

Chapter 9

Economic Development

The Pre-Industrial Revolution Era

1 Introduction

The questions of why some economies grow while others do not, or why economies grow at all, are perhaps the most fascinating (and unresolved) issues in the science of economics. These questions are related, but distinct. The former question asks why less-developed economies simply do not imitate their well-developed counterparts. The latter question asks what triggers economic development in even relatively advanced economies. Given that our current living standards depend on past growth rates and that our future living standards (or those of our children) will depend on current and future growth rates, the question of growth and development is of primary importance.

Most people would agree that the high living standards that we enjoy today (relative to historical levels and to less developed contemporary economies) is directly attributable to the advanced state of technology, which we can define broadly to include basic scientific and engineering knowledge, human capital, organizational design, and so on. Understanding this basic fact, however, is not very helpful since it does not explain how we came to acquire this advanced technology (and why some less developed economies simply do not imitate us). Furthermore, it appears evident that there must be more to the story of rising per capita living standards than just technological progress. As I will describe in this chapter, technological progress has been with us since the beginning of recorded history. And yet, up until the Industrial Revolution (c. 1750), growth in per capita living standards appears to have been modest at best. It appears that technological advances in the Pre-Industrial Revolution era manifested themselves primarily in the form of population growth (i.e., growth in GDP rather than per capita GDP).

In this chapter, I will take some time to outline the evidence pertaining to technological advancements prior to the Industrial Revolution. I will then present a theory of growth (due to Thomas Malthus). Like many so-called growth models, however, the theory does not explain the source of technological advancement. But the model does offer an explanation as to why technological progress (if it occurs at all) manifests itself as population growth, instead of growth in per capita living standards.

2 Technological Developments

This section is not meant to be an exhaustive survey of technological progress throughout the ages. But a sufficient number of examples are provided that should convince you of the remarkable technological advancements that have occurred throughout recorded history.¹ As is the case today (but to a lesser extent), economies varied in their use of available technologies. The diffusion (implementation) of new technologies (and ideas in general) occurred slowly (if at all). Economies that employed the best technology often grew to be world powers, dominating those around them. It is also interesting to note that the centers of power (wealth and knowledge) shifted many times over the course of history.

2.1 Classical Antiquity (500 B.C. - 500 A.D.)

The classical civilizations of Europe (Greek, Hellenistic, and Roman) were in many ways more scientifically advanced than anything Europe had to offer up to the renaissance period (c. 1450 A.D.). Important achievements of classical technology included: coinage, alphabetization, stenography and geometry. In addition to their achievements in literature, advances were made in mathematics, medicine, science, architecture, construction, and political organization. However, in other areas, there was (from our perspective today) a distinct lack of progress in many important areas, such as the development of mechanical devices, chemistry, and farming.

The technological progress in the classical world (especially in Roman times) was typically geared to the public, rather than the private, sector. The Rome of 100 A.D. had better paved streets, sewage, water supply, and fire protection than the capitals of Europe in 1800 A.D. Most agriculture, manufacturing, and services were carried out by the private sector, and achievements there were slow. The lack of progress in developing mechanical devices for commercial uses is particularly interesting, since a great achievement of the classical world was in recognizing fully the important elements of machinery, such as the lever, the wedge and screw, the ratchet, the pulley, the gear and the cam. Apparently, these insights were applied mostly to war machines and clever gadgets that were admired for their own sake but rarely put to useful purposes.

Many of the classical ideas lay dormant for centuries. For example, Hero of Alexandria (1st century A.D.) developed a working steam engine used to open temple doors; a coin-operated vending machine (for holy water in the temple). Similarly, Ctesibius (3rd century A.D.), who has been called by some the Edison of Alexandria, reportedly invented the hydraulic organ, metal springs, the water clock, and the force pump. An important question is why so little of this potential was realized and translated into economic progress. Many inventions

¹These examples are taken from Mokyr (1990).

that could have led to major economic changes were underdeveloped, forgotten or lost. This is especially puzzling in light of the fact that classical civilizations were relatively literate and mobile.

2.2 The Middle Ages (500 A.D. - 1450 A.D.)

Early medieval Europe (sometimes referred to as the *Dark Age*) managed to break through a number of technological barriers that held the Romans back. This is all the more remarkable when one recognizes that many of the ingredients that are commonly thought of as essential to technological progress were absent. Especially during the Dark Ages, the economic and cultural climate in Europe was primitive compared to the Classical period. Literacy had become rare and the upper classes devoted themselves primarily to warfare. Commerce and communications declined to almost nothing. The great infrastructure of the Roman empire was left to depreciate. Law enforcement and the security of life and property became more precarious than ever. And yet toward the end of the Dark Ages, in the eighth and ninth centuries, European society began to show the first signs of what was soon to become a torrent of technological creativity. In contrast to the Classical age, these new technological developments took the form of practical tools and ideas that reduced the daily toil and increased the material comfort (however marginally) of the masses.

In terms of their direct contribution to aggregate output, changes in agricultural technology were of primary importance as the bulk of the population was engaged in farming. Some of the key advances included: the introduction of the heavy plow, the wheelbarrow (both invented in China, c. 300-100 B.C.) and the three-field system; the extensive use of water power; and the modern horse collar (and horseshoe). The widespread application of these technologies allowed medieval Europe to build an economy based on nonhuman power, in contrast to the widespread use of slaves in Classical economies. Other important inventions included the weight-driven mechanical clock, which has been referred to some as the key machine of the modern industrial age, and the printing press, which allowed books to be published on an unprecedented scale.

Medieval Western technology drew from three sources: classical antiquity, contemporary Islamic and Asian societies, and its own original creativity. The second source of ideas is of particular interest, since it indicates a willingness by Europeans to shamelessly adopt the ideas of other cultures.

