Zeitschrift für Wirtschafts- u. Sozialwissenschaften (ZWS) 115 (1995), S. 429 - 472
Duncker & Humblot, Berlin

What's New and What's Old in New Growth Theory: Endogenous Technology, Microfoundation and Growth Rate Predictions

A Critical Overview*

By Johannes Schneider and Thomas Ziesemer**

1. Introduction

Until the beginning of "New Growth Theory" in the middle of the 1980s the economic theory of endogenous technological change was split in three parts.

Firstly, the microeconomic part (see e.g. Kamien/Schwartz 1982) treated the economic decision problems concerned with technology centered around questions of market structure, property rights and absence of insurance as discussed in Arrow (1962b).

Secondly, the growth theoretic part of endogenous technical change – to the best of our knowledge beginning with Arrow (1962a) – treated the generation and consequences of technical change for the growth rates of per capita income and the factor prices without all the ingredients considered in the microeconomic part. These have sometimes been called "black box" models although the term has mostly been used in connection with exogenous technical progress because its users, as well as many authors in new growth theory, were often not aware of the very small literature on endogenous technical change of the 1960s.

Thirdly, evolutionary theory, analysis of economic history, and empirically descriptive work on technological change with a great diversity of approaches has been collected in Dosi/Freeman/Nelson/Silverberg/Soete (1988).

Until then the theory had been quite well integrated (see e.g. Nelson, 1959). The splitting seems to have been the price of transition to the

---

* Verantwortlicher Herausgeber/editor in charge: B.F.

** Helpful comments from two anonymous referees and from the participants of seminars at the Free University of Berlin, the German Institute for Economic Research (DIW) and the University of Regensburg are gratefully acknowledged.

modeltheoretic mode. Thus the technique of model-theoretic work is itself a good example of how the division of labour in the economics profession has influenced society here, split it into non-unanimous groups, created competition between them, and sometimes even stirred up the emotions of the participants.

This paper surveys recent literature in order to show that new growth theory has reintegrated the microeconomic aspect and the growth aspect of the subject by the endogenisation of technology and market structure, but has ignored crucial problems concerning the specification of production functions for the generation of technical change and the prediction of growth rates of per capita income or the wealth of nations that could have been known from the 1960s.

Thus the review of recent models follows the strategy of explaining: 1: the contents of technical change, 2: the market structure assumed or deduced from the assumptions on technology, 3: the growth rate predictions depending on the specification of production functions with emphasis on the impact of population growth and some notes on path dependence.

As a consequence some widely discussed applications of endogenous growth literature will be omitted. This applies to models which offer a suitable explanation of the saving process as well as to the whole literature concerning the incentives of public policy to accumulate capital in its physical and human forms. All these matters have been extensively discussed elsewhere, see e.g. Jones/Stokey (1992) for questions on savings and policy matters, King/Rebelo (1990) for the incentives of public policy to accumulate physical and human capital, Ziesemer (1993) for the impact of public investment and heterogenous individuals, Barro/Sala-i-Martin (1992) on general policy matters, and Lucas (1990) and Jones/Manuelli/Rossi (1993) on the effects of (optimal) taxes to the accumulation of human and physical capital. Moreover, the complex of functional income distribution in endogenous growth models is omitted as well as all the applications of endogenous growth theory to specific fields such as international trade. For matters of functional income distribution see e.g. Bertola (1993), for applications to international trade see e.g. the various articles of Grossman/Helpman (1989, 1990, 1991a, b). Finally we omit all applications of (Schumpeterian) endogenous growth to industrial economics such as Neumann (1989).

As the empirical predictions of growth patterns and growth rates depend heavily on the specification of the sources and behaviour of technical progress in different models we have concentrated on these matters.

Differing opinions about the quality of the empirical predictions made by the various models of growth can be found in the literature. This seems to be because there is no agreement at all about the so-called stylized facts of economic development. Two kinds of stylized facts are in question.

First, many economists reject the traditional view of a worldwide convergence of economic development. For example Baumol (1986) proposed a scenario of three diverging worlds; the industrialized countries, the socialist countries, and the developing countries. As a result of the recent political occurrences this is reduced to a simple North-South scenario. However, the development of some countries in southeast Asia calls the stability of these groups questionable. The identification of such groups seems to be rather a question of the arbitrary choice of the observed time intervalls than of the laws of economic development. Many economists apparently feel unhappy about such arbitrariness and weaken this position in such a way that they simply maintain heterogeneous growth patterns for diverse countries depending on (initial) factor endowments and policy decisions. However, there are still advocates of a weak form of the convergence thesis. For example Helliwell and Chung (1990) and (1992) argue that there is some empirical evidence for the international convergence of the technical progress, at least in industrial countries.

Second, economists who support heterogeneous growth patterns do not agree whether developed economies have constant or increasing growth rates. Nevertheless most economists argue for a constant growth rate in the long run. Romer (1989) insists in an increasing growth rate. Taking these dissensions and the great lack of systematic empirical analysis of this question into account we have abandoned all attempts at the different models. Instead we restrict ourselves to statements about the growth rate predictions of the different models, as these may become the basis of future econometric work.

In section 2 we survey the "old endogenous growth theory" starting with the model of exogenous technical progress of Solow (1956). Further we distinguish three types of models of endogenous technical progress: 1. The externality approach of Arrow (1962a); 2. the production function approaches from Uzawa (1965), Phelps (1966) and Shell (1967); 3. the investment function approach of Conlisk (1967) (1969) and Vogt (1968). "New growth theory" is surveyed in sections 3, 4 and 5. As far as it follows Arrow (1962a) it is discussed in section 3. In section 4 we state those theories which belong to the tradition of Uzawa, Phelps and Shell. Some modern versions of the investment function approach are presented in section 5. Section 6 summarizes the assumptions of the models about technology, market structure and specification of production functions.

This paper differs from surveys of Sala-i-Martin (1990), van Cayseele (1990), Amable/Guellec (1991), Helpman (1992), van de Klundert/Smulders (1992), Verspagen (1992), Flemming/Götz (1993), and Ramser (1993) in that it refers to more modern literature and emphasizes the contents of technology and market structure. Moreover, it relates new to old growth theory in a more detailed way than Pack (1994), Romer (1994) and Solow (1994).

2. Old growth theory: the specification of technology

Before we start discussing the models we would like to mention briefly the prerequisites of the per capita growth of income and capital. Romer (1989, pp. 10 - 14) has pointed out that increasing per capita variables essentially presuppose one of the following conditions:

a) The aggregate production technology of goods is not convex. This may be due to ordinary increasing returns or to various external effects with dynamic increasing returns.

b) In case of a convex aggregate technology either non-reproducable factors are not permitted to be essential for production or they do not occur in any of the fundamental accumulation equations of the whole model. The accumulation of capital goods and the development of the level of productivity must not be restricted by a fixed supply of a non-reproducable factor.

We will see that these prerequisites play an essential role in the old and the new growth theory. The properties of technology which guarantee one of these possibilities will turn out to be the engine of growth.

2.1 The Solow model as a natural starting point and the black-box problem

Old growth theory can be best understood when briefly related to the simplest version of the Solow (1956) growth model. Consider a production function $Y = K^{\alpha}(AL)^{1-\alpha}$ and the goods market equilibrium function $\dot{K} = sY$ with output Y, the capital stock K and the investment $\dot{K}$ as endogenous variables, the level of technology A and population L as exogenous variables and s as a constant savings parameter. The growth process is completely determined by these two equations because one can divide the market equilibrium equation by K, insert the production function for Y and rewrite it in growth rates (denoted by "ˆ") yielding

$$\hat{\hat{K}} = (\alpha - 1)\,\hat{K} + (1 - \alpha)\,(\hat{A} + \hat{L})$$

This can be drawn as a linear function in the $\hat{\hat{K}} - \hat{K}$ – plane with a negative slope for $\alpha < 1$ which implies a decreasing marginal product of capital and an abscissa of $(1 - \alpha)\,(\hat{A} + \hat{L})$.

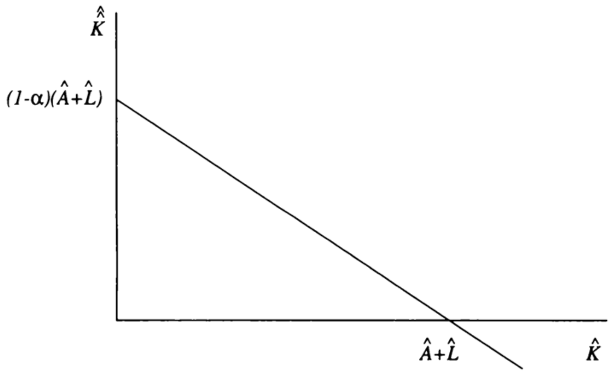

Figure 1

The dynamics drive the system to $\hat{\hat{K}} = 0$ implying $\hat{K} = \hat{A} + \hat{L}$ and $\hat{Y} - \hat{L} = \hat{A}$ from reinserting into the logarithmically differentiated production function. The per capita variables increase as the production function shows increasing returns in K, A and L. Although the straight line indicates a unique path Solow (1956) discussed the possibility of multiple equilibria generated by changes from increasing to decreasing marginal products of capital leading to paths that depend on the initial value, now called path dependence. (See Solow 1956, Figure 2.)

Obviously this theory suffers from at least four weaknesses:

First, it is strange that the long-run growth rate of an economy should be independent of the willingness of its members to accumulate human or physical capital.

Second, the theory leaves ultimatively no room for an economic development other then worldwide convergence unless we assume differences in the parameters and exogenous variables between different countries. Often A is assumed as a free factor (see e.g. Mankiw/Romer/Weil 1992). But in this case, as Rebelo (1992) argued divergent levels of economic development can only exist if there are restrictions on the mobility of capital. As technology is free and by assumption nobody can be excluded from its use, different levels of development imply different marginal products of capital and any firm could increase their profits transferring capital from a high developed to a less developed country. Divergent levels of development thus imply unrealized profit opportunities which conflict with the assumption of the model.

Third, the results derived above are determined without making explicit assumptions about the institutions concerned with property rights such as patent systems, the market behaviour of the technology producing (or purchasing) firms, and the uncertainty problems related to the R&D process. In short, there is no microfoundation which regards the development of technology.

Fourth, it is anything but clear what we should imagine when thinking of A, human capital, organisation, knowledge, better machines, new machines, etc. This is called the black box problem. The central force of economic development is understood as an unspecified function of time.

All of these problems have been extensively discussed in old and new endogenous growth theories.

2.2 Learning by doing (Arrow, 1962a)

The first attempt to explain growth through learning externalities was Kaldor's technical progress function. The rate of growth of output per head depends on the rate of growth of investment per head. Using the goods market equilibrium equation and its time derivative shows that technical progress phases out if the technical progress function has decreasing returns to the rate of growth of investment. Only an added element of exogenous technical progress can guarantee long-run growth. (For a formalisation see Kaldor and Mirrlees, 1962 and Scott 1989).

