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GROWTH THEORY

VOLUME I

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Growth Theory
Volume I
Descriptive Growth Theories

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Introduction

This three-volume work provides a comprehensive selection of the most important articles on growth theory. The readings in Volume I address theories that attempt to explain the stylized facts of growth. Volume II focuses on normative models of the growth process. Volume III integrates the positive analysis found in the first volume with the welfare approach found in the second volume. Taken together, the volumes depict the development of growth models from the early aggregative theory without explicitly optimizing agents to the current practice of formulating growth models with an explicit microeconomic foundation for consumption and investment decisions. Both the questions and methods of the new equilibrium approach to growth theory are adapted from optimal growth theory. In this sense the descriptive and normative theories are intertwined and elements of both points of view may be found in each of the three volumes.

In 1956 Robert M. Solow published 'A Contribution to the Theory of Economic Growth'. This thirty-page paper provides the intellectual and historical roots for much of the work reprinted in these three volumes. There is, of course, much of importance that we could not include; Solow's 1956 paper impacted on virtually every field of economics, especially development, financial economics, international trade, monetary economics, public finance, and resource economics. In 1987 Solow was awarded the Nobel Prize in economics.

Solow's seminal contribution was the concept of economic equilibrium over time as summarized by his differential equation describing the evolution of an economy's capital stock:

$$\dot{K}(t) = sF[K(t), L(t)] ,$$

where K is the stock of a single type of capital good, L is labour input, s is the savings rate, t denotes time, and F[.] is the aggregate production function, assumed to have the usual neoclassical properties. This differential equation – along with other assumptions – completely determines the evolution of an economy over time. In particular, questions such as the convergence (or divergence) of a growth path to a dynamic equilibrium or steady-state can be addressed. Part I contains such models with a single type of capital good.

Solow made the simplifying assumption that aggregate saving is a constant fraction, s, of aggregate income. But what values of s are desirable in some economic sense? The papers of Phelps and Chang investigate this question. Phelps explores the existence of an ideal savings rate across stationary states. The result is the famous Golden-Rule of growth theory. Chang studies the question of whether a particular savings function could be the endogenously determined savings rate for some optimizing, infinitely-lived central planner. His specification of the model allows for technological uncertainty; his optimizing solution is also consistent with the planner holding rational expectations about the future.

More recently, papers by Lucas and Romer have extended Solow's analysis to allow for external economies of scale on an aggregate level. That is, even if individual agents believe that they face constant returns to scale, their collective decisions can lead to increasing returns for the economy as a whole. The resulting dynamic paths do not necessarily converge to a steady-state, and they need not be Pareto optimal. These models help to explain why growth rates differ across countries, and they are potentially of great importance for questions of economic development. The Lucas and Romer contributions are representative of the 'new growth theory' which tries to forge a link between growth, development, demography, and the accumulation of physical as well as human capital. Their articles also focus on equilibrium paths with explicitly optimizing agents. This theme will be the focal point of the studies found in Volume III.

The selections in Part II extend the basic Solow framework in another direction by allowing two or more economic sectors. Three different types of models arise:

(i) Two-sector models with one capital good and a distinctly different consumption good, each produced in different sectors of the economy with different neoclassical production functions.
(ii) Models in which money is added to the original Solow model.
(iii) Models with one (or more) consumption good and more than one distinctly different type of capital good, all of which are produced in different sectors of the economy.

Even with models of type (i), the simple conclusions from Solow's model become more complex: there may be more than one steady-state equilibrium, unstable growth paths are possible, and full-employment cyclical behaviour can occur. When wealth may be held in more than one asset, as in either models with one capital good and money or in models with many different types of capital goods, the dynamic behaviour changes drastically. For example, in models with one consumption good and n different types of capital goods, n differential equations are needed to describe dynamic behaviour:

