	16		Biological maximum	Theoretical	None Individual cases only
(2)	11.4		Very early unions Minimum intervals	Select groups	French Canadians born before 1660
(3)	9		Late unions Minimum intervals	Select groups	Canadian Hutterites, 1926–30 = 8.5
(4)	7.5		Early unions Long intervals	Many developing populations	Egypt, 1960–65 = 7.1
(5)	7		Standard		
(6)	5		Late unions Long intervals	Many European populations (18th–19th century)	England 1751–1800 = 5.1
(7)	3		Voluntary birth control (medium diffusion)	Europe (first half 20th century)	Italy, 1937 = 3.0
(8)	1		Voluntary birth control (high diffusion)	Several present-day European populations)	Liguria (Italy) 1990 = 1.0

Figure 1.5 Fertility models

In addition to the biosocial components determining fertility, human reproductivity must also contend with the hard check of mortality, a factor that we have ignored up to this point. Reproductivity and mortality are not independent of one another for any living species, including humans. When the number of offspring is very large, the risk of death in early infancy increases and the competition for resources within the family can lower resistance at all ages. On the other hand, high fertility is in the long run incompatible with low, or recently lowered, mortality, given the resultant excessive population growth. Nonetheless, mortality is to a large degree rooted in human biology and so is independent of fertility levels.

A fairly simple way to describe human mortality is provided by the survivorship function, l_x, which traces the progressive elimination of a generation of 10^n individuals from birth to the age at which the last member dies.[13] Figure 1.6 shows three survivorship curves. The lower curve corresponds to a life expectancy at birth (e_0) of 20 years. This is a very low figure, near to the minimum compatible with the continued survival of a population, and might characterize a primitive population living in a hostile environment. The upper curve corresponds to an e_0 of 83 years, a level that the more developed countries are about to reach. The third, intermediate curve ($e_0 = 50$) is typical of those countries that have benefited from a limited degree of modern medical progress. In figure 1.6 I have chosen as the maximum age, in all three cases, 100 years, assuming that this is the limit of human longevity. This assumption is not far from the truth, as considerably less than 1 percent of the initial generation survives to this age.[14] Continuing to refer to figure 1.6, if we imagine that no one dies until their hundredth birthday, at which age everyone dies, then the l_x curve will be rectangular (it will be parallel to the abscissa until age 100, at which point it will drop vertically to 0) and e_0 will be equal to 100. The life expectancies at birth described by the other curves are proportional to the areas under those curves. The shape of the survivorship curves depends upon the force of mortality at the various ages. In human populations there is a period of high mortality immediately after birth and during early infancy, the result of fragility in the face of the external environment. Mortality risk reaches a minimum during late infancy or adolescence and then, from maturity, rises exponentially as a function of the gradual weakening of the organism. In high-mortality regimes (see the $e_0 = 20$ curve) the curve tends to be concave up. As mortality improves, infant mortality becomes less of a factor and the curve becomes more and more concave down. From a strictly genetic point of view – the hereditary genetic transmission of characteristics – survival beyond the reproductive years (for simplicity, say 50 years of age) is of course irrelevant. However high or low it might be, the rate of mortality beyond age 50 will have no effect on the genetic patrimony of a population. Before and during the reproductive years, on the other hand, the higher the level of mortality the stronger the selective effect as individuals possessing characteristics unfavorable to survival are eliminated and so do not pass on these characteristics to subsequent generations.

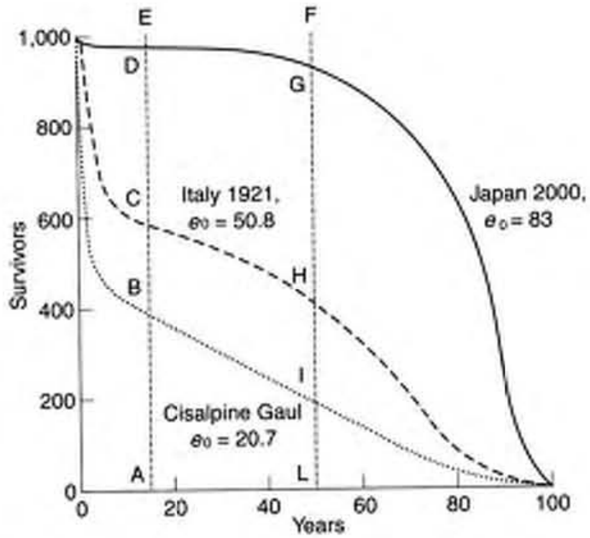


Figure 1.6 Survival curves for three female populations characterized by low, medium, and high life expectancy at birth.

Survival curves trace the numerical decline with age of a generation of 1,000 births. Life expectancy at birth is proportional to the space bounded by the ordinate, the abscissa and the survival curve. The area AEFL, equal to 35 years, describes the length of the reproductive period. The areas ADGL, ACHL and ABIL describe the average effective reproductive lives for the three generations of 1,000 newborn girls equal 34.4, 24.8 and 10.2 years. The ratios ADGL/AEFL, ACHL/AEFL, and ABIL/AEFL are, respectively, 98.2, 70.8, and 29.2%, and represent the average part of the reproductive period lived by the three generations.

Nonetheless, increased survival beyond the reproductive ages may have indirect biological effects, as older adults contribute to the accumulation, organization, and transmission of knowledge, while also favoring parental investments and so can contribute to the improved survival of new generations.

Figure 1.7 shows two survivorship models typical of other species, together with high- and low-mortality human models. Model A typifies those species that are subject to the relatively constant mortality risk presented by other predatory species, while model B is typical of those (r-strategy) species that depend upon prolific reproduction for survival and are subject to very high postnatal mortality.

Let us return to the human species. In order to appreciate its reproductive capacity, we must understand the laws governing its survival until the end of the reproductive period. Afterward, whether or not an individual

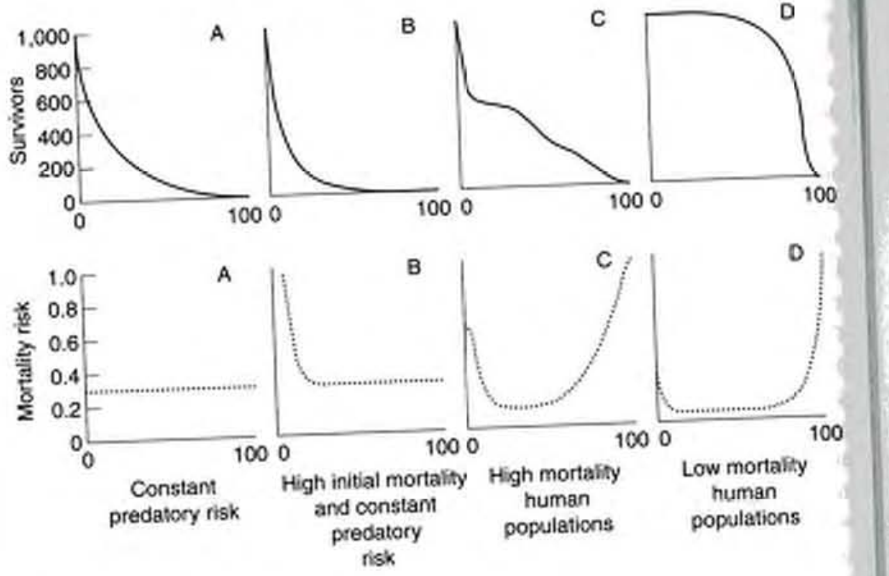


Figure 1.7 Survival models

survives is theoretically unimportant.[15] From figure 1.6 we can see that, with life expectancy at birth equal to 20 years, only 29.2 percent of the potential fecund life of a generation is actually lived due to the decimation caused by high mortality. This proportion increases gradually with increasing life expectancy (and the elevation of the l_x curve). In the examples given, it is 70.8 percent when e_0 equals 50 and 98.2 percent when e_0 equals 80.

It should be clear now that the reproductive success of a population – and so its growth – depends upon the number of children born to those women who survive to reproductive age. If we imagine a level of six children per woman in the absence of mortality, then in that case where only 30 percent of the reproductive space is used ($e_0 = 20$) the number of children born per woman is $6 \times 0.3 = 1.8$. When $e_0 = 50$ and 70 percent of the reproductive space is used, the number of children is $6 \times 0.7 = 4.2$; and when 99 percent is used ($e_0 = 83$), the total is $6 \times 0.99 = 5.94$. Since there are two parents for every child, each hypothetical couple pays its demographic debt (and the number of parents and children is about equal) if our calculation above yields a level of two. A number larger than two implies growth. If the number of surviving children is four, then the population will double in the course of a single generation (about 30 years) and the average annual growth rate will be 2.3 percent.[16]

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5 The Space of Growth

Fertility and mortality, acting in tandem, impose objective limits on the pattern of growth of human populations. If we imagine that in a certain population these remain fixed for a long period of time, then, by resorting to a few simplifying hypotheses,[17] we can express the rate of growth as a function of the number of children per woman (*TFR*) and life expectancy at birth (e_0).

Figure 1.8a shows several "isogrowth" curves. Each curve is the locus of those points that combine life expectancy (the abscissa) and number of children per woman (the ordinate) to give the same rate of growth *r*. Included on this graph are points corresponding to historical and contemporary populations. For the former, life expectancy is neither below 15, as this would be incompatible with the continued survival of the population, nor above 45, as no historical population ever achieved a higher figure. For similar reasons the number of children per woman falls between eight (almost never exceeded in normally constituted populations) and four (recall that these are populations not practicing birth control). For the present-day populations included in figure 1.8a, control of fertility and mortality make possible e_0 values of 80 and *TFR* of 1. Figure 1.8b identifies specific examples within the more restricted boundaries of historical populations. These examples have varying degrees of precision, being in some cases based on

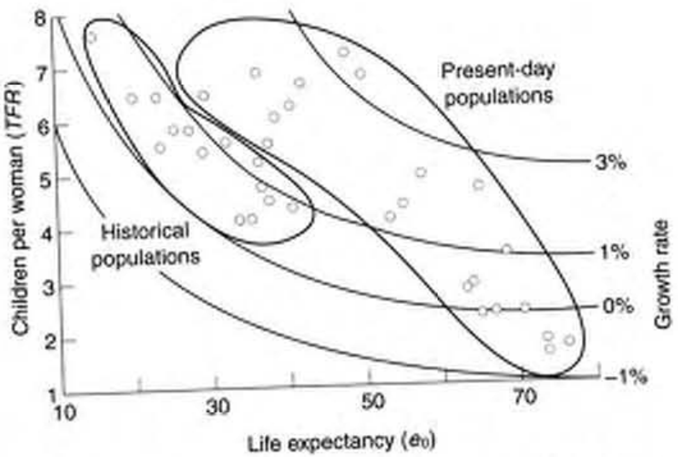


Figure 1.8a Relation between the average number of children per woman (*TFR*) and life expectancy (e_0) in historical and present-day populations