Arrow started his contribution with the observation (Arrow, 1962a, p. 156) that "to produce the N^{th} airframe of a given type, counting from the inception of production, the amount of labour required is proportional to $N^{-1/3}$". This example was given to emphasize "the role of experience in increasing productivity" given a particular level of technology in a purely technocratic sense. Unfortunately Arrow formulated this idea in a rather complicated vintage model, where it is formalized through the assumption that labour per machine is a decreasing function of cumulated investment. Readers who want to learn more about vintage models should refer to d'Autume/Michel (1993). Here we restrict ourselves to a simpler Cobb-Douglas formulation. In the notation of the Solow model this could be read as $L/K = bK^{-n}$ or $L = bK^{1-n}$. Sheshinski (1967) integrated this idea into the Solow model by formulating a function of cumulated investment, K^β, before the production function to express the level of technology. The model then consists of $Y = K^\beta K^\alpha L^{1-\alpha}$ and $\dot{K} = sY$. Dividing again by K, expressing it in growth rates and inserting the production function, one obtains:

$$\hat{\hat{K}} = (\alpha + \beta - 1)\hat{K} + (1 - \alpha)\hat{L}$$

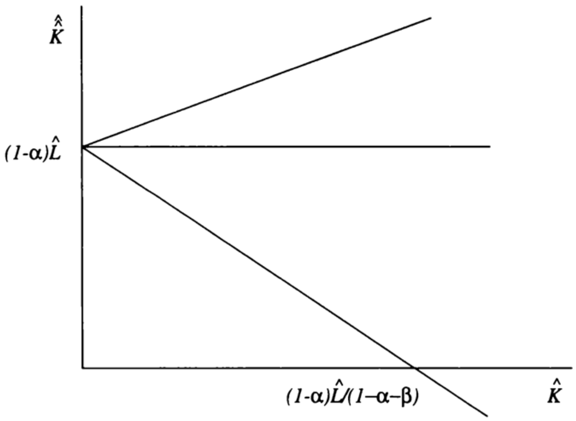

Figure 2

This can again be represented as a graph. A stationary point for $\hat{K}$ is only reached if $\alpha + \beta < 1$. If this is the case $\hat{K}$ converges to $\hat{K} = (1 - \alpha)\hat{L}/(1 - \alpha - \beta)$. Thus, if population growth vanishes, accumulation also vanishes and learning dissolves. On the other hand if $\alpha + \beta \geq 1$ accumulation is continued even without population growth. So, the all in all question is whether the marginal product of capital $(\alpha + \beta) K^{\alpha + \beta - 1} L^{1-\alpha}$ is decreasing in K. Arrow treated only the case of convergence to a constant $\hat{K}$ (see his equation 35), because convergence was the most plausible case for his example. It should be noted that during increasing $\hat{K}$ at constant $\hat{L}$ in the neighbourhood of the stable point $\hat{K} > \hat{L}$ implies that L/K decreases while K increases. We see that in this model aggregate increasing returns, i.e. $\beta > 0$, are not sufficient for per capita income growth. The latter occurs only if $\alpha + \beta \geq 1$ or population growth and β are positive.

In recent models some economists have used the case $\alpha + \beta = 1$ (see Rebelo, 1991, for the first model) to simplify the representation of models without necessarily considering externalities. Technically this has the same effects as changing $\hat{A}$ into an endogenous variable in the Solow model at least for some specifications. As a consequence of this specification the growth rate of the rate of accumulation is a constant (in the model of fig. 2) which is only zero if the population is constant. If one is interested in technological issues this, of course would mean the creation of a new black box. In the area of technology Arrow's emphasis is on learning which is a pure externality.

2.3 The Production Function Approach

In this second approach of the 1960's the technology is the product of a second sector. The production function of the Solow model is used again for the first sector which produces goods and can be rewritten as

$$Y_1 = F(K_1, AL_1)$$

The function is linearly homogeneous in the two arguments which implies increasing returns in K, A and L. This is essential for the further discussion. Then equilibrium requires for capital and labour markets to fulfill:

$$K_1 + K_2 - K = 0$$
$$L_1 + L_2 - L = 0$$

The supply of labour is exogenous and capital is driven by savings out of capital and wage income rK and wL as before:

$$\dot{K} = Y - C = s(rK + wL)$$

The models are completed by the production function of the second sector which produces technology. We find three different specifications of this function in the literature:

Uzawa (1965)

Uzawa specified the output of the sector which produces technology only as a function of the fraction of total labour which is used in this sector. A constant elasticity form of the specification is:

$$\hat{A} = a\left(\frac{L_2}{L}\right)^{1-\alpha}$$

Contrary to his contemporaries Uzawa considered an optimal growth model. The outcome is that there was an optimally chosen rate of technical progress $\hat{A}(l_2^*)$ with $l_2 = L_2/L$. Income and capital per head are growing with the rate of technical progress. Production shows increasing returns in all inputs. These attributes are relevant for later discussions.

Phelps (1966)

Phelps assumed that the change of the productivity level over time is a CD-type function of the inputs of capital and labour in the sector which produces technology:

$$\dot{A} = aK_2^{\alpha} L_2^{1-\alpha}$$

Contrary to Uzawa, Phelps considered a golden rule equilibrium. The outcome was that $\hat{A} = \hat{L}/\alpha$. There is no technical progress if there is no population growth although there are overall increasing returns in the production function. But the resources needed to develop A reduce the inputs into production and as the level of productivity does not support its own development an increase of the long-run effective labour supply is not possible without population growth.

This result seems to have inspired some people to advocate population growth policy (see Kelley, 1988 for a survey). However, the result is due to a pure assumption in the specification of the model and one cannot help the impression that even in countries where population growth has vanished technical progress did not and where population growth, as in Africa, was largest technical progress was low. Obviously the empirical figures show no correlation between technical progress and population growth.

Shell (1967)

Shell assumed that the growth rate of the productivity level is a CD-function of the factor inputs:

$$\hat{A} = aK_2^{\alpha} L_2^{1-\alpha}$$

In this specification factor inputs are even more productive than in those of Uzawa and Phelps. If capital and labour inputs grow so does the rate of technical progress yielding growing growth rates. This in turn seems to be a bit too optimistic about growth rates in retrospect. In fact, Shell added a rate of decay to his production functions of technology and output. As a consequence it is also possible that the growth of technology shrinks to zero. Which of the two possible outcomes occurs depends on the initial value of the technology and the capital intensity, thus implying path dependence.

The problem with the two latter approaches is that they do not even allow the possibility of a constant growth rate with or without population growth. According to the Phelpsian model the growth rate would become zero or negative if the population growth stops or employment is even reduced (Solow, 1988). Shell's approach is not much more useful. Increasing inputs into technology production would lead to increasing growth rates. This idea has been criticized in the literature (see e.g. Weizsäcker 1969). Only Uzawa's model produces a constant growth rate with or without population growth. On the other hand the attraction of this approach is reduced as the convergence or divergence of economic development is determined by assumption. If all profit opportunities are exploited in the sense that marginal products of capital are equal among the countries divergent economic developments can only occur if the production functions of the technology differ among the countries. As the reasons for such (non-)deviations remain vague any statement on growth patterns is to some extent arbitrary. It should be emphasized that these models assume increasing returns in K, A and L. In Shell's model A is a public good which is produced by competitive firms. The other approaches leave these questions open.

2.4 The Investment Function Approach

Conlisk (1967) also suggested an approach which derives a constant stable growth rate which does not depend on the rate of population growth. In addition to the production function $Y = F(K, AL)$ and the equilibrium of the goods market $\dot{K} = sY$ he assumes that the growth rate of productivity obeys the following investment function:

$$\hat{A} = hY/AL = hF(K/AL, 1) \equiv hf(k)$$

These equations can best be analysed using $k \equiv K/AL$ as a variable. Using growth rates of k and inserting the above functions one obtains:

$$\hat{k} = \hat{K} - \hat{A} - \hat{L} = sY/K - hY/AL - \hat{L}$$

Multiplication by k yields:

$$\dot{k} = (s - hk)\, Y/AL - \hat{L}k = (s - hk) f(k) - \hat{L}k$$

The slope of the first part is $(s - hk)f' - hf(k)$. Its second derivative is $(s - hk)f'' - 2hf' = sf'' - hf'(kf''/f' + 2) < 0$ if $kf''/f' + 2) > 0$. This latter condition obviously holds in the Cobb Douglas case because of $2 > -kf''/f' = 1 - \alpha$.

At $k = 0$ a positive slope requires $sf'(0) - hf(0) > 0$. Thus the graph of the two parts of $\dot{k}$ is as follows:

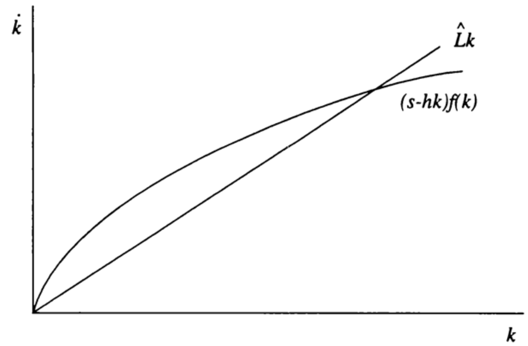

Figure 3

By assuming the Inada conditions $f(0) = 0$ and $f'(0) = \infty$ this is guaranteed. As $f'(0) = \infty$ and the second derivative is negative the curve may cut the $\hat{L}k$ curve and yield either a unique steady state or none. The parameters h and s shift the curve: s shifts it upwards and h shifts it downwards leading to a higher value of k from a higher value of s and to a lower value of k from a higher value of h. Therefore the savings rate is important as higher values of k increase the rate of technical progress, and vice versa.

The same result has been derived by Vogt (1968) using the production function $Y = F(K, AL)$ and the investment-technology trade off:

$$\hat{K} = sY/K - \Phi(\hat{A})$$

with $\Phi' > 0$ and $\Phi' < 0$. He showed the existence of a steady state with a constant $\hat{k}$ under the assumption that entrepreneurs maximize the growth rate of profits.

Conlisk (1969) took a similar approach as Vogt. Indeed he presents a model with two sectors, one of which produces consumption goods with the technology $Y_1 = F(K_1, AL_1)$. The output of the second sector can be used to increase the stock of capital or the level of productivity. These possibilities made use of the following trade-off:

$$H(\dot{K}, \dot{AL}) = Y_2 = G(K_2, AL_2)$$

H and G are linearly homogeneous functions. Conlisk then went on to determine the short-run rate of technical progress by maximizing the rate of growth of Y_2 given the amount of K and L and for the long-run maximizing the rate of growth of Y_2 for the steady state.

The key assumption of these models is, however, that the productivity level can be increased by the use of a reproducable good which can be accumulated over time. It is this feature which drives per capita growth.