From about 700 A.D. - 1200 A.D., the cultural and technological center of gravity of Europe remained to a large extent in the Islamic societies of Spain, Northern Africa and the Middle East. The culture and technology of Islam constituted a synthesis of Hellenistic and Roman elements, together with ideas from central Asia, India, Africa and China. Early Islamic society collected, compiled, and catalogued knowledge avidly. Both rich and poor alike apparently travelled extensively and learned eagerly from other cultures. It was a society literate beyond Europe's wildest dreams. During this time, the Moslems knew

more about the different parts of the known world than any other civilization.

Important Moslem contributions to technology in this era include the development of the lateen sail, tidal mills, and windmills. They were also responsible for the introduction of paper (invented in China, c. 100 A.D.) into the Middle East and Europe (the first paper Islamic paper factory was set up in Baghdad, c. 793 A.D.). Other notable advances occurred in textile production, agriculture, and chemical technology. The great strength of the early Islamic world, however, lay in its ability and willingness to adopt existing technologies from foreign sources.

From about 1200 A.D. on, however, both innovative and imitative activity in the Moslem world slowed down, for reasons that are still not very clear. Some people blame the destruction of the eastern Islamic world by Mongol invasions. Others point to political and religious factors. In any case, by about this time, the economies of western Europe had absorbed most of what the Moslem world had to offer.

The truly great technological powerhouse of the ancient and medieval world was China, which maintained its technological supremacy until about 1400 A.D. Major improvements in the cultivation of rice revolutionized Chinese agriculture. The control of water through hydraulic engineering (dams, ditches, dikes, etc.) allowed the drainage and irrigation of lands. The iron plow was introduced in the sixth century B.C. Chinese agriculture learned to use new fertilizers and chemically based pest control agents. The Chinese led the Europeans by 1500 years in the use of blast furnaces, allowing them to use cast iron and refine wrought iron from pig iron. Other notable (but by no means exhaustive) list of inventions include the invention of the compass, gunpowder, multistage rockets, paper, and the most technologically advanced ships of the time.

The extent of technological development in China by 1300 A.D. was apparently such that “China came within a hair’s breadth of industrializing in the fourteenth century.” (Jones, 1981, pg. 160). And yet, industrialization did not occur. In fact, by about 1400 A.D., technological progress in China slowed down dramatically to the point of almost ceasing altogether and in some cases even regressing. By the end of the Middle ages, Europe became the world’s technological leader.

2.3 The Renaissance and Baroque Periods (1450 A.D. - 1750 A.D.)

Europe is unlike China in that it was never politically unified. Consequently, the centers of influence shifted over time across regions (or countries). The Renaissance (rebirth) era (1450 A.D. - 1600 A.D.) originated in the great Italian city states of Venice, Genoa and Florence with Spain (and to a lesser extent, Portugal) emerging as the world’s leading power in the sixteenth century. With Spain’s gradual decline following the defeat of the *Armada* (1588) at the hands

of the English, the balance of power shifted in the Baroque era (1600 A.D. - 1750 A.D.) toward England, France and Holland.

This episode in European history is known more for art and exploration than for its technological achievements. Technological progress did occur throughout the period, but manifested itself more in the form of sequences of improvements to existing technology. Much of the growth in output were due to an expansion in international trade, facilitated by financial market innovations like commercial banking, as well as innovations in shipbuilding. In agriculture, the so-called new husbandry (the introduction of new crops, stall feeding of cattle, and the elimination of fallowing) led to major productivity gains. In energy use, medieval techniques were improved but not revolutionized, although the slow expansion of coal power was to have significant future ramifications. Major improvements were made in the efficiency of blast furnaces, mining techniques and hydraulic engineering. However, the diffusion of technology occurred very slowly, with old techniques coexisting along side best-practice techniques for centuries.

On the whole, the period was characterized more by its scientific achievements than its technological breakthroughs. The most famous visionary of the Renaissance, Leonardo da Vinci, designed thousands of machines and mechanical devices, including the helicopter, the retractable landing gear, the tank, and the parachute. Most of his ideas, however, defied any practical application until centuries later.

In the field of science, the Renaissance differed from Classical times in that the dichotomy between thinkers and makers broke down. Many scientists made their own instruments and contributed to the solution of practical problems associated with their manufacture. Galileo, for example, built his own telescopes and worked part time fixing machines. But the number of truly important technological breakthroughs brought about by great scientists still remained relatively small.

3 Thomas Malthus

Thomas Malthus (1766-1834) is probably most famous for his provocative work entitled *Essay on the Principle of Population* (1798), which was directed at William Godwin (1756-1836) whose *Enquiry Concerning Political Justice* (1793) argued in favor of a more egalitarian society in order to end poverty. Godwin was a proponent of government welfare programs like the English Poor Law of 1601, which provided direct grants to the poor financed by property taxes. On the matter of the Poor Laws, Malthus had this to say:

“The poor-laws of England tend to depress the general condition of the poor in these two ways. This first obvious tendency is to increase population without increasing the food for its support. A

poor man may marry with little or no prospect of being able to support a family in independence. They may be said therefore in some measure to create the poor which they maintain; and as the provisions of the country must, in consequence of the increased population, be distributed to every man in smaller proportions, it is evident that the labour of those who are not supported by parish assistance will purchase a smaller quantity of provisions than before, and consequently, more of them must be driven to ask for support. Secondly, the quantity of provisions consumed in workhouses upon a part of the society, that cannot in general be considered the most valuable part, diminishes the shares that would otherwise belong to more worthy members; and thus in the same manner forces more to become dependent. ...