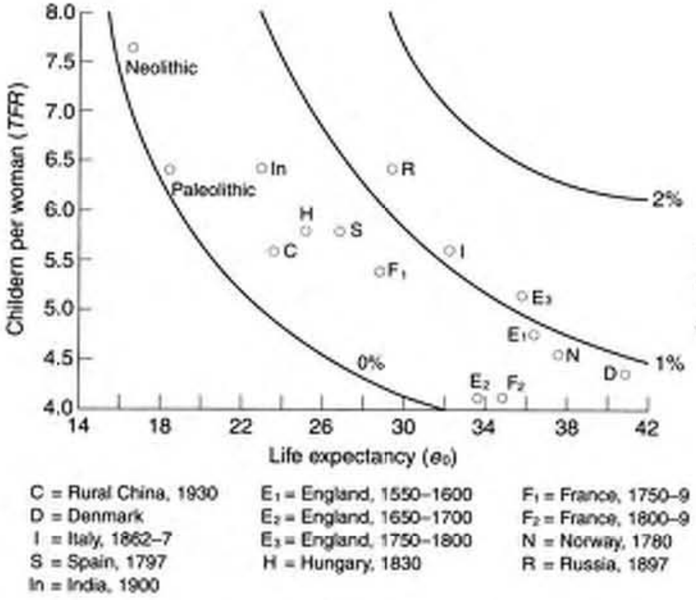


Figure 1.8b Relation between *TFR* and e_0 in historical populations

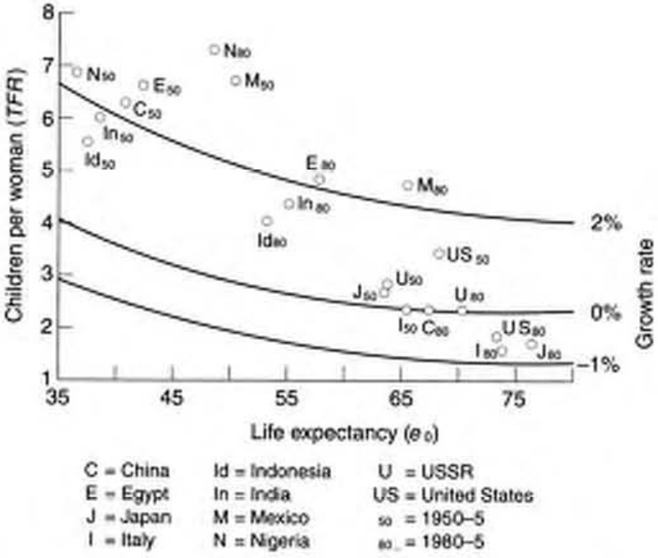


Figure 1.8c Relation between *TFR* and e_0 in present-day populations

direct and dependable observation, in others on estimates drawn from indirect and incomplete indicators, and in others on pure conjecture. Nonetheless, most of these populations fall within a band that extends from growth rates of 0 to 1 percent, a space of growth typical of historical populations. Within this narrow band, however, the fertility and mortality combinations vary widely. Denmark at the end of the eighteenth century and India at the beginning of the twentieth, for example, have similar growth rates, but these are achieved at distant points in the strategic space described: the former example combines high life expectancy (about 40 years) and a small number of children (just over four), while in the latter case low life expectancy (about 25 years) is paired with many children (just under seven).

Although their growth rates must have been similar, the points for Paleolithic and Neolithic populations are assumed to have been far apart. According to a well-accepted opinion (see chapter 2), the Paleolithic, a hunting and gathering population, was characterized by lower mortality, due to its low density, a factor that prevented infectious diseases from taking hold and spreading, and moderate fertility, compatible with its nomadic behavior. For the Neolithic, a sedentary and agricultural population, both mortality and fertility were higher as a result of higher density and lower mobility.

Figure 1.8c includes points for some of the most populous countries of the world since 1950. The strategic space utilized, previously restricted to a narrow band, has expanded dramatically. Medical and sanitary progress has shifted the upper limit of life expectancy from the historical level of about 40 years to the present level of about 80, while the introduction of birth control has reduced the lower limit of fertility to a level of about one child per woman. In this much-expanded space the populations listed vary between a maximum annual potential growth rate of 4 percent (many developing countries have a growth rate of over 3 percent) and a minimum of −1 percent (which will, for example, be realized by Italy should the current fertility and mortality levels remain unchanged). We are able to recognize the exceptional nature of the current situation if we keep in mind that a population growing at an annual rate of 4 percent will double in about 18 years, while another declining by 1 percent per year will halve in 70.[18] Two populations of equal size experiencing these different growth rates will find themselves after 28 years (barely a generation) in a numerical ratio of four-to-one!

The two situations described in figures 1.8b and 1.8c differ not only in the strategic space they occupy, but also, and especially, in their permanence. The first of the two figures represents a situation of great duration, while the second is certainly unstable and destined to change rapidly, since it implies a rate of growth that cannot in the long run be sustained.

6 Environmental Constraints

Although the strategic space of growth is large, only a small portion of it can be permanently occupied by a population. Sustained decline is obviously incompatible with the survival of a human group, while sustained growth can in the long run be incompatible with the resources available. The mechanisms of growth, therefore, must continually adjust to environmental conditions (which we might call environmental friction), conditions with which they interact but which also present obstacles to growth, as attested to by the millennia during which the population growth rate has been very low. For the moment I shall limit myself to the macroscopic aspects of these obstacles to demographic growth, saving for later a more detailed discussion of their operation.

In a justly famous essay, Carlo Cipolla wrote: "It is safe to say that until the Industrial Revolution man continued to rely mainly on plants and animals for energy – plants for food and fuel, and animals for food and mechanical energy."[19] It is this subordination to the natural environment and the resources it provides that constituted a check to population increase, a situation particularly evident for a hunting and gathering society. Imagine a population that utilizes a habitat extending only to those places that can be reached, and returned from, in a single day's walk. The abundance of available food depends upon the ecology of the area, the accessibility of resources, and the related costs (so to speak) of extraction and utilization, and this in turn places a check on the number of inhabitants. In the simplest terms, vegetal biomass production (primary productivity) per unit area is a function of precipitation, and animal biomass production (of herbivores and carnivores – secondary productivity) is in turn a function of the vegetal biomass, so that precipitation is the principal factor limiting both the resources available to hunters and gatherers and their numerical growth.[20] Figure 1.9 shows the relation between vegetal biomass and precipitation in various parts of the world, while figure 1.10 charts the dependence of Australian Aboriginal population density on the intensity of rainfall.

Table 1.1 reports possible values for the population density of hunter-gatherer societies in different ecological systems, according to certain hypotheses regarding biomass and precipitation. This is, of course, only a model, but one that effectively describes a double check on population increase. The first check is imposed by natural limits of vegetal and animal production which define the maximum number of individuals that can be fed. In an area 10 kilometers in diameter, the sustainable population ranges from 3 for an arctic area to 136 for subtropical savanna. The second check relates to the incompatibility of very low population density (arctic and semi-desert areas, for example) with the survival of a stable population group. In order to ensure a reasonable choice of partners and to survive catastrophic events these groups must not be too small.

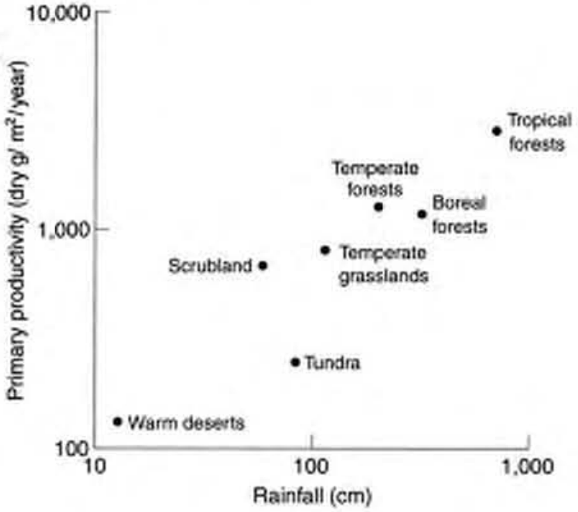


Figure 1.9 Relationship between rainfall and primary productivity for world biomes

Source: F. A. Hassan, *Demographic Archaeology* (Academic Press, New York, 1981), p. 12

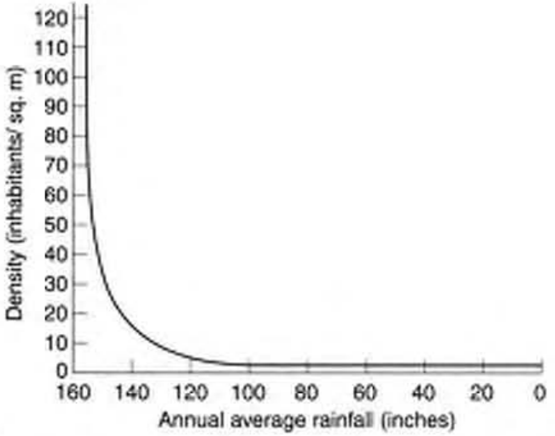


Figure 1.10 Relationship between annual precipitation and population density (Australian Aborigines)

Table 1.1 Estimated population density and size for a catchment territory of 314 km² in different world biomes

Biome	*Biomass (kg/km²)*	*Population density (persons/km²)*	*Number of persons*
Arctic	200	0.0086	3
Subtropical savanna	10,000	0.43	136
Grassland	4,000	0.17	54
Semidesert	800	0.035	11

Source: F. A. Hassan, *Demographic Archaeology* (Academic Press, New York, 1981), p.57.

Archaeological and contemporary observations have placed the density of hunter-gatherer populations at between 0.1 and 1 per square kilometer.[21] Higher densities may be encountered near seas, lakes, and streams, where fishing can effectively supplement the products of the earth. Clearly the limiting factors at this cultural level are essentially precipitation and the availability and accessibility of land.

The Neolithic transition to stable cultivation of the land and raising of livestock certainly represented a dramatic expansion of productive capacity. This transition, which many call a "revolution," developed and spread slowly over millennia in a variety of ways and forms. The progress of cultivation techniques, from slash and burn to triannual rotations (which have coexisted in different cultures up to the present day); the selection of better and better seeds; the domestication of new plants and animals; and the use of animal, air, and water power have all enormously increased the availability of food and energy.[22] Population density as a result also grew; that of major European countries (France, Italy, Germany, England, the Low Countries) in the mid-eighteenth century was about 40–60 persons per square kilometer, 100 times greater than that of the hunters and gatherers. Naturally, productive capacity varied greatly in different epochs as a function of technological and social evolution, a point easily demonstrated by comparing the agriculture of the Po Valley or the Low Countries with the fairly primitive methods used in some parts of the continent. Thoughout the globe, innovation has allowed for the notable expansion of productivity per unit of energy invested. It appears, for example, that productivity per hectare tripled in Teotihuacán (Mexico) between the third and second millennia BC due to the introduction of new varieties of corn;[23] and in various zones of Europe during the modern era the ratio of agricultural production to seed increased thanks to new grains.[24]

Nonetheless, success in mastering the environment has always been dependent upon the availability of energy. As Cipolla observed, "the fact that the main sources of energy other than man's muscular work remained basically plants and animals must have set a limit to the possible expansion of the energy supply in any given agricultural society of the past. The limiting factor in this regard is ultimately the supply of land."[25] In preindustrial Europe, populations seem to have approached with some frequency the limits allowed by the environment and available technology. These limits may be expressed by the per capita availability of energy and, again following Cipolla, must have been below 15,000 calories, or perhaps even 10,000, per day (a level which the richest countries today exceed by a factor of 20 or 30), the majority of which were dedicated to nutrition and heating.[26]

The environmental limits to demographic expansion were again shattered by the enormous increase in available energy that resulted from the industrial and technological revolution of the second half of the eighteenth century and the invention of efficient machines for the conversion of inanimate materials into energy. World production of coal increased tenfold between 1820 and 1860 and again between 1860 and 1950. It has been calculated that worldwide energy availability increased sixfold between 1820 and 1950 (while population in the same period doubled).[27] During this century (between 1900 and 1990), total world energy consumption has increased by a factor of almost 16 and per capita consumption fivefold. The dependency of energy availability on land availability was again (and perhaps definitively) broken and the principal obstacle to the numerical growth of population removed.