2.5 Conclusion and evaluation of the results

It seems worthwhile to point out again that the models of Solow, Uzawa, Conlisk and Vogt allow constant growth rates that are in accordance with the so-called stylized facts of Kaldor. Per capita income growth is constant for all growing and constant levels of population. On the contrary, growth rates tend to explode in Shell's specification if population grows and dissolve without population growth in Phelps' specification. Moreover, Arrow's approach based on externalities includes three cases: increasing, constant and decreasing marginal products which determine whether or not the system converges to the constant growth rates of the capital intensity. All these effects have returned in new growth theory.

The Solow model suffers from the exogenous nature of technical progress. The attempts to endogenize technical progress, which we have discussed in 2.2 - 2.4, are helpful to understand the growth rate solutions of new growth theory. Nevertheless they leave some questions open. They remain rather vague about the market structure and the contents of technology that cause the growth of per capita income and capital. It is the aim of the new growth theory to make this influence explicit.

3. New growth theory: The direct externality approach

The old growth theory was rather vague about the contents of technology or accumulated knowledge, both of which increase productivity through positive externalities. In new growth theory this has been associated with spillovers of knowledge by Romer (1986) and Stokey (1991) and an increasing division of labour by Romer (1987) and Yang/Borland (1991), both provided by the private sector. Moreover, public capital has been used to explain this effect in form of spillovers of public knowledge by Ziesemer (1990) and in form of a direct effect on productivity of the infrastructure public sector by Barro (1990). Learning by doing that spills over from old to new products has been modelled by Stokey (1988), Young (1991) and (1993a), and Lucas (1993), a learning by watching externality by King/Robson (1993).

In Romer's (1986) formulation of the spillovers of privately produced knowledge each individual has a firm with an output production function which is linearly homogeneous in the private choice variables A_j

and L_j, where L_j denotes factors like land and labour. Their supply per head is assumed to be fixed. A_j stands for factors like capital and knowledge that can be accumulated. Moreover, it is assumed that the knowledge generates an external effect. The productivity is increased by the sum of the individual knowledge of all individuals $\sum_j A_j$:

$$Y_j = A_j^{\alpha} L_j^{1-\alpha} \left[\sum_j A_j\right]^{\gamma} \quad \text{where } \alpha + \gamma \geq 1$$

This is an externality similar to that of Arrow (1962a). However, technology A_j is produced by individuals using identical functions $\hat{A}_j = g_j[(F - c_j)/A_j]$ with $g_j^{'} > 0$ and $g_j^{''} < 0$, where F is output and c is per capita consumption. The effect of knowledge produced by the household and used in their firm is characterized by a decreasing marginal productivity. But due to the spillover they all produce public good effects which influence the productivity of private capital. In production the overall accumulated knowledge produces increasing returns which prevents the decrease of the productivity of the reproducable capital in the accumulation process due to fixed factors because $\alpha + \gamma \geq 1$. Of course, a purely private solution is inefficient because of the external effect. A subsidy per unit of A_j financed with lump sum taxes may produce an optimum.

A spillover of human capital also generates growth in Stokey (1991). Private investment in schooling causes growth in the social stock of knowledge. The latter increases the effectiveness of the time spent in school by later cohorts of population. This externality is the only source of growth. Higher quality labour performs higher valued services. Quality is defined in terms of Lancasterian characteristics.

King/Robson (1993) put the learning by watching externality from investment which was inspired by Kaldor, directly into the formula for the rate of technical progress. Its S-shaped form is derived from a Poisson arrival rate for the observation of new ideas. An estimated stochastic process for the rate of taxation, the revenues of which are rebated lump sum, is used to simulate the growth path. Deterministic and stochastic variants of path dependence combined in this way leads to multiple equilibria. Whether or not transitions from high to low growth equilibria occur all values of the variables always depend on the complete history of the model.

The oldest tradition about increases in productivity is based on Adam Smith's notion of the division of labour. The assumption which expresses this in Romer (1987) is that a larger number of factors of production allows them to be combined more productively. They use a production function of the final goods which exhibits constant returns to labour L and the quantity of N different intermediate inputs x_i for a given number N:

$$Y = AL^{1-\alpha}\left(\sum_i^N x_i^\alpha\right) = AL^{1-\alpha}\left(x_1^\alpha + \ldots + x_N^\alpha\right) = AL^{1-\alpha}N^{1-\alpha}(Nx)^\alpha$$

For this production function the output increases with N for a given quantity of labour and aggregate intermediate inputs. The intermediate goods can be produced with a primary input K (without labour) according to a cost function with a U-shaped average cost curve, $h(x_i)$, with zero cost inactivity, i.e. $h(0) = 0$. Therefore the costs can be expressed in terms of the primary input. Each intermediate input is then offered by a single firm in the same quantity. For the economy as a whole we have the restriction:

$$\sum_i^N h(x_i) \leq K$$

If factors are considered as differentiated varieties a larger market producing greater demand for end products implies also a larger demand for intermediate inputs. Moreover, the technologies are such that an increase of the number of varieties improves productivity more than an increase in pure quantities of a given number of intermediate goods. Therefore more and more new intermediate inputs will be supplied because it is profitable to respond with new varieties instead of more of the old. The market structure is as follows: The producers of the final good are price takers in all markets, whereas the producers of the intermediate goods are monopolistic competitors as sellers of their goods and price takers on their input markets. All firms offer at their cost level. In the resulting equilibrium the number of intermediates is determined by the volume of the primary input K. The development of the economy is driven by the accumulation equation $\dot{K} = Y(L, x) - c$ which is determined by the consumers' preferences. Neglecting endogenous labour supply and population growth and assuming an intertemporal utility function with constant discount rate and constant elasticity of consumption σ leads to:

$$U = \int_0^\infty e^{\rho t}\,\frac{c_t^{1-\sigma}}{1-\sigma}\,dt$$

For reasons of brevity we call this utility function with a constant intertemporal elasticity of substitution in the following a CIES-utility function. Romer obtains a long-run growth rate of capital and consumption equal to $(1-\rho)/\sigma$. Growth is ultimately driven by the effects on productivity of the division of labour which acts through an external effect of the number of intermediate goods.

The most similar contribution to Arrow's (1962a) is the model of Yang/Borland (1991). In a multisectoral version of the learning by doing idea, knowledge is associated with accumulated labour instead of accumulated investment. A given number of producer households decide how many goods they produce and sell in an intertemporal equilibrium model where all contracts are negotiated in the first period. The advantage of specialising in the production of one variety when this is done by all individuals, lies in the greater accumulated knowledge. However, the implied trade necessary to exchange goods causes transaction costs. If these transaction costs are high and the learning effects are small and there is a love-of-variety utility function, then autarky, defined as production of all goods by each individual, can be an equilibrium. If learning effects are strong and transaction costs are low specialisation will emerge from the beginning. If both are of intermediate size, individuals specialize slowly over time. In phases where many individuals shift from imperfect to perfect specialisation cumulative learning effects are strong and there are high growth rates. Once specialisation is complete, growth rates decrease over time. As a consequence the three possible outcomes of Arrow's model – increasing, constant and decreasing growth rates – are phases of this model of specialisation. The learning effects widen the market. Higher demand for one's own good is an incentive to specialize more which in turn widens the market again. Due to the assumption that all contracts are made in the initial period, all individuals have to make their decisions before having accumulated experience. Therefore no monopolies exist and all producer households are price takers. As maximisation is from zero to infinity there are also no externalities in the formal structure of the model. However, the question arises why later generations keep the contracts that have been accepted by earlier generations. This requires a third party to make the contracts credible. This third party does not appear in the model. The authors choose their construction of an intertemporal competitive equilibrium without monopoly and externalities for reasons of formal tractability. However, when classifying the model this forces us to choose between its economic coherence leading to intergenerational externalities and monopoly and its formal presentation leading to a Pareto optimal competitive equilibrium. We have chosen the former and therefore put it into the category of "externalities". However, as growth vanishes when specialisation is completed it is questionable to classify the model as a model of endogenous growth at all. We have indicated all results in question by a question mark in the tables of the summary.

Instead of spillovers of private knowledge one might regard public knowledge directly as the principal source of growth. Schultz (1964) argued that public factors, basic education and basic scientific research, are essential in the human capital formation of private households. However, the provision of public factors may be subject to distributional conflict about the individual contributions to pay for them. It is a well known problem in public economics that there is no Pareto optimal tax scheme that is free of redistributional effects (see Cornes/Sandler, chap. 6). Schultz' view as reported so far has been modelled in Ziesemer (1990) in the following way. It is assumed that production of output requires three factors: capital, human capital, and labour.

$$Y = K^{\alpha} H^{\beta} L_1^{1-\alpha-\beta}$$

Human capital H is the sum of individual supplies:

$$H = \sum_j H_j$$

Individuals use different production functions to produce this supply:

$$H_j = (e_j L_{2j})^{\Phi} B^{1-\Phi}$$

e_j denotes the given abilities of the j individuals, L_{2j} the labour inputs chosen by them. B is public knowledge. The formation of public knowledge is assumed to be financed by an income tax:

$$\dot{B} = tY$$

Moreover, the labour market is assumed to be in equilibrium:

$$L - L_2 = L_1 \quad \text{with} \sum L_{2j} = L_2$$

In a competitive equilibrium, the rate of growth corresponds to the number of users (here the population) of public knowledge. The growth rate is proportional to the elasticity of production of B:

$$\hat{y} = \frac{(1-\Phi)\beta\hat{L}}{1-\alpha-\beta(1-\Phi)}$$

The level of per capita income and factor prices depends on the level of public factors because a larger level induces more labour spent in education, L_{2j} which decreases the supply of labour for production and thus increases wages. Due to the different abilities e_j individuals have different willingnesses to pay. Individuals with more capital and lower abilities want to pay less than individuals with low capital and high abilities. One could think of democratisation as a development of a tax level from that preferred by feudal landowners and wealthy rentiers to that preferred by individuals who have average incomes (per unit of labour spent in education) and further to one of a median voter. Then tax levels, steady state levels of public factors, and wages are also rising due to the democratisation. This indicates that public knowledge and policy have a great importance in development issues and issues on policy in technology.

Of course, with no population growth in this simple model growth vanishes, as constant returns to scale are assumed in the production and the fixed primary input is essential in the production of human capital. One could change this result by including a production function for technology A (see section 4).

Some of these approaches allow different levels in the economic development of different countries. High levels of development are responsible for large quantities of accumulated capital and high degrees of labour division which in turn leads to higher accumulation in the models of Romer (1986) and (1987). Because of the increasing returns the marginal return on investment is highest in countries with large stocks of capital and/or a high degree of labour division. A similar effect is caused by an advantage in the accumulation of human capital and public knowledge in the model of Ziesemer (1990). Yet this latter effect is only temporary as the long-run growth is determined by population growth.

In addition to these merits all these models suffer from a substantial weakness. Growth rates are positive if either population growth is positive or if the decrease in the marginal productivity of capital is assumed not to take place.

Stokey (1988), Young (1991) and Lucas (1993) have discussed a solution to the first of these two problems. The basic assumption is that knowledge generated through learning by doing in the production of one good is also useful in the production of other goods. Once the costs of these goods are sufficiently low they are sold on the market because people have increasing income and therefore prefer higher quality. Forward spillovers must be stronger than backward spillovers to make sure that new goods are sold on the market. If income effects are sufficiently strong old products are abandoned. Even without population growth per capita income can continue to grow. The number of varieties in the market increases over time in Young (1991).