Other circumstances being the same, it may be affirmed that countries are populous according to the quantity of human food which they produce or can acquire, and happy according to the liberality with which this food is divided, or the quantity which a day's labour will purchase. Corn countries are more populous than pasture countries, and rice countries more populous than corn countries. But their happiness does not depend upon their being thinly or fully inhabited, upon their poverty or their richness, their youth or their age, but on the proportion which the population and the good bear to each other."

With the publication of his *Essay*, controversial debates swept throughout England. To quote Malthus' biographer, James Bonar:

"For thirty years it rained refutations. Malthus was the most abused man of the age, put down as a man who defended smallpox, slavery and child murder, who denounced soup kitchens, early marriage and parish allowances; who had the impudence to marry after preaching against the evils of a family; who thought the world so badly governed that the best actions do the most harm; who, in short, took all romance out of life."

The historical setting, in which Malthus brought out his work, must be considered. The poor, especially those in the rural areas, were numerous and were generally in a bad state. It was generally thought that the plight of the poor was due to the landed aristocracy, that they had the government levers in their hands and used them to advance the upper classes at the expense of the poor.

In contrast, Malthus explained the existence of the poor in terms of two 'unquenchable passions:' (1) the hunger for food; and (2) the hunger for sex. The only checks on population growth were wars, pestilence, famine, and 'moral restraints' (the willingness to refrain from sex). From these hungers and checks,

Malthus reasoned that the population increases in a geometric ratio, while the means of subsistence increases in an arithmetic ratio. The most disturbing aspect of his theory was the conclusion that well-intentioned programs to help the poor would ultimately manifest themselves in the form of a greater population, leaving per capita incomes at their subsistence levels. It was this conclusion that ultimately led people to refer to economics as ‘the dismal science.’

3.1 The Malthusian Growth Model

The Malthusian ‘growth model’ can be formalized in the following way. There are two key ingredients to his theory: (1) a technology for production of output; and (2) a technology for the production of people. The first technology can be expressed as an aggregate production function:

$$Y_t = F(K, N_t), \tag{1}$$

where Y_t denotes total real GDP, K denotes a fixed stock of capital (i.e., land), and N_t denotes population (i.e., the workforce of peasants). The production function F exhibits constant returns to scale in K and N_t . For example, suppose that F is a Cobb-Douglas function so that $F(K, N) = K^{1-\theta}N^\theta$, where $0 < \theta < 1$.

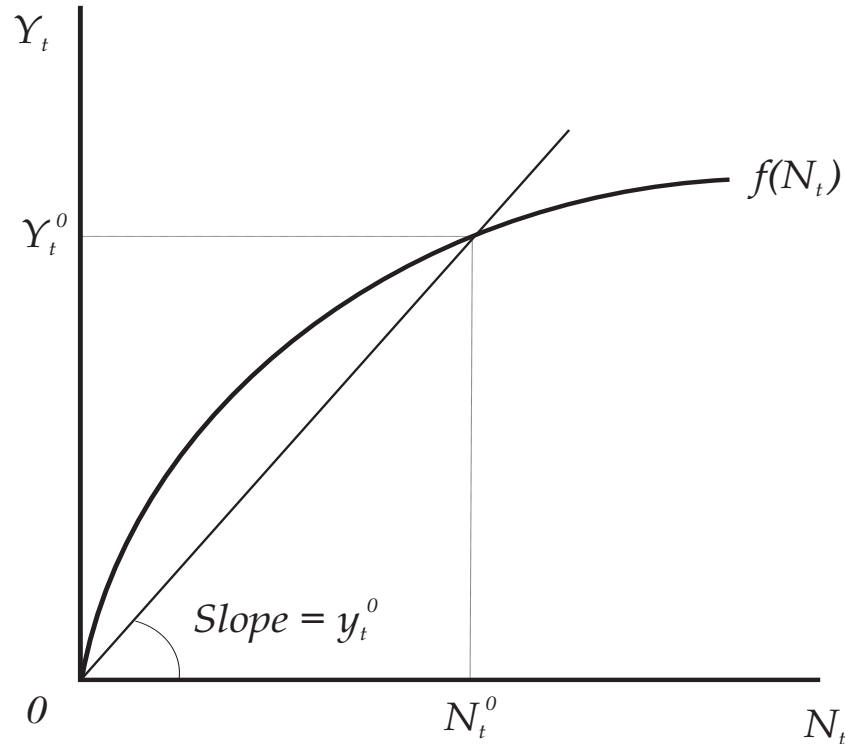
Because F exhibits constant returns to scale, it follows that per capita income $y_t \equiv Y_t/N_t$ is an increasing function of the capital-labor ratio. Since capital (land) is assumed to be in fixed supply, it follows that any increase in the population will lead to a lower capital-labor ratio, and hence a lower level of per capita output. Using our Cobb-Douglas function,

$$y_t = \frac{Y_t}{N_t} = \left(\frac{K}{N_t} \right)^{1-\theta},$$

which is clearly decreasing in N_t . The ‘hunger for food’ is captured by the assumption that all output is consumed.

On the other hand, the *total* GDP is clearly an increasing function of N_t ; i.e., $Y_t = K^{1-\theta}N_t^\theta$. However, since land is fixed in supply, total output increases at a decreasing rate with the size of the population. Let $f(N_t) \equiv K^{1-\theta}N_t^\theta$ denote total output; this production function is depicted in Figure 9.1.

FIGURE 9.1
Malthusian Production Function



The technology for producing people is expressed as follows. First, assume that there is an exogenous birth rate $b > 0$. This assumption captures Malthus' view that the rate of procreation is determined largely by noneconomic factors (such as the passion for sex). On the other hand, the mortality rate (especially among infants and the weaker members of society) was viewed by Malthus as determined in part by economic factors, primarily the level of material well-being as measured by per capita income y_t . An increase in y_t was thought to lower mortality rates (e.g., better fed babies are healthier and are less likely to die). Likewise, a decrease in y_t was thought to increase mortality rates. The dependence of the mortality rate m_t on living standards y_t can be expressed with the function:

$$m_t = m(y_t),$$

where $m(\cdot)$ is a decreasing function of y_t .