$$\dot{k}_i = f_i(k_1,\ldots,k_n, p_1,\ldots,p_n) , \qquad i = 1,\ldots,n,$$

and

$$\dot{p}_i = h_i(k_1,\ldots,k_n, p_1,\ldots,p_n) , \qquad i = 1,\ldots,n.$$

Here k_i denotes the per capita stock of the i-th type capital good and p_i denotes the price of the i-th type capital good in terms of the consumption good. A unique dynamic rest point or steady-state for this system of 2n differential equations is generally a saddlepoint, and Hahn pointed out that such systems are not stable unless the vector of initial prices is exactly right – the 'Hahn instability problem'. However, in these models a *unique* stable path from arbitrary initial conditions does not always exist; Burmeister, Caton, Dobell, and Ross showed that there can be many stable paths, a first example of nonuniqueness in dynamic rational expectations (perfect foresight) models. The dynamic stability problems associated with this class of models can be dealt with by including a good deal of maximizing behaviour on the part of a representative agent, as in Volume II, or on the part of many agents whose collective actions give rise to equilibrium models, as in Volume III.

The existence of many types of capital goods not only causes problems for dynamics, but it also leads to the so-called 'capital theory or Cambridge controversies'. This debate centred on the comparison of alternative steady-state equilibria, and it turns out that these comparisons can violate some of the basic neoclassical intuition stemming from Solow's original growth model. Part III deals with these issues, and one lesson to be learned is that it is treacherous to hold the belief that *all* the important economic implications from a simple model are valid in a more complex world.

Questions of technological change are addressed in Part IV. If per capita consumption is to increase over time, as is observed empirically, then Solow's model must be modified to allow for improving production possibilities over time. Such technological improvements can be modelled by postulating that given levels of capital and labour inputs become more efficient in production with the passage of time, and the success of Solow's neoclassical growth theory is due, in part, to the labour-augmenting technical change variant of the model. Briefly, the following observations on long-run growth patterns hold (at least for advanced industrial economies) and are explained by the Solow model with labour-augmenting technological change:

(i) The investment-output ratio is constant.
(ii) The capital-output ratio is constant.
(iii) The capital-labour ratio and output-labour ratios are rising at a constant rate.
(iv) The rate of interest is constant.
(v) The real wage is rising at a constant rate.
(vi) The relative shares of capital and labour are constant.

Alternative models of technological change entail the notion that more efficient machines that embody the most modern technology are the source of increasing productivity. In this case technological improvement occurs only with new investment in new machines, so that an increase in investment will increase economic growth, as in the paper by Bliss. Finally, technological change may arise because workers learn from experience and therefore can produce the n-th unit of output with fewer hours than the (n-1)-st unit. This idea was put forth in Arrow's pathbreaking 'learning-by-doing' paper.

The papers reprinted in Volume I merely provide a foundation for studying the modern theory of economic growth, and our selections reflect our judgements as to what constitutes a sound foundation. We believe that the subjects treated here are essential for a proper economic understanding of the more complex economic questions dealt with in Volumes II and III.

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Part I
One-Sector Models

[1]

A CONTRIBUTION TO THE THEORY OF ECONOMIC GROWTH

By ROBERT M. SOLOW

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I. INTRODUCTION

All theory depends on assumptions which are not quite true. That is what makes it theory. The art of successful theorizing is to make the inevitable simplifying assumptions in such a way that the final results are not very sensitive.[1] A "crucial" assumption is one on which the conclusions do depend sensitively, and it is important that crucial assumptions be reasonably realistic. When the results of a theory seem to flow specifically from a special crucial assumption, then if the assumption is dubious, the results are suspect.

I wish to argue that something like this is true of the Harrod-Domar model of economic growth. The characteristic and powerful conclusion of the Harrod-Domar line of thought is that even for the long run the economic system is at best balanced on a knife-edge of equilibrium growth. Were the magnitudes of the key parameters — the savings ratio, the capital-output ratio, the rate of increase of the labor force — to slip ever so slightly from dead center, the consequence would be either growing unemployment or prolonged inflation. In Harrod's terms the critical question of balance boils down to a comparison between the natural rate of growth which depends, in the absence of technological change, on the increase of the labor force, and the warranted rate of growth which depends on the saving and investing habits of households and firms.

