# Appendix 3.1

## Components of Economic Growth

Three components of economic growth are of prime importance:

1. Capital accumulation, including all new investments in land, physical equipment, and human resources through improvements in health, education, and job skills
2. Growth in population and hence eventual growth in the labor force
3. Technological progress—new ways of accomplishing tasks

In this appendix, we look briefly at each.

### Capital Accumulation

**Capital accumulation** results when some proportion of present income is saved and invested in order to augment future output and income. New factories, machinery, equipment, and materials increase the physical **capital stock** of a nation (the total net real value of all physically productive capital goods) and make it possible for expanded output levels to be achieved. These directly productive investments are supplemented by investments in what is known as social and **economic infrastructure**—roads, electricity, water and sanitation, communications, and the like—which facilitates and integrates economic activities. For example, investment by a farmer in a new tractor may increase the total output of the crops he can produce, but without adequate transport facilities to get this extra product to local commercial markets, his investment may not add anything to national food production.

**Capital accumulation** Increasing a country's stock of real *capital* (net *investment* in fixed assets). To increase the production of capital *goods* necessitates a reduction in the production of consumer goods.

**Capital stock** The total amount of physical goods existing at a particular time that have been produced for use in the production of other goods and services.

**Economic infrastructure** The amount of physical and financial capital embodied in roads, railways, waterways, airways, and other transportation and communications, plus other facilities such as water supplies, financial institutions, electricity, and public services such as health and education.

There are less direct ways to invest in a nation's resources. The installation of irrigation systems may improve the quality of a nation's agricultural land by raising productivity per hectare. If 100 hectares of irrigated land can produce the same output as 200 hectares of nonirrigated land using the same other inputs, the installation of such irrigation is the equivalent of doubling the quantity of nonirrigated land. Use of chemical fertilizers and the control of insects with pesticides may have equally beneficial effects in raising the productivity of existing farmland. All these forms of investment are ways of improving the quality of existing land resources. Their effect in raising the total stock of productive land is, for all practical purposes, indistinguishable from the simple clearing of hitherto unused arable land.

Similarly, investment in human resources can improve its quality and thereby have the same or even a more powerful effect on production as an increase in human numbers. Formal schooling, vocational and on-the-job training programs, and adult and other types of informal education may all be made more effective in augmenting human skills as a result of direct investments in buildings, equipment, and materials (e.g., books, film projectors, personal computers, science equipment, vocational tools, and machinery such as lathes and grinders). The advanced and relevant training of teachers, as well as good textbooks in economics, may make an enormous difference in the quality, leadership, and productivity of a given labor force. Improved health can also significantly boost productivity. The concept of investment in human resources and the creation of **human capital** is therefore analogous to that of improving the quality and thus the productivity of existing land resources through strategic investments.

All of these phenomena and many others are forms of investment that lead to capital accumulation. Capital accumulation may add new resources (e.g., the clearing of unused land) or upgrade the quality of existing resources (e.g., irrigation), but its essential feature is that it involves a trade-off between present and future consumption—giving up a little now so that more can be had later, such as giving up current income to stay in school.

## Population and Labor Force Growth

Population growth, and the associated eventual increase in the labor force, have traditionally been considered a positive factor in stimulating economic growth. A larger labor force means more productive workers, and a large overall population increases the potential size of domestic markets. However, it is questionable whether rapidly growing supplies of workers in developing countries with a surplus of labor exert a positive or a negative influence on economic progress (see Chapter 6 for an in-depth discussion of the pros and cons of population growth for economic development). Obviously, it will depend on the ability of the economic system to absorb and productively employ these added workers—an ability largely associated with the rate and kind of capital accumulation and the availability of related factors, such as managerial and administrative skills.

**Production possibility curve** A curve on a graph indicating alternative combinations of two commodities or categories of commodities (e.g., agricultural and manufactured goods) that can be produced when all the available factors of production are efficiently employed. Given available resources and technology, the curve sets the boundary between the attainable and the unobtainable.

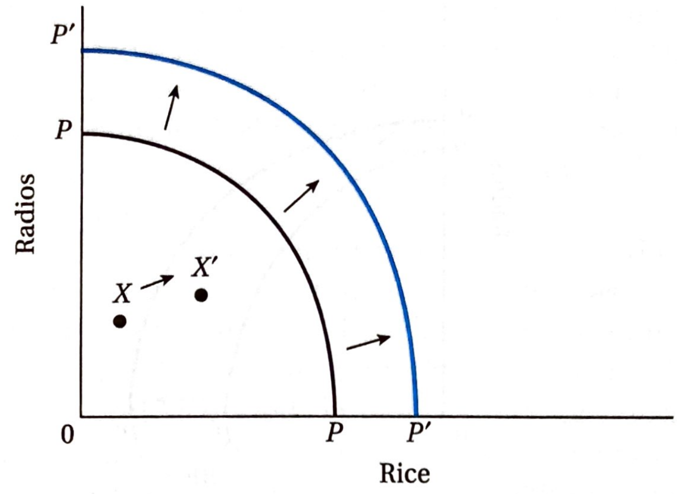
Given an initial understanding of these first two fundamental components of economic growth and disregarding for a moment the third (technology), let us see how they interact via the **production possibility curve** to expand society's potential total output of all goods. For a given technology and a given amount of physical and human resources, the production possibility curve portrays the *maximum* attainable output combinations of any two commodities—say, rice and radios—when all resources are fully and efficiently employed. Figure A3.1.1 shows two production possibility curves for rice and radios.