Let n_t denote the (net) population growth rate; i.e., $n_t \equiv b - m_t$. Then it is clear that the population growth rate is an increasing function of living

standards; a relation that we can write as:

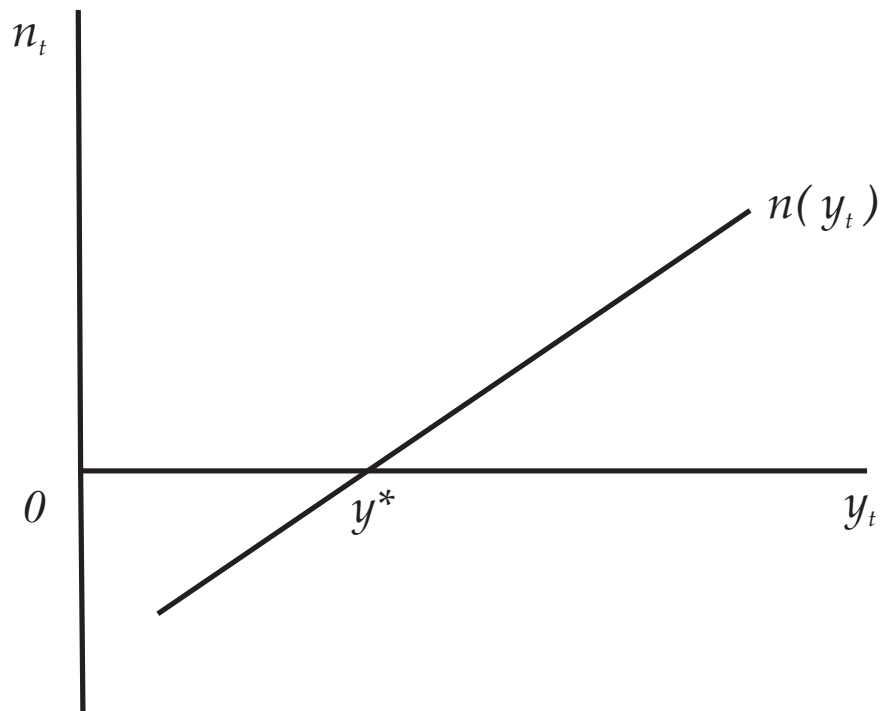
$$n_t = n(y_t), \quad (2)$$

where $n(\cdot)$ is an increasing function of y_t . This relationship is depicted in Figure 9.2. It follows then that the total population N_t grows according to:

$$N_{t+1} = [1 + n(y_t)]N_t. \quad (3)$$

Note that when $y_t = y^*$ (in Figure 9.2), the net population growth rate is equal to zero (the birth rate is equal to the mortality rate) and the population stays constant.

FIGURE 9.2
Population Growth Rate



3.2 Dynamics

The Malthusian growth model has implications for the way real per capita GDP evolves over time, given some initial condition. The initial condition is given

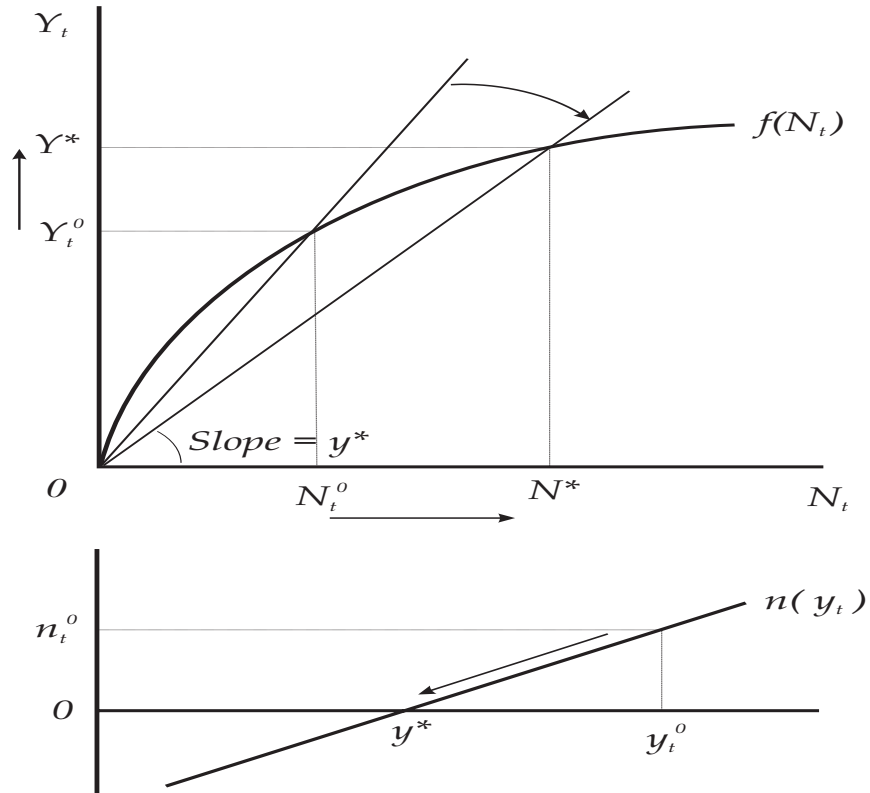
by the initial size of the population N_0 . For example, suppose that N_0 is such that $y_0 = f(N_0) > y^*$, where y^* is the ‘subsistence’ level of income depicted in Figure 9.2. Thus, initially at least, per capita incomes are above subsistence levels.