The papers of this subsection are listed in the first column of table 3 in the summary.

4. New Growth Theory: Produced Technical Progress

4.1 The Neo-Phelpsian models

The first paper in new growth theory which is also the paper most typical for the integration of microeconomics and the growth approach is written by Judd (1985). Technical progress comes in the form of new goods. New goods, different varieties with quantity x, enter a Spence-Dixit-Stiglitz utility function every period which is summed up over time:

$$U = \int_0^\infty e^{-\rho t} \left[\int_0^V x(v,t)^{\frac{\sigma-1}{\sigma}} dv \right] dt \qquad \sigma > 1$$

The invention of new goods with cost k (this has no relation to k used earlier) units of labour thus, $k\dot{V}$ and the production of goods costs one unit of labour. As all goods enter the utility function in the same way and are produced by the same technology they are all produced at the same amount $x(v,t) = y$. The labour demand for the production of goods is thus yV. The labour market constraint is therefore

$$k\dot{V} + yV - L = 0$$

The maximisation of the utility function subject to the labour market constraint yields the optimum for the economy described so far. In the steady state the number of varieties grows at the same rate as population. From the point of view of specifications used for innovation, it is clear that we have a linearly homogeneous production function for $\dot{V}$ which is quite analogous to $\dot{A}$ in the old models. Thus the specification is identical to that of Phelps and so is the dependence of the growth rate on population.

In a second step Judd shows that the optimum can be achieved by Chamberlinian monopolistic competition: each firm produces one variety and the answer to a widening of the market is the invention of new varieties yielding new patents which must have infinite length to be optimal. The optimality property is due to the balancing out of two non-optimalities: on the one hand the number of varieties is given to households where each new variety gives a positive externality to them; as the implicit demand is not articulated there are too few varieties indicating that resources should be shifted to R&D; on the other hand monopolistically competitive firms have to pay an annuity of the R&D costs as fixed costs leading to prices higher than marginal costs indicating that resources should be shifted to production. Under the CES utility function given above the two inefficiencies cancel and therefore the optimum is reached.

A further achievement of Judd's paper is that under finite patent length there are cycles of innovations. If the market has extended strongly, innovators speed up innovations because they can cover fixed costs very quickly. This speed of innovation conflicts with the limits of constant market growth due to constant population growth. Innovation thus slows down. When population growth has widened the market again innovation speeds up.

To summarise, Judd's paper considers endogenous technical change under imperfect competition including the institutional framework of patents. This model has been used by Grossman/Helpman (1989) to analyse the relation between growth and trade.

The papers of this section are listed in the third column of table 3 in the summary.

4.2 The Neo-Uzawaian models

A model with a quite different structure than all previous models has been developed by Prescott/Boyd (1987). A firm is defined as a coalition of old workers who have some knowledge which is useful in producing output. Output production is more productive if young workers are hired. Young workers know that they will be old next period and then will offer the knowledge. So old workers offer a wage plus an education. Thus intergenerational transfer of technology can produce constant growth, if it is sufficiently productive. The relation between current and future knowledge k is specified as

$$k_t = k_0 (x^*)^t$$

where x^* is the common constant growth rate for consumption, knowledge and income. Constant growth rates are thus directly imposed. They are optimally chosen as in Uzawa (1965) and do not disappear if population growth stops as in Phelps (1966) and do not grow as they (possibly) do in Shell (1967).

The neoclassical view on technical change can be summarised by two statements: models have to fit the stylized fact of constant growth rates and it is admitted that there is an imperfection due to the impossibility of keeping knowledge secret. The first aspect is dealt with by Uzawa (1965) and the second by Romer (1986). Lucas (1988) synthesizes them. The technology production function is a modification of Uzawa's:

$$\dot{A} = \delta (L_2/L) A$$

Romer's externality is added to the neoclassical production function:

$$Y = K^{\beta} (AL_1)^{1-\beta} A^{\gamma}$$

The preferences are characterized by the CIES-utility function with elasticity δ. Lucas then derives the growth rate for the central optimum by maximizing the utility function subject to the two production functions and the resource constraints for capital and labour. The result is the optimal rate of technical change

$$\hat{A}^* = \frac{(1 - \beta + \gamma)\delta - (1 - \beta)(\rho - \varepsilon)}{\sigma(1 - \beta + \gamma)} \overset{\varepsilon = \gamma = 0}{=} \frac{\delta - \rho}{\sigma}$$

where ρ is the rate of time preference. In a second step Lucas carries out the same optimisation up to the derivation with respect to A^{γ} the externality. This is interpreted as a second best optimum, competitive equilibrium with an externality. The growth rate thus obtained is

$$\hat{A} = \frac{(1 - \beta)[\delta - (\rho - \varepsilon)]}{\sigma(1 - \beta + \gamma) - \gamma}$$

$\hat{A}^*$ can be shown to be higher than $\hat{A}$ for $\gamma > 0$. Thus neglecting the externality reduces the rate of technical progress. Lucas interprets A as human capital created by the investment of labour time.

Due to increasing marginal productivity of A in this model the productivity of human capital increases with the level of development, i.e. the stock of human capital if $\gamma - \beta > 0$. These differences should explain the migration of both factors to developed countries. But in turn this implies that all mobile capital relocates from underdeveloped to developed countries. In order to avoid this obviously unattractive consequence one has to introduce some mobility barriers to human capital or some immobile factors such as land. This latter would cause some of the resources to remain in the underdeveloped countries.

However, the neoclassical growth results can also be obtained in a different context with externalities internalised (see Ziesemer, 1991). The context has been chosen to check whether it is true that price taking behaviour is inconsistent with endogenous technical progress. The answer is that a firm which has an output and a technical progress division can act as a price taker if the production function of technical progress is homogeneous of degree zero in the control variables H, L_1

$$\dot{A} = G(H/L_1, A) = (H/L_1)^{\alpha} A^{1-\alpha}$$

and the production function of output is linearly homogeneous in the control variables K, H, L_1

$$Y = F(K, H, AL_1)$$

and if a factor is needed in both divisions it must be used simultaneously as expressed in the above specification using the same symbol for H and L_1 in both functions which can be interpreted as externalities. H is mainly used in $G(\cdot)$ but helps transfering technology into $F(\cdot)$ and L_1 is mainly used to produce output but makes diffusion more difficult because an increase in the number of workers make diffusion more difficult. Having both divisions in one firm the externalities are internalized. If there is only one firm that can keep its knowledge of inventions secret, for example by patents, than one receives a horizontal cost function for each point in time where A is a given state variable. If the patents have expired or knowledge has leaked out in some way, then the knowledge is public and there may be many firms j using the same knowledge, each having a production function $F(K^j, H^j, AL_1^j)$. Again perfect competition is no problem. In this case one has to make a distinction between the j-th innovator with function $\hat{A} = G(H^j/L_1^j, A)$ and the imitators who may have no such function but, for example imitate, without costs. Both make zero profits if they behave as price takers as it is optimal and thus required by identical households. The sum of the marginal products of an input in F and G must equal its factor price. So price taking behaviour is logically possible in this context as in the context of Ziesemer (1987). The outcome is the following equilibrium growth rate:

$$\hat{A} = g(h) \qquad\qquad h \equiv H/AL_1$$

If there is no market for the services of A which are used in the production of human capital this rate is lower than the optimum but can be raised through a subsidy payed per unit of A.

A different question is whether or not firms are given the objective function to act as price takers if owner households are heterogeneous with respect to their shares in fixed ownership. Unfortunately this question has not been treated until now. In Ziesemer (1993) the production function of technical progress is combined with the aspect given by Ziesemer (1990) leading to dependence of the rate of technical progress on the rate of public expenditure for education for which individuals have different willingness to pay because of their different abilities. The rate of technical progress is thus dependent on the political resolution of the conflict.

Becker/Murphy/Tamura (1990) identify technical progress with private investment in education. Parents choose between spending their time either on the education of a large number of children with each receiving little education or a small number each receiving a lot of education. Higher numbers and better education both require more labour time. Moreover, parents maximise not only their own well being but also that of their children. The point is that parents who are poor and have only little human capital have a low productivity in educating their children and have a high time preference rate. Thus they invest little in the quality of their children but have many children instead, who are then poorer in the next period then their parents have been before. However, if they are rich because they have much human capital then they have a low rate of time preference and a high productivity in educating their children and therefore they invest much in their children's education, thus making the next generation richer than they are themselves. In the long run the system approaches a constant growth rate. Between these two extremes there may be a threshold level at which children remain as rich as their parents were. Beyond this point the poor get poorer and the rich get richer. This is also an example of path dependence. The dependence of the marginal productivity of labour time on the human capital endowment, the implied threshold level, and the constant growth rate are generated starting with a production function

$$H_{t+1} = Ah_t(bH_0 + H_t)$$

H_0 is the child's endowment, H_t the parent's endowment and h_t the labour time invested by parents. Thus the optimal h_t depends on H_t making dynamic increasing returns possible.

A crucial point seems to be that productivity in children's education depends on the knowledge of the parents instead of that of their teachers. This leads to a rather high emphasis on intergenerational accumulation. Here market structure plays no role because the whole situation is formulated as a family problem. If one could introduce a market for schooling without any additional assumptions about the imperfection of capital markets the entire result could break down if the most able people become teachers and poor families could obtain credits to finance education.

As population is endogenous the Becker/Murphy/Tamura model has the advantage of generating a growth rate that does not depend on the exogenous level or growth rate of the population.

The papers of this section do not use any monopolistic elements. Moreover, they focus the explanation of growth on specific aspects of the development of human capital rather then the role of fixed costs of R&D knowledge. Moreover, Becker/Murphy/Tamura require no assumptions about population growth. They determined the growth of population endogenously and showed that in the long-run population growth will vanish.

The papers summarized in this section are listed in the fourth column of table 3.

4.3 The Neo-Shellians

In the last years models of endogenous growth have been developed where the progress of knowledge is associated with new horizontally differentiated goods (Romer 1990) or with new production techniques on the basis of new vertically differentiated factors and goods (Aghion/Howitt 1992 and Grossman/Helpman 1991a, b). The various models work with imperfect competition in the markets for the differentiated goods or intermediate factors.

The assumptions about the rivalry and the exclusiveness of the knowledge developed by private firms play a key role in the model of Romer (1990). As in most growth models it is assumed that there is no rivalry of organisational and technical knowledge. Moreover, it is suggested that this knowledge can only be partially excluded in the sense that firms can prohibit other firms from direct imitation of their products. They are unable to prevent other firms from the use of their knowledge even in the production of close substitutes. Behind this stands obviously the idea that even extended property rights cannot install perfect markets for this knowledge. Patent systems only induce some temporary or permanent monopolistic position in the markets for intermediate goods of the inventors. As the knowledge does not rival other firms can use this knowledge in a different context. Therefore we have a *free lunch effect* which is in fact a vehicle of growth.