Initial possibilities for the production of rice and radios are shown by the curve *PP*. Now suppose that without any change in technology, the quantity of physical and human resources were to double as a result of either investments that improved the quality of the existing resources or investment in new resources—land, capital, and, in the case of larger families, labor. Figure A3.1.1 shows that this doubling of total resources will cause the entire production possibility curve to shift uniformly outward from *PP* to *P′P′*. More radios and more rice can now be produced.

Because these are assumed to be the only two goods produced by this economy, it follows that the gross domestic product (the total value of all goods and services produced) will be higher than before. In other words, the process of economic growth is under way.

Note that even if the country in question is operating with underutilized physical and human resources, as at point *X* in Figure A3.1.1, a growth

FIGURE A3.1.1 Effect of Increases in Physical and Human Resources on the Production Possibility Frontier




of productive resources can result in a higher total output combination, as at point $X'$, even though there may still be widespread unemployment and underutilized or idle capital and land. But note also that there is nothing deterministic about resource growth leading to higher output growth. This is not an economic law, as attested by the poor growth record of many contemporary developing countries. Nor is resource growth even a necessary condition for *short-run* economic growth because the better utilization of idle existing resources can raise output levels substantially, as portrayed in the movement from $X$ to $X'$ in Figure A3.1.1. Nevertheless, in the *long run*, the improvement and upgrading of the quality of existing resources and new investments designed to expand the quantity of these resources are principal means of accelerating the growth of national output.

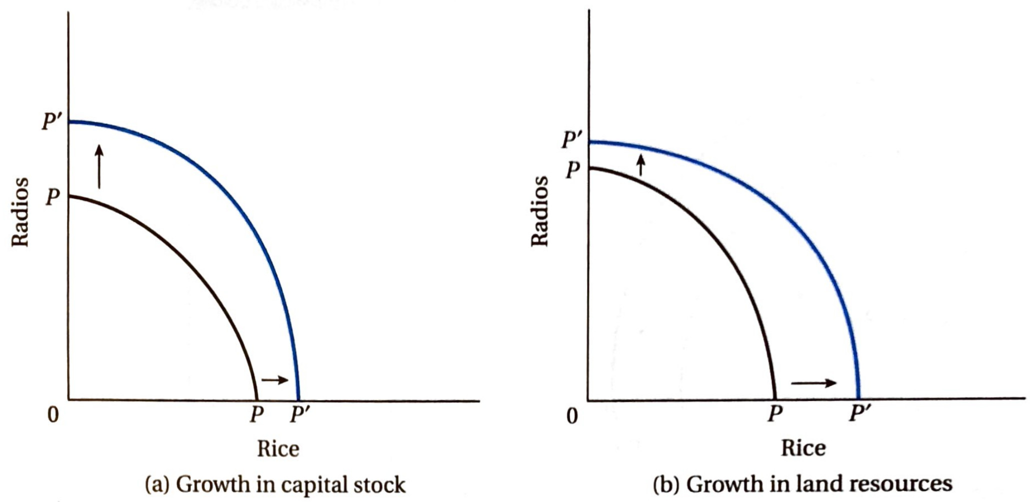
Now, instead of assuming the proportionate growth of *all* factors of production, let us assume that, say, only capital or only land is increased in quality and quantity. Figure A3.1.2 shows that if radio manufacturing is a relatively large user of capital equipment and rice production is a relatively land-intensive process, the shifts in society's production possibility curve will be more pronounced for radios when capital grows rapidly (Figure A3.1.2a) and for rice when the growth is in land quantity or quality (Figure A3.1.2b). However, because under normal conditions both products will require the use of both factors as productive inputs, albeit in different combinations, the production possibility curve still shifts slightly outward along the rice axis in Figure A3.1.2a when only capital is increased and along the radio axis in Figure A3.1.2b when only the quantity or quality of land resources is expanded.

## Technological Progress

It is now time to consider the third, and to many economists the most important, source of economic growth, **technological progress**. In its simplest form, technological progress results from new and improved ways of accomplishing traditional tasks such as growing crops, making clothing, or building

**Technological progress** Increased application of new scientific knowledge in the form of inventions and innovations with regard to both physical and human capital.

FIGURE A3.1.2 Effect of Growth of Capital Stock and Land on the Production Possibility Frontier




a house. There are three basic classifications of technological progress: neutral, laborsaving, and capital-saving.

**Neutral technological progress** Higher output levels achieved with the same quantity or combination of all factor inputs.

**Neutral technological progress** occurs when higher output levels are achieved with the same quantity and combinations of factor inputs. Simple innovations like those that arise from the division of labor can result in higher total output levels and greater consumption for all individuals. In terms of production possibility analysis, a neutral technological change that, say, doubles total output is conceptually equivalent to a doubling of all productive inputs. The outward-shifting production possibility curve of Figure A3.1.1 could therefore also be a diagrammatic representation of neutral technological progress.

By contrast, technological progress may result in savings of either labor or capital (i.e., higher levels of output can be achieved with the same quantity of labor or capital inputs). Computers, the Internet, automated looms, high-speed electric drills, tractors, mechanical ploughs—these and many other kinds of modern machinery and equipment can be classified as products of **laborsaving technological progress**. Technological progress since the late nineteenth century has consisted largely of rapid advances in laborsaving technologies for producing everything from beans to bicycles to bridges.

**Laborsaving technological progress** The achievement of higher output using an unchanged quantity of labor inputs as a result of some invention (e.g., the computer) or innovation (such as assembly-line production).

**Capital-saving technological progress** Technological progress that results from some invention or innovation that facilitates the achievement of higher output levels using the same quantity of inputs of capital.