Figure 1.11, taken from Deevey,[28] describes schematically (on a double logarithmic scale and simplifying drastically the complexities of history) the evolution of population as a function of the three great technological-cultural phases described above: the hunter-gatherer (until the Paleolithic Age), the agricultural (from the Neolithic), and the industrial (since the Industrial Revolution). During these three phases (the last of which we are still in the midst of) population has increased by increments which become progres-

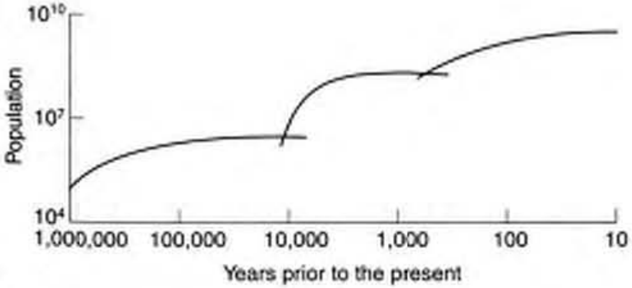


Figure 1.11 Cycles of demographic growth

sively smaller with the passage of time, as the limits of growth are approached. This outline is simply the application of that concept, common to both animal biology and Malthusian demography, according to which the growth of a species (gnat, mouse, human or elephant) in a restricted environment varies inversely with its density. This comes to pass because the available resources are considered fixed and so population growth creates its own checks. For the human species, of course, the environment, and so the available resources, has never been fixed but continually expands due to innovation. In the Deevey outline, demographic growth in the first long period of human history, which continued up until 10,000 years ago, was limited by the biomass available for nutrition and heating at a rate of several thousand calories per day per person. In the second phase, from the Neolithic to the Industrial Revolution, limits were imposed by the availability of land and the limited energy provided by plants, animals, water, and wind. In the present phase, the limits to growth are not so well defined, but may be connected to the adverse environmental effects of combined demographic and technological growth and the attendant cultural choices.

7 A Few Figures

In July 1990, the People's Republic of China carried out its fourth census since the revolution and, with the help of seven million carefully trained census takers, counted 1.134 billion inhabitants. It was the largest social investigation ever undertaken. Until the middle of this century there were still quite a few areas of the less-developed world for which there existed at best fragmentary and incomplete demographic estimates. In Western countries the modern statistical era began in the nineteenth century, when the practice of taking censuses of the population at regular intervals, begun by some countries in the preceding century, became general. The 10.4 million persons counted in the Kingdom of Spain in the summer of 1787 by order of Charles III's prime minister, Floridablanca, or the 3.9 million counted in the United States in 1790 as instructed by the first article of the constitution approved three years earlier in Philadelphia, are the first examples of modern censuses in large countries.[29] In previous centuries there were, of course, head counts and estimates – often serving fiscal purposes – for limited areas and often of limited coverage. Included among the latter are the family lists from the Han to the Ching dynasties in China (covering a period of almost two millennia ending in the previous century).[30] For the evaluation of these the work of the statistician must be complemented by that of the historian, who is able to evaluate, integrate, and interpret the sources. In many parts of the world before this century, in Europe prior to the late Middle Ages or in China before the present era, one can only estimate population size on the basis of qualitative information – the existence or extension of cities, villages, or other settlements, the extension of cultivated land – or on the basis of calculations of the possible population density in relation to the ecosystem, the level of technology, or social organization. The contributions of paleontologists, archaeologists, and anthropologists are all needed.

The data on world demographic growth in tables 1.2 and 1.3 are largely based on conjectures and inferences drawn from non-quantitative information. Table 1.2 presents a synthesis of these trends. The long-term rates of growth are, of course, an abstraction, as they imply a constant variation of demographic forces in each period, while in reality population evolves cyclically. Following Biraben's hypothesis, according to which human population prior to the High Paleolithic era (35,000–30,000 BC) did not exceed several hundred thousand, growth during the 30,000 years leading up to the Neolithic era averaged less than 0.1 per 1,000 per year, an almost imperceptible level consistent with a doubling time of 8,000–9,000 years.[31] In the 10,000 years prior to the birth of Christ, during which Neolithic civilization spread from the Near East and Upper Egypt, the rate increased to 0.4 per 1,000 (which implies a doubling in less than 2,000 years) and population grew from several million to about 0.25 billion. This rate of increase, in spite of important cycles of growth and decline, was reinforced during the subsequent 17 and a half centuries. The population tripled to about 0.75 billion on the eve of the Industrial Revolution (an overall rate of growth of 0.6 per 1,000). It was, however, the Industrial Revolution which initiated a period of decisive and sustained growth. During the following two centuries population increased about tenfold, at an annual growth rate of 6 per 1,000 (doubling time 118 years). This process of growth was the result of a rapid accumulation of resources, control of the environment, and mortality decline, and has culminated in the second half of the twentieth century. In the four decades since 1950 population has again doubled and the rate of growth has tripled to 18 per 1,000. In spite of signs that growth is slowing, the present momentum will certainly carry world population to eight billion by about the year 2030 and ten billion close to the end of this century. The acceleration of the growth rate and shortening of the doubling time (which was expressed in thousands of years prior to the Industrial Revolution and is expressed in tens of years at present) give some indication of the speed with which the historical checks to population growth have been relaxed.

Table 1.2 responds to another question which, at first glance, appears to be simply a statistical curiosity. How many people have lived on the earth? The answer requires calculation of the total number of births in each of the periods indicated. Following the courageous hypotheses of Bourgeois-

Pichat,[32] we can estimate the total number of births from the origin of the human species to the present day at 82 billion, of which 6 billion occurred in the last 50 years, 3 billion less than took place in the hundreds of thousands of years of human existence prior to the Neolithic era. In the year 2000 the 6 billion inhabitants of the globe represented 7.3 percent of the total number of human beings ever born. Taking a different approach, and keeping in mind that what we are today represents the accumulated experiences of our progenitors – selected, mediated, modified, and passed on to us – we can observe that 11 percent of these experiences were accumulated prior to the Neolithic era and more than 80 percent before 1750 and the industrial-technological revolution.

If we assign an estimated life expectancy at birth to the individuals in each epoch (these estimates are statistical only for the last period; for the preceding period they are based on fragmentary evidence and before that they are pure conjecture), then we can calculate the total number of years lived by each of these groups. Those born between 1950 and 2000 will have lived (at the end of their lives) about 334 billion years, almost twice the total number of years lived by all those born prior to the Neolithic era. The 420 billion years that will presumably be lived (during their whole lives) by those alive in 2000 represents a little less than one-fifth of all the years lived since the origin of the human race.

Table 1.2 Population, total births, and years lived (10,000 BC to AD 2000)

Demographic index	*10,000 BC*	*0*	*1750*	*1950*	*2000*
Population (millions)	6	252	771	2521	6055
Annual growth (%)	0.008	0.037	0.064	0.594	1.752
Doubling time (years)	8369	1854	1083	116	40
Births (billions)	9.29	33.6	22.64	10.42	5.97
Births (%)	11.4	41.0	27.6	12.7	7.3
Life expectancy (e_0)	20	22	27	35	56
Years lived (billions)	185.8	739.2	611.3	364.7	334.3
Years lived (%)	8.3	33.1	27.3	16.3	18.0

Finally, if we consider energy resources used, we can make one further observation. It is estimated that in 1990 annual world energy consumption amounted to almost 290,000 petajoules[33] and that consumption in the 1980s was about equal to the total energy consumption of humankind in the hundreds of thousands of years leading up to the Neolithic era. These figures are not presented for their shock value, but to demonstrate the extraordinary expansion of resources available to humanity today as compared to earlier agricultural societies.

Table 1.3 Continental populations (400 BC to AD 2000, data in millions)

Year	*Asia*	*Europe*	*USSR*[a]	*Africa*	*America*	*Oceania*	*World*
400 BC	95	19	13	17	8	1	153
0	170	31	12	26	12	1	252
200	158	44	13	30	11	1	257
600	134	22	11	24	16	1	208
1000	152	30	13	39	18	1	253
1200	258	49	17	48	26	2	400
1340	238	74	16	80	32	2	442
1400	201	52	13	68	39	2	375
1500	245	67	17	87	42	3	461
1600	338	89	22	113	13	3	578
1700	433	95	30	107	12	3	680
1750	500	111	35	104	18	3	771
1800	631	146	49	102	24	2	954
1850	790	209	79	102	59	2	1,241
1900	903	295	127	138	165	6	1,634
1950	1,376	393	182	224	332	13	2,520
2000	3,611	510	291	784	829	30	6,055
0–1750	0.06	0.07	0.06	0.08	0.02	0.06	0.06
1750–1950	0.51	0.63	0.82	0.38	1.46	0.74	0.59
1950–2000	1.9	0.53	0.97	2.51	1.83	1.67	1.75

Note: For births, life expectancy, and years lived, the data refer to interval between the date at the head of the column and that of the preceding column (for the first column the interval runs from the hypothetical origin of the human species to 10,000 BC).
[a] 2000: territories of former USSR.
Sources: J. N. Biraben, "Essai sur l'évolution du nombre des hommes," *Population* 34 (1979), p. 16. For 1950 and 2000: United Nations, *World Population Prospects: The 1998 Revision* (New York, 1999).

Population, of course, did not grow continuously, but experienced cycles of growth and decline, the long-term aspects of which are summarized in table 1.3 and figure 1.11. Limiting ourselves to Europe, the tripling of population between the birth of Christ and the eighteenth century did not occur gradually, but was the result of successive waves of expansion and crisis: crisis during the late Roman Empire and the Justinian era as a result of barbarian invasions and disease; expansion in the twelfth and thirteenth centuries; crisis again as a result of recurring and devastating bouts of the plague beginning in the mid-fourteenth century; a strong rallying from the mid-fifteenth to the end of the sixteenth century; and crisis or stagnation until the beginning of the eighteenth century, when the forces of modern expansion came to the fore. Nor do these cycles run parallel in different areas, so that relative demographic weight changes with time: the European share of world population grew from 14.5 to 18.1 percent between 1500 and 1900, only to decline again to 8.2 percent in the year 2000. The entire American continent contained probably less than 2 percent of the world population at the beginning of the seventeenth century, while today the figure is 13.3 percent.

2

Demographic Growth: Between Choice and Constraint

1 Constraint, Choice, Adaptation

We have established a few points of reference: demographic growth takes place with varying degrees of intensity and within a fairly large strategic space, large enough so that rates of growth or decline can lead a population to rapid expansion or extinction. The upper limits of this strategic space are defined by reproductive capacity and survival and so by the biological characteristics of the human species. In the long run, demographic growth moves in tandem with the growth of available resources, the latter imposing an impassable limit on the former. These resources, of course, are not static, but expand in response to incessant human activity. New lands are settled and put to use; knowledge increases and new technology is developed. In a later chapter we shall discuss which is the engine and which the caboose between resources and population – that is, whether the development of the first pulls along the second or vice versa; whether the availability of an additional unit of food and energy allows one more individual to survive or, instead, the fact of there being another pair of hands leads to the production of that extra unit; or, finally, whether they do not both function a little as engine and a little as caboose according to the historical situation.

For the moment, we shall turn our attention to another problem already mentioned in the previous chapter. We have identified three great population cycles: from the first humans to the beginning of the Neolithic era, from the Neolithic to the Industrial Revolution, and from the Industrial Revolution to the present day. The transitional phases between these entailed the breakdown of fragile equilibria between population and resources. However, as we have seen for European populations, demographic growth proceeded irregularly within these cycles as well. Periods of growth alternated with others of stagnation and decline. What were the causes?

generous reading, the nutritional hypothesis stands up to scrutiny less well than others. It is nonetheless the case that increased agricultural production accompanied European demographic expansion (population almost doubled in a century), even if nutritional levels did not improve notably. While the possibility of farming new lands – once pasture, swamp, or wild – together with improved technology and the introduction of new crops may not have been responsible for mortality decline, these elements did allow the agricultural population to expand, forming new centers and increasing nuptiality levels. The growth of the industrial sector, urbanization, and a general increase in demand for nonagricultural labor assisted this process and created an outlet for the rural population.

