ECONOMICS OF INNOVATION:

BIACK HOLE OR POSITIVE SUM?

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"A civilisation which cannot burst through its abstractions is doomed to sterility after a very limited period of progress"
A.M. Whitehead[1]

In recent decades, the dominant theory of macroeconomic growth has been the neoclassical model based on the work of Solow (1956, 1957) and Swan (1956). Technological change is acknowledged as the crucial driving force behind economic growth, but is treated as an exogenous variable. In consequence this basic neoclassical model is quite limited in its ability to explain economic growth.[2] Sheehan (1992) suggests this constitutes "something of an admission of defeat for economic analysis".

The view that technical change is endogenous rather than exogenous to economic growth is not new. Schumpeter 1942 and Arrow 1962 both emphasised investment in innovation as central to economic growth. Schumpeter stressed the importance of economic incentives for entrepreneurs to introduce innovation, and the diffusion process whilst Arrow focussed on the spillover effects of increased knowledge due to "leaning by doing". The work of Schumpeter and Arrow form the acknowledged antecedents for the new economic growth models.

Disatisfaction with the basic neoclassical model was also a stimulus for the evolutionary theory of innovation and growth which built on the seminal work of Nelson and Winter 1974. This body of literature treats technological change and innovation as endogenous to the process of economic growth and seeks to eliminate the gap between the basic neoclassical model and the empirical evidence of the microeconomic literature pertaining to the economics of innovation (Dosi 1988; Dosi *et al* 1988; Freeman 1990).

Similarly the new economic growth models have grown out of dissatification with the performance of the neoclassical model in explaining and predicting economic growth. This work has been pioneered by Romer (1986). Features of these new growth theories include endogenous technical change, investment in human capital and/or research and innovation as key sources of growth, and increasing returns. Despite the correspondence of their origins and the overlap of their subject matter, there is surprisingly little or no cross referencing between the economics of innovation literature and that of the new economic growth theories. Nevertheless, the rapidly expanding new economic growth literature has been hailed by Sheehan 1992 as bringing "greater realism to growth theory" and being a contributor to "a fundamental

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1 Quoted in Clark 1985.

2 For recent reviews of the basic neoclassical model and its limitations see BIE 1992, Lucas 1988 and Sheehan 1992.

change in the way economists; and ultimately government and business leaders in Anglo-Saxon countries think about basic issues of growth and trade and the way they develop policies for industry and technology".

The aim of this paper is to consider the processes of innovation specified in the new, growth models and their policy implications, to assess these innovation processes in the context of the innovation economics literature and to look at possible future directions for research.

The Processes of Innovation in the New Growth Models

The literature on the new growth theories has been extensively reviewed recently by BIE, 1992, Sheehan 1992 and Verspagen 1992, I do not propose to replicate their work, but will draw on it to focus on the processes of innovation specified in the new growth theories.

A feature of the new growth models is that innovation and growth are endogenous. This implies that these models face the problem of accommodating increasing returns. Following Sheehan 1992, two basic approaches have been adopted.

- treat increasing returns as externalities;
- treat increasing returns as monopolistic competition.

These are important and novel features of the new growth models and are associated with the public good aspect of technical knowledge and the appropriability of innovation ie the private good aspects.

The different approaches to incorporating externabilities and increasing returns to scale are summarised in tabular form by Verspagen 1992 and are shown in Table 1.

In the early papers by Romer (1986) and Lucas (1988), competitive markets are assumed and increasing returns are based on externalities in production associated with knowledge accumulation (learning by doing) and human capital accumulation via increasing skill levels.

Romer 1990 acknowledges that the learning by doing formulation has the advantage of making the rate of accumulation of nonrival knowledge endogenous but "is unsatisfactory because it takes the strict proportionality between knowledge and physical capital or knowledge and education as an unexplained and exogenously given feature of the technology". This formulation thus ignores the appropriability issue and "rules out the possibility that firms make intentional investments in research and development".