According to Figure 9.2, if per capita income is above the subsistence level, then the population grows in size (the mortality rate is lower than the birth rate); i.e., $n_0 > 0$. Consequently, $N_1 > N_0$. However, according to Figure 9.1, the added population (working the same amount of land) leads to a reduction in living standards (the average product of labor falls); i.e., $y_1 < y_0$.

Since living standards are lower in period 1, Figure 9.2 tells us that mortality rates will be higher, leading to a decline in the population growth rate; i.e., $n_1 < n_0$. However, since the population growth rate is still positive, the population will continue to grow (although at a slower rate); i.e., $N_2 > N_1$. Again, referring to Figure 9.1, we see that the higher population continues to put pressure on the land, leading to a further decline in living standards; i.e., $y_2 < y_1$.

By applying this logic repeatedly, we see that per capita income will eventually (the process could take several years or even decades) converge to its subsistence level; i.e., $y_t \searrow y^*$. At the same time, total GDP and population will rise to higher ‘long run’ values; i.e., $Y_t \nearrow Y^*$ and $N_t \nearrow N^*$. These ‘long run’ values are sometimes referred to as ‘steady states.’ Figure 9.3 depicts these transition dynamics.

FIGURE 9.3
Transition Dynamics



- **Exercise 9.1.** Using a diagram similar to Figure 9.3, describe the dynamics that result when the initial population is such that $N_0 > N^*$.

3.3 Technological Progress in the Malthus Model

We know that Medieval Europe (800 - 1400 A.D.) did experience a considerable amount of technological progress and population growth (e.g., the population roughly doubled from 800 A.D. to 1300 A.D.). Less is known about how living standards changed, but there appears to be a general view that at least moderate improvements were realized.

We can model an exogenous technological advance (e.g., the invention of the wheelbarrow) as an outward shift of the aggregate production function. Let us assume that initially, the economy is in a steady state with living standards

equal to y^* . In the period of the technology shock, per capita incomes rise as the improved technology makes the existing population more productive; i.e., $y_1 > y^*$. However, since living standards are now above subsistence levels, the population begins to grow; i.e., $N_1 > N_0$. Using the same argument described in the previous section, we can conclude that after the initial rise in per capita income, living standards will gradually decline back to their original level. In the meantime, the total population (and total GDP) expands to a new and higher steady state.

- **Exercise 9.2.** Using a diagram similar to Figure 9.3, describe the dynamics that result after the arrival of a new technology. Is the Malthus model consistent with the growth experience in Medieval Europe? Explain.

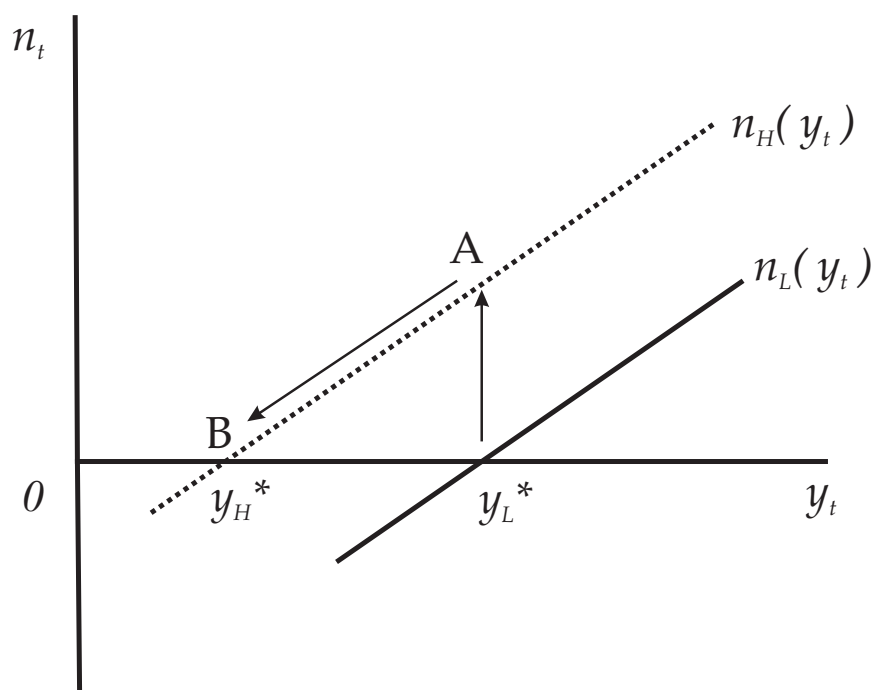
3.4 An Improvement in Health Conditions

The number one cause of death in the history of mankind has not been war, but disease.² Slowly, medical science progressed to the point of identifying the primary causes of various diseases and recommending preventative measures (such as boiling water). For example, during the 1854 Cholera epidemic in London, John Snow (who had experienced the previous epidemics of 1832 and 1854) became convinced that Cholera was a water-borne disease (caused by all the human waste and pollution being dumped into the Thames river). Public works projects, like the Thames Embankment (which was motivated more by Parliamentarians' aversion to the 'Great Stink' emanating from the polluted Thames, than by concerns over Cholera), led to greatly improved health conditions and reduced mortality rates.

We can model a technological improvement in the 'health technology' as an upward shift in the function $n(y_t)$; i.e., a decline in the mortality rate associated with any given living standard y_t . Again, assume that the economy is initially at a steady state y^* , depicted as point A in Figure 9.4. The effect of such a change is to immediately reduce mortality rates which, according to Malthusian reasoning, then leads to an increase in population. But as the population expands, the effect is to reduce per capita income. Eventually, per capita incomes fall to a new and lower subsistence level y_N^* , depicted by point B in Figure 9.4. That is, while the improved health conditions have the short run effect of lowering mortality rates, the subsequent decline in per capita reverses the effect so that in the long run, people are even worse off than before!

