CHAPTER 1

Economic Growth in Historical Perspective

1.1 Historical Perspective

Over the past two hundred years, countries have varied widely in their patterns of economic growth. In the nineteenth century, the United Kingdom was the leading industrialized country, with Germany and France catching up, and then the United States leapfrogged the European countries around the turn of the century. In the period after World War II, per capita income in Japan and Germany increased dramatically. Out of these spurts of growth emerges a long-term historical trend: the United States and other countries that now belong to the Organization for Economic Cooperation and Development (OECD) have seen a persistent increase in per capita income of roughly 2 percent per annum over the last century. Yet during the same period, other countries have continued to languish in poverty. This marked difference in economic performance is not accidental, for in some countries major forces of growth were set in motion that were lacking in other countries.

The problem of economic growth has been studied for as long as economics has been a recognizable discipline. In the eighteenth century, Adam Smith (1976) saw that the forces of growth were released by freeing market agents from external restrictions. He predicted that the increasing size of markets, as well as increasing returns and externalities due to a rising division of labor, would spur development. Early in the nineteenth century, David Ricardo (1951) emphasized investment in machinery as a cause of the increase in per capita income. Karl Marx (1967), following Ricardo, also saw investment in machinery and capital accumulation as major sources of growth. John Stuart Mill (1900), by contrast, emphasized education and the sciences as engines of growth. All of the classical authors understood that economic activity, carried out by private agents in markets, must be complemented by social and public infrastructure.

The classical economists also knew that the development of market forces and economic growth would likely be accompanied by inequality. As economies expand, traditional sectors and traditional methods of production are rendered obsolete, the workforce is deskilled, and the income of some groups is depressed—while other agents grasp opportunities, create wealth, and accumulate fortunes. Joseph Schumpeter (1935) in particular perceived economic growth as a process of "creative destruction" in which some actors gain and others lose.

In addition to recognizing the divergence in income between sectors and groups, the classical economists (as did Schumpeter) conceived growth as a process that converges in the long run toward a stationary state of per capita income. In the modern period, after John Maynard Keynes (1936), growth theory was furthered by the seminal contributions of Roy Harrod (1939, 1948) and Evsey Domar (1946, 1957) and then of Robert Solow (1956, 1957) and Trevor Swan (1956) and of Nicholas Kaldor (1956, 1961, 1966). Kaldor (1961), taking a position contrary to the classical economists, was the first to state that persistent growth of income per capita is one of the major stylized facts (that is, phenomena that can be observed in a number of countries over a long period) of advanced countries. The revival of growth theory, with important contributions by Hirofumi Uzawa (1968), Robert Lucas (1988), Paul Romer (1986, 1990), and Robert Barro (1990), has taken roughly the same view as Kaldor in identifying the causes of persistent economic growth. Classical forces of growth have been rediscovered and presented in formal models by building on intertemporal behavior and the dynamic optimization of economic agents.

As Angus Maddison (2001) shows, forces of economic growth were set in motion in western Europe a long time ago through its encounter with parts of the world where high cultures had developed. The major sources of growth since the Renaissance, as Maddison demonstrates, have been learning from others, education, collecting and diffusing technological knowledge, and improvement of scientific methods. The diffusion of new knowledge and new technology was, in western Europe, accelerated by the interaction and institutionalized cooperation of scientists in institutions of higher learning and scientific academies, which encouraged discussion, collection, and publication of theoretical and practical research. In European countries this was always a matter of public discourse and public policy.

It is well understood by now that different forces of economic growth characterize each stage of development. This book takes a time series perspective on development, employing dynamic and time series methods to study the major sources of growth. We concur with recent criticism of cross-country studies that maintain that the forces of growth are the same at all times and in all countries. In taking a time series perspective, we support the view that in earlier stages, learning from others, externalities, and increasing returns are major sources of economic growth. At a later stage, education and the build-up of human capital are important, as growth effects are visible that appear to be proportional to efforts devoted to education.