Later models building on the seminal efforts of Romer 1986 and Lucas 1988 have attempted to address this issue. Most notable are the papers by Romer 1990 and Grossman and Helpman 1989, 1990, 1991. It is on these that we focus our attention.

In introducing monopoly power, two alternative approaches are adopted - one involves innovative products which add to the existing variety; the other involves innovation products which are of higher quality (Sheehan 1992).

Romer 1990 specifies three premises to justify his introduction of monopoly power:

- technological change - improvement in the instructions for mixing together raw materials - lies at the heart of economic growth

- technological change arises in large part because of intentional actions taken by people who respond to market incentives ie endogenous technological change

- instructions for working with raw materials are inherently different from other economic goods. Once the (fixed) cost of creating a new set of instructions has been incurred, the instructions can be repeatedly used without additional cost.

To incorporate these premises in his model, Romer specifies two components of knowledge: human capital, H, which is rival, and technological knowledge, A, which is non-rival and can grow without bound; three sectors : a research sector which produces designs for new durables, an intermediate goods sector which uses the designs to produce durable goods and a final goods sector which uses the intermediate goods to produce final consumer goods; and four inputs : capital (K), labour (L), human capital (H) and an index of the level of technology (A). K and L are fixed.

In the research sector, the accumulation in the stock of designs evolves according to:

$$\mathring{A} = 8\ H_A A$$

where: 8 = a constant
H_A = the quantity of human capital employed in research
ie $H_A + H_Y = H$ and H_Y = the amount of H and devoted to production.

On this basis, the productivity of research varies linearly with the growth in technological knowledge and the marginal productivity of H_A continues to grow in proportion to A. According to Romer, the crucial feature of this specification is that "knowledge enters into production in two distinct ways. A new design enables the production of a new good that can be used to produce output. A new design also increases the total stock of knowledge and thereby increases the productivity of human capital in the research sector".

The intermediate goods sector is monopolistic with one firm i for each durable good i, using a fixed number of units of foregone consumption n to produce each unit of durable good. The initial expenditure on the new design is a sunk cost, and hence the monopolistic firm chooses the level of output (x) to maximise its revenue minus variable cost at every date. The flow of rental income is p(x) times x and it turns out that the monopoly price is a simple mark up over marginal cost.

In addition there are two non-convexities in the model.[3] One is in final output - the existence of monopolistic competition in the intermediate sector means that the price of durable goods to the consumer goods sector will be higher than in competition, while in the research sector, investment in research will ignore the impact of the stock of designs, A, on the productivity of the research sector (Sheehan 1992).

Romer also shows that in the equilibrium steady state, growth occurs at a rate equal to the rate of endogenous innovation, a rate which is less than the social (command economy) solution, implying a role for government to support the accumulation of A.

Paralleling the analysis of growth based on increasing variety of products, has been the analysis of quality improvement in products. The key contributors are Aghion and Howitt 1990 and Grossman and Helpman 1991.

A major feature underlying the model developed by Grossman and Helpman is the concept of a quality ladder of a fixed range of consumer goods. The highest quality product enables the producer to capture monopoly profits. R&D activities achieve quality increments and hence with each new innovation building on the previous one, the productivity/quality of the intermediate/consumer goods is always higher for the next innovation. The research technology is similar to the product variety case with technological spillovers to all firms from prior research and the capturing of monopoly profits by quality leaders.

There is also a negative externality in the model - labelled "creative destruction" or "business stealing", it arises because a new innovator destroys the monopoly rents for the previous innovator.

In these quality models, technological advances are essentially stochastic, with research success being dependent on the amount of human capital. As a result, this specification captures the uncertainty which characterises the innovation process in the real world (Verspagen 1992).

In summary the achievement of endogenous technological change is based on the assumption of a distinction between appropriable and non-appropriable effects in the production of innovation, which in turn is required to provide incentives to produce innovation in the presence of externabilities associated with the non-appropriable effects of innovation. To achieve appropriability some degree of monopoly power is assumed.