But this fundamental opposition of warranted and natural rates turns out in the end to flow from the crucial assumption that production takes place under conditions of *fixed proportions.* There is no possibility of substituting labor for capital in production. If this assumption is abandoned, the knife-edge notion of unstable balance seems to go with it. Indeed it is hardly surprising that such a gross

1. Thus transport costs were merely a negligible complication to Ricardian trade theory, but a vital characteristic of reality to von Thünen.

rigidity in one part of the system should entail lack of flexibility in another.

A remarkable characteristic of the Harrod-Domar model is that it consistently studies long-run problems with the usual short-run tools. One usually thinks of the long run as the domain of the neoclassical analysis, the land of the margin. Instead Harrod and Domar talk of the long run in terms of the multiplier, the accelerator, "the" capital coefficient. The bulk of this paper is devoted to a model of long-run growth which accepts all the Harrod-Domar assumptions except that of fixed proportions. Instead I suppose that the single composite commodity is produced by labor and capital under the standard neoclassical conditions. The adaptation of the system to an exogenously given rate of increase of the labor force is worked out in some detail, to see if the Harrod instability appears. The price-wage-interest reactions play an important role in this neoclassical adjustment process, so they are analyzed too. Then some of the other rigid assumptions are relaxed slightly to see what qualitative changes result: neutral technological change is allowed, and an interest-elastic savings schedule. Finally the consequences of certain more "Keynesian" relations and rigidities are briefly considered.

II. A Model of Long-Run Growth

There is only one commodity, output as a whole, whose rate of production is designated $Y(t)$. Thus we can speak unambiguously of the community's real income. Part of each instant's output is consumed and the rest is saved and invested. The fraction of output saved is a constant s, so that the rate of saving is $sY(t)$. The community's stock of capital $K(t)$ takes the form of an accumulation of the composite commodity. Net investment is then just the rate of increase of this capital stock dK/dt or $\dot{K}$, so we have the basic identity at every instant of time:

$$\dot{K} = sY. \tag{1}$$

Output is produced with the help of two factors of production, capital and labor, whose rate of input is $L(t)$. Technological possibilities are represented by a production function

$$Y = F(K,L). \tag{2}$$

Output is to be understood as net output after making good the depreciation of capital. About production all we will say at the moment is that it shows constant returns to scale. Hence the production function is homogeneous of first degree. This amounts to assuming that there is no scarce nonaugmentable resource like land. Constant returns to scale seems the natural assumption to make in a theory of growth. The scarce-land case would lead to decreasing returns to scale in capital and labor and the model would become more Ricardian.[2]

Inserting (2) in (1) we get

$$\dot{K} = sF(K,L). \tag{3}$$

This is one equation in two unknowns. One way to close the system would be to add a demand-for-labor equation: marginal physical productivity of labor equals real wage rate; and a supply-of-labor equation. The latter could take the general form of making labor supply a function of the real wage, or more classically of putting the real wage equal to a conventional subsistence level. In any case there would be three equations in the three unknowns K, L, real wage.

Instead we proceed more in the spirit of the Harrod model. As a result of exogenous population growth the labor force increases at a constant relative rate n. In the absence of technological change n is Harrod's natural rate of growth. Thus:

$$L(t) = L_0e^{nt}. \tag{4}$$

In (3) L stands for total employment; in (4) L stands for the available supply of labor. By identifying the two we are assuming that full employment is perpetually maintained. When we insert (4) in (3) to get

$$\dot{K} = sF(K,L_0e^{nt}) \tag{5}$$

we have the basic equation which determines the time path of capital accumulation that must be followed if all available labor is to be employed.

Alternatively (4) can be looked at as a supply curve of labor. It says that the exponentially growing labor force is offered for employment completely inelastically. The labor supply curve is a vertical

2. See, for example, Haavelmo: *A Study in the Theory of Economic Evolution* (Amsterdam, 1954), pp. 9–11. Not all "underdeveloped" countries are areas of land shortage. Ethiopia is a counterexample. One can imagine the theory as applying as long as arable land can be hacked out of the wilderness at essentially constant cost.