However, such scale effects of education and human capital may not hold for still later stages of development. Nonlinearities now seem to be at work, since educational efforts show less than proportional effects on growth rates in advanced countries.[1] A growth model with human capital, such as the Uzawa-Lucas model, might be an appropriate one to describe the stage of development at which the creation of human capital is effective in increasing per capita income. At a later stage, the creation and diffusion of knowledge and new technology through research and development (R&D) spending and a high proportion of scientists and engineers in the total working population seem to become important. Only countries at the forefront of such efforts may be successful in keeping growth rates high. The Romer model, which analyzes some of these forces, seems to be suited to describe this stage of growth. Social and public infrastructure appears to be important for all stages of growth, yet each stage may need specific social and public infrastructure. Last, the connection between economic growth and inequality, to which a great many theorists, both classical and contemporary, have alluded (see Aghion 2002), appears to be an important factor at all stages of development.

Basing our conclusions on a time series perspective and allowing for nonlinearities, we will discuss the implications of our study for policy. We note, however, that economic growth may not only increase potential per capita income for future generations but may also create negative externalities by reducing renewable and nonrenewable resources, as well as by degrading the environment.[2] Although this is an important problem in the context of a study on economic growth, it will be left aside here. Finally, in taking a time series perspective in our modeling and estimation strategy, we are very much aware of thresholds in development and growth. Only countries that have crossed those thresholds may enjoy the stages of growth sketched above.[3]

1.2 New Growth Theory and Cross-Country Studies

As we have mentioned, important studies of the persistent growth of per capita income were provided by Harrod (1939, 1948),

[1] The view that growth models should allow for nonlinearities has recently also been put forward by Solow (2003).

[2] For an empirical approach to the estimation of the stock of nonrenewable resources in the context of a growth model, see Scholl and Semmler (2002).

[3] An early theoretical study of this problem can be found in Skiba (1978); see also Azariadis and Drazen (1990). More recent empirical studies include Durlauf and Johnson (1995), Bernard and Durlauf (1995), Durlauf and Quah (1999), Quah (1996), and Kremer, Onatski, and Stock (2001).

Domar (1946, 1957), and Kaldor (1961, 1966). Harrod and Domar were primarily concerned with the stability of the steady-state growth path. The knife-edge problem stated by Harrod and Domar was contested by Solow (1956), who, assuming smooth factor substitution, could demonstrate global stability and convergence toward the steady-state path. Kaldor (1966) obtained stability results by referring to different saving rates from class income with changing income levels. However, the growth theory of the 1950s and 1960s did not sufficiently identify the major sources of growth. In Solow, growth of per capita income occurs only because of exogenous technical change. Modern growth theory, by contrast, attempts to explain economic growth endogenously.

The new growth theory started with Romer's 1986 paper. This model explains persistent economic growth by referring to the role of externalities. This idea had been formalized earlier by Arrow (1962), who argued that externalities, arising from learning by doing and knowledge spillover, positively affect the productivity of labor on the aggregate level of an economy. Lucas (1988), whose model goes back to Uzawa (1965), stresses the creation of human capital, and Romer (1990) and Grossmann and Helpman (1991) focus on the creation of new knowledge as important sources of economic growth. The latter authors have developed an R&D model of economic growth. In the Romer model, the creation of knowledge capital (stock of ideas) is the most important source of growth. In Grossman and Helpman, a variety of consumer goods enters the utility function of the household, and spillover effects in the research sector bring about sustained per capita growth. A similar model, which can be termed Schumpeterian, was presented by Aghion and Howitt (1992, 1998). In it the process of creative destruction is integrated in a formal model; the quality grades for a product are modeled as substitutes; in the extreme case the different qualities are perfect substitutes, implying that the discovery of a new intermediate good replaces the old one. Consequently, innovations are the source of sustained economic growth. Perpetual growth can also arise due to productive public capital or investment in public infrastructure. This line of research was initiated by Arrow and Kurz (1970), who, however, only considered exogenous growth models. Barro (1990) demonstrated that this approach may also generate sustained per capita growth in the long run.[4]

Numerous empirical studies have been generated by the new growth theory. The first round of empirical tests by and large focused on cross-country studies. There are a great many cross-country empirical estimations of recent growth theory, using either an extended Solow-based

[4] See also Futagami, Morita, and Shibata (1993) and Greiner and Semmler (2000).

approach or endogenous growth theory.[5] Here we do not exhaustively survey the cross-country studies on endogenous growth theory. Their success or failure is reviewed by Sala-i-Martin (1997) and Durlauf and Quah (1999). However, we have to point out that criticism has been raised against cross-country econometric studies. It has been demonstrated that these studies, by lumping together countries at different stages of development, may miss the thresholds of development (Bernard and Durlauf 1995). Moreover, cross-country studies rely on imprecise measures of the economic variables involved, and the results are amazingly nonrobust (Sala-i-Martin 1997).