²Even during wars, most soldiers evidently died from disease rather than combat wounds. For an interesting account of the role of disease in human history, I would recommend reading Jared Diamond's book *Guns, Germs and Steel* (1997).

FIGURE 9.4
An Improvement in Health Technology



- **Exercise 9.3.** In 1347, the population of Europe was around 75 million. In that year, the continent was ravaged by a bubonic plague (the Black Death), which killed approximately 25 million people over a five year period (roughly one-third of the population). The ensuing labor shortages apparently led to a significant increase in real wages (per capita incomes), although total output fell. Using a diagram similar to Figure 9.4, describe the dynamics for per capita income in the Malthusian model when the economy is subject to a transitory increase in the mortality rate.

3.5 Confronting the Evidence

For most economies prior to 1800, growth in real per capita incomes were moderate to nonexistent. Since 1800, most economies have exhibited at least some growth in per capita incomes, but for many economies (that today comprise the world's underdeveloped nations), growth rates have been relatively low, leaving

their per capita income levels far behind the leading economies of the world.

The Malthusian model has a difficult time accounting for the sustained increase in per capita income experienced by many countries since 1800, especially in light of the sharp declines in mortality rates that have been brought about by continuing advancements in medical science. It is conceivable that persistent declines in the birth rate offset the declines in mortality rates (downward shifts of the population growth function in Figure 9.2) together with the continual appearance of technological advancements together could result in long periods of growth in per capita incomes. But the birth rate has a lower bound of zero and in any case, while birth rates do seem to decline with per capita income, most advanced economies continue to exhibit positive population growth.

In accounting for cross-section differences in per capita incomes, the Malthusian model suggests that countries with high population densities (owing to high birth rates) will be those economies exhibiting the lowest per capita incomes. One can certainly find modern day countries, like Bangladesh, that fit this description. On the other hand, many densely populated economies, such as Hong Kong, Japan and the Netherlands have higher than average living standards. As well, there are many cases in which low living standards are found in economies with low population density. China, for example, has more than twice as much cultivated land per capita as Great Britain or Germany.

At best, the Malthusian model can be regarded as giving a reasonable account of the pattern of economic development in the world prior to the Industrial Revolution. Certainly, it seems to be true that the vast bulk of technological improvements prior to 1800 manifested themselves primarily in the form of larger populations (and total output), with only modest improvements in per capita incomes.

4 Fertility Choice

The Malthusian model does not actually model the fertility choices that households make. The model simply assumes that the husband and wife decide to create children for really no reason at all. Perhaps children are simply the by-product of uncontrollable passion or some primeval urge to propagate one's genetic material. Or perhaps in some cultures, men perceive that their status is enhanced with prolific displays of fertility. Implicitly, it is assumed that the fertility choices that people make are 'irrational.' In particular, some simple family planning (choosing to reduce the birth rate) would appear to go a long way to improving the living standards of future generations.

- **Exercise 9.4.** Suppose that individuals could be taught to choose the birth rate according to: $b(y) = m(y)$ (i.e., to produce just enough children to replace those people who die). Explain how technological progress would now result in higher per capita incomes.

While it is certainly the case that the family planning practices of some households seem to defy rational explanation, perhaps it is going too far to suggest that the majority of fertility choices are made largely independent of economic considerations. In fact, it seems more likely to suppose that fertility is a rational choice, even in lesser developed economies. A 1984 World Bank report puts it this way (quoted from Razin and Sadka, 1995, pg. 5):

All parents everywhere get pleasure from children. But children involve economic costs; parents have to spend time and money bringing them up. Children are also a form of investment—providing short-term benefits if they work during childhood, long-term benefits if they support parents in old age. There are several good reasons why, for poor parents, the economic costs of children are low, the economic (and other) benefits of children are high, and having many children makes economic sense.

Here, I would like to focus on the idea of children as constituting a form of investment. What appears to be true of many primitive societies is a distinct lack in the ability for large segments of society to accumulate wealth in the form of capital goods or (claims to) land. Partly this was due to a lack of well-developed financial markets and partly this was due to the problem of theft (only the very rich could afford to spend the resources necessary to protect their property). Given such constraints, it may well make sense for poorer families to store their wealth through other means, for example, by investing in children (although, children can also be stolen, for example, by conscription into the military).

Let us try to formalize this idea by way of a simple model. Consider an economy in which time evolves according to $t = 0, 1, 2, \dots, \infty$. For simplicity, assume that individuals live for two periods. In period one they are ‘young’ and in period two they are ‘old.’ Let $c_t(j)$ denote the consumption enjoyed by an individual at period t in the j^{th} period of life, where $j = 1, 2$. Assume that individuals have preferences defined over their lifetime consumption profile $(c_t(1), c_{t+1}(2))$, with:

$$U_t = \ln c_t(1) + \beta \ln c_{t+1}(2),$$

where $0 < \beta < 1$ is a subjective discount factor. For these preferences, the marginal rate of substitution between time-dated consumption is given by $MRS = c_{t+1}(2)/(\beta c_t(1))$.

Let N_t denote the number of young people alive at date t , so that N_{t-1} represents the number of old people alive at date t . The population of young people grows according to:

$$N_{t+1} = n_t N_t,$$

where n_t here is the *gross* population growth rate; i.e., the average number of children per (young) family. Note that $n_t > 1$ means that the population is expanding, while $n_t < 1$ means that the population is contracting. We will

assume that n_t is chosen by the young according to some rational economic principle.