Horizontally differentiated intermediate factors – quite analogous to Judd's horizontally differentiated consumer products – have been connected to the traditional growth approach by Romer (1990). In the production function for output we call $x(i)$ the different intermediate goods, A the number of their varieties, $\bar{x}$ the quantity and $A\bar{x}\eta$ the accumulated stock of capital needed to produce Ax. Other symbols are used as above:

$$Y = H_1^{\alpha} L^{\beta} \int_0^A x(i)^{1-\alpha-\beta}\, di = H_1^{\alpha} L^{\beta} A \bar{x}^{1-\alpha-\beta}$$

The production function is linearly homogeneous in the rival inputs H_1, L and $\bar{x}$. Moreover, the nonrival input A has an increasing influence on the productivity of the rival inputs. A is an externality to the firm that acts as a price taker in the output market. Technical progress consists of the percentage change in the number of varieties using the following production function:

$$\dot{A} = \delta H_2 A$$

This is linear in all variables but A as in Shell (1967). With a CIES-utility function this leads to a long-run growth rate

$$g = \frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \frac{\delta H - \Lambda\rho}{\Lambda\sigma + 1}$$

depending on the exogenous stock of human capital and the parameters of the utility function and the production function. Λ is a constant determined by the elasticities of the production function:

$$\Lambda = \frac{\alpha}{(1 - \alpha - \beta)(\alpha + \beta)}$$

The growth rate increases if the human capital increases. If the latter were growing, perhaps parallel with the population, there would again be increasing technical progress rates. Romer is a protagonist of the idea of an increasing growth rate and supports his position with some empirical evidence (Romer 1986). It is strange that the per capita growth rate should increase with the aggregated human capital H_2 and the variety A of the intermediates. In the model this is caused by the assumption of constant returns to the human capital. In the empirical investigation this is caused by adding data from before 1870. This phase could, however, be interpreted as a transitional phase in the times of industrialisation in the United States.

Horizontally differentiated intermediates have been applied to trade theory in Grossman/Helpman (1990).

Schumpeter's idea of creative destruction has been formalised by Aghion/Howitt (1992). The basic idea is that consumer goods are produced by a fixed and exogenous quantity M of unskilled labour and an intermediate factor x. It is assumed that firms act as perfect competitors and the production function is linearly homogeneous:

$$y = AF(x)$$

A is a parameter which represents the productivity of the intermediate input which can be increased by the use of the new intermediate goods which replaces the old intermediate good; this is represented by a higher value of A. Intermediate inputs are produced by the use of skilled labour L according to a simple linear technology.

$$x = L$$

A firm can buy a patent from an innovator and produce the intermediate goods. The producer of the new intermediate good can act as a monopolist until the next innovation occurs. Innovations are produced by innovators who use a flow of skilled labour n and a flow of specialised labour R. These labour inputs produce a random sequence of innovations with the Poisson arrival rate $\lambda\phi(n, R)$ where λ is an arrival parameter and $\phi(n, R)$ is a linearly homogeneous production function with positive marginal products of n and R. This arrival rate is independent of past activities.

Each innovation consists of a blue print for new intermediate goods which allow a more efficient production of the consumer goods. The innovators sell patents to a producer of intermediate goods for the expected value of the monopoly rent. The use of the new intermediate good increases the productivity parameter A by a factor γ. The productivity of the new intermediate good in t is thus:

$$A_t = A_0 \gamma^t$$

If n_t and R_t are the labour inputs applied in the interval t, the length of the time interval to the next innovation is an exponentially distributed random variable with the parameter $\lambda\phi(n, R)$. In the mean time the producer of the new intermediate good acts as a monopolistic competitor.

This model produces a unique stationary equilibrium. In a simplified case, where $\phi(n) = n$ and $F(x) = x^{\alpha}$, the equilibrium input n^* is determined by the equation

$$\lambda\gamma \frac{1-\alpha}{\alpha}(N - n^*) = r + \lambda n^*$$

where N stands for the exogenous supply of skilled labour, and r for the discount rate. If a growing population would imply also an increasing N the growth rate of output would increase as in Romer (1990). However, for positive per capita income growth at a rate $\lambda n(-\ln\gamma)$ the following condition is necessary and sufficient:

$$\lambda\gamma \frac{1-\alpha}{\alpha} N > r$$

Given values of γ, λ, N and r positive balanced growth is possible if and only if α is sufficiently small:

$$\alpha < \alpha^* = \frac{\lambda\gamma N}{\lambda\gamma N + r} < 1.$$

Positive balanced growth can only occur if $1 - \alpha$ which is equal to the Lerner measure of monopoly power is sufficiently high. If the degree of monopoly power is not sufficiently high ($\alpha \geq \alpha^*$), the flow of monopoly rents which the innovator achieves by the sale of the patent is not high enough to provide an incentive for a positive research effort n^* in the steady state.

In the model of Aghion/Howitt there are three deviations from a social planning optimum, the first two leading to underinvestment and the third leading to overinvestment by the innovators in the laissez-faire case. The private innovator does not internalise consumers' surplus induced by his innovation; thus we have an underinvestment in research. The private innovator can obtain the rent from innovation for only one period whereas the social planer considers the whole stream of future rents. Thus the positive impact of an innovation on future innovations is not taken into account and the laissez-faire economy tends to underinvestment. Finally, there is a kind of "business stealing effect" which leads to overinvestment in the laissez-faire case: The innovator does not internalize the loss of surplus of his predecessors whose rent he destroys.

Grossman/Helpman (1991a) have applied this to quality ladders in consumer products with a temporary monopoly as in Aghion/Howitt (1992) and in Grossman/Helpman (1991b) to product cycle theory in a North-South context with Bertrand competition due to the existence of a southern imitator who has lower wage costs.

A Schumpeterian Model of the Product Life Cycle has been discussed by Segerstrom/Anant/Dinopoulos (1990) in a North-South context. In their model technological progress results from a sequence of R&D races in each of which – in contrast to Schumpeter and Aghion/Howitt – a (technology for a) new product will be developed. As they assume that only northern workers are capable of doing R&D work only northern firms can take part in these R&D races. Each R&D race is modelled as an "invention lottery" whose winner gets the exclusiveness of this production patented for a certain period of time after which the patent expires and the technology of the product gets common knowledge to all firms in North and South. The length of a race t^j for the product depends on the overall R&D labour L_R^j which the North invested in this product in the following way:

$$t^j = h(L_R^j) \qquad \text{with } h(L_R^j) > 0,\ h'(L_R^j) < 0,\ h''(L_R^j) \geq 0, \text{ and } h(0) < \infty$$

This means that invention takes some time. The span of time decreases with the overall amount of labour which is invested in a certain product in a diminishing manner. Moreover, some invention takes place even without R&D effort. The probability of a single firm i to win such a race depends on its part of the R&D labour, L_R^{ij}/L_R^j, invested in this product. Apart from some technical assumptions they need one critical assumption to prove the uniqueness and the existence of a steady state of a general equilibrium model with (Bertrand) competition among the R&D firms. They only have to assume that the discounted labour costs of developing a new product rise as the firms try to speed up the R&D process by devoting more resources to R&D (see eq. (5) Segerstrom/Anant/Dinopoulos 1990). This means that apart from the external effect of overall investment in R&D labour inputs the private costs of these inputs increase if the overall input of labour in R&D increases. Otherwise the per capita growth could be driven over all limits.

Rebelo (1991) has shown that the non-convexity caused by the external effect is not essential for positive per capita growth. He uses a description which is similar to that of Lucas with two main differences. First there is no external effect in the production function of the goods which is linearly homogeneous in the effective factor inputs:

$$Y = K_1^{\alpha}(AL_1)^{1-\alpha} = \dot{K} + C$$

The time available is set constant and equal to one. Individuals can enjoy leisure $1 - L$ with

$$L = L_1 + L_2.$$

Second physical capital is used in the production of the technology:

$$\dot{A} = K_2^{1-\beta}(AL_2)^{\beta}$$

The growth rate is (see eq. 14 in Rebelo's paper)

$$g = \max\left[\frac{\Psi A_1^{\nu} A_2^{1-\nu}(1-L)^{1-\nu} - \delta - \rho}{\sigma}, -\delta\right]$$

The interesting result is that the growth rate increases with the total number of work hours in the output sector and in the accumulation of human capital. Thus the harder people work the faster the economy grows.

In Rebelo's model constant per capita growth is possible as no fixed factors such as labour or land are used in the specification of technology in this model. Only reproducible products are used as factors in technologies which show constant returns to scale with respect to them. Of course the assumption that production as a whole does not use any non-reproducable factor is heroic. In fact Rebelo returns to the Harrod-Domar production function and makes the savings ratio endogenous in a neoclassical manner. The results are constant growth rates if the number of labour hours is constant, but increasing growth rates if the number of labour hours or the quantity of any other primary factor are growing. Only with this assumption can the model be reconciled with the Kaldorian stylized facts. The trick is to use a production function which is linearly homogeneous in augmentable factors where technology is identical to human capital which is also augmentable. Except for the introduction of leisure this model is identical to the model of Shell. The difference in the interpretation is that Shell calls A a public good that is produced by the government whereas Rebelo calls A human capital and assumes that it is produced by households.

Jones/Manuelli (1990) have presented a similar result in a different but finally not more satisfying context. They assumed that the production of goods can be described by a CES-production function with fixed factors as inputs. In this specification of technology non-reproducable factors are not essential. Whenever one thinks that some non-augmentable factor is essential to the technology, per capita growth cannot occur without some form of non-convexities.

The development of endogenous growth models with constant returns to a broad concept of capital is extended by Barro (1990). He presents a model of tax-financed public investment also increasing the productivity of private capital, production and private welfare as well. As the basic concept he introduces a production function which is linearly homogeneous in private capital, including human and real capital, and public services which affect the productivity of private capital. In close analogy to Rebelo's specification output per head, y, is written as a linearly homogeneous function of private capital per head, k, and public services per head, g:

$$y = k\phi(g/k) = Ak^{1-\alpha}g^{\alpha} \qquad 0 < \alpha < 1$$

The public services are understood as public goods which do not rival such as non-overloaded infrastructure. Neglecting public debt he assumes that public expenditure is financed by a flat rate income tax τ

$$g = \tau y = \tau k \phi(g/k) = \tau A k^{1-\alpha} g^{\alpha} = (\tau A)^{1/(1-\alpha)} k \Rightarrow \hat{g} = \hat{k} = \hat{y}$$

Assuming a CIES-utility function and using the accumulation equation $\dot{k} = y - c$ Barro obtains the following growth pattern:

$$\frac{\hat{y}}{y} = \frac{\hat{k}}{k} = \frac{\hat{c}}{c} = \frac{1}{\sigma}\left[(1-\tau)\phi(\cdot)(1-\eta) - \rho\right]$$

where η denotes the elasticity of y with respect to g and equal to α in the CD case. This economy moves always in a steady state and has no transitional dynamics as in Rebelo (1991). All quantities grow with the rate above. This results from the convexity of the production technology and the fact that no fixed factors are used to produce the capital goods – private and public. For $\alpha = 0$ the model is driven by the linearity of the technology in its reproducable factor, whereas in Rebelo there are two reproducable factors. Labour is ignored in this model and therefore the role of population growth cannot be considered, but it can be understood from Rebelo's version.