In addition, cross-country studies imply that the forces of growth, as well as technology and preference parameters, are the same for all countries in the sample. When estimating the Solow growth model using a sample consisting of, say, one hundred countries, the obtained parameter values are identical for each country. However, if the countries in this sample are highly heterogeneous in their states of development, different parameter values will characterize their technology or preferences.

It is also to be expected that different institutional conditions and social infrastructure in the countries under consideration will affect estimations and will make the countries heterogeneous, leading to differences in the estimated parameters. Brock and Durlauf (2001) therefore argue that cross-country studies tend to fail because they do not admit uncertainty and heterogeneity of parameters into the model.

An influential cross-country study that assumes an exogenous growth model is the paper by Mankiw, Romer, and Weil (1992), who augment the Solow-Swan exogenous growth model by integrating human capital. The production function then is given by

$$Y(t) = K(t)^{\psi} H(t)^{\omega} (A(t)L(t))^{1-\psi-\omega},$$

with $Y(t)$ aggregate output, $K(t)$ physical capital, $H(t)$ human capital, $L(t)$ labour, and $A(t)$ the level of technology, which grows at an exogenously determined rate. Physical capital and human capital are formed by saving a certain fraction of output, which is then devoted to the formation of these capital stocks. Denoting with s_k and s_h, $s_k + s_h < 1$, the constant fraction of aggregate output in the formation of physical capital and human capital, the evolution of the capital stocks is given by

$$\dot{k}(t) = s_k\, y(t) - (n + g_A + \delta)k(t)$$

$$\dot{h}(t) = s_h\, y(t) - (n + g_A + \delta)h(t),$$

[5] For the former, see, e.g., Mankiw, Romer, and Weil (1992); for the latter, see Barro and Sala-i-Martin (1995).

where $y(t) = Y(t)/A(t)L(t)$, $k(t) = K(t)/A(t)L(t)$ and $h(t) = H(t)/A(t)L(t)$ give quantities per effective unit of labor. n is the exogenous growth rate of the labor force; δ is the depreciation rate of physical and human capital, which is the same for the two stocks; and $g_A = \dot{A}(t)/A(t)$ is the exogenous growth rate of technology.

Assuming diminishing returns to scale in physical and human capital, that is, $\psi + \omega < 1$, this economy converges to a steady state, which is defined as a rest point of the two equations $\dot{k}(t)$ and $\dot{h}(t)$. Setting $\dot{k}(t) = \dot{h}(t) = 0$ and solving these equations simultaneously gives the steady-state values for k and h as

$$k^\star = \left(\frac{s_k^{1-\omega} s_h^{\omega}}{n + g_A + \delta}\right)^{1/(1-\psi-\omega)}$$

$$h^\star = \left(\frac{s_k^{\psi} s_h^{1-\psi}}{n + g_A + \delta}\right)^{1/(1-\psi-\omega)}.$$

Inserting $k^\star$ and $h^\star$ in $Y(t)$ and taking logarithms yields an equation that gives aggregate per capita output at the steady state. This equation is given by

$$\ln\left(\frac{Y(t)}{L(t)}\right) = \ln A(t) + \frac{\psi}{1-\psi-\omega}\ln s_k + \frac{\omega}{1-\psi-\omega}\ln s_h - \frac{\psi+\omega}{1-\psi-\omega}\ln(n + g_A + \delta).$$

Mankiw, Romer, and Weil (1992) estimate this equation using a cross-country sample of ninety-eight countries. They assume that all economies are at their steady-state position. The result is that the augmented Solow model explains almost 80 percent of the variation in income in the countries of their sample. The implied physical capital, human capital, and labor shares are about one-third each. Mankiw, Romer, and Weil conclude that these findings cast doubt on endogenous growth models and claim that the augmented Solow exogenous growth model is able to explain much of the cross-country differences in income.

