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Per Botolf Maurseth

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Besøksadresse: Grønlandsleiret 25
Addresse: Postboks 8159 Dep.
0033 Oslo
Internett: www.nupi.no
E-post: pub@nupi.no
Fax: [+ 47] 22 17 70 15
Tel: [+ 47] 22 05 65 00

Recent Advances in Growth Theory. A Comparison of Neoclassical and Evolutionary Perspectives

Per Botolf Maurseth*

[Abstract] Research on economic growth has experienced remarkable progress the last decade. The neoclassical perspective has benefited from development of new mathematical methods and new approaches to market structure, economics of scale and spillover effects. At the same time evolutionary theories on economic development have appeared, partly competing but also complementary to neoclassical theorising. In this paper, the development of the two perspectives on economic growth is reviewed and they are compared with each other. Despite evident differences there seems to be convergence between the two traditions. The two perspectives therefore do not belong to different paradigms in the Kuhnian sense and they can hardly be categorised as two isolated research programmes in the sense of Imre Lakatos. Evolutionary and neoclassical growth economics draw inspiration from similar sources, they are overlapping and to some extent complementary. The two traditions also interact with each other.

JEL classification numbers: B22, O30, O40

* The Norwegian Institute of International Affairs, P.O. Box 8159 Dep., N-0033 Oslo. Telephone: + 47 22 05 65 45. E-mail: PerB.Maurseth@nupi.no. I thank Karl Ove Moene, Jan Fagerberg, Jens Chr. Andvig, Leo Andreas Grünfeld and Nicolai J. Foss for comments on previous drafts of this paper.

1. Introduction

Klette (1989) provides a comparative survey of neoclassical theories of economic growth, the New-Austrian research programme and evolutionary economics from a philosophy of science perspective. Klette's conclusions were pessimistic. The dominating neoclassical programme, at least as regards growth theory, was stagnating, striving with lack of explanatory power. The New-Austrian programme was dying out because of few new contributions. The evolutionary programme was deemed to be too new to undergo evaluation, but an unclear scientific core and unclear heuristics within the research programme made Klette seem pessimistic also towards evolutionary economics.

Not so now. Research on technological change and economic growth has experienced a renaissance. This applies especially within the neoclassical tradition where the emergence of endogenous growth models has triggered new interest and large amounts of research efforts. The evolutionary perspective has proved a promising strategy and numerous important contributions have emerged. Most important, however, from the point of view taken in this paper, evolutionary and neoclassical theory both build on similar sources of inspiration and interact with each other along converging lines of thought.

The pessimism towards growth theory described above was partly due to difficulties of formal treatment of technological change in economic growth models. Economists have for a long time agreed that technological progress forms a basis for economic progress. In the theories of classical economists like David Ricardo, Karl Marx and Adam Smith, technological change plays crucial roles. Schumpeter (1934 and 1944) had presented convincing arguments that technological change is the driving force in capitalist development. Empirical work lent support to Schumpeter's emphasis on technological change. Technological change, as expressed in the residual (see below), was revealed as the main contributor to economic growth. Formal theoretical growth theories however, did not succeed in explaining technological change, and they lagged considerably behind economic intuition and empirical findings. The renaissance of growth theory consists in treating technological change as an inherent result of the economic mechanisms rather than as "manna from heaven" as in the preceding growth models. Both the neoclassical endogenous growth models and the evolutionary perspective have as one common point of departure attempts at incorporating technological change into analysis of economic development.

This essay describes recent developments in economic growth theory and compares the two perspectives in light of some selected predecessors. The discussion is constrained to neoclassical endogenous growth theories and the evolutionary perspective.[1] The choice of neoclassical endogenous growth theories and evolutionary theories as objects of comparison is made because the two traditions seem to be the most progressing at the time. The two perspectives also interact, as will become clear, making comparison more interesting. In addition the main topics of research in the two perspectives are the same. They both provide explanations of growth based on technological change and innovation.

The rest of this essay is organised as follows: The next section deals mainly with terminology. We will seek to reach definitions or descriptions of 'neoclassical' and 'evolutionary' economics, respectively, appropriate for our discussion. The third section discusses the stagnation in growth theorising in the 1970s. Even if there were attempts at endogenising technological change in some early models, economic growth theory as a whole was 'dormant' (Barro and Sala-I-Martin, 1995, xv). Section four describes the early attempts at endogenising growth. These early contributions preceded the recent growth models in both the neo-classical tradition and in the more heterogeneous evolutionary growth theories. Sections five and six describe the recent neoclassical reawakening and the evolutionary perspective, respectively. The cognitive history of economic growth sketched in sections three through six will serve as background for the discussion in section six. Section seven is devoted to a comparative discussion of the two perspectives from a philosophy of science perspective. I discuss whether the two perspectives are competing paradigms in the sense of Kuhn or rivalling research programmes in the sense of Lakatos. Evolutionary economics has so far not revolutionised economics, and does not seem to have the potential for doing so. Even if evolutionary economics emerged as an alternative to a stagnating tradition, the neoclassical tradition was revitalised. The discussion of the two perspectives as distinct paradigms therefore concludes negatively. Evolutionary economics and neoclassical growth theory may be more like distinct research programmes in the sense of Lakatos. The two perspectives, however, seem to have overlapping elements both in terms of 'protecting belt' and the so-called 'hard core'. As research programmes, the two perspectives seem to be complementary, despite distinct features characterising both. Importantly, elements of the seemingly hard core in evolutionary economics are being integrated into neoclassical economics. In addition, the two approaches have started applying similar tools of analysis which seem progressive for the field of economics as a whole. Section eight concludes.

2. Neoclassical and evolutionary Economics

[1] This disregards several other important perspectives in the theory of economic growth. Neither Keynesian, New-Austrian nor structural approaches to economic growth will be discussed. McCombie and Thirlwall (1994) present a wide variety of Keynesian-inspired theories of economic growth. Taylor (1991) gives an introduction to structuralist approaches. Hicks (1973) is the main reference on New-Austrian growth theory.

The term *Neoclassical* is widely used in economic literature. It is harder to find a clear cut definition of the term. For the purpose of the discussion in this essay the definition proposed in *The New Palgrave*[2] will be used. According to this definition neo-classical denotes the marginalist approach in economics. This definition seems to include as necessary elements: a) well-behaved production and utility functions, b) rational and optimising behaviour and c) static or dynamic equilibria as the topic of analysis. These characteristics stem from the studies of Menger, Jevons and Walras in the 19th century, and have come to be the basis for most economic thinking ever since. The definition above is a wide one, wider than several other proposals. Barro and Sala-I-Martin define the neo-classical *production function* as one characterised by positive and diminishing marginal products with respect to each factor of production, constant returns to scale and fulfilment of the Inada conditions.[3] Several authors have proposed to include atomistic and price-taking behaviour in the definition of neo-classical economics. The main reason for the wider definition of neo-classical is the context of this essay: The narrower definitions of neo-classical do not capture the core of recent growth theory which is the topic here.[4]

The proposed definition of neo-classical includes most of the new growth theories in the tradition of Romer and Lucas. Most of them are based on well-behaved production functions (in the sense that they are differentiable) and agents' optimising behaviour, and most of them seek to establish the existence of steady state equilibrium growth paths in the economy. As will be demonstrated, several contributions to growth theory within the same tradition do not fulfil even the broader definition of neo-classical proposed above. This illustrates the difficulties of organising cognitive history into distinct traditions.