Assume that only the young can work and that they supply one unit of labor at the market wage rate w_t . Because the old cannot work and because they have no financial wealth to draw on, they must rely on the current generation of young people (their children) to support them. Suppose that these intergenerational transfers take the following simple form: The young set aside some fraction $0 < \theta < 1$ of their current income for the old. Since the old at date t have n_{t-1} children, the old end up consuming:

$$c_t(2) = n_{t-1}\theta w_t. \quad (4)$$

This expression tells us that the living standards of old people are an increasing function of the number of children they have supporting them. As well, their living standards are an increasing function of the real wage earned by their children.

Creating and raising children entails costs. Assume that the cost of n_t children is n_t units of output. In this case, the consumption accruing to a young person (or family) at date t is given by:

$$c_t(1) = (1 - \theta)w_t - n_t. \quad (5)$$

By substituting equation (5) into equation (4), with the latter equation updated one period, we can derive the following lifetime budget constraint for a representative young person:

$$c_t(1) + \frac{c_{t+1}(2)}{\theta w_{t+1}} = (1 - \theta)w_t. \quad (6)$$

Equation (6) should look familiar to you. In particular, the left hand side of the constraint represents the present value of lifetime consumption spending. But instead of discounting future consumption by the interest rate (which does not exist here since there are no financial markets), future consumption is discounted by a number that is proportional to the *future* wage rate. In a sense, the future wage rate represents the implicit interest rate that is earned from investing in children today. Figure 9.5 displays the optimal choice for a given pattern of wages (w_t, w_{t+1}) .

FIGURE 9.5
Optimal Family Size

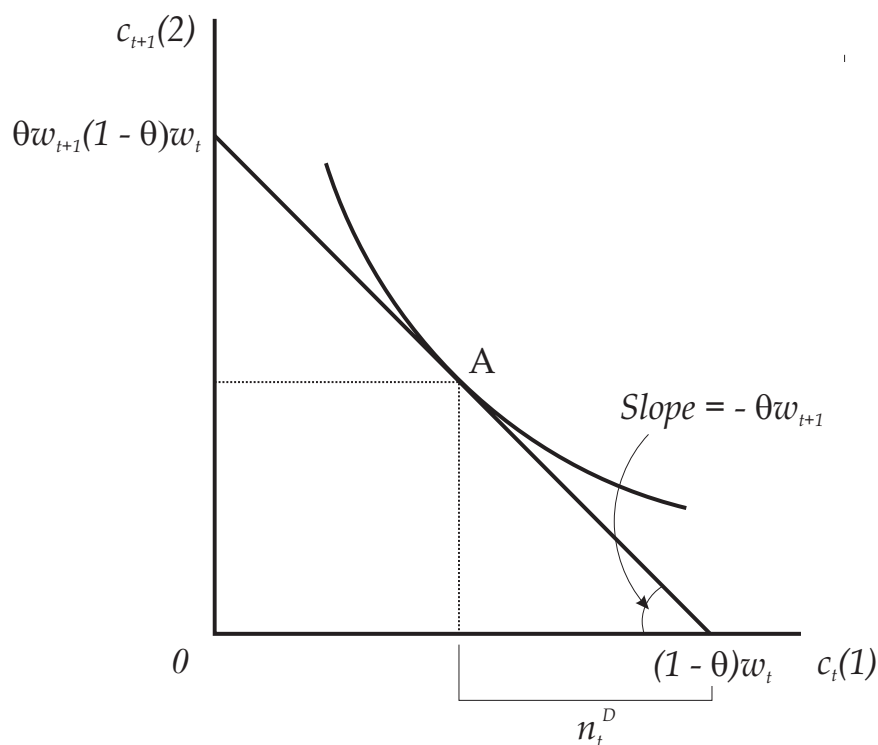


Figure 9.5 makes clear the analog between the savings decision analyzed in Chapter 6 and the investment choice in children as a vehicle for saving in the absence of any financial market. While having more children reduces the living standards when young, it increases living standards when old. At point A, the marginal cost and benefit of children are exactly equal. Note that the desired family size generally depends on both current and future wages; i.e., $n_t^D = n^D(w_t, w_{t+1})$.

- **Exercise 9.5.** How does desired family size depend on current and future wages? Explain.

We will now explain how wages are determined. Assume that the aggregate production technology is given by (1). The fixed factor K , which we interpret to be land, is owned by a separate class of individuals (landlords). Imagine that landlords are relatively few in number and that they form an exclusive club (so

that most people are excluded from owning land). Landowners hire workers at the competitive wage rate w_t in order to maximize the return on their land $D_t = F(K, N_t) - w_t N_t$. As in Appendix 2.1, the profit maximizing labor input $N_t^D = N^D(w_t)$ is the one that just equates the marginal benefit of labor (the marginal product of labor) to the marginal cost (the wage rate); i.e.,

$$MPL(N^D) = w_t.$$

The equilibrium wage rate w_t^* is determined by equating the supply and demand for labor; i.e.,

$$N^D(w_t^*) = N_t.$$

Alternatively, you should be able to show that the equilibrium wage rate can also be expressed as: $w_t^* = MPL(N_t)$.

- **Exercise 9.6.** How does the equilibrium wage rate depend on the supply of labor N_t ? Explain.