Policy Implications

Sheehan 1992, following his review of the new growth models, identifies four main policy related themes which are "often quite at variance with received doctrine".

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3 For a discussion of the relevance of nonconvexities for growth, see Romer 1990a. Romer concludes that "nonrival goods exist, that they are important for aggregate growth, and that they create nonconvexities that matter for aggregate level analysis".

These are:

- Suboptimal market solution - the market growth rate is typically less than the social optimum, but in the case of models incorporating negative externalities (Aghion and Howitt 1990, and Grossman and Helpman 1991), the direction of the net effect is ambiguous[4].

- policy action will increase growth ie interventions targeted at the source of the deviation from the social optimum will increase growth. Examples include subsidies to R&D, subsidies to investment in human capital and subsidies to innovation.

- Generating comparative advantage - when growth is driven by innovation or other externalities which are geographically concentrated, initial conditions can generate major long term differences between countries in comparative advantage and growth potential.

- Low growth traps - an implication of many of the models is that a country which is specialised in industries which are deficient in relevant respects may be trapped in a low growth situation under free trade. (see also BIE 1992).

Romer 1990 makes the point in relation to input subsidies that "when the decision to invest in physical capital is uncoupled from the decision to invest in research, the effects of a subsidy to physical capital are quite different from the effects of a reduction in the market interest rate". Romer concludes that "Although all the research is embodied in capital goods, a subsidy to physical capital accumulation may be a very poor substitute for direct subsidies that increase the incentive to undertake research."

The research sector in the Romer 1990 model is characterised by increasing returns, such that doubling of both human capital and the stock of knowledge leads to an increase in the marginal product of human capital and a more than proportional increase in the amount of human capital devoted to the research sector - see Figure 1. Romer considers this result to be consistent with trends observed in the real world.

Romer 1990 also points to the possibility of stagnation occurring if H is too low because of a binding nonnegativity constraint on the amount of human capital in the research sector (H_A). In such a situation growth does not take place - see Figure 1. Romer explains this phenomenon in terms of all feasible rates of growth for A being too small relative to the discount rate to justify the sacrifice in current output necessary for growth to take place, and suggests that this result offers an explanation for the wide variation in growth rates observed among countries. The proposed solution for such a country is to engage in trade with other countries which has a large amount of human capital. The stimulus to growth in India and China resulting from the (partial) deregulation of trade and investment may provide support for this view.

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4 At an aggregate economy level, it is not clear that business stealing will reduce consumer surplus since each succeeding innovation must represent an improvement over the previous one. At an industry level, however, this may not be the case as Grossman and Helpman acknowledge.

In the context of subsidising researc', Romer 1990 comments that two reasons can be expected to account for insufficient human capital devoted to research. One is that research has positive external effects but because these take the form of nonexcludable benefits, they are not reflected in the market price of the research, output. The second reason is that research produces an input to a sector which engages in monopoly pricing which "forces a wedge between the marginal social product of an input used in this sector and its market compensation". Both of these effects cause human capital to be undercompensated which in turn will cause the supply to be "too low", Romer proposes that a government which cannot affect the allocation of human capital between different sectors should adopt a second-best policy of subsidising the production of human capital.

Microeconomic Aspects of the Innovation Process

Attempts in the more recent models of the new growth literature to develop a microeconomic framework to incorporate various aspects of the innovation process undoubtedly achieve a greater degree of realism. Inevitably, a significant level of abstraction is also involved. In this section, the aim is to review the main features of the innovation process identified in the recent innovation economics literature and to assess whether any significant gaps still remain to be addressed by the new growth models.

Features of the innovation process which are repeatedly stressed in the innovation economics literature are the complexity of the innovation process, and the significant differences between sectors (see for example Dosi 1988, Scherer 1992, Pavitt 1984, Nelson and Winter 1974). It is usually taken as read that technological innovation represents a crucial factor in the dynamics of economic growth.

Four basic modes of technological advance are identified by Dosi 1988a:

- formalised and economically expensive processes of search eg R&D laboratories
- informal processes of diffusion eg publications, technical associations
- learning by doing and learning by using
- adoption of innovation developed in other industries and embodied in capital equipment and intermediate inputs.