Yet in this analysis, structural parameters are posited to be the same, independent of whether a highly industrialized country or developing country is considered. This aspect is taken into account by Durlauf and Johnson (1995), who use the same data set as Mankiw, Romer, and Weil (1992) but allow for different aggregate production functions depending on 1960 per capita incomes and on literacy rates. Durlauf and

Johnson use a regression-tree procedure[6] in order to identify threshold levels endogenously. They find that the Mankiw, Romer, and Weil (1992) data set can be divided into four distinct regimes: low-income countries, middle-income countries, and high-income countries, with the middle regime divided into two subgroups, one with high, and one with low, literacy rates. The result of this study is that different groups of countries are characterized by different production possibilities, implying different coefficients on inputs in the aggregate production functions. Further, in contrast to Mankiw, Romer, and Weil (1992), initial conditions matter for long-run incomes, a result that is in line with endogenous growth models but in contrast to exogenous growth models. This outcome questions the empirical validity of the augmented Solow growth model, implying that cross-country differences in income cannot be explained entirely by differences in the rates of growth of physical capital, human capital, and population.

The contribution by Mankiw, Romer, and Weil (1992) is also criticized by Klenow and Rodriguez-Clare (1998) and Hall and Jones (1999). Hall and Jones show that differences in social infrastructure play an important role in explaining the difference in output per worker across countries. By social infrastructure these authors mean institutions and government policies that determine the economic environment. Proper social infrastructure favors the accumulation of physical and human capital and leads to high output per worker. In particular, Hall and Jones demonstrate that differences in physical capital and educational attainment can only partially explain differences in output per worker. Instead, there is a large residual that varies considerably across countries. They claim that these differences in per capita income can be explained if the effects of social infrastructure are taken into account.

Klenow and Rodriguez-Clare (1998) also reexamine the study by Mankiw, Romer, and Weil (1992). They take the same aggregate production function as Mankiw, Romer, and Weil and write it as follows: $Y/L = AX$, with A the level of technology, as above, and X a composite of the physical and human capital intensities. According to Klenow and Rodriguez-Clare, the two variables A and X are correlated. This holds because countries with policies that favor capital accumulation are also likely to have policies that lead to higher values for A. As a consequence, there is no unique decomposition of the variance of $\ln(Y/L)$ into the variance of $\ln X$ and $\ln A$. Klenow and Rodriguez-Clare propose to split the covariance term and give half to $\ln X$ and half to $\ln A$. This is equivalent to estimating the coefficients by independently regressing $\ln X$ and

[6] For a description see Breiman et al. (1984).

$\ln A$ on $\ln(Y/L)$, respectively. With this assumption, the authors then estimate the same equation Mankiw, Romer, and Weil estimated and, in addition, make some further modifications.

A first modification made in the empirical estimation is to resort to that part of physical capital and human capital which is employed only in the production of aggregate output. The results are slightly different from the ones obtained by Mankiw, Romer, and Weil but the differences are not quantitatively important. With this change, a 1 percent increase in Y/L is expected to go along with a 76 percent increase in X and a 24 percent increase in A, compared to a 78 percent increase in X and a 22 percent increase in A in Mankiw, Romer, and Weil (1992). Klenow and Rodriguez-Clare then again estimate the model but take aggregate output per worker as the dependent variable instead of aggregate output per capita. Their results are basically the same as those obtained by Mankiw, Romer, and Weil.

The third modification undertaken by Klenow and Rodriguez-Clare (1998) is to estimate the regression equation with three enrollment rates, namely with primary, secondary, and tertiary schooling. This modification causes large differences: now a 1 percent increase in Y/L goes along with a 40 percent increase in X and a 60 percent increase in A. The reason for this result is that primary enrollment rates do not vary as much across countries as secondary enrollment rates. Therefore, primary schooling does not vary as much with Y/L across countries as secondary schooling does. So if one focuses on secondary schooling in explaining differences in Y/L, one overstates the percentage variation in human capital across countries and its covariance with per worker output.