The above definition of neoclassical for example, does not include other widely used and accepted tools in economic analysis. One example is game theory. Most modelling of game theory is in accordance with rational behaviour and well-behaved utility functions[5], but game theories often analyse processes out of equilibrium and also situations without any equilibrium. Game theory is therefore not exclusively a neo-classical method of analysis. Haavelmo (1962) discusses several problems of using static equilibrium models in economics, and demonstrates that such models lack a

[2] Eatwell, Milgate and Newman (1987).

[3] The Inada conditions require the marginal product of the factors of production approaching infinity when their use goes to zero and zero when their use goes to infinity.

[4] This, however, does not mean that other definitions of neo-classical may not be appropriate in other contexts. The definition of neoclassical above is also somewhat apart from the usual one in discussions of economic growth. The notion neoclassical in growth-theoretical contexts is most often taken to be Solow's growth models and their subsequent extensions.

[5] Even if rational behaviour more often than not is assumed without any discussion of well-behaved utility functions.

theoretical basis for how equilibrium may happen to be established.[6] Game theory (and evolutionary economics) may be regarded as attempts at handling such challenges.

Nor does the definition above include such assumptions as near-rationality which has become widespread in economics. Game theory is again an example[7], but so are several models of price rigidities in macroeconomics or discussions of time inconsistency in intertemporal models[8]. Similarly, recent attempts at describing discrete choice situations rely on models that are in accordance with deviations from perfect rationality.[9] This will illustrate my point later on of the problems of discussing evolutionary economics and neo-classical economics as distinct research programmes.

It is harder to find accepted definitions of evolutionary economics than of neo-classical economics.[10] The term *evolutionary* has been used by economists as different as Trygve Haavelmo, Paul Krugman and Paul David. Most often evolutionary economics is used to describe a heterogeneous tradition in economics focusing on the role of technical change in economic development without basing their arguments on any notion of 'equilibrium'.[11] Here we will restrict ourselves to a smaller tradition tracing back to Nelson and Winter (1982). Authors within this tradition have applied formal modelling of evolutionary ideas.[12] Restricting the discussion to formal models of economic growth limits the task of comparison. For the purpose of comparison of two traditions of cognitive lines of thought, it is appropriate with definitions that potentially demarcate contributions belonging to the two traditions. Evolutionary theorising on economic growth has so far concentrated mostly on the behaviour of firms. Evolutionary consumer theory has not been elaborated to the same extent, and we disregard it in the following.[13] Evolutionary economics is explicitly dynamic: Evolutionary theories' 'purpose is to explain the movement of something over time, or to explain why that something is what it is at a moment in time in terms of how it got there' (Dosi and Nelson 1994). Evolutionary economics draws heavily on analogies from biology, and includes selection mechanisms (replicator equations) and explanations of how firms get born, grow, shrink and eventually die. Nelson (1987)

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[6] Haavelmo (1962) is in Norwegian. An English translation is Haavelmo (1974).

[7] Kreps (1990a and 1990b) and Tirole (1988) provide examples.

[8] Blanchard and Fischer (1989), ch. 8.

[9] In modelling discrete choice, a common approach is stochastic utility functions. The stochastic elements are interpreted either as modellers' inability to formulate individual behaviour or as if individual behaviour is intrinsically probabilistic (or both). For an overview, see Anderson *et al.* (1992).

[10] One illustrating example of this is Dosi (1994). Dosi defines evolutionary economics while explicitly stating that his definition is personal and one with which many evolutionary economists certainly would disagree.

[11] See, for instance, Freeman (1988).

[12] A review of this literature is provided by Silverberg (1988).

[13] There is a long tradition of theory of the consumer that deviates from neo-classical theory, but which is not necessarily evolutionary. Furthermore, evolutionary game theory focuses on interaction between agents, but not necessarily consumers.

states that an evolutionary theory has as necessary elements both ‘a mechanism that introduces novelties into the system’ and ‘some understandable mechanism that “selects on” entities present in the system.’ In many applications, the selection mechanism is assumed to be a function of the profit performance of firms. Most contributions within the evolutionary tradition reject firms as profit-maximising entities. Firm behaviour is modelled as *routines* or rules of thumb (Dosi, 1988). In analogy with biology, the term routines is the paraphrase of genes.[14] The routines are assumed to be stickier than maximising behaviour, and they are assumed being created by the historical experience of the firm. Nevertheless, it is important that the routines are continuously changing. Firms learn from experience and are capable of adapting to changing environments. The adaptation, however, is supposed to be slow. ‘Firms tend to work with relatively general and event-independent routines’ (Dosi 1988, p. 1134). Technological change is defined as *search* for an increase in the known set of production processes (Nelson 1987, Dosi 1988 and Verspagen 1993). It is stressed that a significant amount of innovations and improvements originates through ‘learning by doing’ and ‘learning by using’. It is also important that technological change is viewed as a cumulative process, giving rise to path dependency in the economic system (Dosi 1988). Important in evolutionary economics is heterogeneity. In neo-classical economics, a common simplification is the assumption of representative agents. In evolutionary economics it is often (but not always) heterogeneity that drives the economic dynamics. Since firms are assumed to be governed by routines, differences in routines will produce heterogeneity. An important reason for the abandoning of rational behaviour underlying the evolutionary perspective is that the world is genuinely uncertain, and that this uncertainty cannot be reduced to calculable probabilities. Keynes (1936, p.161) expressed the idea clearly in stating that ‘… our decisions to do something positive, (…) can only be taken as a result of animal spirits - of a spontaneous urge to action rather than inaction, and not as the outcome of a weighted average of quantitative benefits multiplied by quantitative probabilities’. Even if genuine uncertainty cannot be modelled, evolutionary economists frequently apply stochastic formal models.

The descriptions of neo-classical and evolutionary economics above do not do justice to any of the two traditions. There will be researchers who do not fit into any of the two descriptions. Others will fit into both of them. Some would surely deny belonging to the group our description puts them into. This illustrates the problems of codifying scientific research into specific traditions. The above descriptions are meant to be rough sketches only to be used in comparative discussion of the two traditions.

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[14] Despite the clear analogy, evolutionary economists stress that there is no precise isomorphism between biological and economic theories of evolution.

3. The slowdown in theorising on economic growth in the 1970s

Solow (1994) traces out three stages or waves in the history of growth theory the last 50 years. The first was associated with the Harrod Domar models of economic growth. The second stage was the development of the traditional neo-classical growth model in the 1960s. The third wave of growth theorising was the emergence of the endogenous growth theories in the early 1980s. For the purpose of the present paper, it is the second and the third wave that are most interesting. Formal evolutionary modelling that is to be contrasted with neo-classical theory appeared between these two waves.

Solow's growth model (Solow 1956 and 1960) triggered the second wave of interest in growth theory and empirical research on economic growth. Solow abandoned the assumption of fixed coefficients in production and introduced possibilities of substitution in the macro production function. This demonstrated that full capacity utilisation of both labour and capital was not a knife-edge phenomenon that would occur only by chance, as predicted by earlier models. Thus, Solow's model and its subsequent extensions changed the approach in growth theory from analyses of conditions for full employment to determinants of growth when full capacity utilisation was assumed. Even so, production technology with fixed coefficients in production has successfully been implemented in important contributions that focus explicitly on technical change (see below).