Dosi 1988a summarises the innovation process in the following terms....." the process of innovation in Western economies embodies complex and varying balances between public and proprietary forms of knowledge, and different combinations between notional opportunities of innovation, firm based capabilities to reap these opportunities and economic incentives to do so (related to appropriability mechansisms, market conditions, relative prices, broader socio-economic conditions such as industrial relations) .... technology-specific forms of dynamic increasing returns tend to "lock-in" the processes of technical change into particular trajectories, entailing a mutual reinforcement (a positive feedback) between a certain pattern of learning and a pattern of allocation of resources into innovative activities where learning has already occurred in the past".

Particular aspects of the innovation process are highlighted by Dosi 1988 as "stylised facts".

- innovation involves a fundamental element of uncertainty
- increasing reliance of major new technological opportunities on advances in scientific knowledge
- increasing complexity of research and innovation militates in favour of formal organisations rather than individual innovators
- a significant amount of innovations and improvements originate from learning by doing and learning by using
- technical change is a cumulative activity, and the probability of making a technological advance is a function of the technological levels already achieved.

The introduction of stochastic product improvements by Aghian and Howitt 1990 and Grossman and Helpman 1991 represents a step towards dealing with the uncertainty issue. However, Dosi 1988a claims that innovation search is characterised by strong uncertainty, which is more than the imperfect information of economic analysis. The solution proposed by Gold 1980, and Winter 1986 is to employ the concept of bounded rationality to the adaptive and learning behaviour of economic agents subject to severe limitions on the capacity of firms to make *ex ante* assessments of future changes in the environment.

Many of the other features of the innovation process identified in the innovation economic literature including the endogenous nature of the process (see Allen 1988, Clark and Juma 1988); the cumulative and path dependent nature of technical change based on technological paradigms and trajectories (see Arthur 1988, Freeman 1988; Dosi 1988, 1988a; Nelson 1988); the interaction of demand and supply forces in the selection process (see Nelson 1986, Dosi 1988; Kline and Rosenberg 1986), and the distinction between public and private aspects of knowledge and the associated externalities and need for monopoly power which from the basis of increasing returns (see Allen 1988; Arthur 1988, Freeman 1990, Dosi 1988); appear to have been incorporated into the latest versions of the new growth models (see for example Romer 1990).

The most trenchant criticism of the orthodox view relates to the dynamic and evolutionary nature of the innovation process which is better characterised by disequilibrium and profit seeking rather than equilibrium and profit maximising. Nelson and Winter 1974 observe that neoclassical theory has an "explicit or implicit commitment to the assumptions of faultless maximisation and equilibrium. Very few of the studies [in a survey by Kennedy and Thirwall]......concerned with the processes of technical change employ these assumptions. Several .... implicitly deny them. However if equilibrium is not used to "close" the model, some alternative is required. Just as the macroeconomic growth theories are evolving to encompass a more sophisticated microeconomic framework, the evolutionary theories of growth seem also to be evolving from the descriptive to a more formal modelling basis, building on the early simulation work of Nelson and Winter 1974. One example is the use of the principle of economic selection in a modelling framework by Silverberg 1988.

Future Directions

A number of fundamental problems for economic analysis are raised by the new growth models and Sheehan indicates that these will form an important basis for future research. These are issues which have also been identified in the innovation economics literature referred to earlier.

- Increasing returns: the nonconvexities associated with increasing returns means that "standard competitive analysis will not apply" (Sheehan 1992). Sheehan 1992 and BIE 1992 refer to evidence indicating that many modern industries are characterised by large economies of scale which arise from "massive sunk cost investment" in plant and equipment, in R&D, and in education and training, from cumulative learning by doing benefits and from complementarities and cooperative linkages. Sheehan argues that these elements are neither external nor exploited in a monopolistic situation, but are key elements of competitive strategy. The issues of increasing returns and market power are likely to receive continuing attention in future research.