The last modification, finally, is the use of different proxies for human capital. Klenow and Rodriguez-Clare (1998) argue that the technology for producing human capital is more labor intensive than the technology for producing goods. They cite a study by Kendrick (1976) suggesting factor shares of 10 percent, 40 percent, and 50 percent for physical capital, human capital, and raw labor in the production process for human capital. Constructing data for human capital using a Cobb-Douglas production function with these factor shares drastically changes the outcome of the empirical estimation. The estimation now results in a split of 33 percent $\ln X$ versus 67 percent $\ln A$, while the original decomposition in Mankiw, Romer, and Weil (1992) was 78 percent $\ln X$ and 22 percent $\ln A$.

Another line of criticism of Mankiw, Romer, and Weil (1992), similar to the last modification made by Klenow and Rodriguez-Clare, is offered by Dinopoulos and Thompson (1999). They show that the results obtained by Mankiw, Romer, and Weil are not robust as concerns the proxy used for the human capital variable. Mankiw, Romer, and Weil resort to the secondary school enrollment rate as a proxy for the saving rate determining that part of aggregate income which is invested in the formation of human capital. Dinopoulos and Thompson suggest two other proxies for human capital: the first is an input-based index that relies heavily on school enrollment rates;[7] the second is an output-based index constructed by Hanushek and Kimko (2000). The latter index tries to directly measure the quality of the labor input from performances on six internationally comparable mathematics and science test scores. Those tests were taken at different points in time, and each test had a different number of participating countries.

The empirical estimation of the augmented Solow model using these alternative proxies for human capital can still explain about 70 percent of the international variation in income per capita. However, the implied coefficients are no longer plausible. The physical capital share now is 0.44 and 0.48, respectively, which is a little high but acceptable. The human capital share, however, is 1.62 and 0.73, implausibly high figures.

Another point of criticism raised by Dinopoulos and Thompson (1999) is that the Mankiw, Romer, and Weil (1992) study assumes that technology is the same for all countries in the sample, a point we have already mentioned. Therefore, they test the alternative assumption that a country's technology level depends on its endowment of human capital. The estimation of the model shows that the null hypothesis of a common technology is rejected. Instead, there is strong evidence that the levels of human capital are positively correlated with the level of technology. This evidence implies that the assumption of a common technology available to all countries in the sample is not supported by the data, since human capital differs in the countries under consideration.

Durlauf and Johnson (1995) and Dinopoulos and Thompson (1999) demonstrate that the outcomes of cross-country studies that assume the same technology and preferences for all countries must be considered with caution. However, we do not assert that such studies are useless. Roughly the same stylized facts, which are often seen as a starting point for discussions about economic growth, are observed for numerous countries. Therefore, it is to be expected that these countries share some common structure that can explain the facts. Nevertheless, this does not mean that all countries have identical aggregate production functions and preference parameters, for example. This point should be kept in mind when cross-country studies are considered.

Why, then, are cross-country studies so numerous in the literature on economic growth? The answer is that cross-country studies have some advantages over time series analysis. One advantage is that the growth

[7] For details see the appendix in Dinopoulos and Thompson (1999).

rate in cross-country studies is taken over long time periods. For example, when one wants to estimate the effect of some predetermined variables on the growth rate, one may take the average growth rate over ten years, which then is posited to depend on the variables at the beginning of the period under consideration. This method permits the elimination of effects of business cycles that may dominate fluctuations in economic variables at a higher frequency. Because growth theory is primarily concerned with long-term development, this property of cross-sectional studies can be a great advantage.

Further, because the time horizon is rather long, cross-country studies are less susceptible to structural breaks. If one takes the growth rate as the average over ten years, a structural break leading to different parameters in the production function will have less drastic effects than in a time series study, in which the parameters are assumed to be time invariant. Another practical advantage of cross-sectional studies is that data are available for several countries for short periods of time, whereas long-term time series data for single countries are difficult to obtain. Although the data for a larger number of countries may be of lower quality, data for several countries over a time period of, say, twenty years is easier to obtain than high-quality time series data for one country for, say, fifty years.