In the 1960s several important contributions to the field of economic growth emerged.[15] Important extensions to the Solow model were models with more than one sector and models in which exhaustion of natural resources was analysed. There was also a great amount of work besides the neo-classical tradition. These are important in our respect because they seem to precede the evolutionary tradition. Several researchers followed Schumpeter in informal treatments of economic growth, but only a few of them were evolutionary in the sense we have described above. Fagerberg (1994) gives an overview over elements of this literature.

Solow's growth model is in essence a model of capital accumulation. Parts of production are invested and give rise to an increase in the stock of capital in later production. Because of decreasing returns to capital, the marginal product of capital shrinks towards zero. On a steady state growth path investments exactly outweigh increase in other factors of production. Thus, the capital-labour ratio is constant, and so is the production-labour ratio.

Solow's growth model treated technological change as stemming from outside the model, as an exogenous factor. In the absence of exogenous productivity growth, the model predicted output growing at the same rate as population leaving output per worker constant. Technology was treated as a public good, available to all or none, and there was no treatment of production of knowledge. Thus it turned out that the model assumed what it should explain: Growth of output per worker was predicted to be equal to the rate of productivity growth, which was exogenous. Arrow (1962) states that '… a view of economic growth that depends so heavily on an exogenous variable, let alone one so difficult to measure as the quantity of knowledge, is hardly intellectually satisfactory'.

A particular feature of the Solow growth model was that it provided a method for decomposing the sources of economic growth. By use of the shares of the factors of production it was possible to identify the parts of growth stemming from increase in use of tangible factors of production. Empirical investigations found these sources explaining only a small share of observed growth. Seven-eighths of the observed increase in output per worker in the United States in the period 1909-49 was traced back to increase in productivity, leaving only one-eighth explained by increase in the capital-labour ratio.[16] Although not contradicting the underlying theory, the significance of the residual revealed that existing models of economic growth did not succeed in explaining the observed growth performance in industrial countries. The residual thus came to be known as 'a measure of our ignorance'.[17] Several attempts were made at 'squeezing down the residual' (Nelson 1981) by including several variables of explanation, and there was some success. As Solow (1994) points out, however, including a somewhat arbitrary set of explanatory variables in regression models of economic growth raises new problems regarding the direction of causality. Furthermore, it seems to be hard to disentangle all relevant variables from insignificant variables (Levine and Renelt, 1992). Thus, there seemed to be a need for including technological change as an endogenous variable in growth processes instead of treating it as an exogenous variable. There were several early contributions where technological change was analysed as endogenous (see below), though it is not fair to date the breakthrough before the occurrence of 'new growth theory' in the 1980s.

An important question for students of economic growth is whether per capita income in different countries will equalise over time. The neo-classical growth model predicts such a converging pattern. A richer country should *ceteris paribus* experience lower marginal productivity of capital. For such a country to grow at the same rate or faster than poorer ones, a substantially higher and increasing saving rate would be necessary. Facts did not seem to support this. Studies of changes in factor endowments did not succeed in explaining countries' growth performance.[18]

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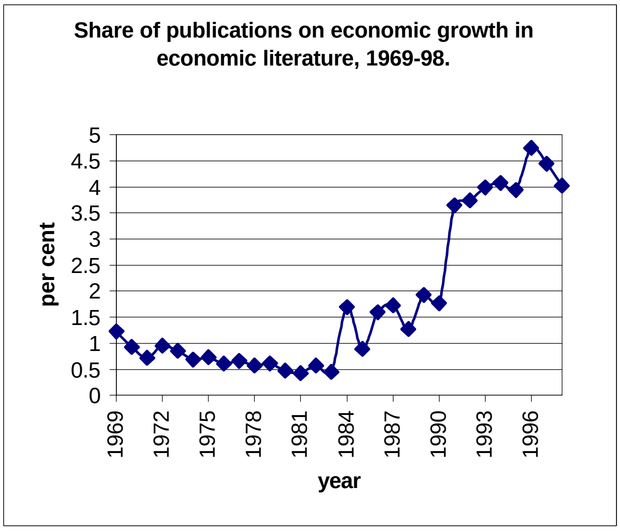
[15] Sen (1970) provides a sample of some contributions and a survey of the literature.
[16] Solow (1957).
[17] Abramovitz (1956). For a review of early growth accounting, giving credit to several authors, see Griliches (1996).
[18] The picture is somewhat mixed, however. In the world economy there is not convergence. Within regions, as e.g. the European Union, there has historically been very clear convergence, even if it paused during the 1980s. Also, there is a large literature on whether Solow's growth theory predicts unconditional convergence or whether convergence is expected when other variables are controlled

Despite an apparent need for new theorising, there were few new significant contributions in economic growth theory in the 1970s. In fact, the field went out of fashion. The chart below illustrates this in terms of the falling percentage of growth-related publications in economics and the subsequent explosion in the 1980s and 90s.[19]



In general one should be careful in using quantitative measures on cognitive progress. Numbers of publications on a specific field do not tell us anything about the theoretical or empirical significance of the contributions. The numbers may nevertheless be taken as an indicator of the interest in economic growth among economists. Regarded as no more than this, the chart seems to be convincing. There was a falling interest in economic growth in the 1970s, and an explosion in the two succeeding decades.

4. Early attempts at endogenising growth

The chart above indicates a growing interest in economics of growth succeeding the dormant 1970s. The revitalising of the field was due to developments of endogenous neo-classical models of growth and the emerging evolutionary models. This section will describe the reawakening in neo-classical theories.

Attempts had been made at endogenising technological change at an early stage. Nelson (1987) discriminates between *appreciative* and *formal theorising*.

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for. Barro (1997) gives an overview. See also Durlauf and Quah (1998) for a thorough discussion on empirical measures of convergence versus divergence.

Appreciation theorising denotes ‘the way economists write and talk about phenomena where the emphasis is on understanding these, rather than advancing a specifically theoretical point. … Formal theorising is more self-consciously analytical, more concerned with how a logical structure works, ...’ Within the appreciative tradition there were several contributions analysing technology as the source of growth. Schmookler (1966) is particularly important. Schmookler presents a coherent analysis of the role of technological change for economic growth in which the production of knowledge, the diffusion of knowledge and the feedback from growth to knowledge creation are discussed. As such, Schmookler preceded endogenous growth theory with his emphasis on the two-way causation of technology to growth and back to technology. Three notable examples of early formal theorising are Haavelmo (1954), Kaldor and Mirrles (1962) and Arrow (1962). Haavelmo’s theories of economic evolution were maybe the first attempt at endogenising technological change in growth models. Haavelmo introduced educational level in growth models. In one version, of his model, Haavelmo assumed a society’s educational level accumulate proportionally with time, to capture ‘the length of experience of the society considered’. In another version, the educational level was assumed to depend on investments in physical capital. Haavelmo demonstrated that his model could give rise to balanced growth paths, stationary levels, exploding developments and a rich set of other trajectories in economic development. Haavelmo’s analysis was frequently cited in the literature in the 1960s, but more seldom later on. One possible reason may be that there was no explicit micro-foundation in Haavelmo’s models. Thus, his analysis was apart from the hard core in the neo-classical research programme arising with the emergence of Solow’s growth model. This will be discussed in section six.