- Multiple Equilibria: one example, the low grow[illegible] ready been referred to. Sheehan 1992 identifies four distinct sou[illegible] iple eqilibria in the new growth models and suggests that this issue wil[illegible] centre of future growth model analysis.

- Expectations: most of the new growth models are based on perfect foresight equilibria. The assumption of rational expections on the part of economic agents has been criticised in the evolutionary theory literature. Verspagen 1992 observes that the implicit assumption of rational technological expectations in the new growth theories combined with the assumption of optimising behaviour gives most of these models strong equilibrium characteristics. Empirical research is needed to determine whether the latter approach, or the disequilibrium process characterised by evolutionary theories is more useful.

Indeed, there is wide agreement (Romer 1990a; BIE 1992, Sheehan 1992, Verspagen 1992) that further research is required not only to make the new growth models more useful for policy guidance but also to give them empirical validation.

In the context of innovation strategy for Australia, BIE 1992 concludes that it is too early to draw positive conclusions, and that more research is required before the models can be accepted as providing an adequate explanation of the growth process. It seems likely that the contributors to the new growth theories would ,not disagree with such a view.

Nevertheless, to the extent that there is agreement that the new growth models achieve a greater degree of realism, and it can be assumed that further modelling work is likely to confirm the view that government has a positive role to play, the question arises as to what form this role may take. In a recent analysis of the Australian innovation system, Gregory questions the demand for adjustment aimed at increasing productivity and economic growth. The demand for adjustment is focussed on increasing private sector R&D, targeting government research more towards national priorities, increasing competition in the research community and expanding the education system. These measures might have plausibly come straight from a proponent of the new growth theories.

Gregory's concern is based on a number of factors:

- Those parts of manufacturing involved is substantial R&D expenditure are shrinking as a share of total employment;

- The paradox that a country which has never had a comparative advantage in high technology manufacturing is discussing solutions to balance of payments dificulties in terms of R&D expenditure to stimulate high technology manufacturing; and

- The concentration of R&D within a few firms and industries suggests R&D policy will not have sufficient leverage on the economy as a whole.

Gregory concludes that "there has been a significant overselling of the economic benefits of a government led science and technology push", and that it may be best to think of the National Innovation System in terms of micro reforms, that is doing things better rather than thinking of the system as an instrument of macro policy that will significantly change the structure of the Australian economy."

Recent events in the Australian economy including the very rapid growth in the export of ETM's and the emergence of high value-added manufacturing firms which accounted for $8.3Billion in exports in 1992 and are growing at 13% compound real per annum (McKinsey & Co. 1992) suggest that there may be more prospects for a demand pull than an S&T push in relation to R&D and innovation. Rather than wait for events to unfold in the traditional "she'll be right" idiom, there may be merit in giving some urgency and priority to the research needed for the empirical testing of the new growth models in an Australian context.