1.3 Time Series Perspective and Econometric Issues

To overcome the disadvantages of cross-country studies, recent research has shifted toward a time series perspective. Jones (1995a, 1995b, 1997) in particular has directed attention toward the time series predictions of endogenous growth models. Jones shows that, by confronting endogenous growth models with facts, one is faced with the prediction that a rise in the level of an economic variable, such as an increase in human capital or knowledge capital, implies strong and lasting effects on the growth rate of the economy. This property is referred to as a scale effect. In fact, in the Lucas model (1988) and in the original Romer (1990) model, which takes labor input and human capital as fixed, the growth rate is predicted to monotonically increase with educational attainment or with the level of human capital devoted to R&D. These permanent growth effects of human capital are present in the models by Lucas (1988), Romer (1990), Grossmann and Helpman (1991), and Aghion and Howitt (1992). As stylized facts show, however, measures of human capital or research intensity in most advanced countries have dramatically increased, usually beyond the increase in gross domestic product (GDP). Yet growth rates have remained roughly constant. Why have growth rates not increased? This is a serious question, indeed, since a country would like to know if it can expect a higher growth rate by spending more resources on creating human capital, on increasing its stock of knowledge, or on increasing its stock of public infrastructure.

In this book we pursue a time series approach. By estimating the preference and technology parameters of the various models with time series data, we want to help answer the question of which endogenous growth models are compatible with empirical observations. Further, we intend to modify these endogenous growth models by allowing for nonlinearities so that the property of scale effects disappears, and then test whether the modified models are compatible with time series evidence. For some stages of growth, the scale effect may indeed be operative, whereas in later stages nonlinearities become relevant.

As we have already indicated, current literature on economic growth has advanced a variety of endogenous growth models. In this book, however, we will consider only basic models of endogenous growth. We proceed in this manner because these models have been most influential in the new growth literature and because they seem to capture the major forces of economic growth. The models in question are: (1) growth models with positive externalities of investment based on the model by Romer (1986); (2) growth models with human capital based on the approach of Uzawa (1965) and Lucas (1988); (3) growth models with R&D expenditures and knowledge creation starting with Romer (1990), Grossmann and Helpman (1991), and Aghion and Howitt (1992); and (4) growth models with public infrastructure based on Barro (1990), Futagami, Morita, and Shibata (1993), and Greiner and Semmler (2000).

In the last chapter we will also consider the classic problem of economic growth and inequality. Not all countries grow at the same rate, and, within a country, not everybody gains equally from economic growth. With high and persistent growth rates accompanied by the ascension of some industries and occupations and the decline of others, inequality will increase. Following the seminal work of Schumpeter, as originally suggested by Kaldor (1961), Acemoglu (1998, 2002) and Aghion (2000, 2002) have redirected our attention to this fact.

Having shifted our attention to time series studies of endogenous growth models, Jones (1995b, 1997) contrasts time series data taken from different countries with the predictions of endogenous growth models. The present work takes the same time perspective, but in our empirical evaluation of the time series implications of endogenous growth models we actually estimate the different models with U.S. and European time series data. In contrast to other empirical work, we neither solely estimate the predictions of the model nor match it with the empirical data; rather, we directly estimate the implied parameters of the model. Although the predictions of the new growth theory have been studied indirectly through time series methods such as unit root or cointegration tests, endogenous growth models and their parameters have not been directly estimated by transforming the models into an estimable form. This is no surprise, since the models allow for growth that implies unbounded and nonstationary time series.

Finally, we want to make some remarks on our estimation methods. Estimating endogenous growth models with time series data is not an easy task. First, there are difficulties with data. Many time series data, such as human capital, are not readily available; therefore, we have to use some method (for example, the perpetual inventory method) to construct them through flow data, such as education expenditures.

Second, the moment restrictions of the estimation equations often appear to be nonlinear and simultaneous in the sense that the structural parameters appear in different equations. This requires that our estimation method be able to deal with nonlinear systems simultaneously, with correction for possible autocorrelation in the disturbance terms. In this regard we basically employ two estimation methods. One is the generalized method of moments (GMM) estimation; the other is the nonlinear least square (NLLS) estimation. In the technical appendix we briefly present the GMM method and the NLLS estimation (which are more extensively treated in many advanced econometric text books; see, for instance, Judge et al. 1988 and Hamilton 1994). It should also be noted that both methods must be somewhat modified to correct for possible autocorrelation in the disturbance terms. The modification of both of the methods is described in the technical appendix.