The demographic growth of the eighteenth century occurred along with the extension of agriculture to previously uncultivated lands. In France during the last 30 years of the *ancien régime*, cultivated land increased from 19 to 24 million hectares.[120] In England the enclosure movement was proceeding at a few hundred acres per year at the beginning of the eighteenth century and 70,000 per year during the latter half of the same century. Swamps and marshes were dried in Prussia and the Italian Maremma, and the draining of bogs and fens helped to satisfy the demand for land in both Ireland and England.[121]

3

Land, Labor, and Population

1 Diminishing Returns and Demographic Growth

The question of the effect of demographic growth on the economic development of agricultural societies remains open and unresolved. It is a question over which two hardened points of view oppose one another. The first sees demographic growth as an essentially negative force, which strains the relationship between fixed or limited resources (land, minerals) and population, leading in the long run to increased poverty. According to the second, demographic growth instead stimulates human ingenuity so as to cancel and reverse the disadvantages imposed by limited resources. A larger population generates economies of scale and more product and surplus, and these in turn support technical progress.

The first position finds immediate and short-term empirical verification: increased population density creates competition for the use of fixed resources that must satisfy a larger number of people. Historical observation, however, presents a valid objection to this position, as economic progress is generally accompanied by demographic growth. A large population allows for better organization and specialization of tasks; it can easily find more ways to substitute fixed resources, creating systems which a small or sparse population could not maintain. The reconciliation of short- and long-term observations has not proved to be easy.

The second, opposing, theory has to resolve another and perhaps more serious contradiction. Even if we admit that demographic growth stimulates the human spirit of innovation and inventiveness (what economists call "technical progress"), it is hard to imagine how this spirit can expand those fixed resources (land, space, and other essential natural elements) necessary to human survival and well-being.

Consider an agricultural population isolated in a deep valley. The difference between births and deaths results in slow growth, so that the population doubles every two centuries. Initially the more fertile, easily irrigated, and accessible lands are cultivated – those in the plain along the river. As population grows, and so the need for food, all the best land will be used, until it becomes necessary to cultivate more distant plots on the slopes of the valley, difficult to irrigate and less fertile than the others. Continued growth will require the planting of still less productive lands, higher up the sides of the valley and more exposed to erosion. When all the land has been used up, further increase of production can still be obtained by more intensive cultivation, but these gains too are limited, as the point will eventually be reached when additional inputs of labor will no longer effectively increase production. In this way demographic growth in a fixed environment (and, it must be added, given a fixed level of technology) leads to the cultivation of progressively less fertile lands with ever greater inputs of labor, while returns per unit of land or labor eventually diminish.

The concept of diminishing returns is fundamental to the thought of both Malthus and Ricardo[1] and can be applied to nonagricultural situations as well. It is easy to imagine that while the contribution of each additional worker to a fixed stock of capital (the workers operating a single machine) may increase overall production, nonetheless the contribution to that increase made by each additional worker will progressively decline.

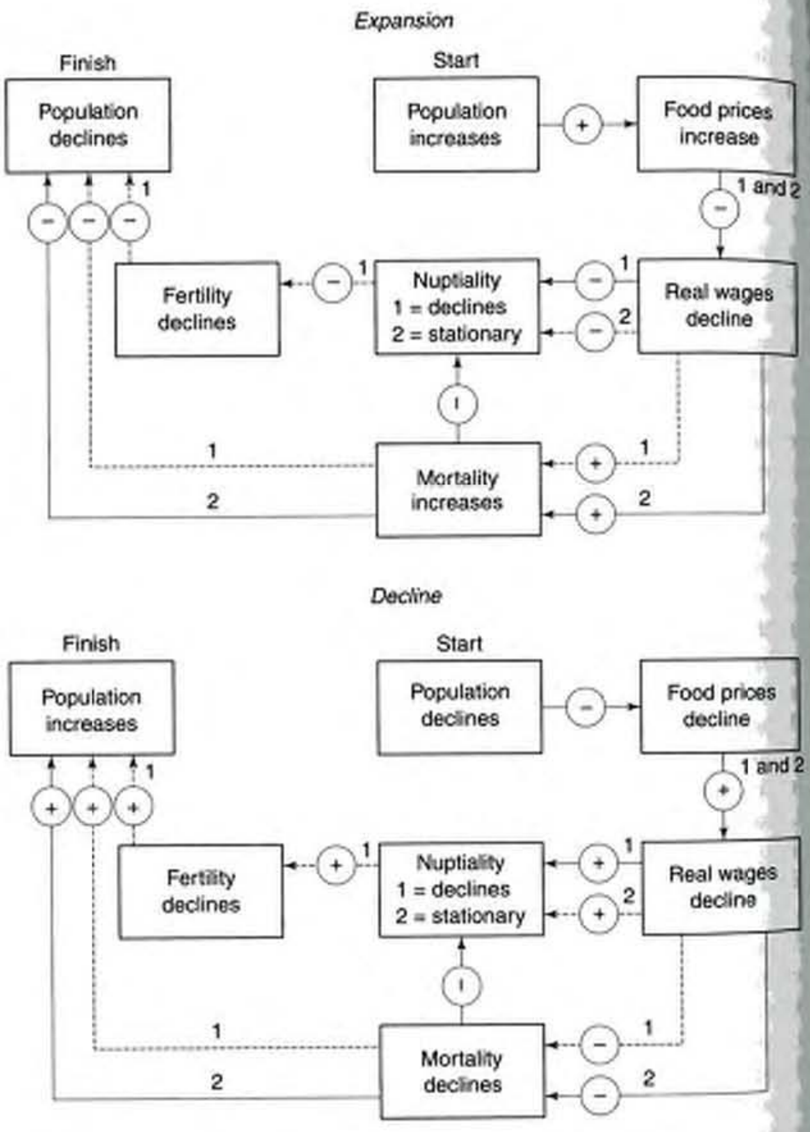
The law of diminishing returns, then, would seem to dictate a per capita decline of production given the combination of population increase and a fixed supply of land or capital. Worker productivity, however, is not constant, and throughout human history innovations and inventions have continuously caused it to increase. In agriculture, metal tools replaced those of wood, the hoe gave way to the plough, and animal power was added to human power. Analogous progress has characterized the technical innovations of production: crop rotation, the selection of seed strains, and improvements in fertilization. In short, the introduction of a technological innovation, whether it increases production per unit of land or of labor, entails an increase in available resources. The positive effects of this increase, however, may be only temporary, since continued demographic growth will neutralize the gains achieved. It should also be added that no degree of progress can indefinitely increase the productivity of a fixed resource like land.

In 1798, Malthus described the above relationship in the first edition of his famous *Essay*, asserting the incompatibility of the growth potential of population, "which increases in a geometrical ratio," and that of the resources necessary for survival, especially food, which "increases only in an arithmetical ratio." Because laws of nature require that humans have food, "this natural inequality of the two powers of population and of production in the earth and that great law of our nature which must constantly keep their effects equal form the great difficulty that to me appears insurmountable."[2] Demographic increase strains the relation between resources and population until a check to further growth intervenes. Malthus calls these "positive" checks; famine, disease, or war reduce population size (as happened with the medieval cycles of the plague or the Thirty Years' War) and reestablish a more suitable balance with resources. Reachieved equilibrium, however, will only last until another negative cycle begins, unless population can find some other way to limit its reproductive capacity. This "preventive" and virtuous check exists in the form of celibacy or at least the delay of marriage, practices that reduce the reproductivity of populations wise enough to choose this alternative. The fate of population depends upon the battle between positive and preventive checks, between careless and responsible behavior, between being a victim of constraint and necessity or making an active choice.

The Malthusian model, though repeatedly revised and updated over the years, is still basically contained in its initial formulation, and may be summarized as follows:

1 The primary resource is food. Its scarcity causes mortality to increase, slowing (or reversing) population growth and reestablishing equilibrium.
2 The law of diminishing returns is unavoidable. Cultivation of new land and intensification of labor in response to demographic growth adds progressively smaller increments to production for each additional unit of land or labor.
3 Production or productivity increases resulting from invention or innovation provide only temporary relief, since any gains achieved are inevitably canceled by demographic growth.
4 Awareness of the vicious cycle of population growth and positive checks may lead a population to check its prolificity (and so demographic increase) by means of nuptial restraint.

Figure 3.1 depicts the relationship between population and resources according to which equilibrium is reestablished after a period of growth or decline. In both cases the figure shows two paths, according to whether or not the preventive check is operating. As population grows so does the demand for food, and prices consequently rise. At the same time labor is less well paid as its supply increases. The combination of increased prices and decreased wages results in a still greater decrease in real wages, which is to say a worsening of the population's standard of living. This worsening cannot continue indefinitely and must eventually lead to a new equilibrium imposed either by the wise choice of the preventive check (path 1), the consequences of its refusal, namely increased mortality (path 2), or a combination of the two. Whichever path is followed, a worsening standard of living leads to a reduction of population (or at least slower growth) as a result of increased mortality



Arrows indicate the presumed direction of causality, + and – symbols indicate positive and negative effects on the next step. Dotted lines indicate a weaker relationship than do solid lines. The role of fertility is strong for path 1 and weak for path 2.

Figure 3.1 The Malthusian system of positive and preventive checks during phases of demographic expansion and decline

or reduced nuptiality and fertility and so to the reestablishment of equilibrium between population and resources.

Innovations and discoveries only delay operation of the restabilizing mechanism by introducing a discontinuity, without, however, altering its basic functioning. The above model applies particularly to agricultural economies, the growth of which is limited by the availability of land, and to poor populations, which spend a good part of their income acquiring food. Until the time of Malthus and the Industrial Revolution, almost all the countries of the world fit into these categories; many poor countries still do today.

The application of the Malthusian model to industrial societies (which has been done in the seventies with considerable public, if not scientific, success by the Club of Rome) presents no logical problems. However, the forceful logic of Malthus becomes less compelling when dealing with industrial processes, subject to continual technological innovation and employing resources which are for the most part renewable or replaceable.

2 Historical Confirmations

According to the Malthusian scheme, population must suffer periodic mortality increases in the absence of the virtuous preventive check because of the declining standard of living. However, if the preventive check is operating, then population growth can be controlled and both the accumulation of wealth and a general improvement of living standards becomes possible.[3] According to Malthus the preventive check was stronger in his day than it had been in ancient Europe, an implicit proof of human progress. Preventive checks, however, act slowly and only in highly civilized societies. Unfortunately, the positive check seems to have been historically more prevalent, as demonstrated by the frequency and intensity of catastrophes and mortality crises. Mortality crises, it is true, were often caused by epidemic cycles largely independent of living standards (see chapter 2, section 3 on the plague), but in modern times subsistence crises have been frequently accompanied by mortality increase. Increases in the price of grain – which made up two-thirds of the pre-industrial population's caloric intake – by factors of two, three, four, and more above that of normal years, were followed after several months of violent mortality increases. One or more bad harvests, generally caused by weather conditions, caused jumps in the price of grain, a situation possibly made worse by a lack of reserves, the impossibility of substitution with other foods, obstacles to trade, and the basic poverty of the populations affected. The periodic elimination of excess population in crisis years is one of the more frequent arguments cited in support of the Malthusian model. Figure 3.2 charts the price of wheat in Siena and deaths in the same city (together with several other localities in Tuscany) for a number of periods, centered on