**Capital-saving technological progress** is a much rarer phenomenon. But this is primarily because most of the world's scientific and technological research is conducted in developed countries, where the mandate is to save labor, not capital. In the labor-abundant (capital-scarce) developing countries, however, capital-saving technological progress is what is needed most. Such progress results in more efficient (lower-cost) labor-intensive methods of production—for example, hand- or rotary-powered weeders and threshers, foot-operated bellows pumps, and back-mounted mechanical sprayers for small-scale agriculture. The indigenous development of low-cost, efficient, labor-intensive (capital-saving) techniques of production is one of the essential ingredients in any long-run employment-oriented development strategy (see Appendix 5.1).

Technological progress may also be labor- or capital-augmenting. **Labor-augmenting technological progress** occurs when the quality or skills of the labor force are upgraded—for example, by the use of videotapes, televisions, and other electronic communications media for classroom instruction. Similarly, **capital-augmenting technological progress** results in the more productive use of existing capital goods—for example, the substitution of steel for wooden plows in agricultural production.

**Labor-augmenting technological progress** Technological progress that raises the productivity of an existing quantity of labor by general education, on-the-job training programs, and so on.

**Capital-augmenting technological progress** Technological progress that raises the productivity of capital by innovation and inventions.

We can use our production possibility curve for rice and radios to examine two very specific examples of technological progress as it relates to output growth in developing countries. In the 1960s, agricultural scientists at the International Rice Research Institute in the Philippines developed a new and highly productive hybrid rice seed, known as IR-8, or "miracle rice." These new seeds, along with later further scientific improvements, enabled some rice farmers in parts of South and Southeast Asia to double or triple their yields in a matter of a few years. In effect, this technological progress was "embodied" in the new rice seeds (one could also say it was "land-augmenting"), which permitted higher output levels to be achieved with essentially the same complementary inputs (although more fertilizer and pesticides were recommended). In terms of our production possibility analysis, the higher-yielding varieties of hybrid rice could be depicted, as in Figure A3.1.3, by an outward shift of the curve along the rice axis with the intercept on the radio axis remaining essentially unchanged (i.e., the new rice seeds could not be directly used to increase radio production).

In terms of the technology of radio production, the invention of transistors has probably had as significant an impact on communications as the development of the steam engine had on transportation. Even in the remotest parts of Africa, Asia, and Latin America, the transistor radio has become a prized possession. The introduction of the transistor, by obviating the need

**FIGURE A3.1.3** Effect of Technological Change in the Agricultural Sector on the Production Possibility Frontier

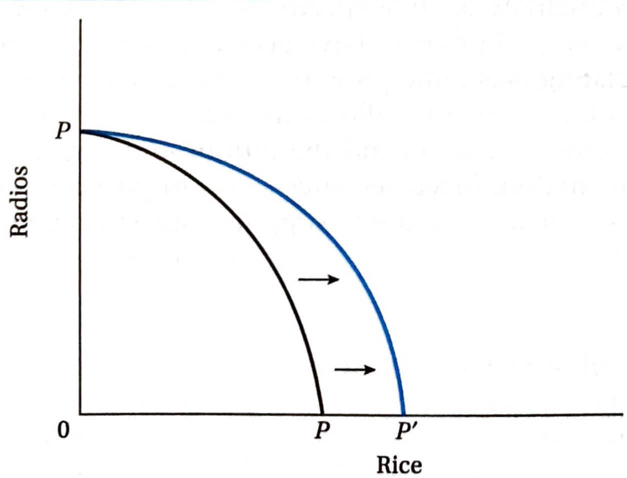
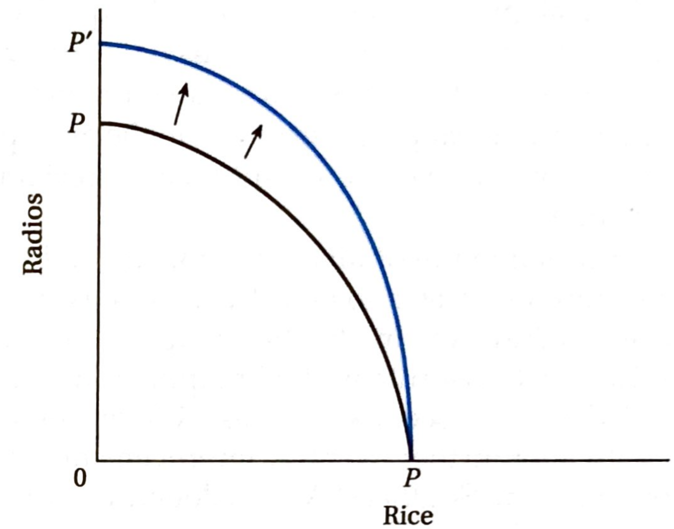


FIGURE A3.1.4 Effect of Technological Change in the Industrial Sector on the Production Possibility Frontier




for complicated, unwieldy, and fragile tubes, led to an enormous growth of radio production. The production process became less complicated, and workers were able to increase their total productivity significantly. Figure A3.1.4 shows that as in the case of higher-yielding rice seeds, the technology of the transistor can be said to have caused the production possibility curve to rotate outward along the vertical axis. For the most part, the rice axis intercept remains unchanged (although perhaps the ability of rice paddy workers to listen to music on their transistor radio while working may have made them more productive!).

## Conclusion

The sources of economic progress can be traced to a variety of factors, but by and large, investments that improve the quality of existing physical and human resources, increase the quantity of these same productive resources, and raise the productivity of all or specific resources through invention, innovation, and technological progress have been and will continue to be primary factors in stimulating economic growth in any society. The production possibility framework conveniently allows us to analyze the production choices open to an economy, to understand the output and opportunity cost implications of idle or underutilized resources, and to portray the effects on economic growth of increased resource supplies and improved technologies of production.