Third, all the estimations need a numerical optimization algorithm. In this study we basically employ two such algorithms. One is the Newton-Raphson algorithm; the other is the simulated annealing algorithm. The Newton-Raphson algorithm can often detect only a local optimum. We apply this algorithm to the NLLS method when only a single equation is to be estimated. When the estimation becomes more complicated, as in the simultaneous nonlinear system where we use the GMM estimation, we will employ the simulated annealing method. This will allow us to escape from local optima and eventually find a global optimum instead. Although this algorithm usually requires a much longer computation time, sometimes two to three days on a personal computer, we believe it is necessary in order to obtain plausible results of the estimations. The technical appendix again provides a detailed description of the procedure of the simulated annealing. A description of the Newton-Raphson algorithm can be found in many econometric textbooks (such as Hamilton 1994).

Since we have formulated and estimated different variants of endogenous growth models, one easily might get the impression that we allow for some model misspecification to occur. This impression might arise if one presumes that there should have been only one true model. However, the assumption that there is only one true model needs some further consideration. Suppose A_t is what we want to explain in the models. If one model says that A_t is determined by X_t while in another model it is determined by Y_t, that is,

$$A_t = f(X_t)$$
$$A_t = g(Y_t),$$

then, it is true that one model must be misspecified if there is no relation between X_t and Y_t. However, if there is a relationship between X_t and Y_t, that is,

$$X_t = y(Y_t)$$

then either model can be true and is not a misspecified model. This is exactly what happens in models of endogenous growth. One could regard A_t as technology, and X_t and Y_t as knowledge capital and human capital. There is no doubt that a relationship between X_t and Y_t exists.

To be more specific, let us look at the problem from an econometric point of view. There are basically two types of misspecifications. One is the argument of missing relevant variables and the other is the inclusion of irrelevant variables. It is well known that missing relevant variables will cause biased estimates and thus fitting (and matching of empirical data) is usually not successful. Adding irrelevant variables will usually cause overfitting, but the standard deviation will be inflated. Therefore, if we look at both the fitting and standard deviation of estimates, we can judge how serious a misspecified problem could be there. We have provided both results (fitting and standard deviation) in our book. This will allow readers to make a judgment on our results. Moreover, we want to note that in some of the models we have allowed for time trends of some parameters that allow us to capture other forces of growth.

Another justification for our procedure is that we intend to combine theoretical and empirical analysis. So, our goal is to analyze basic endogenous growth models theoretically and to evaluate each model using empirical data in order to check whether it should be rejected or not. Constructing a theoretical framework that contains all relevant growth factors would lead to large-scale models that do not represent the classical core models of economic growth and that, in addition, are not analytically solvable any longer. Further, it is doubtful whether such models would permit results that would help us to understand the process of economic growth.

1.4 Further Outlook

The remainder of the book is organized as follows. Chapter 2 discusses time series facts particularly for the U.S. and German economies, the latter being one of the core countries of the European Monetary Union. Among the Euro-area countries, the German economy has the largest population and represents about one-third of total GDP. Thus, it could be considered an engine of growth for the area. We will, therefore, restrict the empirical application of our study primarily to the U.S. and German economies. One could, of course, apply our methodology of constructing time series data and time series estimation to other countries for which time series data of high quality are available. By and large, we focus here on only two countries to exemplify our method.

Chapter 3 presents and discusses the models that explain endogenous growth due to externalities. We present empirical evidence for a variety of countries and study whether externalities are a driving force for growth. Chapter 4 presents the analytical structure of the Uzawa-Lucas model of endogenous growth, in which education and human capital are the driving force, and estimates a slightly modified model with U.S. and German time series data. As it turns out, the introduction of nonlinearities in the effect of educational attainment on economic growth makes the model fit the data. Chapter 5 introduces the Romer (1990) model of endogenous growth, which stresses the role of knowledge accumulation (the role of ideas) and estimates an extended version of the model with time series methods. Here also nonlinearities come into play.

Chapter 6 presents and estimates an endogenous growth model in which public infrastructural investment and public capital contribute to economic growth. In contrast with Barro (1990), we take into account public deficit and debt. This requires an evaluation of the intertemporal budget constraint of the government by studying empirically the sustainability of the debt policy. In chapter 7 we are concerned with endogenous growth, income distribution, and wage inequality, a topic that has not been considered much in the context of modern growth models, but recently has become an important node of economic research. Chapter 8, finally, presents our conclusions.