Both Kaldor and Mirrles (1962) and Arrow (1962) developed the ideas proposed by Haavelmo in which know-how, and therefore productivity, depended on society’s economic activities. In Kaldor and Mirrles’s growth model productivity growth is assumed to depend positively, but decreasingly on the level of investments. Kaldor and Mirrles explicitly avoided formulating a production function, but their model is in essence similar to Arrow (1962) in their vintage approach to economic dynamics. In such vintage models, new vintages of production facilities appear that are more productive than older vintages (endogenously or exogenously). The higher productivity in new vintages of capital draws labour from the obsolete ones with lower ability to pay wages. Johansen (1959) and Salter (1960) initiated this approach.[20]

Arrow (1962) introduced the concept ‘learning by doing’ in economic theorising. His model was based on microobservations of productivity increases in

[19] The numbers are taken from the Econ.Lit. database (produced by the American Economic Association). The numbers used in the figure are those returned from searches on “economic growth”.

absence of investments.[21] Like Kaldor and Mirrles, Arrow hypothesised that investments lead to learning, but in a context of diminishing returns. When an activity becomes a routine, the rate of learning will decrease. Learning was therefore analysed as depending on introduction of new physical capital. Arrow's model, therefore, shed new perspectives in the putty-clay technology introduced by Johansen (1959). Arrow's analysis suggests that investments in decentralised markets may be too small due to positive externalities stemming from learning by doing. Sheshinski (1967) explicitly traced conditions for optimal accumulation in the presence of learning by doing. Similarly, Frankel (1962) analysed externalities from capital accumulation in a way surprisingly similar to that of Romer (1986). Frankel analysed possible co-existence of constant returns to scale with decentralised markets because of external effects.

Neither Haavelmo's nor Arrow's contributions triggered any new wave of interest in economic growth. Nevertheless, their analysis preceded the endogenous growth models introduced in the 1980s. As will become clear, both of them, but especially Haavelmos's contribution may also be regarded as a precursor of evolutionary growth models.

A particular characteristic of 'new growth theory' is the analyses of technological progress, not as externalities from production or investments, but as the result of conscious profit-motivated investments. As such the above cited contributions did not contribute very much. They preceded the neo-classical growth models in endogenising technological change and as such they nuanced the 'stripped down neo-classical model' (Nelson 1981). Early attempts at analysing profit-motivated conscious investments were Shell (1967) and Gomulka (1971). Shell analysed public investments in technological progress, acknowledging the public character of some types of knowledge, while Gomulka analysed possible catch-up of poor countries to the level of advanced countries by means of learning by doing, imitation from abroad and public investments in technological progress.

5. Neo-classical endogenous growth models

The third wave of interest in economic growth was the introduction of the endogenous growth models in the 1980s. These models explicitly analyse production of knowledge, knowledge's effect on economic growth and growth's repercussion back to production of knowledge. The first publications in this tradition were Romer (1986) and Lucas (1988). These first models were simple as regards endogenising productivity growth and resembled the earlier contributions. They assumed firm's production being dependent both on knowledge acquired by the firms themselves but also by the

[20] Recent contributions within this approach are Caballero and Hammour (1994) and (discussing effects of pay inequalty) Moene and Wallerstein (1997).

[21] Among other studies Arrow cited Lundberg's 'Horndal effect'.

aggregate knowledge in the economy. The effect of this assumption was twofold. Firstly, their assumption introduced external effects into the economy. Firms investing for the sake of their own productivity do not take into account the effect of these investments on the aggregate knowledge. Importantly, these models imply too little investments in human capital in decentralised markets. Secondly, the models were capable of analysing long-run growth. Solow's growth model predicted stagnating growth in the absence of productivity increase. In the new growth models, technological change was inherent in the economic process, but in a way that allowed increasing returns to scale in the aggregate production function. In a competitive decentralised economy it is hard to analyse increasing returns to scale. In the presence of increasing returns larger entities would be more effective than smaller ones, making the decentralised nature of the economy unstable. By the external effects through learning, increasing returns to scale in aggregate are possible, while keeping the assumption of perfect competition in all markets.[22] These models therefore allowed sustained growth without depending on exogenous variables. It is important, however, that the occurrence of steady state growth in these models are due to a knife-edge parameter property: If the expression for growth contains the growing variable raised to the power of exactly one, there is steady state growth. If this variable is raised to the power of a parameter less than one, growth will cease. If the parameter is larger than one, there will be exploding growth.[23]

Both Lucas and Romer were concerned about convergence between countries and regions. Their analyses show that countries may very well experience diverging economic development. In essence, this is due to making comparative advantages *dynamic* and functions of investments in knowledge and technological change. When comparative advantages are evolving over time, both path-dependency and hysteresis become inherent in the economic evolution in countries or regions. Economic specialisation becomes a cumulative process. If one sector has a larger potential for productivity increase than another one, the country that happened to get specialised in the former may experience higher growth than the one that specialised in the latter sector. Still, it may be the case that it is not rational to try to shift specialisation: If another country has got a head start, it may demand large R&D subsidies to increase productivity enough to get competitive in the high-productivity sector for countries lagging behind in this sector. Despite these important conclusions, neither Lucas's nor

[22] Very often constant returns to scale is assumed in economic models. This is because of the replicator argument. It seems sensible that production can be quadrupled by quadrupling all factors of production including the means of production. If knowledge is introduced into the model, quadrupling is possible by quadrupling the physical factors of production, implying increasing returns in all factors (including knowledge).

[23] Solow (1997) discusses thoroughly this problem in the endogenous models of economic growth.

Romer's early model were dramatically different from the endogenous growth models of the 1960s.

A shortcoming in the first endogenous growth models was the treatment of production of knowledge. Knowledge is a very special good in economic sense. As Haavelmo pointed out, knowledge has the peculiar property that it can be sold and still kept.[24] Knowledge shares characteristics with public goods in that it is not rivalling. Knowledge may be used without being exhausted. At the same time knowledge is like private goods in being at least partly excludable. It is possible to make use of knowledge while hindering others in using it. These are important aspects analysed in the economics of research and technological change. Theories in industrial organisation have for a long time analysed incentives in the production of knowledge. So have traditions in less formal theorising on economic growth tracing back to Schumpeter. In formal neo-classical growth models, however, these peculiarities regarding knowledge could be analysed first when coherent models of monopolistic production were available. The celebrated Dixit-Stiglitz model of monopolistic competition opened this 'window of opportunities' in growth theory (Dixit and Stiglitz 1977). In this model, the representative consumer has an explicit preference for variation in consumption. Therefore, he seeks to spread his consumption over several product varieties. This gives producers of varieties monopolistic power towards the consumer, allowing them to obtain pure profits. In a model of free entry, the pure profits allow development costs for new varieties and there is no need to assume decreasing or constant returns to scale in production. Therefore, monopolistic production becomes compatible with competition among producers. The degree of monopoly becomes an endogenous feature of characteristics in consumers' preferences and production technology. The Dixit-Stiglitz *constant elasticity of substition* (CES) preferences has been incorporated into most endogenous growth models in the neo-classical tradition during the 1990s.