# Appendix 3.2

## The Solow Neoclassical Growth Model

The Solow neoclassical growth model, for which Robert Solow of the Massachusetts Institute of Technology received the Nobel Prize, is probably the best-known model of economic growth.[1] Although in some respects Solow's model describes a developed economy better than a developing one, it remains a basic reference point for the literature on growth and development. It implies that economies will conditionally converge to the same level of income if they have the same rates of savings, depreciation, labor force growth, and productivity growth. Thus, the Solow model is the basic framework for the study of convergence across countries (see Chapter 2). In this appendix, we consider this model in further detail.

The key modification from the Harrod-Domar (or *AK*) growth model, considered in this chapter, is that the Solow model allows for substitution between capital and labor. In the process, it assumes that there are diminishing returns to the use of these inputs.

The aggregate production function, $Y = F(K, L)$ is assumed characterized by constant returns to scale. For example, in the special case known as the Cobb-Douglas production function, at any time $t$ we have

$$Y(t) = K(t)^{\alpha}(A(t)L(t))^{1-\alpha} \tag{A3.2.1}$$

where $Y$ is gross domestic product, $K$ is the stock of capital (which may include human capital as well as physical capital), $L$ is labor, and $A(t)$ represents the productivity of labor, which grows over time at an exogenous rate.

Because of constant returns to scale, if all inputs are increased by the same amount, say 10%, then output will increase by the same amount (10% in this case). More generally,

$$\gamma Y = F(\gamma K, \gamma L)$$

where $\gamma$ is some positive amount (1.1 in the case of a 10% increase).

Because $\gamma$ can be any positive real number, a mathematical trick useful in analyzing the implications of the model is to set $\gamma = 1/L$ so that

$$Y/L = f(K/L, 1) \text{ or } y = f(k) \tag{A3.2.2}$$

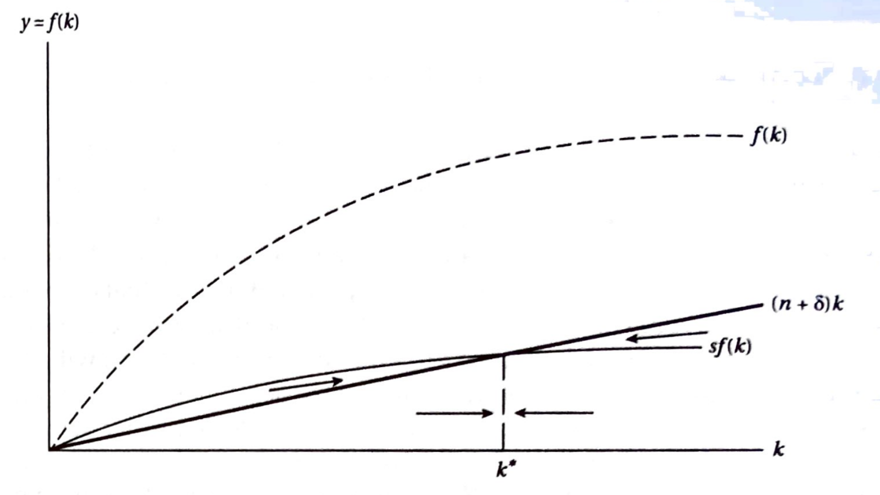
Lowercase variables are expressed in per-worker terms in these equations. The concave shape of $f(k)$—that is, increasing at a decreasing rate—reflects diminishing returns to capital per worker, as can be seen in Figure A3.2.1.[2] In the Harrod-Domar model, this would instead be a straight, upward-sloping line.

This simplification allows us to deal with just one argument in the production function. For example, in the Cobb-Douglas case introduced in Equation A3.2.1,

$$y = Ak^{\alpha} \tag{A3.2.3}$$

This represents an alternative way to think about a production function, in which everything is measured in quantities per worker. Equation A3.2.3 states that output per worker is a function that depends on the amount of capital per worker. The more capital with which each worker has to work, the more output that worker can produce. The labor force grows at rate $n$ per year, say,

FIGURE A3.2.1 Equilibrium in the Solow Growth Model




and labor productivity growth, the rate at which the value of $A$ in the production function increases, occurs at rate $\lambda$. The total capital stock grows when savings are greater than depreciation, but capital per worker grows when savings are also greater than what is needed to equip new workers with the same amount of capital as existing workers have.

The Solow equation (Equation A3.2.4) gives the growth of the capital-labor ratio, $k$ (known as capital deepening), and shows that the growth of $k$ depends on savings $sf(k)$, after allowing for the amount of capital required to service depreciation, $\delta k$, and after capital widening, that is, providing the existing amount of capital per worker to net new workers joining the labor force, $nk$. That is,

$$\Delta k = sf(k) - (\delta + n)k \qquad \text{(A3.2.4)}$$

Versions of the Solow equation are also valid for other growth models, such as the Harrod-Domar model.