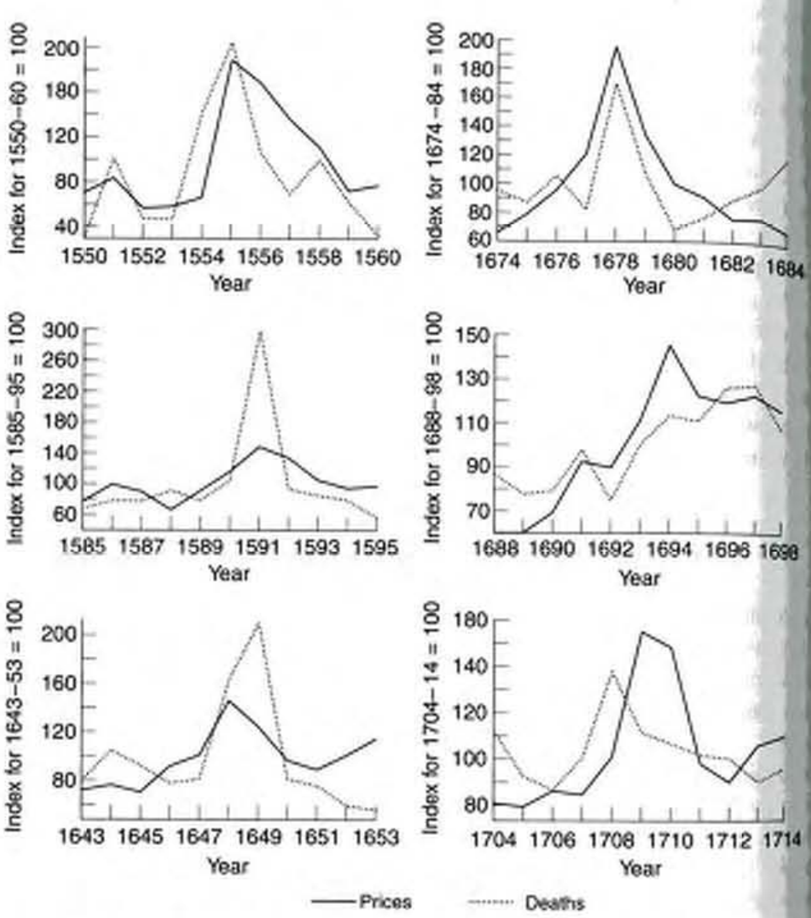


Figure 3.2 Sienese death and grain-price indices (sixteenth and seventeenth centuries)

Sources: For prices, G. Parenti, *Prezzi e mercato a Siena (1546–1765)* (Cya, Florence, 1942), pp. 27–8. For deaths, an unpublished study by the Department of Statistics of the University of Florence.

years of large price increases coinciding with peaks in mortality between the middle of the sixteenth century and the beginning of the eighteenth.[4] Similarly, years of want are often years of nuptiality decline, since marriages are postponed until conditions improve, a situation that leads also to temporary fertility decline.

The situation for the various European countries is not much different from that of Siena. The sixteenth, seventeenth, and early eighteenth centuries are characterized by subsistence crises, with the attendant adverse demographic consequences, at a rate of two, three, four, or more per century.[5] The great crises of 1693–4 and 1709–10 doubled the number of deaths in France relative to normal years in the period and left a lasting mark on both the demographic structure and historical memory of the populations affected.[6]

The negative effects of a decline in living standards should be more persistent and the operation of the Malthusian model more clearly in evidence in the long run than in the short. In fact, if we ignore the effects of epidemic crises not attributable to food shortages (plague and smallpox, for example), then it turns out that the demographic impact of subsistence crises does not adequately explain the cyclical succession of growth and decline. These cycles are better explained by the less transitory action of the positive and preventive checks – that is, by the long-term modification of mortality and nuptiality in reaction to periods of improving or worsening living standards. Wage and price series provide a clue to the relationship between population and the economy, since by these measures the latter two quantities progress in keeping with the Malthusian model over the long run (see figure 3.3). During the negative phase of a demographic cycle – as, for example, in the century after the Black Death or during the seventeenth century – the decline or stagnation of population, and so demand, contributes to a reduction of prices and at the same time to an increase in the demand for labor, and so wages. Between the early fourteenth and the late fifteenth centuries, for example, wheat prices were more than halved, only to rise again afterward in both France and England. As Slicher van Bath writes: "Then came the recession of the fourteenth and fifteenth centuries. The population had been

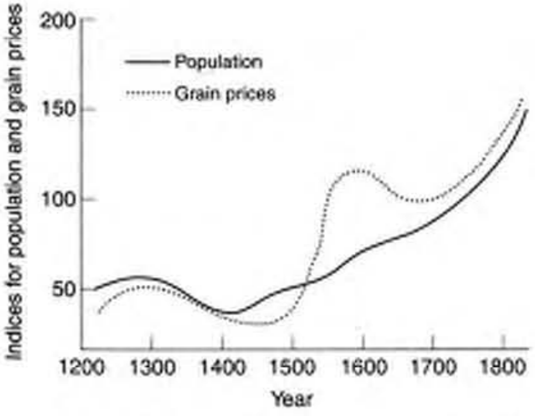


Figure 3.3 Population and grain prices in Europe (1200–1800; 1721–45 = 100)

Sources: B. H. Slicher van Bath, *The Agrarian History of Western Europe*, AD *500–1850* (Edward Arnold, London, 1963), p. 103.

reduced by epidemics, and because the area of cultivation was now larger than necessary for the people's sustenance, cereal prices fell. Through the decline in population, labour became scarce, so that money wages and real wages rose considerably."[7] Strong demographic recovery in the sixteenth century reversed the situation: increasing demand forced up the price of grain and other foods while real wages declined,[8] a trend which reached a critical point at the beginning of the seventeenth century.[9] The demographic slowdown of the seventeenth century and the catastrophic decline of the German population as a result of the Thirty Years' War are among the causes of a new inversion of the cycle (accompanied by declining demand and prices and increasing wages) that continued until the mid-eighteenth century, when demographic growth reversed the situation once again.

The English case – from the sixteenth to the eighteenth century – seems to conform well to the Malthusian model. Changing population size and an index of real wages are shown in figure 3.4.[10] Statistics reveal an apparently direct link between population and prices – in keeping with the idea that demographic growth or decline leads to an increase or decrease in prices – particularly at the two points of inversion occurring in the middle of the seventeenth and eighteenth centuries. The figure highlights the inverse relationship between demographic and wage movement, though there is a discrepancy regarding the timing of the turning points. Finally, figure 3.5 clearly reveals that of the two factors in demographic change – mortality, expressed by estimates of life expectancy at birth, e_0, and fertility, expressed by total fertility rate (*TFR*) – the first varies independently of the standard of living (expressed by real wages) while the second (reacting to changing nuptiality) seems to follow, after a delay, its variations.

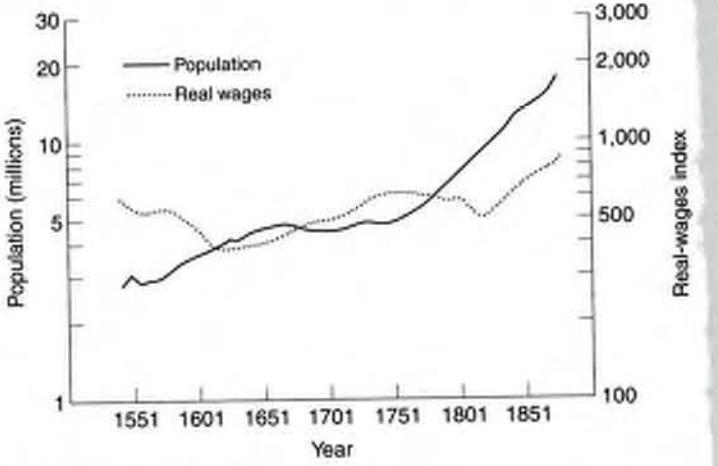


Figure 3.4 Population and real wages in England (1551–1851)

Source E. A. Wrigley and R. S. Schofield, *The Population History of England, 1541–1871* (Edward Arnold, London, 1981), p. 408.

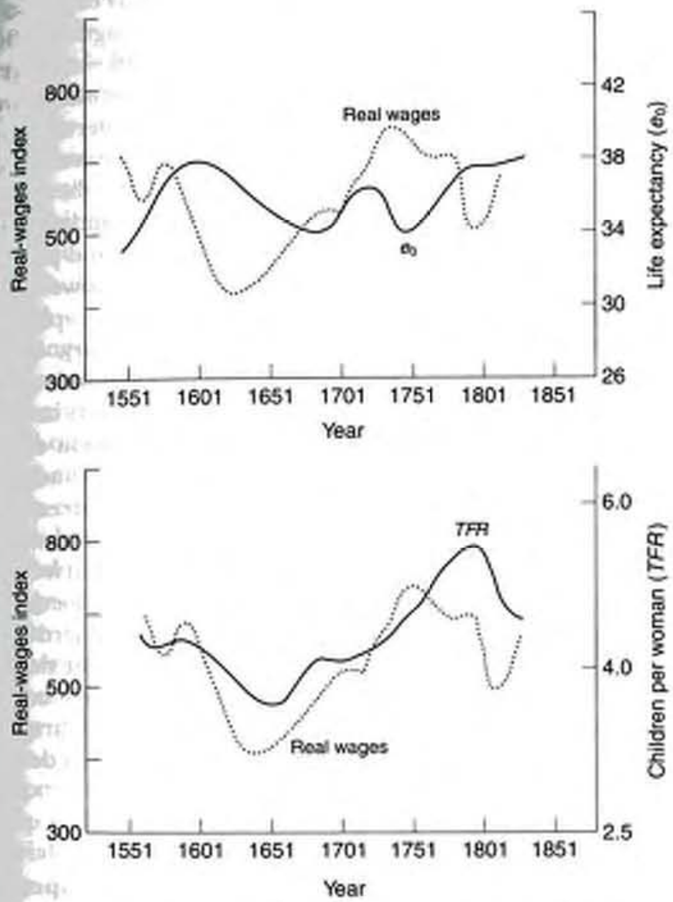


Figure 3.5 Real wages, fertility (*TFR*), and life expectancy (e_0) in England (1551–1801)

Source: Adapted from E. A. Wrigley and R. Schofield, *The Population History of England, 1541–1871* (Edward Arnold, London, 1981).

The English example would appear to conform to path 1 (figure 3.1) of the Malthusian model, according to which the balance between population and resources is restored by means of changing nuptiality and fertility rather than the dreary check of mortality.

Other studies covering long chronological periods, while not so rich in data, nonetheless provide similar interpretations. The social life of the area of

Languedoc in southern France is characterized by marked economic – demographic cycles.[11] A first cycle was completed prior to the plague of 1348. As in much of Europe, population expanded and marginal land – rugged and not very productive – was progressively settled. Signs of frequent famine and demographic slowdown are evident at the end of the thirteenth and in the first half of the fourteenth centuries, followed by plague and population decline. This decline had several sociodemographic effects – for example, the recombination of family nuclei into extended families and land redistribution, both suited to an agricultural system suddenly rich in land and poor in labor. The most significant economic effect for our purposes, however, was the reduction of prices and the increase of wages until demographic recovery gained momentum and accelerated in the sixteenth century. Once again land became scarce; new and progressively less productive land was tilled; real wages declined; the society became poorer; and, in the period spanning the seventeenth and eighteenth centuries, population declined. Le Roy Ladurie interprets these alternating cycles of growth and decline in Malthusian terms. Population grows more rapidly than resources, and in the long run, in the absence of technological improvements, positive checks intervene. The case of Languedoc differs from that of England in that it follows path 2 of figure 3.1, according to which mortality is the regulating mechanism.

Similar interpretations exist for other regions of both southern and northern Europe.[12] Common to all of these is the observation that demographic growth and the process of diminishing returns lead to a decline in per capita production and so increased poverty and that this spiral, or "trap," can be avoided or at least attenuated by innovation or by the control of demographic growth.

3 Demographic Pressure and Economic Development

The logic of diminishing returns implies a continual contest between the growth of resources and population, unless the latter is controlled by reproductive restraint and so permits the accumulation of wealth and increased well-being. Demographic growth, in any case, acts as a check to economic development.