Romer (1990) presented a model of growth incorporating the incentives stemming from monopoly rents for production of technological change. Grossman and Helpman (1991) analysed similar models in an international context. Aghion and Howitt (1992 and 1998) have presented models explicitly analysing the Schumpeterian idea of creative destruction. In Romer (1987 and 1990) and Grossman and Helpman (1991), focus is on expanding product variety. Aggregate production in a society is hypothesised to depend not only on the amount of factors of production but also on the number of different intermediates. Intermediates take innovation to occur and are therefore costly to develop. Innovators are therefore assumed to supply blueprints of new products monopolistically to producers of final goods. In the models provided by Aghion and Howitt and also Klette and Griliches (2000) growth is assumed to depend on, not the number of intermediates, but on their quality. Aghion and Howitt model creative destruction by assuming that incumbents' blueprints for intermediates are becoming obsolete by newcomers who invent in order to take the incumbents' place (and therefore their profits). Klette and Griliches discuss growth patterns in light of empirical patterns of firm heterogeneity in terms of size, growth and the empirical regularity that R&D investments are proportional to sales. Their model, therefore, combines profit maximisation with heterogeneity between firms.

As noted above, endogenous growth models in which a steady state growth rate is determined, face a knife-edge problem not very different from that in Harrod and Domar's theories of growth. Only if the growth rate is exactly constant over time, there will be balanced growth. If the growth rate is slightly decreasing, growth ceases in the long run (or one would have to rely on exogenous growth). If the growth rate is slightly increasing, the economy will reach infinite production within finite time. Both scenarios are grim. Two types of solutions within the neo-classical tradition are proposed. The first is to leave steady state growth. In Aghion and Howitt (1992) there is a potential for growth cycles in which the growth rate fluctuates over time. On average, however, there is a steady state growth rate in the economy. In recent literature on so-called *general purpose technology* the possibility of differing growth rates over time is explicitly analysed (Helpman 1998). This literature focuses on economic reactions to (often exogenous) occurrence of new path-breaking technologies. When such technologies occur, windows of opportunities open and the technology spurs innovative activity in order to develop the opportunities. The resulting economic development is one of ups and downs. After a new general purpose technology has occurred, consumption and production of final goods decrease as a result of large investments in developing the new technology. When these investments yield returns, consumption and production increases.

Weitzman (1995) proposes the other type of solution to the knife-edge problem. He analyses technological progress as a recombinant process in which new knowledge is the result of combinations of older knowledge. Weitzman demonstrates that under some conditions, availability of new knowledge may well grow without limits. In Weitzman's model, therefore, potential growth will not be limited by technology, but by availability of physical resources. As such, Weitzman succeeded Schmookler (1966), who raised similar thoughts. Schmookler, however, paid more attention to limits for useful innovations than to the limits for the number of innovations.

These are only a few examples on the progress made in neo-classical theorising on economic growth in the third wave. Models like the ones sketched above have a far greater explanatory power than the models based on exogenous technological change.

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[24] Haavelmo (1954, p. 85)

In this sense they revitalised the tradition and resulted in progress in the Lakatosian sense as will be discussed in section six.

6. Evolutionary growth models

The work of Nelson and Winter (1982), summarised in their book *An evolutionary theory of Economic Change*, marked a new era of evolutionary theorising on economic growth. Earlier contributions were often less formal than the models of Nelson and Winter. This was partly due to the treatment of uncertainty in evolutionary economics. Uncertainty is regarded as genuine and not reducible to calculable probabilities. In such environments rational behaviour in the neo-classical sense becomes impossible.

This, however, also made formal treatments of evolutionary processes harder. Genuine uncertainty cannot be modelled, so formal modelling must rely on calculable uncertainty. This is the strategy chosen by the formalising evolutionary economists. Also in this respect, Haavelmo (1954) preceded the modern models of economic growth. Haavelmo introduced stochastic processes in models of economic evolution. He also discusses the value of doing so, and in this respect Haavelmo considered three aspects: A) Do the stochastic processes have 'exact' counterparts and how do we define such a counterpart? If there is an exact counterpart, the dynamics of the model may be analysed without introducing random processes. Haavelmo stresses, however, that there is no generally accepted way to trace out the exact counterpart of a random process. A random process is characterised by shocks. Putting all the random elements identically equal to zero may give a different result from replacing the stochastic variables by their mathematical expectations. Haavelmo's discussion lends support to the evolutionary modellers sticking to explicitly including stochastic processes. B) Haavelmo raises the question 'whether phenomena that we call shocks should rightly be thought of as coming from the outside or whether they should not rather be considered as produced by the economic mechanism considered' (p. 66). He concludes that 'we may have to choose the less ambitious approach of simply assuming that there are external forces of certain specified stochastic nature'. This is to some extent the same critique as Arrow (1962) raised against the Solow growth model of 'depending heavily on exogenous variables'. C) Haavelmo discriminates between random disturbances that are 'absorbed' and disturbances that are 'propagated' in dynamic models. This is an important distinction because it may be used as a guideline for whether stochastic processes may enrich models or only make them more complicated. Haavelmo clearly regarded proper treatment of uncertainty as essential for models of economic growth. He gives an example of this in modelling cumulating diverging economic processes in regions. Recent technological development has made computer simulations of dynamic stochastic processes possible. These are methods applied intensively in evolutionary modelling.

The microeconomics of evolutionary models presented in section two above explicitly presumes that firms are heterogeneous. In the models used this is both a consequence of the modeller's assumptions about the initial situation but also of the evolutionary processes the models describe. The heterogeneity in the models stem from differences in techniques, differences in routines and different search behaviour for new techniques, products or processes. In addition, as already mentioned, there are random elements introduced in the models. One example is that the result of search behaviour is a function of drawings from certain probability functions and the amount of search activity invested by the firm. Search activity is assumed to be subject to rules of thumb. In Nelson and Winter (1982) search is triggered whenever the rate of return falls below an arbitrarily set value of 16 per cent. Search activity is assumed to take two different forms: Local search that denotes search for better techniques in the vicinity of the technique already used, and imitation of other firms' techniques. In addition to established firms there are potential firms doing search for profitable techniques. If they succeed in finding such a technique (defined as resulting in a rate of return exceeding some arbitrarily set value), the potential firms enter the market. The wage rate is determined in the labour market as a function of exogenous labour supply and labour demand. Demand for labour is a function of production. The growth process is driven by capital accumulation as in the neo-classical models, but investment is taken to be a function of profits of the individual firms. Negative profits result in negative investments. The model is described in discrete time where the outcome of period t determines (probabilisticallly) the state in period t+1. Thus the model describes an evolving economy in terms of a Markov process where some firms enter, some exit, while others expand or shrink according to partly random and partly predetermined profit performance.

Nelson and Winter apply computer simulations to trace the evolving economy their model prescribes. Their model is calibrated so as to resemble time series for the United States in the period 1909-49 (in fact they use exactly the same numbers as in Solow (1957)). Nelson and Winter's simulations give very nice results indeed. There is close correlation between their simulation and the real data. They extend their investigation by using Solow's proposed method to decompose the sources of growth, and run similar regression as Solow did on the American data on the data generated by their own simulations. The result is remarkable in that Solow's model fits the simulated data equally well as the real data.[25] Thus Nelson and Winter demonstrated that their model was able to resemble real growth processes but also that the processes they hypothesise may result in data which neo-classical models fit equally well as the real world.

[25] Nelson and Winter obtain a R^2 of 99 per cent in some of the regressions.