For simplicity, we are assuming for now that $A$ remains constant. In this case, there will be a state in which output and capital per worker are no longer changing, known as the *steady state*. (If $A$ is increasing, the corresponding state will be one in which capital per effective worker is no longer changing. In that case, the number of effective workers rises as $A$ rises; this is because when workers have higher productivity, it is as if there were extra workers on the job.) To find this steady state, set $\Delta k = 0$:

$$sf(k^*) = (\delta + n)k^* \qquad \text{(A3.2.5)}$$

The notation $k^*$ means the level of capital per worker when the economy is in its steady state. That this equilibrium is stable can be seen from Figure A3.2.1.[3]

The capital per worker $k^*$ represents the steady state. If $k$ is higher or lower than $k^*$, the economy will return to it; thus $k^*$ is a stable equilibrium. This stability is seen in the diagram by noting that to the left of $k^*$, $k < k^*$. Looking at the diagram, we see that in this case, $(n + \delta)k < sf(k)$. But now looking at the Solow equation (Equation A3.2.4), we see that when $(n + \delta)k < sf(k)$, $\Delta k > 0$. As a result, $k$ in the economy is growing toward the equilibrium point $k^*$. By similar reasoning to the right of $k^*$, $(n + \delta)k > sf(k)$, and as a result, $\Delta k < 0$

(again refer to Equation A3.2.4), and capital per worker is actually shrinking toward the equilibrium $k^*$.[4] Note that in the Harrod-Domar model, $sf(k)$ would be a straight line, and provided that it was above the $(n + \delta)k$ line, growth in capital per worker—and output per worker—would continue indefinitely.

Equation (A3.2.5) has an interpretation that the savings per worker, $sf(k^*)$, is just equal to $\delta k^*$, the amount of capital (per worker) needed to replace depreciating capital, plus $nk^*$, the amount of capital (per worker) that needs to be added due to population (labor force) growth.

The Solow model has a (single) equilibrium income per worker, again given by Equation (A3.2.5) above. In contrast, the Harrod Domar equilibrium is (constant, balanced) growth—there is no equilibrium income per worker. Essentially, this is because $f(k)$—and hence $sf(k)$—does not exhibit diminishing returns; rather, it is a straight line. That is, growth continues as long as the line $sf(k)$ stays above the line $(\delta + n)k$.

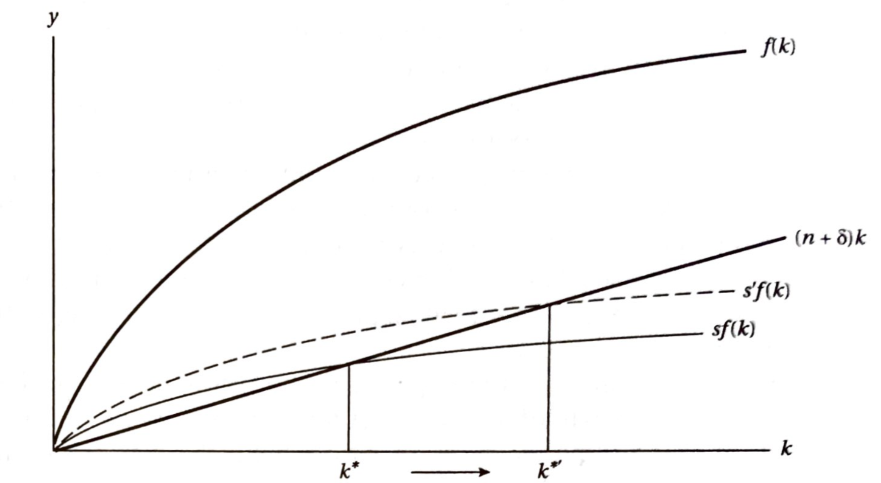
It is instructive to consider what happens in the Solow neoclassical growth model if we increase the rate of savings, $s$. A temporary increase in the rate of output growth is realized as we increase $k$ by raising the rate of savings. We return to the original steady-state growth rate later, though at a higher level of output per worker in each later year. The key implication is that unlike in the Harrod-Domar ($AK$) analysis, in the Solow model an increase in $s$ will not increase growth in the long run; it will only increase the equilibrium $k^*$. That is, after the economy has time to adjust, the capital-labor ratio increases, and so does the output-labor ratio, but not the rate of growth. The effect is shown in Figure A3.2.2, in which savings is raised to $s'$. In contrast, in the Harrod-Domar model, an increase in $s$ raises the growth rate. (This is because in the Harrod-Domar model, $sf(k)$ becomes a straight line from the origin that does not cross $(n + \delta)k$; and so, as we assume that $sf(k)$ lies above $(n + \delta)k$, growth continues at the now higher Harrod-Domar rate—a result that was represented, for example, in the comparison of Equations 3.8 and 3.9.)

Note that the neoclassical growth model (Equation A3.2.5 and Figure A3.2.1) implies that while economies will (conditionally) converge to the same level of income per worker *other things equal*, it does not imply unconditional convergence. This can be seen clearly in Figure A3.2.2: We can interpret the alternative savings rates ($s$ and $s'$) in the figure as corresponding to those prevailing in two different countries; the country with the higher savings rate converges to a higher equilibrium income per worker.

Note carefully that in the Solow model, an increase in $s$ does raise equilibrium output per person—which is certainly a valuable contribution to development—just not the equilibrium rate of growth. And the growth rate does increase temporarily as the economy kicks up toward the higher equilibrium capital per worker. Moreover, simulations based on cross-national data suggest that if $s$ is increased, the economy may not return even halfway to its steady state for decades.[5] That is, for practical purposes of policymaking in developing countries, even if the Solow model is an accurate depiction of the economy, an increase in savings may substantially increase the growth rate for many decades to come. (Both theoretically and empirically, the link between the rate of savings and the rate of growth remains controversial.)

Finally, it is possible that the rate of savings (and hence investment) is positively related to the rate of technological progress itself so that the growth of $A$ depends on $s$. This could be the case if investment uses newer-vintage

FIGURE A3.2.2 The Long-Run Effect of Changing the Savings Rate in the Solow Model




capital and hence is more productive, if investment represents innovation in that it solves problems faced by the firm, and if other firms see what the investing firm has done and imitate it ("learning by watching"), generating externalities. This leads to a model between the standard Solow model and the endogenous growth models such as the one examined in Appendix 3.3.