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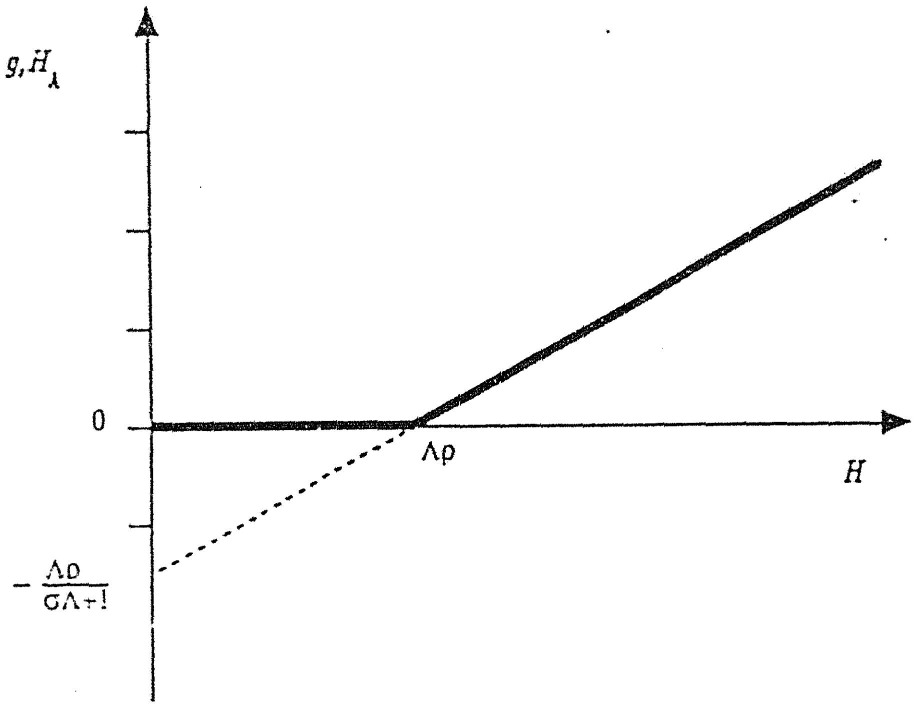
TABLE 1 *A Schematic Description of the Endogenization of Technological Change in New Neo-Classical Growth Models*

Reference	Sectors in model*	Type of innovation process	Production of innovation model structure	Effects of innovation: model structure	Externalities of innovation	Notation
Romer (1986)	one consumer good	process innovation through knowledge accumulation	$\dot{T} = v(I/T)$ v bounded from above	in consumer good sector $F_i\left(T_i, L_i, \sum_{i=1}^{m} T_i\right)$	knowledge spillovers (positive)	T = growth in stock of knowled I = investment in research L = conventional input eg labou i = ith firm
Lucas (1988)–I	one consumer good	human capital accumulation through saving	$\frac{\dot{H}}{H} = \delta(1 - u)$	in consumer good sector: $F(A, H, \hat{H})$	productivity stimulus from average human capital (positive)	H - human capital u - there invested in skill enhanc A = technology level
Lucas (1988)–II	two consumer goods	human capital accumulation through learning by doing	$\frac{\dot{H}}{H} = \delta u$	in consumer good sector. $F(\hat{H})$	productivity stimulus from average human capital (positive)	see above
Aghion and Howitt (1990)	research; intermediate goods; consumer good	stochastic (poisson) improvements in blueprints for intermediate goods	$c_i(t) = c_0\gamma^t$	in consumer good sector: $\int_0^1 \left(\frac{x(i)}{c(i)}\right) di$	intertemporal improvements (positive); business stealing effect (negative)	c = production costs i = intermediate good γ = size of innovation
Grossman and Helpman (1989) and (1990)	research & intermediate goods, consumer good	addition of new intermediate goods (Ethier production function)	$\dot{n} = N(A_n, H_n, n)$	in consumer good sector: $F\left(L, \left[\int_0^n x(i)^\alpha di\right]^{1/\alpha}\right)$	knowledge spillovers research & intermediate sector (positive)	n = number of designs/blueprints A = productivity parameter H = human capital x = intermediate good
Grossman and Helpman (1991)	research & consumer good	improvements in quality of consumer good	$g(i) = \mu^j$	via utility function	intertemporal improvements, consumer surplus (positive); business stealing effect (negative)	g = fixed range of consumer goo μ = a parameter j = index for highest position on
Romer (1990)	research & intermediate goods; consumer goods	addition of new intermediate goods (Ethier production function)	$\dot{n} = N(A_n, H_n, n)$	in consumer good sector: $H^\alpha L^\beta \int_0^\infty x(i)^{1-\alpha-\beta} di$ with $x(i) = 0$ for $i > n$	knowledge spillovers research & intermediate sector (positive)	n = number of designs A = productivity parameter H = human capital x = intermediate good

*Entries in this column not separated by a ";" should be interpreted as "in one combined sector."

Source: Verspagen 1992

FIGURE 1



—Growth rate and amount of human capital in research as a function of total human capital (for $\delta = 1$).

Source: Romer 1990