Despite the clear resemblance between the results of the evolutionary and the neo-classical framework, Nelson and Winter emphasise the differences in the underlying story: '...the neo-classical interpretation of long run productivity change is sharply different from our own. It is based on a clean distinction between "moving along" an existing production function and shifting to a new one. In the evolutionary theory, substitution of the "search and selection" metaphor for the maximising and equilibrium metaphor blurs the notion of a production function.' Nelson and Winter therefore follow Kaldor and Mirrles (1962) in avoiding formulation of a macro-production function.

Evolutionary modelling of economic growth got a head start with the success of Nelson and Winter. However, the making of models which one, with careful calibration, succeed in getting resemble data from one specific historic period is of limited value in its own right. Later on there have been a number of refinements and developments of Nelson and Winter's basic model seeking to analyse and describe economic growth in general. There is no space here for a thorough survey of the literature, and we will restrict ourselves to a rough description of a sample of a few models.[26]

Silverberg and Verspagen (1994) model diffusion of technology and spillover effects in an evolutionary framework. This approach has obvious counterparts among the neo-classical growth models. The micro-foundation in Silverberg and Verspagen is essentially the same as in Nelson and Winter. Their modelling of technological change, however, differs in some respects. It is supposed that in each period, firms devote part either of their profits or their sale revenues on R&D, the outcome of which is assumed to be stochastic. The innovation potential is determined by the firms' own R&D activity but also their ability to profit from technological spillovers from other firms. The ability to profit from spillovers is assumed to be a function of the firms' own research activity. An R&D frontier is introduced and the firms' innovation potential also depends on the distance to this frontier. Therefore, there is a catching-up effect in the model, believed to be important from empirical research (Fagerberg 1987). Computer simulations of the system are run, which give results to be interpreted.[27]

Silverberg and Verspagen build on Silverberg *et al.* (1988) who analyse diffusion of a new technology to a heterogeneous population of firms initially using an old, less productive technology. In Silverberg *et al.* firms are equipped with different characteristics, such as profits, learning capabilities etc. These differences between firms and stochastic processes in learning and innovation determine the time when the new technology is adopted and the subsequent firm-specific consequences of adopting.

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[26] Nelson (1995) and Verspagen and Silverberg (1995) are two references surveying recent evolutionary growth modelling.

Among other macroeconomic patterns, the model of Silverberg *et al*. reproduces the well-known **S**-shaped curve for the cumulative distribution of firms having adopted a new technology.[28]

In Winter *et al.* (2000) entry of innovative firms into industries is analysed. It is assumed that only entrants in an industry have a positive probability of advancing the current state of technological knowledge. They show that under specific conditions the model predicts persistent fluctuations of aggregate variables, turbulence of market shares and skewed size distribution of firms, all features believed to be of importance from empirical research. In line with most endogenous growth theories, Winter *et al.* demonstrate that necessary conditions for exponential growth is persistent enlargement of notional opportunities for innovation. This view has its explicit counterpart in Weitzman's recombinant growth. Self-sustained growth stems from the interplay between learning opportunities (innovations) and demand patterns. Important characteristics in this model are strong path-dependent patterns. It is demonstrated that many types of exponential growth functions may fit the model, although which growth pattern that turns out to be realised depends on initial conditions. The model provided by Winter *et al.* demonstrates that a wide set of possible trajectories can be realised based on very simple principles for entry, selection and exit.

Quite different, and probably not within the hard core of evolutionary economics is Thompson (1996). Thompson provides a model similar in spirit to that of Klette and Griliches (2000) in which a simple relationship between firms' stock market valuations, their R&D expenditures and profits is predicted. This relationship is shown to depend on the market's expectations of the long-run rate of growth of knowledge and the rate of creative destruction in the economy. Thompson's model is neoclassical in style, while it still keeps major evolutionary characteristics, as e.g. firm heterogeneity, path dependence and a major role for entrants in influencing on market conditions. While Silverberg *et al.* (1988) focused on diffusion and Winter *et al.* (2000) focused on entry into industries, the model provided by Thompson (1996) is occupied with *innovation.*

The tradition of formal evolutionary modelling in economics has provided a viable alternative to neo-classical theorising of economic growth. An important discussion is whether the attempts at evolutionary modelling are complementary or a competitor to the neo-classical perspective. Paul Romer, the 'father' of neoclassical endogenous growth theory, evaluates the evolutionary perspective as complementary

[27] The targeting of R&D strategies gives rise to different dynamics of the system, with R&D determined by sales giving a more smooth evolution of the economy than R&D determined by sales.
[28] For general discussions of logistic diffusion curves and their possible interpretations, see Karshenas and Stoneman (1995) or Metcalfe (1988).

to the neo-classical one. We will discuss this in light of theories on cognitive development proposed by Kuhn and Lakatos.

7. Evolutionary and neo-classical economics as paradigms or research programmes?

This section will discuss Kuhnian paradigms and Lakatonian research programmes using evolutionary and neoclassical economics as special cases. The conclusion is that neither paradigms nor research programmes are appropriate notions for descriptions of controversies in economics. Both notions were developed for studies of cognitive development in physics, not in social sciences. Use of these terms may nevertheless be useful to clarify similarities and differences between branches in economics.

It has been usual to describe much more similar parts of economics than evolutionary and neoclassical economics as research programmes. The point of view taken here may seem somewhat counterintuitive and unnecessarily complicating. A detour into the development and construction of the Kuhnian and Lakatosian terminology may therefore be enlightening.

Thomas Kuhn introduced the notion *paradigms* as a reaction to Karl Popper's falsificationism (Kuhn 1962). Popper's criteria of intellectual honesty (disregarding Lakatos's discussion of the various versions of Popper; Popper_0, Popper_1 and Popper_2[29]) demanded that a theory be specified so that it was testable and refutable, and a *willingness* to give up the theory once it was refuted by observation.[30] Kuhn observed that Popper's falsificationism both contradicted the cognitive history of sciences and was a normative rule impossible to fulfil. Abandoning all refuted theories seemed to contradict trial and error methodology in many sciences. It was noted that a hypothesis often is supported by other more accepted hypotheses that are not subject to testing in the tests carried out. Falsificationism in the naï ve sense of the term therefore did not provide a coherent normative rule for scientific progress. Neither were Popper's criteria a positive theory of cognitive development. Kuhn observed that scientific development had been revolutionary with dramatic shifts between different *Weltanschauungen*. These scientific revolutions were not results of scientific falsificationism, but of more shifts in quasi-metaphysical convictions.[31] These methaphysical convictions were dominating in society and scientific thought. Scientific change - from one paradigm to another- was therefore 'a kind of religious change'[32] not subject to rational consideration. Kuhn noted, however, that shifts of paradigms

[29] See Lakatos (1970, p. 181). The discussion of the various versions of Popper is important, however, both for obtaining a nuanced impression of Popper and for constructing own criteria of intellectual honesty.

[30] For a discussion of use of Popper's ideas in economics, see Caldwell (1991).

[31] Kuhn (1970a, p. 41).

[32] Lakatos (1970, p. 93).

were triggered by crisis and the emergence of new paradigms that seemed to explain puzzles better than the previous one. During the regimes of paradigms, Kuhn described scientific activities as 'normal science'. Normal science is characterised as puzzle-solving within the limits of the ruling paradigm. Later on Kuhn renamed the metatheoretical structures 'disciplinary matrices' or just 'ideas' for more thorough discussions of scientific development.[33] These types of matrices consisted of four elements: 1) symbolic generalisations, 2) metaphysical and heuristic commitments, 3) values and 4) exemplars. The symbolic generalisations are the presumed fundamental laws which are held tenaciously among scientists. The metaphysical and heuristic commitments set the standards for the questions being asked. The scientific values are the normative commitments held up for the researchers, such as honesty and respect for data. The exemplars are a kind of ideals for the researchers made up by previous research.