## Notes

1. Robert M. Solow, "A contribution to the theory of economic growth," *Quarterly Journal of Economics* 70 (1956): 65–94.
2. Note that the symbol $k$ is used for $K/L$ and not for $K/Y$, as it is used in many expositions (including previous editions of this text) of the $AK$ or Harrod-Domar model.
3. Readers with more advanced mathematical training may note that Figure A3.2.1 is a phase diagram, which applies given that the Inada conditions hold: that the marginal product of $k$ goes to infinity as $k$ goes to zero and goes to zero as $k$ goes to infinity (this follows from Inada conditions assumed separately for capital and labor inputs). This diminishing-returns feature drives results of the Solow model.
4. Note that in the Solow model with technological progress, that is, growth of $A$, the capital-labor ratio grows to keep pace with the effective labor force, which is labor power that is augmented by its increasing productivity over time.
5. See N. Gregory Mankiw, David Romer, and David N. Weil, "A contribution to the empirics of economic growth," *Quarterly Journal of Economics* 107 (1992): 407–437. This article shows that when human capital is accounted for, as well as physical capital, the Solow model does a rather good job of explaining incomes and growth across countries. For a critical view, see William Easterly and Ross Levine, "It's not factor accumulation: Stylized facts and growth models," *World Bank Economic Review* 15 (2001): 177–219, with the reply by Robert M. Solow, "Applying growth theory across countries," *World Bank Economic Review* 15 (2001): 283–288. For time-series evidence that the Solow model does a good job of explaining even the case of South Korean growth, see Edward Feasel, Yongbeom Kim, and Stephen C. Smith, "Investment, exports, and output in South Korea: A VAR approach to growth empirics," *Review of Development Economics* 5 (2001): 421–432.

# Appendix 3.3

## Endogenous Growth Theory

### Motivation for Endogenous Growth Theory

The mixed performance of neoclassical theories in illuminating the sources of long-term economic growth has led to dissatisfaction with traditional growth theory. In fact, according to traditional theory, there is no intrinsic characteristic of economies that causes them to grow over extended periods of time. The literature is instead concerned with the dynamic process through which capital-labor ratios approach long-run equilibrium levels. In the absence of external "shocks" or technological change, which is not explained in the neoclassical model, all economies will converge to zero growth. Hence, rising per capita GNI is considered a temporary phenomenon resulting from a change in technology or a short-term equilibrating process in which an economy approaches its long-run equilibrium.

Any increases in GNI that cannot be attributed to short-term adjustments in stocks of either labor or capital are ascribed to a third category, commonly referred to as the **Solow residual**. This residual is responsible for roughly 50% of historical growth in the industrialized nations.[1] In a rather ad hoc manner, neoclassical theory credits the bulk of economic growth to an exogenous or completely independent process of technological progress. Though intuitively plausible, this approach has at least two insurmountable drawbacks. First, using the neoclassical framework, it is impossible to analyze the determinants of technological advance because it is completely independent of the decisions of economic agents. And second, the theory fails to explain large differences in residuals across countries with similar technologies.

**Solow residual** The proportion of long-term economic growth not explained by growth in labor or capital and therefore assigned primarily to exogenous technological change.

According to neoclassical theory, the low capital-labor ratios of developing countries promise exceptionally high rates of return on investment. The free-market reforms impressed on highly indebted countries by the World Bank and the International Monetary Fund should therefore have prompted higher investment, rising productivity, and improved standards of living. Yet even after the prescribed liberalization of trade and domestic markets, many developing countries experienced little or no growth and failed to attract new foreign investment or to halt the flight of domestic capital. The frequently anomalous behavior of developing-world capital flows (from poor to rich nations) helped provide the impetus for the development of the concept of **endogenous growth theory** or, more simply, the **new growth theory**.

**Endogenous growth theory (new growth theory)** Economic growth generated by factors within the production process (e.g., increasing returns or induced technological change) that are studied as part of a growth model.

The new growth theory provides a theoretical framework for analyzing endogenous growth, persistent GNI growth that is determined by the system governing the production process rather than by forces outside that system. In contrast to traditional neoclassical theory, these models hold GNI growth to be a natural consequence of long-run equilibrium. The principal motivations of the new growth theory are to explain both growth rate differentials across countries and a greater proportion of the growth observed. More succinctly, endogenous growth theorists seek to explain the factors that determine the size of $\lambda$, the rate of growth of GDP that is left unexplained and exogenously determined in the Solow neoclassical growth equation (i.e., the Solow residual).

Models of endogenous growth bear some structural resemblance to their neoclassical counterparts, but they differ considerably in their underlying assumptions and the conclusions drawn. The most significant theoretical differences stem from discarding the neoclassical assumption of diminishing marginal returns to capital investments, permitting increasing returns to scale in aggregate production, and frequently focusing on the role of externalities in determining the rate of return on capital investments.[2] By assuming that public and private investments in human capital generate external economies and productivity improvements that offset the natural tendency for diminishing returns, endogenous growth theory seeks to explain the existence of increasing returns to scale and the divergent long-term growth patterns among countries. And whereas technology still plays an important role in these models, exogenous changes in technology are no longer necessary to explain long-run growth.