According to Barro (1990) differences in the level of development would persist for equal preferences and technologies if each country chooses the optimal tax rate $\tau = \alpha$.

Young (1993a) derived a Shellian model of growth with a constant (increasing) growth rate and a constant (growing) population from a combination of pure learning by doing externality as discussed in section 3 with a Phelpsian concept of innovation as discussed in section 4.1. He assumes that the economy experiences bounded learning by doing with spillovers to other goods. At each time a society knows how to produce goods represented by the subset of the real line $[0, N(t)]$. Learning by doing consists of a decrease of the single productive input labour. Although it assumed that this learning arises from the productive use of labour and that it applies to the production of all goods it is bounded in the following sense. The input coefficients cannot decrease under a certain minimum, a restriction which obviously applies to older goods. Therefore the function $a(s,t)$ describes the input coefficient of good s at time t where more recent goods have a higher index s:

$$a(s,t) = a_0 e^{-s} \qquad \forall s \in [0, T(t)]$$

$$a(s,t) = a_0 e^{-T(t)} e^{s-T(t)} \qquad \forall s \in [T(t), N(t)]$$

The speed of obtaining the limit $T(t)$ evolves according to the learning by doing function

$$\dot{T}(t) = \int_{T(t)}^{N(t)} \Psi L(s,t)\, ds$$

where Ψ denotes the learning rates of the workers.

The variety of (techniques for the production of) new goods develops according to the following Phelpsian concept of innovation

$$\dot{N}(t) = \frac{L_R}{a_R}$$

where L_R and a_R denote the labour input and the labour coefficient in research activities.

The model can generate three possible steady state equilibria in which $N - T$ must be constant. The first one $\dot{T} = \dot{N} = 0$ occurs if the discounted flow of profits out of inventions are less then the costs of inventions, in the context of this model if $a_R \geq L/\rho$ where L and ρ denote total labour supply and the discount rate. The profits out of inventions depend on the size of the market which is here measured by the labour input. If no labour is invested to invention the whole labour supply is put into the production of goods. If $a_R < L/\rho$ there are two possible steady states. For small ρ and Ψ the long run growth rates of T and N which are equal to the growth rate of per capita income are

$$\dot{T} = \dot{N} = \frac{\Psi L}{2 + \Psi a_R}$$

otherwise

$$\dot{T} = \dot{N} = \frac{\Psi h(N-T)L}{1 + a_R \Psi h(N-T)} \qquad \text{with } h'(\cdot) > 0.$$

Beside the first case where the technology of invention is not productive enough the model generates a constant growth rate of income although the specification of the invention process is Phelpsian. This is due to the combination of the learning by doing externality with the Phelpsian concept of the invention function.

Amable (1993) combines the concept of technical progress as formalised by Aghion/Howitt (1992) called radical innovation and that of Romer (1990) called incremental innovation. Here incremental innovation is specified in a Phelpsian manner to make sure that it cannot drive the economy alone. Radical innovation is specified to be Shellian and drives the economy. Clearly radical innovation substitutes intermediate goods whereas the incremental technical progress is complementary to them.

Young (1993b) also provides a combination of substitutable and complementary technical progress. New variants of intermediate goods N are produced by R&D in competitive laboratories using the production function

$$\dot{N} = N L_R / a_R$$

with labour input in research L_R and its coefficient a_R.

This is a typically Shellian specification. New intermediate goods can be used in the production of goods and can even lead to the possibility of making new goods without additional costs. By assumption relatively new goods can use all existing intermediate goods. Relatively old goods, however, are unable to use new intermediates. The use of new intermediate goods by relatively new goods increases the productivity of their production. Consumers shift expenditure to the new goods because they become cheaper and buy less of the old goods. New intermediates are thus complements to intermediates in the production of new goods, but substitutes with respect to intermediates in the production of old goods. The model generates multiple equilibria with different growth rates. The high growth equilibrium is dominated by substitutability and the low growth equilibrium is dominated by complementarity.

In models using love-of-variety functions variety is always increasing because no variant is selected away. In Young (1991) variety is increasing although some old goods are selected away. In Young (1993a) the range of goods with learning as well as the range of goods produced is constant. In the quality ladders models the range of goods is also constant and the number of variants equals one. There is no model with a decreasing range of variants discussed so far.

Acharya and Ziesemer (1994) develop a model which allows for increasing, decreasing and for long periods in time approximately constant numbers of variants. They introduce quality weights that are exponential in the index of goods – where a higher index indicates a more recent variant as in Young's papers – into the utility function. The utility function is of the love-of-variety type and the quality weight is multiplied to the quantity of goods. Consumers don't buy goods which are too expensive relative to the quality. Labour is the only factor of production. Producers have lower labour-input coefficients for more recent variants as in Young (1991, 1993a) and have fixed costs from the licensing fees, that they pay to the inventing R&D firm. The R&D firm has a Shellian or Phelpsian production function for making new variants. In the Shellian case cumulated knowledge results in a decline in the licensing fees for old and new variants. As this generates lower fixed costs for producers the quantity at which the firm breaks even, decreases and leaves more room for variety in the budget of households. If this effect is strong enough variety is increasing not only as a result of new goods coming in but also because of goods being reselected that had not been selected before. In the limit in this instance, the pure love-of-variety case will be reached. If the fixed cost decreasing effect is weak, variety is decreasing because the quality weight is exponential and therefore new goods are strongly preferred to old ones which are selected away. In this case the quality ladders' result of only one variant remaining in the market is reached in the limit although this may take 40 periods each of which is longer than one year, in simulations which contain long phases of approximately constant variety. If the specification is Phelpsian, fixed costs are not decreasing and variety is reduced quickly. If the elasticity of the stock of knowledge in the R&D production function lies between zero and one, an intermediate case between those of Phelps and Shell, a case can be constructed in which there is first a reselection of variants due to decreasing fixed costs, but later as growth phases out under zero population growth the decrease in fixed costs does the same and therefore the range of variety shrinks to unity after some periods. Increasing, constant and decreasing variety are thus all possible outcomes of the model in which the dynamics of product selection is driven by the dynamics of fixed costs for licensing which in turn depend on learning effects.

5. The investment function approach

Stiglitz (1987) develops the idea in Solow (1956) that there may be multiple equilibria if the savings function is S-shaped. He uses Conlisk's (1967) version of the endogenous growth model and makes the savings ratio dependent on the interest rate. This allows an S-shaped savings function in the $\dot{k} - k$ plane if preferences are homothetic and the substitution effect is sufficiently low to allow a negative impact of the interest rate on the savings ratio. The upper and lower equilibrium are stable. The equilibrium at the higher level of the capital-labour ratio has the higher growth rate.

Scott (1989) suggested dropping distinctions between investment in capital and other purposes. This implies that there is no special role for technology and market structure. The allocation of labour and capital as in the production function approach and the allocation of capital as in the investment function approach of Vogt (1968) is not considered further. Although Scott's approach deals with optimising households and perfectly competitive firms (see van de Klundert 1990 on this point) as can be done with the standard neoclassical growth model (see Abel and Blanchard 1983) this does not seem to be a way of making progress in the direction of microfoundations which is the subject of this paper.

6. Summary

Summarising the literature along the three standard problems of property rights, monopoly, and insurance as discussed in Arrow (1962b) we find the following results:

i) New growth theory has extensively discussed the consequences of the imperfections of patenting in Shell (1967), Romer (1986) and Ziesemer (1990, 1993) as a public externality, in Judd (1985), Lucas (1988), Romer (1990), Ziesemer (1991), Aghion/Howitt (1992), Grossman/Helpman (1991a) with private externality; however, explicit modelling of patents can only be found in Judd's paper.

ii) Different forms of market structure, the second strength of new growth theory, are summarised in table 1 [see also Amable/Guellec (1991) for a similar table in a survey of endogenous knowledge].

iii) Uncertainty is explicitly treated in Aghion/Howitt (1992), Amable (1993), Grossman/Helpman (1991a), King/Robson (1993), and Segerstrom/Anant/Dinopoulos (1990); in some of them it is reduced to a certainty equivalent by use of the law of large numbers. The integration of uncertainty can be viewed as a third major contribution of new growth theory. An interesting general framework into which almost all types of new growth models can be integrated has been provided by Conlisk (1989). This general formulation may turn out to be very helpful for future research.

iv) Finally, the forces driving growth have become more explicit in the new growth theory. The contents of these forces are summarised in table 2. The specifications according to those of old growth theory is summarised in table 3.

Policy is a corrective taxation – to correct externalities or make prices equal to marginal costs or to pay for government factors (see Barro/Sala-i-Martin 1992 for a survey with respect to government) – but implies distributional conflict in the case of public factors if users have different production functions as in Ziesemer (1990, 1993). The predictions of convergence or divergence of growth rates in the former depends on the treatment of policy – Pareto optimal or inferior – whereas in the

Table 1

Forms of Competition	used in
Perfect Competition	Arrow 1962 a King/Robson Lucas 1988 Prescott/Boyd 1987 Rebelo 1991 Romer 1986 Stokey 1991 Yang/Borland 1991 Ziesemer 1990, 1991, 1993
Chamberlain Monopolistic Competition	Acharya/Ziesemer 1992 Amable 1993 Grossman/Helpman 1990, 1991 a Judd 1985 Romer 1987 Young 1991, 1993 a, b
Bertrand Competition	Grossman/Helpman 1991 b Segerstrom/Anant/Dinopoulos 1990
Temporary Innovative Monopoly	Aghion/Howitt 1992 Grossman/Helpman 1991a
Permanent Monopoly	Yang/Borland 1991

contributions last mentioned it depends on the outcome of a distributional conflict.

The relation between endogenous population growth and endogenous technical change has been discussed earlier by Pryor and Maurer (1982) starting from the Boserup thesis. From the point of view of new growth theory this is discussed by Kremer (1993) with much emphasis on the empirics. Schulstad (1993) softens the strong impact of population growth known from Shellian models by introducing diffusion.

Technologically generated growth cycles can be found in Shell (1967), Judd (1985), Aghion/Howitt (1992), Amable (1993) and King/Robson (1993).