Lakatos's theory of research programmes may be regarded as a compromise between Popper's falsificationism and Kuhn's paradigms. A research programme is characterised by having negative heuristics constituting the programme's 'hard core' and a 'protecting belt' of positive heuristics. The hard core of a research programme is the base assumptions and hypotheses of the research programme that are not subject to research: 'the negative heuristic of the programme forbids us to direct the modus tollens at this 'hard core''.[34] The 'protecting belt' in a research programme is constituted by assumptions and hypotheses that are the subject for research and investigation. All theoretical constructions underlying a research programme entail anomalies. The distinction between the hard core and the positive heuristics is on which of these that are refutable. The hard core is irrefutable while the positive heuristic 'consists of a partially articulated set of suggestions and hints on how to change, develop the "refutable variants" of the research programme, how to modify, sophisticate, the "refutable" protective belt'.[35]

Lakatos's notion of research programmes is more rational and optimistic than Kuhn's idea of paradigms. Lakatos's theories on cognitive development are theories of progress, not of religious changes. One research programme is not necessarily dominating. Instead Lakatos states that: 'The history of science has been a history of competing research programmes, (...)' and the objective reason to reject a programme 'is provided by a rival research programme which explains the previous success of its rival and supersedes it by a further display of heuristic power'.[36]

The two perspectives on economics we have discussed, evolutionary and neoclassical economics, do not seem to fit into the description Kuhn's scheme of

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[33] Kuhn, (1970a and 1970b). For a discussion of Kuhn in relation to economics, see Hausman (1992).
[34] Lakatos (1970, p. 133).
[35] Lakatos (1970, p. 135).

different paradigms. Firstly, the conflict between them does not seem to be like a revolt. It is true that the evolutionary tradition is in opposition to the neo-classical economics (which they often call ‘orthodox’, ‘mainstream’ etc.). Also, some researchers (including Nelson and Winter) have called for a paradigm shift in economics, and launched their own lines of thought as the alternative (and more progressive) paradigm. However, the notion of paradigms is one of clashes between different lines of thought. In this respect the two traditions are too much of the same kind. They are both based on methodological individualism and on intentional explanations as discussed in Elster (1983). Evolutionary economics share the methodological individualism with neoclassical economics in the sense that it explicitly formulates the micro-foundation for macroeconomic development. Macroeconomic behaviour is regarded as the result of individual behaviour. Evolutionary economics is also based on intentional explanations, but less so than neoclassical economics. In the literature reviewed above, it is underlined that firms are profit-motivated and profit seeking. In neoclassical economics, where maximising behaviour is assumed, the intentional explanations is more pronounced. [37]

Regarding the two traditions as distinct paradigms would therefore have to allow the existence of several competing paradigms in social sciences. Such a proposition seems to contradict the notion of paradigms in the Kuhnian sense.

Secondly, the two perspectives seem to apply to related (but not similar) descriptions of capital accumulation in the theory of growth. Capital accumulation is regarded as a driving force for economic growth together with technological change in both traditions. Also the treatment of technology in neoclassical and evolutionary economics, which is essential in the endogenous models of growth, is closely related. Both traditions analyse knowledge as an excludable but non-rival good, subject both to accumulation and investment. This is what makes the two traditions very different from the Solow model of growth, and more related to each other. The treatment of human behaviour in the two traditions, however, distinguishes them clearly from each other. Where the evolutionary firm is profit seeking and satisficing, the neo-classical firm is profit maximising. The neo-classical man is rational but he does not have any evolutionary brother or sister yet. Simon’s bounded rational man inspired the development of evolutionary economics,[38] but we regard him more like a relative than as belonging to another specie.

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[36] Lakatos (1970, p. 155).

[37] Some economist would surely disagree with this proposition. It should be underlined that only a narrow part of evolutionary economics is compared with neoclassical economics in this paper. Evolutionary modelling in the Nelson and Winter tradition seems to be well into the tradition of methodological individualism and intentional explanations.

[38] Nelson and Winter (1982).

Thirdly, and most importantly, essential elements from both 'paradigms' are used by researchers in both camps. Nelson and Winter modelled factor reward being consistent with marginal productivity, and the labour market is cleared by the wage rate. Similarly, elements of deviations from rationality are applied widespreadly in economics, also by economists who normally are committed to the neo-classical tradition. The same applies to explicit evolutionary reasoning with a clearer analogy to biology than the models of evolutionary growth. Stark (1997) is a recent example of modelling evolution of altruism, and this contribution does not abandon rationality as such. The notion of paradigms does not allow researchers jumping from one paradigm to another according to what is appropriate for the subject of his research.

Lakatos's notion of research programmes seems to fit better as a description of the two perspectives. The hard cores of the two programmes may accordingly be taken as the descriptions sketched in section two above. Examples of elements of the protecting belts in the neoclassical programme may be factors such as the treatment of certainty, the contradiction between static and dynamic efficiency as regards monopoly rents of innovation, the problems of behaviour out of equilibrium, how equilibria happen to get established, questions regarding market structure and the problem of assuming homogeneous firms. These are all issues that are extensively studied in neo-classical growth economics. As such, they form a part of the positive heuristics in this 'research programme'. The protective belt in the evolutionary programme may be questions regarding the assumption of genuine uncertainty as compared to the use of calculable stochastic processes in the formal models, the problem of these processes being exogenous and questions regarding the somewhat *ad hoc* choice of routines and rules of thumb as behaviour presumptions in the evolutionary programme.[39] Within the neoclassical programme there has been what Lakatos calls a *creative push* in the positive heuristics[40] the last decades with the introduction of endogenous technological change. The formal modelling in evolutionary economics introduced by Nelson and Winter may be regarded as a corresponding creative shift in the heuristics of evolutionary economics. In addition, especially in evolutionary economics there seems to be a specific identity characterising their research community.[41] This may be regarded as an inherent strategy for an evolving research programme in opposition to the orthodoxy.

However, what would have to be described as elements of the hard core in the two 'programmes' seems to be exchanged between the two. The hesitation above towards using the term *paradigm* as a description will have to be present also as regards characterising the two traditions as *research programmes*. The hard cores of

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[39] See below on this point.
[40] Lakatos (1970, p. 137)
[41] In 1991 an explicit Journal of Evolutionary Economics was founded.

evolutionary and neo-classical economics do not seem to be really hard. With elements of the hard core being interchanged between the two research programmes, with discussions regarding what is the hard core and with researchers shopping around in elements of the hard cores as it suits them, it gets difficult to trace out a clear demarcation between the two 'research programmes'. Their hard cores are fairly soft. An illustration of this is Solow's evaluation of the endogenous growth models (Solow 1994). Solow honours the progress these models have resulted in. However, Solow who himself assumed a fixed saving ratio in his model of growth, does not regard the use if intertemporally-optimizing representative agent useful. He states: 'It adds little of nothing to the story anyway, while encumbering it with unnecessary implausibilities and complexities' (p. 49). The use of maximising agents is seen as one major characteristic of neoclassical economics. As such it is interesting that the inventor of the classical neoclassical growth model characterise the use of maximisation as Solow does.