A useful way to contrast the new (endogenous) growth theory with traditional neoclassical theory is to recognize that many endogenous growth theories can be expressed by the simple equation $Y = AK$, as in the Harrod-Domar model. In this formulation, $A$ is intended to represent any factor that affects technology, and $K$ again includes both physical and human capital. But notice that there are no diminishing returns to capital in this formula, and the possibility exists that investments in physical and human capital can generate external economies and productivity improvements that exceed private gains by an amount sufficient to offset diminishing returns. The net result is sustained long-term growth—an outcome prohibited by traditional neoclassical growth theory. Thus, even though the new growth theory reemphasizes the importance of savings and human capital investments for achieving rapid growth, it also leads to several implications for growth that are in direct conflict with traditional theory. First, there is no force leading to the equilibration of growth rates across closed economies; national growth rates remain constant and differ across countries, depending on national savings rates and technology levels. Furthermore, there is no tendency for per capita income levels in capital-poor countries to catch up with those in rich countries with similar savings and population growth rates. A serious consequence of these facts is that a temporary or prolonged recession in one country can lead to a permanent increase in the income gap between itself and wealthier countries.

But perhaps the most interesting aspect of endogenous growth models is that they help explain anomalous international flows of capital that exacerbate wealth disparities between developed and developing countries. The potentially high rates of return on investment offered by developing economies with low capital-labor ratios are greatly eroded by lower levels of **complementary investments** in human capital (education), infrastructure, or research and development (R&D).[3] In turn, poor countries benefit less from the broader social gains associated with each of these alternative forms of capital expenditure.[4] Because individuals receive no personal gain from the positive externalities created by their own investments, the free market leads to the accumulation of less than the optimal level of complementary capital. (We examine these issues further in Chapter 4.)

**Complementary investments** Investments that complement and facilitate other productive factors.

Where complementary investments produce social as well as private benefits, governments may improve the efficiency of resource allocation. They can do this by providing public goods (infrastructure) or encouraging private investment in knowledge-intensive industries, where human capital can be accumulated and subsequent increasing returns to scale generated. Unlike the Solow model, new growth theory models explain technological change as an endogenous outcome of public and private investments in human capital and knowledge-intensive industries. Thus, in contrast to the neoclassical counter-revolution theories examined in Appendix 3.2, models of endogenous growth suggest an active role for public policy in promoting economic development through direct and indirect investments in human capital formation and the encouragement of foreign private investment in knowledge-intensive industries such as computer software and telecommunications.

## The Romer Model

To illustrate the endogenous growth approach, we examine the **Romer endogenous growth model** in detail because it addresses technological spillovers (in which one firm or industry's productivity gains lead to productivity gains in other firms or industries) that may be present in the process of industrialization. Thus, it is not only the seminal model of endogenous growth but also one of particular relevance for developing countries. We use a simplified version of Romer's model that keeps his main innovation—in modeling technology spillovers—without presenting unnecessary details of savings determination and other general equilibrium issues.

**Romer endogenous growth model** An endogenous growth model in which technological spillovers are present; the economy-wide capital stock positively affects output at the industry level, so there may be increasing returns to scale at the economy-wide level.

The model begins by assuming that growth processes derive from the firm or industry level. Each industry individually produces with constant returns to scale, so the model is consistent with perfect competition; and up to this point it matches assumptions of the Solow model. But Romer departs from Solow by assuming that the economy-wide capital stock, $\overline{K}$, positively affects output at the industry level so that there may be increasing returns to scale at the economy-wide level.

It is valuable to think of each firm's capital stock as including its knowledge. The knowledge part of the firm's capital stock is essentially a **public good**, like $A$ in the Solow model, that is spilling over instantly to the other firms in the economy. As a result, this model treats learning by doing as "learning by investing." You can think of Romer's model as spelling out—endogenizing—the reason why growth might depend on the rate of investment (as in the Harrod-Domar model). In this simplification, we abstract from the household sector an important feature of the original model, in order to concentrate on issues concerning industrialization.[5] Formally,

**Public good** An entity that provides benefits to all individuals simultaneously and whose enjoyment by one person in no way diminishes that of anyone else.

$$Y_i = AK_i^{\alpha}L_i^{1-\alpha}\overline{K}^{\beta} \tag{A3.3.1}$$

We assume symmetry across industries for simplicity, so each industry will use the same level of capital and labor. Then we have the aggregate production function:

$$Y = AK^{\alpha+\beta}L^{1-\alpha} \tag{A3.3.2}$$

To make endogenous growth stand out clearly, we assume that $A$ is constant rather than rising over time; that is, we assume for now that there is no technological progress. With a little calculus,[6] it can be shown that the resulting growth rate for per capita income in the economy would be

$$g - n = \frac{\beta n}{1 - \alpha - \beta} \tag{A3.3.3}$$

where $g$ is the output growth rate and $n$ is the population growth rate. Without spillovers, as in the Solow model with constant returns to scale, $\beta = 0$, and so per capita growth would be zero (without technological progress).[7]

However, with Romer's assumption of a positive capital externality, $(\beta > 0)$, we have that $g - n > 0$ and $Y/L$ is growing. Now we have endogenous growth, not driven exogenously by increases in productivity. If we also allowed for technological progress, so that $\lambda$ in the Solow model is greater than zero, growth would be increased to that extent.[8]