The opposing theory to that of Malthus, according to which population increase stimulates development, has a still longer history. Economists of the seventeenth and much of the eighteenth centuries, worried by the negative economic effects associated with the depopulation of a number of countries (especially Spain and Germany) and convinced that the poverty of many others rich in resources was connected with population scarcity, viewed demographic growth favorably: "With rare exceptions they were enthusiastic about "populousness" and rapid increase in numbers. In fact, until the middle of the eighteenth century, they were as nearly unanimous in this "populationist" attitude as they have ever been in anything. A numerous and increasing population was the most important *symptom* of wealth; it was the chief *cause* of wealth; it *was* wealth itself – the greatest asset for any nation to have."[13] In the context of the limited development and low-density population of the period, demographic growth meant a multiplication of resources and therefore the increase of individual income.[14] This opinion was, as I have said, fairly widespread, and only at the end of the eighteenth century did the negative effects associated with the first phase of the Industrial Revolution induce Malthus, and many others with him, to take the opposite point of view.

Can demographic growth generate economic development? If "fixed" resources are abundant or can be substituted, then there is no reason why not, an observation that social and economic history confirms. It is easy to see how, within certain limits, development may be checked or absent for small populations, characterized by low density, limited trade, minimal possibilities for division or specialization of labor, and inability to make substantial investments. Historically, areas depopulated or in the process of losing population have almost always been characterized by backward economies. Many European governments in the seventeenth and eighteenth centuries took action (often unsuccessfully) to populate sparsely inhabited areas or areas where demographic decline had lowered the standard of living.[15]

It is important to understand the logic of the link between development and demographic growth. How can increasing population pressure and the consequent straining of available resources possibly constitute the prerequisite for development? A recent theory proposed by Ester Boserup explains this relationship with reference to agricultural economies.[16]

The variable population density of rural areas is naturally associated with the fertility of the land: high density in areas of rich, easily irrigated soil; decreasing density in areas less well suited to cultivation. This interpretation can, however, be reversed so that demographic growth is seen to create the conditions necessary for the adaptation of progressively more intensive methods of cultivation. Population pressure is then the cause and not the consequence of agricultural innovation.

The various systems of land cultivation spread across a continuum that stretches from forest-fallow systems (slash and burn preparation of the terrain followed by one or two years of cultivation and then a long fallow period of 20 to 25 years during which the forest reestablishes itself and the fertility of the soil is restored) at one end to multiannual cropping on the same piece of land at the other. Between the two extremes brush-fallow cultivation is identical in method to forest-fallow, but shorter, as a covering of shrubs reestablishes itself after six to eight years. In a short-fallow system (one or two years) there is only time for a grassy covering to grow back, while annual cropping allows but a few months for the soil to rest. Demographic growth determines the transition to progressively more intensive and shorter fallow cultivation systems which permit the feeding of a progressively larger population in a fixed area. This intensification process, however, is accompanied by an ever greater labor requirement and often also by declining worker productivity. For example, land preparation and the sowing of seed is extremely rudimentary in a slash and burn system: hatchet and fire clear the terrain of forest, ash fertilizes the soil, a pointed stick is all that is needed to sow the soft earth, and productivity per hour of work is high. Shorter fallow periods require more laborious soil preparation, and the simple action of fire must be replaced by work with hoe or plough; fertilization, weeding, and irrigation all become necessary. In a forest-fallow system, "fire does most of the work and there is no need for the removal of roots, which is such a time-consuming task when land has to be cleared for the preparation of permanent fields. The time used for superficial clearing under the system of forest fallow therefore seems to be only a fraction – perhaps ten or twenty per cent – of the time needed for complete clearing."[17] Tools, too, change at the various stages: while a pointed stick suffices for the sowing of seed in a slash and burn system, a hoe is needed to clear the soil of shrub when fallow is shorter and a plough to eradicate weeds when it is shorter still. When animal power is introduced for ploughing, the livestock produce fertilizer, but at the same time must be fed and cared for, tasks requiring additional labor. In order to obtain the same product, each farmer must work longer; in other words, his productivity per hour worked (in the absence of technological innovations) tends to decline. When population becomes too large in relation to available land, farmers are forced to use new techniques which, by virtue of increased inputs of labor, allow for greater production per unit of land. In many cases, so goes the argument, certain populations do not adopt more intensive techniques not because they are unaware of these alternatives but because land availability renders them disadvantageous. In fact, intensification would mean lower production per unit of labor.

This process of agricultural innovation differs from that according to which innovations or discoveries are "immediately" adopted because they are labor saving. In the first case, innovation is a consequence of demographic growth and the fact that a certain threshold of population density has been attained. In the second, innovation is independent of demographic factors.

The link between agricultural systems and population density is also supported by the fact that the above process of agricultural innovation seems to have been reversed in periods of population decline (several of which are discussed in chapter 2): lower density favors a return to less intensive systems. "Many of the permanent fields which were abandoned after wars or epidemics . . . remained uncultivated for centuries after. The use of labor-intensive methods of fertilization, such as marling, were abandoned

for several centuries in France and then reappeared in the same region, when population again became dense."[18] More recent examples of this "technological" regression may be found in developing countries, for example in Latin America, "when migrants from more densely populated regions with much higher technical levels become settlers in . . . sparsely populated regions."[19] The slash and burn agriculture practiced in equatorial forests by new colonists, for example in the Amazon, is an unfortunate contemporary example of this phenomenon.

Boserup's model (synthesized schematically in figure 3.6) refers generally to the slow transformation of historical societies under the pressure of gradual population increase, the latter seen as an independent variable, external to the model.[20] It loses much, although not all, as we shall see below, of its explanatory force when applied to mixed economies or to developing countries experiencing modern demographic acceleration. This model does not rule out the operation of other factors, but posits demographic growth as one of the driving forces of economic transformation. It overturns the Malthusian model as population becomes not a variable dependent upon development but one which itself determines that development.

4 More on Demographic Pressure and Development: Examples from the Stone Age to the Present Day

The positive theory of demographic pressure has been applied with intriguing results to the "rapid" transition from hunting and gathering to agriculture which I discussed earlier. This transition allowed the human race – which for hundreds of thousands of years had depended on those animal and vegetable products supplied spontaneously by the ecosystem – to develop, in

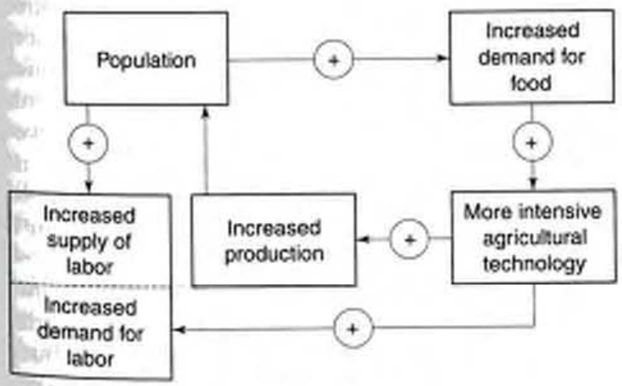


Figure 3.6 Population and agricultural intensification

just a few thousand more, a system for the man-made production of resources.

According to the traditional theory, this transition is explained by the development and diffusion of innovations and inventions. The invention of new techniques of animal domestication, planting, and harvesting led to increased and more stable production and so provoked demographic acceleration.[21] In other words, people modified the environment and so established the conditions for population growth. Mark Cohen, like Boserup, turns the process around.[22] When, 11,000 to 12,000 years ago, hunter-gatherer societies had settled all the land then available, demographic growth forced them to enlarge their range of gathering to include inferior foods, less nutritional and lacking in flavor. Then, beginning 9,000 years ago, hunter-gatherers were forced to enlarge still further this range of food, cultivating not tastier foods but those easily reproduced, and so the transition to agriculture began. This argument is based on two primary arguments and a series of corollaries.

According to the first argument, agriculture consists of a series of practices and techniques which were known to hunter-gatherers but not adopted because unnecessary: "Any human group dependent in some degree on plant materials, possessing the rudiments of human intelligence, and having any sort of home-base camp structure . . . will be almost bound to observe the basic process by which a seed or shoot becomes a plant . . . Agriculture is . . . a combination of behaviors . . . including such things as the creation of clearings in which certain plants thrive; the enrichment of certain soils; the planting of seeds; the irrigation of plants; the removal of competing species; the practice of conservation measures; the transporting of species beyond their original ecological boundaries; or the selection of preferred types. None of these behaviors alone constitutes agriculture; taken together they *are* agriculture."[23]

The second argument involves the level of nutrition and the work required to obtain this level with the transition to agriculture. In the first place, this transition entailed a deterioration of both the quality and variety of diet, as the food acquired by fishing, hunting, and gathering is much richer in nutrition and flavor than that of sedentary agriculture, dominated by a monotony of grain. Consequently, this transition would not have been expedient in the absence of the demographic growth that made it necessary. In addition, the work of a sedentary farmer was considerably more onerous than that of a hunter-gatherer who often considered the search for food not so much a form of labor as a natural way of life.

This theory is based primarily on observation of groups of hunter-gatherers that have survived to the present day. The hypothesis regarding the light workload entailed by this survival model is confirmed by the Bushmen of the Kalahari, among whom the adult males devote on average two or three hours a day to obtaining food, by the Arnhem Land Aborigines, who average three to five hours, and by the tribes of Tanzania, at barely two.[24] Similar observations were made in the nineteenth century by Grey.[25] Comparisons between primitive farmers and their hunter-gatherer predecessors presumably also confirm the lesser effort exerted by the hunter-gatherers for acquiring adequate food. In conclusion, "agriculture permits denser food growth supporting denser populations and larger social units, but at the cost of reduced dietary quality, reduced reliability of harvest, and equal or probably greater labor per unit food."[26] Agriculture spreads, then, when demographic growth requires greater production per unit area. Keeping in mind the fact that there existed a reequilibration mechanism (migration) which distributed excess population among areas, reducing demographic pressure, one can understand why the transition to agriculture (driven by demographic growth) took place in a relatively short period of time as compared to the duration of human history.

Cohen's approach has provoked intense debate and many attempts at confirmation. In particular, attention has been focused on the hypothesis that the period leading up to agricultural transition was characterized by a decline in living standards and nutritional levels. Confirmation, however, remains elusive, and both archaeological finds and paleopathological studies are inconclusive on this point.[27]

The theory according to which the first known demographic revolution led to the invention of agriculture shares with that of Boserup the belief that population acts as a stimulus to development. Later demographic developments – the period of growth in medieval Europe prior to the plague, for example – also provoked changes in the organization of production in keeping with the above model. "The new system, which spread in the period between the ninth and fourteenth centuries, was a three-course rotation of all the fields in a village, in which two cereal crops were followed by one year of fallow. The stubble and fallow were utilized for supervised grazing by domestic animals belonging to all the villagers. Stubble-grazing animals fertilized the fields with their droppings, helping to compensate for loss of soil fertility by shorter fallowing, and for loss of natural pastures due to expansion of the cultivated area. Even so, it is possible that crop yields were lower than they had been under the long-fallow system, and it is likely that there was some shift of diet from animal to vegetable food as population continued to increase. When the Black Death later reduced population densities, an opposite shift to less vegetable food took place, as arable fields, made superfluous by the decline of population, returned to pasture."[28] In the Low Countries – the most densely settled area of Europe – the agricultural system was able to avoid the recurrent bouts of famine and starvation typical of other parts of Europe. And it is in the Low Countries, according to Boserup, that major innovations such as short fallows and root crops with high caloric content per unit of land were first introduced.