It seems to us that new growth theory has brought about considerable theoretical progress since Judd's pioneering paper in 1985. However, we should not finish this survey without making some notes on the evaluation of the different approaches. The desire for such an evaluation is

Table 2

Contents of Technology		used in
learning by doing learning by watching		Arrow 1962 a King/Robson Stokey 1988 Yang/Borland 1991 Young 1991, 1993 a, b
new varieties of consumer goods	horizontally differentiated	Judd 1985 Grossman/Helpman 1989 Young 1993 a, b
	vertically differentiated	Grossman/Helpman 1991a
new varieties of factors	horizontally differentiated	Acharya/Ziesemer 1993 Grossman/Helpman 1990 Romer 1987, 1990
	vertically differentiated	Acharya/Ziesemer 1992 Amable 1993 Grossman/Helpman 1991b
private knowledge spillovers		Lucas 1988 Romer 1986
intergenerational technology transfer		Prescott/Boyd 1987
households' knowledge		Becker/Murphy/Tamura 1990 Lucas 1988 Rebelo 1991
firms' knowledge		Ziesemer 1991
public basic scientific research		Ziesemer 1990, 1993
core capital goods		Rebelo 1991

comprehensible as progress in economics results from the quality rather than the variety of the models. Unfortunately the evaluation of the quality is anything but unanimous. Viewing the contemporary results of empirical analysis an evaluation of the competing approaches is in our opinion neither senseful nor possible. Because of the complexity of the problems it is convenient to sketch our arguments in two parts:

1. Is there some need for or an advantage to be gained from new (endogenous) growth theory?

2. Should we favour any elements or structures from particular endogenous theories of growth?

Table 3

Arrow	Conlisk/Vogt
King/Robson Romer 1986 Romer 1987 Stokey 1988, 1991 Yang/Borland 1991 ? Young 1991 Ziesemer 1990	Stiglitz 1987 van de Klundert 1990

Phelps	Uzawa	Shell
Judd 1985 Grossman/Helpman 1989	Becker/Murphy/Tamura 1990 Lucas 1988 Prescott/Boyd 1987 Ziesemer 1991, 1993	Aghion/Howitt 1992 Amable 1993 Barro 1990 Grossman/Helpman 1990 Grossman/Helpman 1991 a,b Jones/Manuelli 1990 Rebelo 1991 Romer 1990 Segerstrom/Anant/Dinopoulos 1990 Young 1993 a, b

Old versus New Growth Theory

The discussion between protagonists of the old and the new growth theories sometimes seems to be dominated by technical questions such as the degree of the homogeneity of the aggregate production function with respect to reproduceable capital. See, for example, Solow (1994). However, as Romer (1994) argued convincingly this is merely a expositional question of specific models rather than an essential attribute of new growth theory. It is however essential for some specific formulations of models of endogenous growth, especially the linear modells of Becker/Murphy/Tamura (1990), Jones/Manuelli (1990) and Rebelo (1991), but also the linear homogeneous model of Romer (1986).

In our opinion the so-called convergence controversy is the core of the disagreement. The proponents of the new growth theory allege a central empirical anomaly of the old growth theory; it implies a relatively fast conditional convergence of the per capita income because low per capita income go together with high marginal productivity of capital and incentives for investment, and vice versa. This implication follows immediately from the Solow model if uniform saving ratios and technolgies are assumed. This line of arguments contradicts Baumol (1986), who supports the convergence hypothesis by a regression of the growth rates of countries with their initial per capita income, which however is limited to the postwar era and the industrialized countries. In contrast Romer (1994) describes a test of convergence for industrialized and non-industrialized countries which shows that countries with low initial per capita income by no means have systematically higher growth rates than countries with high initial per capita income. However the data used which are taken from Heston/Summers (1991) are only from 1960 to 1985.

The supporters of old growth theory place this criticism in context by basing the critical implications on inessential oversimplifications in the assumptions of the traditional neoclassical model. See Solow (1994) and Pack (1994). For example Solow regards different rates of technical progress in the various countries as one of the factors which causes different growth. Pack emphasizes the influence of the political and institutional framework on the productivity of factors. Neither Solow nor Pack provide an explizit modelling of these effects. As a result it remains unclear how neoclassical models which generate such effects differ from endogenous growth models.

Mankiw/Romer/Weil (1992) provide a far more interesting and substantial contribution to this debate. They extend Solow's model by including an additional factor, human capital. Doing this they can explain considerable parts of the differing development of per capita income by different rates of savings and population growth in different countries. However, their cross country analysis using Heston/Summers data for 98 non-oilproducing industrialized and non-industrialized countries is based on some restrictive assumptions. Firstly, they do not allow for international capital flows, and therefore different rates of savings are measured by the differences in the investment-GDP ratio. Secondly, and even more questionably, they assume that there are no differences in the depreciation rates, capital shares, and the rates of technical progress in the various countries. According to Grossman/Helpman (1994) their argumentation is basically flawed by the assumption of equal rates of productivity growth. If there are in reality large differences in the rate of technical progress and these lead to corresponding differences in the investment-GDP ratios, then the coefficient of the latter is too high and the estimation is biased. The coefficient in fact not only catches the influence of different saving rates but also to some extend the influence of differing rates of technical progress. Finally Mankiw/Romer/Weil state that there is some evidence that the good fit of the model is due to large differences in investment-GDP ratios and rates of population growth. If only the 22 OECD-countries are used instead of 94 countries R^2 reduces from 0.78 to 0.28, unless a convergence variable is imposed.

Finally it is worth to mention that divergence of per capita income is not implied by all models of new growth theory. Especially the models of section 4.1 and 4.2 are compatible with the convergence hypothesis. It is the specification of the model, particularly the specification of the technical progress function which implies convergence or divergence of per capita income.

There is no doubt that new growth theoriy has several theoretical advantages over the old growth theory. Also the supporters of old growth theory recognise the implementation of imperfect competition as a great advantage (c.f. Solow 1994, p. 49). Moreover savings, and even more important, the development of technical progress are endogenous. Finally the various models of endogenous growth provide a framework for the analysis of a rational policy for growth and development. Protagonists of new growth theory promise that the consequences of this analysis will be rather different from laissez-faire (cf. Romer 1994, p. 20).

The Variety of New Growth Models

The presence of so many different models in a particular area of economics, such as endogenous growth, leads to the desire to evaluate the various models. In particular one may want to test the models empirically.

The literature contains many cross-country regressions which claim to explain the sources of differences in the long-term growth rates of various countries although they are not derived from growth models. The structure of these numerous regressions is shortly and precisely summarized by Grossman and Helpman as follws: "These regressions invariably include the beginning-of-period income level and the investment-GDP ratio, along with a number of the researchers own favorite variables." (See Grossman and Helpman 1994, p. 29). These assessments are discussed in the literature critically and at length. See especially Levine/Renelt (1992) and Fagerberg (1994).

Levine/Renelt (1992) confirm that the coefficients of regressions of the growth rates of countries with a big variety of politico-economic variables are siginificant. Yet they regard these models very sceptically as they find out that these regressions are very sensitive to the choice of explanatory variables. Even small changes in the specification of the models cause some coefficients to become insignificant. From the point of view of these *ad hoc* regressions it seems impossible to favour a specific variant of an endogenous growth model.

The general question arises whether these simple regression models are at all suitable for testing the empirical validity of particular approaches of the new growth theory. In particular Fagerberg has pointed out that these single equation regressions never can catch the complexity of elaborated and sophisticated new growth models. Instead of estimating reduced form models one should test more complete models, where only the exogenous variables of a particular theoretical model have to be estimated. Moreover we should have "a sharper focus on the underlying assumptions of the competing views" (c.f. Fagerberg 1994, p. 1171). Moreover we would like to add that models that want to help explaining empirical phenomena should include international factor movements and trade and clarify the role of immobile factors like infrastructural investments before running regressions. Progress has been made with respect to technology and market structure issues, but the role of international trade, factor movements and government seems to be insufficiently elaborated.

Taking these problems into account we are not able to evaluate the empirical validity of particular approaches of new growth theory.

Literature

Abel, A. B./*Blanchard,* O. J., 1983, An Intertemporal Model of Saving and Investment, Econometrica, 51, May, 675 - 92.

Acharya, R./*Ziesemer,* T., 1994, A Closed Economy Model of Horizontal and Vertical Product Differentiation: The Case of Innovation in Biotechnology, Paper prepared for the Eunetic Conference on "Evolutionary Economics of Technical change", Strasbourg, October, 1994.

Aghion, P./*Howitt,* P., 1992, A Model of Growth through Creative Destruction, Econometrica, vol. 60, No. 2, 323 - 351.

Amable, B., 1993, Radical and Incremental Innovation: A Model of endogenous and unsteady growth, mimeo, January.

Amable, B./*Guellec,* D., 1991, Un panorama des theorie de la croissance endogène, Document de Travail, insee, Juillet.

Arrow, K. J., 1962a, The Economic Implications of Learning by Doing, Review of Economic Studies, vol. 29, 155 - 173.

— 1962b, Economic Welfare and the Allocation of Resources for Invention. The Journal of Law and Economics, vol. 12, pp. 609 - 24.

d'Autume, A./*Michel,* P., 1993, Endogenous growth in Arrow's learning by doing model, European Economic Review, vol. 37, 1175 - 1184.

Barro, R. J., 1990, Government Spending in a Simple Model of Endogenous Growth, Journal of Political Economy, vol. 98, October, S103 - S125.

Barro, R. J./*Sala-i-Martin,* X., 1992, Public Finance in Models of Economic Growth, Review of Economic Studies, vol. 59, 645 - 661.

Baumol, W. J., 1986, Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show, The American Economic Review, vol. 76, December, 1072 - 1085.

Becker, G. S./*Murphy,* K. M./*Tamura,* R., 1990, Human Capital, Fertility and Economic Growth, Journal of Political Economy, vol. 98, 13 - 37.

Bertola, G., 1993, Factor Shares and Savings in Endogenous Growth, American Economic Review, vol. 83, 1184 - 1198.

Van Cayseele, P., 1990, Theorie van de Economische Groei, Acco, Leuven, 104 p.

Conlisk, J., 1967, A Modified Neoclassical Growth Model with Endogenous Technical Change, The Southern Economic Journal, vol. 34, no. 2, October, 199 - 208.

— 1969, A Neoclassical Growth Model with Endogenously Positioned Technical Change Frontier, Economic Journal, vol. 79, June, 348 - 362.

— 1989, An Aggregate Model of Technical Change, Quarterly Journal of Economics, vol. 104, November, 787 - 821.

Cornes, R./*Sandler,* T., 1986, The theory of externalities, public goods, and club goods, Cambridge University Press, London/New York, Chapter 6.

Dosi, G./*Freeman,* C./*Nelson,* R. R./*Silverberg,* G./*Soete,* L. L. G. (eds.), 1988, Technical Change and Economic Theory, Pinter Publishers, London and New York.

Fagerberg, J., 1994, Technology and International Differences in Growth Rates, Journal of Economic Literature, vol. 32, September, 1147 - 1175

Flemming, J./*Götz,* G., 1993, Externalitäten, Nichtkonvexitäten und endogener technischer Fortschritt, Jahrbuch für Sozialwissenschaften, Bd. 44, 203 - 215.

Grossman, G. M./*Helpman,* E., 1989, Product Development and International Trade, Journal of Political Economy, vol. 97, no. 6, 1261 - 83.

—/— 1990, Comparative Advantage and Long Run Growth, The American Economic Review, vol. 80, 796 - 815.