## Criticisms of Endogenous Growth Theory

An important shortcoming of the new growth theory is that it remains dependent on a number of traditional neoclassical assumptions that are often inappropriate for developing economies. For example, it assumes that there is but a single sector of production or that all sectors are symmetrical. This does not permit the crucial growth-generating reallocation of labor and capital among the sectors that are transformed during the process of structural change.[9] Moreover, economic growth in developing countries is frequently impeded by inefficiencies arising from poor infrastructure, inadequate institutional structures, and imperfect capital and goods markets. Because endogenous growth theory overlooks these very influential factors, its applicability for the study of economic development is limited, especially when country-to-country comparisons are involved. For example, existing theory fails to explain low rates of factory capacity utilization in low-income countries where capital is scarce. In fact, poor incentive structures may be as responsible for sluggish GNI growth as low rates of saving and human capital accumulation. Allocational inefficiencies are common in economies undergoing the transition from traditional to commercialized markets. However, their impact on short- and medium-term growth has been neglected due to the new theory's emphasis on the determinants of long-term growth rates. Finally, empirical studies of the predictive value of endogenous growth theories have to date offered only limited support.[10]

## Notes

1. Oliver J. Blanchard and Stanley Fischer, *Lectures on Macroeconomics* (Cambridge, Mass.: MIT Press, 1989).
2. For a short history of the evolution of theoretical models of growth, see Nicholas Stern, "'The determinants of growth," *Economic Journal* 101 (1991): 122–134. For a more detailed but technical discussion of endogenous growth models, see Robert Barro and Xavier Sala-i-Martin, *Economic Growth*, 2nd ed. (Cambridge, Mass.: MIT Press, 2003), and Elhanan Helpman, "Endogenous macroeconomic growth theory," *European Economic Review* 36 (1992): 237–268.
3. See Paul M. Romer, "Increasing returns and long-run growth," *Journal of Political Economy* 94 (1986): 1002–1037; Robert E. Lucas, "On the mechanics of

economic development," *Journal of Monetary Economics* 22 (1988): 3–42; and Robert Barro, "Government spending in a simple model of endogenous growth," *Journal of Political Economy* 98 (1990): 5103–5125.

4. For a concise technical discussion of the importance of human capital as a complementary input, see Robert B. Lucas, "Why doesn't capital flow from rich to poor countries?" *AEA Papers and Proceedings* 80 (1990): 92–96.

5. The specific functional form in Equation A3.3.1, known as Cobb-Douglas production functions, will be assumed for simplicity.

6. By the chain rule,

$$\dot{Y} = \frac{dY}{dt} = \frac{\partial Y}{\partial K}\frac{\partial K}{\partial t} + \frac{\partial Y}{\partial L}\frac{\partial L}{\partial t}$$

By the exponent rule, we know that

$$\frac{\partial Y}{\partial K} = A(\alpha + \beta)K^{\alpha+\beta-1}L^{1-\alpha}$$

$$\frac{\partial Y}{\partial L} = AK^{\alpha+\beta}(1 - \alpha)L^{1-\alpha-1}$$

Combining these three equations, we have

$$\dot{Y} = dY/dt = [AK^{\alpha+\beta}L^{1-\alpha}]\left[(\alpha + \beta)\frac{\dot{K}}{K} + (1 - \alpha)\frac{\dot{L}}{L}\right]$$

The first term in brackets in the preceding expression is of course output, $Y$. For a steady state, $\dot{K}/K$, $\dot{L}/L$, and $\dot{Y}/Y$ are all constant. From earlier discussion of the Harrod-Domar and Solow models, we know that

$$\dot{K} = I - \delta K = sY - \delta K$$

where $\delta$ stands for the depreciation rate.

Dividing this expression through by $K$, we have

$$\frac{\dot{K}}{K} = \frac{sY}{K} - \delta$$

For $\dot{K}/K$ constant in the preceding expression, we must have $Y/K$ constant. If this ratio is constant, we have

$$\frac{\dot{K}}{K} = \frac{\dot{Y}}{Y} = g, \text{ a constant growth rate}$$

So from the expression for $dY/dt$ above, for the aggregate production function, with $\dot{L}/L = n$, which is also a constant, we have

$$\begin{aligned}\frac{\dot{Y}}{Y} &= (\alpha + \beta)\frac{\dot{K}}{K} + (1 - \alpha)\frac{\dot{L}}{L} \rightarrow g \\ &= (\alpha + \beta)g + (1 - \alpha)n \rightarrow g - n \\ &= \left[\frac{(1 - \alpha) + (\alpha + \beta) - 1}{1 - (\alpha + \beta)}\right]n\end{aligned}$$

which is Equation A3.3.3. This may also be expressed as

$$g = \frac{n(1 - \alpha)}{1 - \alpha - \beta}$$

7. Recall that there is no technological progress, so $\lambda$ in the Solow model is zero.

8. In a more complex model, decisions about, and effects of, factors such as research and development investment can be modeled explicitly. Firms would decide on general investment and R&D investment. The effect of the latter on overall output would enter in a manner similar to $\overline{K}$ in Equation A3.3.1. For a discussion and references, see Gene M. Grossman and Elhanan Helpman, "Endogenous innovation in the theory of growth" in the symposium on new growth theory in the *Journal of Economic Perspectives* 8 (1994): 3–72.

9. Syed Nawab Haider Naqvi, "The significance of development economics," *World Development* 24 (1996): 977.

10. For an excellent review and empirical critique of the new growth theory, see Howard Pack, "Endogenous growth theory: Intellectual appeal and empirical shortcomings," *Journal of Economic Perspectives* 8 (1994): 55–72. See also articles by Paul M. Romer and Robert M. Solow in the same issue. For an argument that endogenous theory performs well in explaining differences in growth rates among countries, see Barro and Sala-i-Martin, *Economic Growth*. An excellent survey of quantitative growth research disputing this claim and indicating widening gaps between rich and poor countries can be found in Jonathan Temple, "The new growth evidence," *Journal of Economic Literature* 37 (1999): 112–156.