Evidence from present-day agricultural societies using traditional technique also confirms the theory of the propulsive role of demographic growth. For instance, between 1962 and 1992, in the developing countries, a positive association has been found between changes in labor/land ratios (generally increasing) and land productivity, also on the increase. Population pressure on land has increased in most countries, determining a Boserupian response of augmented land yields. An influential study employs a series of cases taken from Latin America, Africa, and Asia during the last half century.[29] In these, the level of population pressure has been much greater than in the past due to higher rates of growth. The cases analyzed illustrate the response of agricultural societies to growth rates of 2 to 3 percent per year; in almost all cases urban growth has absorbed a fraction of rural demographic excess (or excess rural population), and in some the nonagricultural sector has actually come to dominate.

Given approximately equal technological levels, the work required for the cultivation of a given crop on a given unit of land increases with increasingly intensive cultivation systems. For example, comparing forest-fallow cultivation – employing the slash and burn technique and long fallow periods – to annual cultivation, the yearly total of hours worked per hectare jumps from 770 to 3,300 in Cameroon.[30] The increased labor requirement is the result of both the greater amount of work needed for each phase of cultivation (preparation of the soil, weeding and so forth) and the larger number of phases (irrigation and fertilization, for example). Three operations are sufficient for slash and burn agriculture: preparation of the soil by burning, which requires 300 to 400 hours per hectare in Liberia or the Ivory Coast; planting with a stick or hoe in the fire-softened terrain; and harvesting. Virtually no work is performed in the period between sowing and harvesting, since neither fertilization nor weeding nor irrigation are required. As cultivation intensifies, the latter operations become indispensable and progressively more laborious. Considering all 52 of the cases studied by Pingali and Binswagen, and calculating indices of cultivation and labor intensity,[31] one notes a positive correlation between the two variables: a 10 percent increase in cultivation intensity corresponds on average to a 4.6 percent increase in hours worked per hectare. The same analysis reveals that the 10 percent increase in cultivation intensity corresponds to a 3.9 percent increase in production per hectare. Productivity per hour worked, then, declines slightly, but if we also take into account the work hours not strictly employed in cultivation (such as the raising and care of livestock, maintenance of irrigation systems and of tools) the decline in productivity per hour worked is greater. This productivity decline (calculated in the absence of innovations) can, of course, be compensated for by sufficient investment and by new technology.

The experience of developing countries confirms many aspects of the theory. Agricultural intensification implies more work per unit of cultivated terrain and, given a constant level of technology, more work per unit of production. This trend has been effectively countered in recent history by technological innovation, but it is conceivable that in earlier epochs, when the pace of such innovation was either slow or static, the adoption of new methods of cultivation came about as a result of necessity and at the price of greater workloads.

5 Space, Land, and Development

For much of human history, the well-being of a population has depended upon the availability of space and land, and on the constraints imposed by their lack or limited supply. The ways in which populations have succeeded in overcoming or sidestepping these constraints by means of innovation and adaptation have been the leading determinants of survival and growth. The models described above, whether Malthusian or Boserupian, depend on space; in the first case primarily as a determining factor of demographic change and, in the second, as a dimension which responds to and is altered by population growth or decline. In the course of the history of population, these models have alternated, overlapped, and intersected; nor is it easy to make out their separate influences. In order to study long-term demographic growth, we must take "space" into account and all that it implies, in particular land, the products of the land (food, manufactured goods, energy), and those characteristics which determine settlement patterns. Demography has for too long ignored or at best paid scant attention to these themes and so deprived itself of valuable interpretative tools. Indeed the relevance of space for the understanding of demographic trends should be both directly and indirectly evident throughout this book, whether in relation to the Neolithic revolution, the settlement of new territories, or the events in Ireland and Japan.

Let us take Europe as an example, a continent – or perhaps more appropriately the western extension of the large Eurasian continent – for which we have access to abundant information for studying the relationships between space and demography. It is a continent marked by at least three fundamental characteristics. The first is its relatively easy access; it is almost entirely surrounded by seas, is penetrated by numerous waterways, and includes important orographic features that regulate but do not prevent communications. The second is its favorable climate, for the most part temperate and supportive of a wide range of crops. The third is the great variability of its environmental conditions which require adaptation on the part of the populations but at the same time favor specialization.

The area of Europe (taken to extend to the Urals, the Caspian Sea, and the Caucasus) measures 9.6 million square kilometers of which about half belongs to Russia. It would be superficial in this context to examine the complex relations between space and population in such a vast and varied area, though there are many interesting points to be made. According to Cavalli-Sforza and Ammerman, it was because of the availability of space that agriculturalists progressively migrated northwest from Asia Minor to Europe bringing new settlement and cultivation techniques and either causing or at least encouraging the Neolithic revolution there. Similarly, the increasing pressure exerted by nomadic peoples against the eastern borders of the Roman Empire must be ascribed to the conquest of space and resources.

In order to understand better the relationship between space and demographic change at least three lines of analysis need to be investigated. The first concerns the occupation of uninhabited or sparsely populated regions within a settled area; the second the transformation of existing space by means of deforestation, land reclamation, and swamp draining; and the third the expansion outside of settled areas through emigration and the colonization of new territories. These three processes are intimately linked and can conceptually be put in chronological order (though in fact they can all happen at the same time) according to the growing economic, social, and human costs they require.

The occupation of uninhabited or sparsely populated regions

This sort of expansion accompanied the Medieval demographic growth of the eleventh to thirteenth centuries, a period during which European population multiplied by a factor of two or three. According to Grigg, "In AD 900 much of Europe was covered by forest, but the following centuries saw the removal of woodland to allow cultivation. Between AD 1000 and 1300 much of the lowland forest was removed in central and western Europe, and cultivation also extended into mountain areas, notably in the Vosges, Alps and Pyrenees."[32] It was a widespread process as already-settled territories were expanded by means of the cultivation of new land, often accompanied by the consolidation of population in towns, castles, and new cities.[33] The expansion of cultivated land came about in varied ways, though in the majority of cases it was the individual peasant who put to the plow open space bordering already cultivated fields or else cleared woodland. In other cases new settlements were organized by landlords.[34] This process is a well-documented one, in Italy, Spain, France, Germany, and elsewhere. Obviously, the increasing demand for resources made by an expanding population were also satisfied to some extent by land reclamation, settlement at higher elevations, and costly land transformations (within the limits of available technology and usually by means of that intensification of agriculture we have already discussed). Still, it is hard to imagine that Medieval expansion would have been as dynamic as it was without an abundance of easily acquired land.

Transformation and land reclamation

At considerably higher costs, land reclamation helped to sustain Medieval population growth. Dams were built to control stream waters and to protect lowlands from flooding by both rivers and the sea: "Coastal areas saw much reclamation, and embankments were built to protect low-lying land both from the sea and from estuarine flooding in Lincolnshire and Norfolk, on the Elbe, the Loire, the coast of Flanders, and most notably in the Zuiderzee."[35] Similar hydraulic work was carried out in the Po Valley including projects financed by cities in Lombardy, Emilia, Romagna, and in the Venetian plain.[36]

Land reclamation took on larger proportions during the demographic recovery that followed the crisis of the fourteenth and fifteenth centuries. In England wet and swampy areas, both internal (in Lancashire and in the Fenlands) and along the coasts of Sussex, Norfolk, and Essex, were drained.[37] Similar work was carried out in France, along the northern coast with the help of Dutch workers and also in the south along the malarial and swampy coasts of Provence and Languedoc.[38] And in Italy reclamation activity took off again as well: "all of the lower Po Valley was affected by the great reclamation movement in the sixteenth century. To the west the first rice paddies were created in the eastern part of Piedmont between Novara and Vercelli, but the greatest activity was in the east; massive and surprising transformations took place on either side of the Po: in the Venetian *terra firma*, in the Duchies of Parma, Reggio, Mantua, and Ferrara, and in Emilia."[39] Yet it was in the Netherlands in response to population growth and the increase in grain prices between the late fifteenth and mid-seventeenth centuries that the reclamation of land from sea and marsh by means of dikes, canals, and pump-works took on formidable dimensions. "Between 1540 and 1565, 125,000 hectares of polders were diked; one-half of this was in Zeeland and North Brabant, one-third in Holland, the remaining sixth in Friesland and Groningen."[40] There were also reclaimed lands in the interior of the country: "The area brought into cultivation was remarkable: between 1550 and 1650 the population of the Netherlands increased by some 600,000 but the area reclaimed was some 162,000 hectares."[41] If we assume that one hectare can sustain on average two or three people then the added land would have fed between one-half and three-quarters of the added population. In the Netherlands land reclamation followed demographic growth apace. Elsewhere the demographic awakening of the second half of the eighteenth century was accompanied by the revival of reclamation projects as well: in

England and Ireland, Poitou and Provence, Schleswig-Holstein and Prussia, and Catalonia and the Italian Maremma.

External expansion

The third element in the complex relationship between space and population is the existence of accessible space outside of already-settled areas. Europe has been both a receiver and a supplier of population in this regard. Prior to the Middle Ages, population flowed in from the steppes to the east and the Mediterranean to the south. In the period since the Middle Ages, it would be difficult to understand the development of European demography and society without taking into account the availability of inhabitable spaces to the west and east and so the phenomena of emigration and colonization. The accessibility of these spaces and the force of attraction they exert is one of the two major factors behind the great migrations; the other is the existence of forces of expulsion tied to economic difficulties in the sending regions. We shall discuss at greater length below the great nineteenth-century transoceanic migrations, which took place in a period of rapid economic and industrial change, but for the moment let us restrict our attention to Europe between the Middle Ages and the Industrial Revolution and focus on three great movements. The first is the German colonization of the territory east of the Elbe River between the eleventh and the fourteenth centuries. The second includes the Iberian migration to Central and South America and the British migration to North America as well as the relatively minor movements of the Dutch and the French to their respective colonies in the period from the sixteenth to the eighteenth centuries; these movements constitute the prelude to the great migrations of the nineteenth century. The third is the expansion of the Russian frontier to the east and to the south.

The drive to the east – *Drang nach Osten* – was a phenomenon of great proportions as it determined the peopling of large areas east of the Elbe and then successively of Poland, the Sudetenland, and Transylvania. It was a colonization process begun in the twelfth century by Dutch and Flemish pioneers – in part organized, in part spontaneous – who moved into open areas sparsely inhabited by Slavs. It is estimated that this migration involved 200,000 people who in the course of the twelfth century occupied the region between the Elbe and the Oder and that the wave of the thirteenth century that helped populate Silesia and Pomerania was of a similar size. It was a relatively modest migratory flow but one of considerable importance in the long run: at the end of the nineteenth century the Germanic population east of the Elbe-Saale line was about 30 million.[42] In the eighteenth century, by calling on several tens of thousands of German colonists, Catherine the Great of Russia produced a new wave of migration into the valley of the Volga in an attempt to push the border southward. Between 1764 and 1768, 104 colonies were founded on the banks of the Volga for 27,000 immigrants. Other settlements in the Crimea, North Caucasus, Kazakhstan, and Siberia followed.[43] From a demographic point of view, the interest of these migrations lies not so much in their size, which was modest in both absolute and relative terms, but in their makeup: the migrants were for the most part young workers, many without families; they represented a significant portion of the reproductive age population and so an outlet for demographic increase. Their progeny was considerable: as with the French Canadian pioneers (see chapter 2, section 5), their reproductivity was high, because of both the selective effects of migration and the abundance of available resources better exploited by large families. A few hundred thousand Germanic colonists then became a few centuries later tens of millions, and the few tens of thousands who migrated to Russia founded colonies which grew into large settlements by the end of the nineteenth century.

The second great migratory outlet was the American continent and, to a lesser extent, other overseas settlements. At the end of the eighteenth century, as the colonial system was collapsing, the American continent was home to modest but significant European settlements: about 4 million in Latin America and 4.5 in North America.[44] These settlements, fed by migrations from Spain and the British Isles and to a lesser degree Portugal, were small in comparison to the physical dimensions of the continent but nonetheless constituted a third of its population. As compared to the population of Europe (excluding Russia) they amounted to only about a fifteenth.