The quote from Solow above demonstrates the problems of finding the hard core of a research programme in economics. The lack of identifiable hard cores in neo-classical and evolutionary economics contradicts the notion of research programmes in the sense of Lakatos. Research programmes are supposed to be characterised by clear-cut negative heuristics, well accepted by the researchers belonging to the research programme. Cross (1982) and Hausman (1992) reach the same conclusion in their discussions of research programmes in economics. Cross abandons the use of a hard core in discussing monetarist economics for two reasons: Firstly, within a research programme, it is difficult to formulate a hard core in which the researcher always believes. Secondly, researchers belonging to a research programme will differ in their opinions of what the hard core is. Cross, therefore, characterise monetarist economics by the features of its positive heuristics. Hausman concludes the same way. He states that 'in attempting to make economics fit Lakatos' scheme one must construe its hard core as extraordinarily weak, (…)'. It is noteworthy however, that Cross refers to monetarist economics as a distinct research programme and that Hausman refers to neo-classical economics as a research programme. They do not compare traditions as different as neo-classical and evolutionary economics. I hope to have demonstrated that the same problem arises for that purpose.

Even if the notion of research programmes may not be suited for distinguishing schools of thought in economics, Lakatos's criteria for evaluating progress and stagnation in science are useful. In the following we will use the term research programme as a synonym for traditions or schools in economics, not distinguished by hard cores. In particular we will, contradicting the abandoning of the term above, 'name' the neo-classical and the evolutionary tradition research programmes. The purpose is to keep the discussion on scientific progress in line with Lakatos. A research programme is successful, according to Lakatos, if it leads to a progressive problemshift, unsuccessful if it leads to a degenerating problemshift.[42] Criteria for a progressive problemshift are that such a shift should both be theoretically and empirically progressive. A series of theories is ‘theoretically progressive if it has some excessive empirical content over its predecessor, that is, if it predicts some novel, hitherto unexpected fact’. A series of theories is ‘also empirically progressive (…) if some of this excess empirical content is also corrobated, that is, if each new theory leads us to the actual discovery of some new fact’.[43]

The success criterion in the Lakatosian sense is therefore dependent on what happened when the research programme was introduced, as compared to the situation before it was established. In this sense, both neo-classical and evolutionary economics may be deemed successful.

Within the class of neo-classical growth models, examples of progressive problemshifts have been in the debate on convergence in income levels (Barro and Sala-I-Martin 1995), in modelling R&D as an economic activity (Romer 1990 and Aghion and Howitt 1992), in approaches to heterogeneity among firms (Klette and Griliches 2000) and in theories of long waves in economic development (Helpman, 1998). Within the class of evolutionary growth models, examples of progressive problemshifts are studies of diffusion (Silverberg *et al.* 1988), the role of entrants in economic growth (Winter *et al*. 2000), debates on convergence among countries (Verspagen 1993) and on the role of heterogeneity (important in all these contributions).

Lakatos underlines the importance of *positive heuristics* in research programmes. New progressive research programmes produce new anomalies and the positive heuristics provide a guideline for handling such anomalies. Both evolutionary economics and neo-classical growth economics face such ‘puzzles’ (to use Kuhnian terminology).

One example in evolutionary economics is the intensive use of routines and rules of thumb as behaviour characteristics. This raises two problems, of which I think the second is the gravest. Firstly the choice of routines and rules of thumb seems to be somewhat arbitrary and ad hoc. One example is the modelling of research efforts in the evolutionary models. Three distinct proposals are made in Nelson and Winter (1982) and in Silverberg and Verspagen (1994) without any specific intuition or theory as an underlying basis.[44] It is somewhat unsatisfactory that evolutionary economists do not provide clearer theory on such vital aspects of their models. Their notion of heterogeneity in economics may be one possible answer. Lacatos hypothesises that ad

[42] Lakatos (1970, p. 118).
[43] Lakatos (1970, p. 118).

hoc explanations are a device of protection from an old research programme being attacked by a new and vital one. Lacatos states that such efforts should be rejected as unscientific.[45] We will not raise this accusation against evolutionary economics. In the interaction between neoclassical and evolutionary economics, the evolutionary approach is the new research programme and the neoclassical the old one. The 'evolutionarists' would surely answer the critics that their proposals on possible firm behaviour are useful as objects for further investigation and that they are pending empirical work. The arbitrariness of behaviour patterns is, however, illustrative for the graver problem of near rational behaviour: Neoclassical economics in principle provides one and only one answer on how firms and people behave in specific situations: in the optimising way. Extending the behaviour assumptions to some near- or bounded rationality in principle paves the way for an infinity of behaviour patterns. There is thus no general theory of behaviour, and any proposal may be met with the question: Why? Why not presume another type of behaviour, at least a slightly different one? This applies even if we regard the bounded rationality assumption as the most realistic one.

We have mentioned that researchers normally leaning on assumptions of complete rationality frequently presume near-rationality in some types of models. Thus, they are also subject to the criticism above. Often, however, models of near- or bounded rationality are applied when it clearly matters. In some models it does not matter for the result whether the economic agent optimises or not. In others, it may be of crucial importance. Some models of game theory and menu cost pricing in macro-economic models are examples. In the latter, the agents do not suffer any significant loss even if the aggregate effects of near-rationality matter a lot. One may argue therefore, that researchers should analyse situations where the rationality assumption really matters more carefully than when the optimising agents only serve to close the model. This applies to both camps.

Within neo-classical growth models, the use of representative agents is a 'puzzle'. Representative agents are only useful if they really are representative. If heterogeneity as such is important for the outcome of economic processes, the use of representative agents may obscure instead of enlighten. Progress in this respect has been in theories of discrete choice in economics (Anderson *et al.* 1992) in which consumers are equipped with random utility functions that do permit heterogeneous consumers and do not exclude possible deviations from rationality. In growth theory, Klette and Griliches (2000) is one recent contribution in which this approach is taken.[46]

[44] The three are R&D depending on sales and depending negatively and positively of profits, respectively.

[45] Lakatos (1970, p. 158).

[46] It should also be noted that CES utility functions for a representative consumer is compatible with aggregations over some specific random utility functions for discrete choice (Anderson *et al*. 1992).

8. Concluding remarks

This essay has discussed some elements of evolutionary and neoclassical theorising on economic growth. The two traditions approach the topic from very different points of view. Neoclassical economics is based on rational economic agents, well-behaved objective production and utility functions and equilibrium. Evolutionary economics, on the other hand, is based on assumptions of economic behaviour resembling (but not being identical to) evolutionary processes in biology. Despite huge differences in the two approaches, the discussion has showed that the similarities may be equally important. The thematic choice in the two traditions is the same: the interdependence between economic growth and technological change. The two approaches lean on the same historical trajectories in economic theories (excluding the importance of Solow's growth model for neoclassical growth economics). The common historical forerunners are often acknowledged (like Schumpeter, Schmookler, Kaldor or Arrow) but not always (like Haavelmo or Gomulka). More important than common forerunners and topics of research is that basic assumptions in both traditions are being applied by the other one. We did therefore not succeed in establishing the two approaches being distinct paradigms nor research programmes. Rather, in one sense, there seems to be cognitive convergence in studies of the relations between technology and growth.

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