—/— 1991a, Quality Ladders in the Theory of Growth, Review of Economic Studies, vol. 58, 43 - 61.

—/— 1991b, Quality Ladders and Product Cycles, Quarterly Journal of Economics, vol. 106, May, 557 - 586.

—/— 1994, Endogenous Innovation in the Theory of Growth, Journal of Economic Perspectives, vol. 8, Winter, 23 - 44.

Helliwell, J. F./*Chung,* A., 1990, Macroeconomic Convergence: International Transmission of Growth and Technological Progress, NBER Working Paper Series, ISSN 0898 - 2937, No. 3264.

—/— 1992, Convergence and Growth Linkages between North and South, NBER Working Paper Series, ISSN 0898 - 2937, No. 3948.

Helpman, E., 1992, Endogenous Macroeconomic Growth Theory, European Economic Review, vol. 36, 237 - 267.

Heston, A./*Summers,* R., 1991, The Penn World Trade (Mark 5): An Expanded Set of International Comparisons, 1950 - 1988, Quarterly Journal of Economics, vol. 106, May, 327 - 368.

Jones, L. E./*Manuelli,* R. E., 1990, A Convex Model of Equilibrium Growth: Theory and Policy Implications, Journal of Political Economy, vol. 98, no. 5, Part 1, 1008 - 38.

Jones, L. E./*Manuelli,* R. E./*Rossi,* P. E., 1993, Optimal Taxation in Models of Endogenous Growth, Journal of Political Economy, vol. 101, no. 3, 485 - 517.

Jones, L. E./*Stokey,* N., 1992, Symposium on Economic Growth, Theory and Computation: Introduction, Journal of Economic Theory, vol. 58(2), 117 - 134.

Judd, K. L., 1985, On the Performance of Patents, Econometrica, vol. 53, No. 3, 567 - 585.

Kaldor, N./*Mirrlees,* J. A., 1962, A Growth Model with Induced Technical Progress, Review of Economic Studies, vol. 29, 174 - 90.

Kamien, M. I./*Schwartz,* N. L., 1982, Market Structure and Innovation, Cambridge University Press.

Kelley, A. C., 1988, Economic Consequences of Population Change in the Third World, Journal of Economic Literature, vol. 26, no. 4, 1685 - 1728.

King, M. A./*Robson,* M. H., 1993, A Dynamic Model of Investment and Endogenous Growth , Scandinavian Journal of Economics, vol. 95, no. 4, 445 - 466.

King, R. G./*Rebelo,* S., 1990, Public Policy and Economic Growth: Developing Neoclassical Implications, Journal of Political Economy, vol. 98, no. 5, Part 2, S126 - S150.

van de Klundert, T., 1990, The Ultimate Consequences of the New Growth Theory; An Introduction to the Views of M. Fitzgerald Scott, Working Paper, April.

van de Klundert, T./*Smulders,* S., 1992, Reconstructing Growth Theory: A Survey, De Economist, 140, 177 - 203.

Kremer, M., 1993, Population growth and technological change: One million B.C. to 1990, Quarterly Journal of Economics, vol. 108, Aug., 681 - 716.

Levine, D./*Renelt,* D., 1992, A Sensitivity Analysis of Cross-Country Growth Regressions, American Economic Review, vol. 82, September, 942 - 963.

Lucas, R. E. Jr., 1988, On the Mechanics of Economic Development, Journal of Monetary Economics, 22, July, 3 - 42.

— 1990, Supply-Side Economics: An Analytical Review, Oxford Economic Papers, vol. 42, 293 - 316.

— 1993, Making a Miracle, Econometrica, vol. 61, 251 - 272.

Mankiw, N. G./*Romer,* D./*Weil,* D. N., (1992), A Contribution to the Empirics of Economic Growth, Quarterly Journal of Economics, Vol. 107, May, 407 - 437.

Nelson, R. R., (1959), The Simple Economics of Basic Scientific Research, Journal of Political Economy, vol. 67, 297 - 306.

Neumann, M., 1989, Market Size, Monopoly Power and Innovations under Uncertainty, 295 - 306, in: D. B. Audretsch, L. Sleuwaegen and H. Yamawaki (eds.), The Convergence of International and Domestics markets, North-Holland, Amsterdam.

Pack, H., 1994, Endogenous Growth Theory: Intellectual Appeal and Empirical Shortcommings, Journal of Economic Perspectives, vol. 8, Winter, 55 - 72.

Phelps, E. S., 1966, Models of Technical Progress and the Golden Rule of Research, Review of Economic Studies, vol. 33, 133 - 45.

Prescott, E. C./*Boyd,* J. H., 1987, Dynamic Coalitions: Engines of Growth, The American Economic Review, vol. 77, no. 2, May, 63 - 67.

Pryor, F. L./*Maurer,* S. B., 1982, On Induced Economic Change in Precapitalist Societies, Journal of Development Economics, vol. 10, June, 325 - 353.

Ramser, H. J., 1993, Grundlagen der "neuen" Wachstumstheorie, Wirtschaftswissenschaftliches Studium, Bd. 22, 117 - 123.

Rebelo, S., 1991, Long-Run Policy Analysis and Long-Run Growth, Journal of Political Economy, vol. 99, no. 3, 500 - 521.

— 1992, Growth in Open Economies, Carnegie-Rochester Conference Series on Public Policy, vol. 36, July, 5 - 46.

Romer, P. M., 1986, Increasing Returns and Long-Run Growth, Journal of Political Economy, vol. 94, no. 5, 1002 - 37.

— 1987, Growth Based on Increasing Returns Due to Specialization, The American Economic Review, vol. 77, no. 2, May, 56 - 62.

— 1989, Increasing Returns and New Developments in the Theory of Growth, NBER Working Paper Series, ISSN 0898 - 2937, No. 3098.

— 1990, Endogenous Technological Change, Journal of Political Economy, vol. 98, no. 5, Part 2, S71 - S102.

— 1994, The Origins of Endogenous Growth, Journal of Economic Perspectives, vol. 8, Winter, 3 - 22.

Sala-i-Martin, X., 1990, Lecture Notes on Economic Growth I and II, NBER Working Papers No. 3563 and 3564.

Schulstad, P., 1993, Knowledge diffusion in an endogenous growth model, Economic Letters, vol. 42, 275 - 278.

Schultz, T. W., 1964, Transforming Traditional Agriculture, New Haven, Yale University Press.

Scott, M. FG., 1989, A New View of Economic Growth, Clarendon Press.

Segerstrom, P. S./*Anant,*T. C. A./*Dinopoulos*, E., 1990, A Schumpeterian Model of the Product Life Cycle, American Economic Review, vol. 80, no. 5, 1077 - 91.

Shell, K., 1967, A Model of Inventive Activity and Capital Accumulation, in: Essays in the Theory of Optimal Growth, K. Shell, ed., Cambridge Mass.: MIT Press.

Sheshinski, E., 1967, Optimal Accumulation with Learning by Doing, in: Essays in the Theory of Optimal Growth, K. Shell, ed., Cambridge Mass.: MIT Press.

Solow, R. M., 1956, A Contribution to the Theory of Economic Growth, Quarterly Journal of Economics, vol. 70, 65 - 94.

— 1988, Growth Theory and After, American Economic Review, vol. 78, no. 3, 307 - 317.

— 1994, Perspectives on Growth Theory, Journal of Economic Perspectives, vol. 8, Winter, 45 - 54.

Stiglitz, J. E., 1987, Learning to Learn, Localized Learning and Technical Progress, chap. 5, in P. Dasgupta and P. Stoneman, Economic Policy and Technological Performance, 125 - 153. Cambridge University press 1987.

Stokey, N., 1988, Learning by Doing and the Introduction of New Goods, Journal of Political Economy, vol. 96, no. 4, 701 - 747.

— 1991, Human Capital, Product Quality and Growth, Quarterly Journal of Economics, vol. 106, May , 587 - 616.

Uzawa, 1965, Optimum Technical Change in an Aggregative Model of Economic Growth, International Economic Review, vol. 6, January, 18 - 31.

Verspagen, B., 1992, Endogenous Innovation in Neoclassical Growth Models: A Survey, Journal of Macroeconomics, vol. 14, No. 4, 631 - 662.

Vogt, W., 1968, Kapitalakkumulation und Technischer Fortschritt, Weltwirtschaftliches Archiv, Bd. 100, 185 - 196.

von Weizsäcker, C. C., 1969, Forschungsinvestitionen und makroökonomische Modelle – ein wirtschaftstheoretisches Dilemma, Kyklos, Bd. 12, 454 - 65.

Yang, X./*Borland,* J., 1991, A Microeconomic Mechanism for Economic Growth, Journal of Political Economy, vol. 99, no. 3, 460 - 482.

Young, A., 1991, Learning by doing and the dynamic effects of international trade, Quarterly Journal of Economics, vol. 106, 369 - 405.

— 1993a, Invention and Bounded Learning by Doing, Journal of Political Economy, vol. 101, no. 3, 443 - 472.

— 1993b, Substitution and Complementarity in Endogenous Innovation, Quarterly Journal of Economics, vol. 108, 775 - 807.

Ziesemer, T., 1987, Economic Theory of Underdevelopment, Transfer Verlag, Regensburg.

— 1990, Public Factors and Democracy in Poverty Analysis, Oxford Economic Papers, vol. 42, Special Issue, January, 268 - 280. Reprinted in P. J. N. Sinclair and M. D. E. Slater (eds.), Taxation, Private Information and Capital, Oxford University Press, 1991.

— 1991, Human Capital, Market Structure and Taxation in a Growth Model with Endogenous Technical Progress, Journal of Macroeconomics, vol. 13, Winter, 47 - 68.

— 1993, Endogenous Growth with Public Factors and Heterogeneous Human Capital Producers, MERIT Research Memorandum 93 - 022.

Zusammenfassung

Dieser Artikel bietet einen Überblick über die zentralen Entwicklungen der neuen Wachstumstheorie. Es wird untersucht, welche Lösungen die verschiedenen Ansätze für drei offene Probleme der alten (endogenen) Wachstumstheorie anbieten: i) Eine explizite Formulierung der Black-Box "Technologie". ii) Die Entwicklung geeigneter Marktstrukturen, wenn über die Zeit zunehmende Skalenerträge vorliegen. iii) Begründungen für verschiedene Spezifikationen der Produktionsfunktion des technischen Fortschritts. Es stellt sich heraus, daß die neue Wachstumstheorie beträchtlichen Fortschritt in den beiden ersten Punkten erzielen konnte, wohingegen sie im dritten Punkt über den Wissensstand der 60er Jahre nicht hinauskommt.

Abstract

This paper surveys new growth theory with emphasis on three open issues known from old endogenous growth theory of the sixties: i) What is the content of the black-box variable 'technology'? ii) Which market structure prevails when endogenous technology generates dynamically increasing returns? iii) What are the justifications for and implications of different specifications of production functions for technical progress? We show that new growth theory has made progress on the first two problems but almost none with respect to the third.

JEL-Klassifikation: O 30, O 40.