Mathematically, the general equilibrium of our model economy is characterized by the following condition:

$$N_{t+1} = n^D(w_t^*, w_{t+1}^*)N_t$$

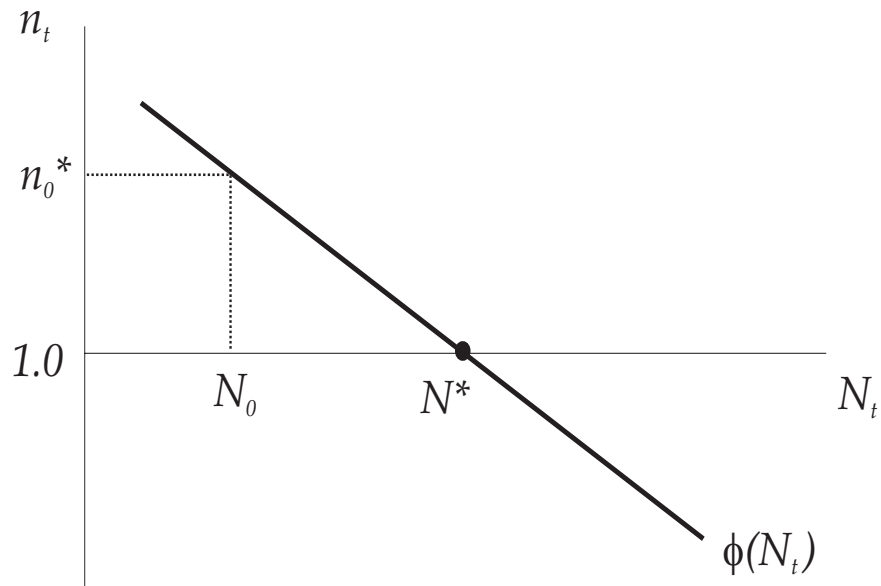
where $w_t^* = MPL(N_t)$, with N_t given as of period t . These expressions implicitly defines a function $n_t^* = \phi(N_t)$.³ A stable steady state will exist if $\phi'(N) < 0$, so let us make this assumption here.⁴ This condition asserts that the equilibrium population growth rate is a decreasing function of population size; see Figure 9.6.

³The function ϕ is defined implicitly by:

$$\phi(N_t) = n^D(MPL(N_t), MPL(\phi(N_t)N_t)).$$

⁴I am pretty sure that for sufficiently large populations, the function ϕ must eventually decline with population since land is in fixed supply.

FIGURE 9.6
Equilibrium Population Dynamics



In Figure 9.6, the initial population of young people is given by N_0 , which results in population growth. In the subsequent period, $N_1 > N_0$, which puts added pressure on the limited supply of land (just as in the Malthusian model), resulting in a decline in the equilibrium wage.⁵ Unlike the Malthusian model, however, people here are making rational choices about family size. As the population expands, it is rational to reduce family size. Eventually, the population reaches a steady state level N^* .

From the condition that characterizes optimal family size (Figure 9.5), the steady state consumption levels must satisfy:

$$\frac{1}{\beta} \frac{c^*(1)}{c^*(2)} = w^* = MPL(N^*).$$

Now, assume that the share parameter θ is chosen according to a principle of ‘long-run fairness,’ so that $c^*(1) = c^*(2)$. Notice that this does not necessarily imply that consumption is equated across generations during the transition to

⁵As the future wage rate is expected to decline, the return to investing in children also declines (the substitution effect) would further curtail the production of children.

a steady state; it only implies that consumption is equated in the steady state. In this case, the equilibrium steady state population size (and wage rate) is determined by:

$$MPL(N^*) = \frac{1}{\beta} = w^*. \quad (7)$$

Condition (7) tells us that the steady state population N^* is determined by the nature of the production technology (MPL) and the nature of preferences (β).

Now, beginning in some steady state, let us examine how this economy reacts to a technology shock that improves production methods. The effect of the shock is to increase the marginal product of labor at every level of employment (so that the function ϕ in Figure 9.6 shifts upward). From equation (7), we see that the initial effect of the shock is to increase the wage rate above w^* . A standard consumption-smoothing argument suggests that consumption rises initially for both the young and old. The way that the initial young can guarantee higher future consumption is by having more children (re: Exercise 9.5). The increasing population, however, puts downward pressure on the wage until it eventually falls to its initial value w^* . From equation (7), we see that the long-run wage rate depends only on β and not on the nature of technology. It follows, therefore, that the long-run living standards of those individuals who must save by investing in children remains unaffected by technological progress.

The effect of technological progress on per capita income depends on the breeding habits of landlord families and the relative importance of land versus labor in the production process. If landlord family size remains constant over time, then per capita income will rise since the shock increases the return to land. But if land accounts for a relatively small fraction of total output, then the impact on per capita GDP will be small.

4.1 Policy Implications

The basic point of this analysis is to show that what appears (to us) to be irrational family planning may in fact be the consequence of rational choices made by individuals who are prevented from saving through the accumulation of financial assets or physical capital. The policy implications here differ quite radically from those that one might deduce from the Malthusian model. In particular, the Malthusian model suggests that a government program designed to limit the breeding rate of peasants might be a good idea. An example of this is the ‘one-child’ policy implemented by the Chinese government in 1980.⁶ In contrast, the model developed in this section suggests that a better idea might be to make participation in capital markets more accessible for the poor. Less reliance on children to finance retirement living standards would imply lower population growth rates and higher material living standards for all people.

⁶<http://nhs.needham.k12.ma.us/cur/kane98/kanep2/chinas1kid/dcva2.html>

5 Problems

1. Many countries have implemented *pay-as-you-go* (PAYG) public pension systems. A PAYG system taxes current income earnings (the young) and transfers these resources to the initial old. Explain how such a system could also serve to reduce population growth.
2. Many countries with PAYG pension systems are currently struggling with the problem of population growth rates that are *too low*; e.g., see: www.oecdobserver.org/news/fullstory.php/aid/563/Can_governments_influence_population_growth_.html, for the case of Sweden. Use the model developed in this section to interpret this phenomenon.
3. Economists have advocated replacing the PAYG pension system with a *fully funded* (FF) pension system. Whereas the PAYG system transfers resources across generations (from the young to the old in perpetuity), the FF system taxes the young and invests the proceeds in capital markets (so that there are no intergenerational transfers). Does the FF system sound like a good idea? Explain.

6 References

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