On the basis of indirect estimates derived from maritime traffic, the Spanish contribution is thought to be 3,000–5,000 emigrants per year for the 150 years ending in the mid-seventeenth century. They came almost exclusively from Castile and constituted a loss (according to the highest estimate) of one per thousand per year, a significant figure given their young age structure and the weak demographic growth of the period. After 1630, and in conjunction with the general (including demographic) crisis, emigration declined and reached a minimum between 1700 and 1720.[45] The drain on England was greater, amounting to a net figure of 7,000 emigrants a year during the seventeenth century from a population that numbered little more than 4 million at its beginning.[46] The emigration from Holland was comparable to that from England; it is estimated that 230,000 net emigrants went to Asian locations between the beginning of the seventeenth century and the end of the eighteenth, to which were added 15,000 to Latin America and the Caribbean and 10,000 to the United States.[47] France, the most populous country in Europe (see chapter 2, section 5), contributed relatively little to these migrations. Transoceanic migration between the beginning of the sixteenth century and the end of the eighteenth was numerically significant and constituted the demographic and political base for the great migrations of the nineteenth century; it made possible then an enormous expansion of European space beyond the Atlantic barrier that had enormous long-term demographic consequences.

The third movement consisted of the shift of the Russian border to the south and east. The peopling of Siberia in the nineteenth century – which takes us beyond the chronological limits here imposed – resembled that of the American continent though the numbers were smaller. As McNeil writes: "By 1796, therefore, when the Empress Catherine II died, the Russian flood had engulfed the once-formidable Tartar society... All the vast steppe region north of the Crimea and west of the Don had been occupied by landlords and settlers, and their political and social institutions had been effectively assimilated to those prevailing in the Russian empire as a whole... Yet new towns had arisen (Kherson, 1778; Nikolaev, 1788; Odessa, 1794) and throve as administrative centers and grain ports; and with urban life the manifestations of higher culture – flavored by a distinctly cosmopolitan tincture owing to admixture of Greeks, Bulgars, Poles, Jews, and a few western Europeans – soon appeared."[48]

These notes on an enormously complex and little-known story should give some idea of the intimate relation between demographic change and the availability of space, whether internal or external, to the relevant population. It is an argument with ties naturally to the migrations which have traversed the continent in various directions. It helps us in turn to understand how in the space of a millennium the availability of new spaces not strictly defined by political boundaries played a great and varied role in shaping demographic change. Space, then, has made possible the expansion of the European economy into a wider world.

6 Population Size and Prosperity

In the preceding pages I have discussed several possible dynamic relations between population and economic development. It is also worth taking a moment to consider the effect of the simple "number" of inhabitants on societal well-being. I have already touched this argument in passing; it merits, however, something more than the observation that the level of complexity of social organization is also a function of numerical size. Many scholars have grappled with the question of whether there exists an "optimum" population size,[49] but this academic exercise is not particularly helpful for understanding the historical reasons for demographic development. The concept of an optimum population, which may be defined as that theoretical population size at which individual well-being is maximized (and above or below which well-being declines), is an essentially static concept and applies poorly to dynamic populations.

Population size acts by means of two mechanisms well known to classical economists. The first is linked to the principle of division of labor and so to the more efficient use of individual abilities. The second derives from the observation that the complexity of societal organization is also a function of demographic dimensions, both absolutely and relative to a given unit of territory (density).

The benefits of division of labor were masterfully demonstrated by Adam Smith, and before him by William Petty. Referring to the advantages of large cities, Petty wrote: "In the making of a Watch, If one Man shall make the Wheels, another the Spring, another shall Engrave the Dial-plate, and another shall make the Cases, then the Watch will be better and cheaper, than if the whole Work be put upon any one Man."[50] Smith's examples of the blacksmith making nails and of the advantages to be gained from dividing up the work required for the production of pins are classic: "One man draws out the wire, another straights it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving the head, to make the head requires two or three distinct operations, to put it on is a peculiar business, to whiten the pins is another; it is even a trade by itself to put them into paper; and the important business of making a pin is, in this manner, divided into about eighteen distinct operations, which in some manufactories, are all performed by distinct hands,"[51] and while a single worker might turn out at most 20 pins a day, a factory employing a team of 10 workers manages to produce 12 pounds a day, or 48,000 pins, 4,800 per worker. Division of labor, however, is a function of the size of the market. If the market is small, division is moderate, as are the advantages to be gained. Smith observed that in the Highlands of his native Scotland, where families were widely scattered, each performed the tasks of butcher, baker, and brewer for itself. Smiths, carpenters, and masons were few, and those families 8 or 10 miles from town did much of this work themselves.[52]

Where it has been impossible to adequately divide labor, this situation has contributed in some measure to the backwardness of scattered groups; to the development difficulties encountered by small, isolated communities, the dimensions of which do not allow specialization; to the failure of colonization undertaken by small nuclei; and to the instability of small island populations even when the environment is favorable. The maximum of inefficiency according to this formula is that population consisting only of Robinson Crusoe.

The second advantage to be gained from population size or density is the economies of scale acquired at increasing population levels. Better systems of resource utilization and production are only feasible when population attains a certain density in relation to the territory inhabited. We have already considered an example according to which the processes of agricultural intensification respond to the incitement of demographic growth. In our own time, a country like Canada is considered, by representatives of both the government and the citizenry at large, too "empty" to maintain that development which its extension and natural wealth would seem to ensure. Other classic examples include the development of irrigation systems, the establishment of cities, the improvement of communications, and, in general, those investments in infrastructure which require a critical mass of resources and a critical mass of demand – neither of which are obtainable from small groups and limited markets. These infrastructures can be developed at a lower cost per-capita in a larger population.

The development of irrigation systems in Mesopotamia allowed the few hunter-gatherers living in the Zagros Mountains in 8000 BC to evolve into a large population of plain-dwellers in the following millennia. "This dense population used intensive systems of agriculture based upon flow irrigation; multicropping was also introduced. Fields were prepared by plows with moldboards and iron shares, drawn by oxen. The irrigation system used waterwheels for lifting water to fields located above the major river, which provided the water. Thus over a period of some eight thousand years, Mesopotamia became densely populated.... Gradually, the population changed from primitive food gatherers to people who applied the most sophisticated systems of food production existing in the ancient world."[53] The transformation of the Italian Maremma into swampland that accompanied the medieval population decline was a result of the reverse process which saw the deterioration of water control systems.

Considerations of this sort have also been applied to the development of road networks, which is strongly correlated to population density.[54] Clearly the advantage and usefulness of a road is a function of how heavily it is traveled. Once built, it exerts multiple effects on development, speeding up communication, helping trade, and allowing the creation of a larger market. The differences in prices for basic goods in primitive societies are largely explained by difficulties of transportation and uncertain communications.

City growth too has obvious links to demography. I take for granted that the creation of cities allows for greater specialization and more efficient organization of the economy. While these advantages may well be compromised in the present day by the ever more evident "diseconomies" of scale created in the great urban centers, for the primarily rural economies that we are discussing the situation was altogether different. Clearly the maintenance of an important centralized population, not directly involved in food production, implies the creation of an agricultural surplus by the rural population; and the wealthier the latter, the greater the available resources. The early growth of cities in Mesopotamia, northern India, and China is certainly a function of the large populations allowed by the fertility of the land and agricultural abundance. It is once again Ester Boserup who provides an original explanation for this situation, proposing a causal chain: Demographic growth drives agricultural intensification, but it is not so much the level of per capita production – which increases with increasingly intensive cultivation – as it is increasing population density that allows for the creation of the surplus resources requisite for the birth of cities. More farmers within a given radius from the city imply a larger product and a larger surplus for support of a more numerous urban population. "Even the best technologies available to the ancient world, when used on the best land, did not allow one agricultural family to supply many nonagricultural families.... The size of the population available to supply an urban center was far more important than how much food could be delivered or sold per agricultural worker."[55]

The links between division of labor, economies of scale, and demographic dimensions are easily grasped and demonstrated by numerous historical examples. Less easily demonstrated is another thesis, upheld by a number of scholars, which employs the following logical sequence: When resources are available, development is a function of what Kuznets calls "tested knowledge."[56] Employing a restrictive hypothesis, the "creators" of "new knowledge" (investors, innovators) exist in proportion to population size. The creation of "new knowledge," however, is probably helped by factors of scale (the existence of schools, universities, and academies that multiply both the efficiency of already acquired knowledge and also the opportunities for the creation of new knowledge) and so enjoys increasing returns as population grows. In this way, all things being equal, population increase leads to increased per capita production.

As Kuznets himself confesses, this is a hazardous argument,[57] though he is not its sole advocate. Indeed, it was Petty who remarked: "And it is more likely that one Ingenious Curious Man may rather be found out amongst 4 Millions than 400 Persons."[58]

7 Increasing or Decreasing Returns?

During the last 10,000 years the human race has managed to multiply by a factor of 1,000 and at the same time increase the per capita availability of resources. Those who argue for the inevitability of decreasing returns maintain that this has come about because the limits of fixed resources have never been reached, either because these limits have been repeatedly pushed back as new land is cultivated and sparsely populated continents inhabited or because resources have been used more productively thanks to innovations and discoveries. Nonetheless, for long historical periods the bite of diminishing returns has severely tested the ability of population to react. Moreover, certain resources would seem to be not only limited but non-substitutable, and so in the long run neither innovation nor invention can avert the onset of diminishing returns and impoverishment.

According to the opposing view, there is no reason to believe that the onset of diminishing returns is inevitable. Kuznets expresses this position well in historical terms, asking: "Why, if it is man who was the architect of economic and social growth in the past and responsible for the vast contributions to knowledge and technological and social power, a larger number of human beings need result in a lower rate of increase in per capita product? More population means more creators and producers, both of goods along established production patterns and of new knowledge and inventions. Why shouldn't the larger numbers achieve what the smaller numbers accomplished in the modern past – raise total output to provide not only for the current population increase but also for a rapidly rising supply per capita?"[59] In other words, diminishing returns from fixed resources are more than compensated for by the increasing returns of human ingenuity and by the ever more favorable conditions created by demographic growth.

This dilemma is unresolvable only if we insist on finding hard and fast rules to explain complex phenomena. Time is a factor of primary importance. The bite of diminishing returns can create insurmountable obstacles in the short and medium run, lasting a few decades or a few generations. The costs generated by these obstacles are not easily evaluated. Nor are they necessarily reflected by mortality fluctuations, as population is characterized by a high level of resistance to hardships and historically the infectious and epidemic disease component has been largely independent of the human condition. They are, however, reflected in a general increase of poverty that in the long run can only be checked or reversed by innovation. The price paid in terms of human suffering can be high, though historically one is more impressed by the ability of societies to reverse a negative trend. If we transfer this dilemma to the present day, it takes on dramatic proportions. Rapid demographic growth may in the long run be accompanied by unexpected development, but meanwhile the medium-term problems are serious. Even innovation has its price. The green revolution in India provides a good case. High-yielding seeds introduced in the sixties meant more wheat production, an expensive staple consumed mainly by urban middle classes while the poor ate rice or bread of inferior quality. The poor would supplement their rice diet with pulses (dal), rich in proteins. But since wheat was more profitable, the farmers started growing wheat at the expense of pulses. Between 1960 and 1980 the production of cereals increased 72 percent against 57 percent for the total population and a decline of 17 percent of the production of pulses. So the diet of the poor deteriorated. In the long run, however, the green revolution meant more jobs and more income for the poor offsetting the initial negative effects of a worsening diet.[60]

So the time scale is important: what is bad for the medium term may be good for the long term, and vice versa. Should we judge historically in terms of *generations*, centuries, or millennia, or with greater attention to problems foreseeable in our own lifetime?