APPENDIX A: ECONOMIC GROWTH, DEVELOPMENT AND THE ENVIRONMENT

The multiple approaches to production and consumption, the perceptions on DD&PW (degradation and depletion, pollution and waste) and the valuation of environmental changes, as discussed in previous sections, bring forward the question of how economic growth and development theories have included or can include these different approaches (Vellinga 1999).

Economic growth theories

Economic growth is one of the most extensively studied areas in economic theory. Growth theory tries to shed light on the factors that contribute (and constrain) changes in economic growth (see Vellinga 1999:5). In general, two approaches can be distinguished in growth theory: exogenous growth and endogenous growth. Exogenous growth models include one developed by Ramsey (1928) and endogenous growth models include the models of Rebelo (1991), Romer (1986), Romer (1990), Barro (1990) and Lucas (1988). It was Romer's article in 1986 that started the revival of (endogenous) growth theory. His thesis was that research leads to new knowledge, which is a positive externality to other firms. This increasing-returns-to-scale is the perpetuating engine of growth in the economy.

In exogenous growth models the long-term growth is determined solely by population growth and technological progress, defined as constants **ex ante**, while in endogenous models the long-term economic growth rate is also influenced by parameters which describe technology and preferences (Vellinga 1999:5). Solow (1992a:9) observes that the novelty of the endogenous growth models is that each particular version rests on a strong assumption about production that gives investment decisions very great leverage on growth rates. In almost all cases, the suspension of diminishing returns on some factor of production that can be accumulated, is a key assumption. The two novel results of these models are firstly, that an increase in investment can create a permanent increase in the growth rate and secondly, that even temporarily adverse shocks to investment or a one-time loss of capital leave major scars that never heal or may get worse (Solow 1992a:9-10).

Environmental concerns have been included in both exogenous and endogenous growth models. Keeler, Spence and Zeckhauser (1972) argue that a model specification depends on the way in which pollution manifests itself. Pollution either enters the model as an inevitable side-effect (externality) of economic activity or as an input to production. In the Coddington-model (see Figure 3.1) this is illustrated as lines CE and PE, respectively. Externalities are modelled for both flow and flow/stock pollutants, while pollution as input in production has only been modelled as flow/stock pollutants.

In exogenous growth models, environmental preservation would always result in lower economic growth rates, because technological and preferential changes on the short-term are assumed to be constant. Preservation is calculated as a cost to human welfare. However, the results of endogenous environmental growth models show more lenient results when both economic growth and environmental preservation is to be achieved. If there is more environmental preservation, resources are diverted from consumption and investment to the control of pollution. However, if the long-term costs of DD&PW are internalised in preferences and technological progress, the opportunity cost of environmental preservation is relatively low when compared to the results of exogenous growth models. People will benefit in the long term from more environmental preservation (see Vellinga 1999:198). Some endogenous growth models, where more types of capital other than man-made capital is included in the production function, indicate that investment in the environment will lead to short-term costs, while the long-term outcome of the decision might still be preferred (Vellinga 1999:196; Lucas 1988). In another endogenous growth model nature is assumed to be constant in the long-term, which is a reflection of the ecological economic carrying capacity argument as developed in the discussion on ecological limits to production (section 3.3.2). In these models the influence of nature on the marginal utility of consumption will determine the substitutability or complementarity of natural & environmental resources and economic growth. Therefore, in these models environmental preservation will only improve economic growth when nature influences the marginal utility of consumption positively. In these models there is the danger of limiting the possible outcomes, solely due to the specification of the model (Vellinga 1999:205). There is a need for better modelling of natural phenomena and for recognition of spatial differentiation (e.g. more sectoral analysis) in these endogenous growth models (Vellinga 1999:204-205).

When exhaustible resources and environmental issues are included in endogenous growth models, the situation looks slightly different. When capital accumulation, which leads to pollution, is not discouraged enough, a non-optimal situation will occur. In these situations environmental preservation is a function of a broader preservation for the environment than individual preferences; either voluntarily or through governmental policing or incentive structures.

Despite the limitations, environmental endogenous growth models help to provide two important insights (Carraro 1998:375):

- The endogenous growth literature, by neglecting the environmental dimension, may be wrong when predicting the possibility of sustained growth.
- Increasing returns to scale in the R&D or abatement sector (such as increasing impact of technical progress on emissions per unit of production) are the crucial factors that may enable

economies to reach sustainable development, consistent with the preservation of the stock of natural and environmental resources.

The growth models studied so far, whether exogenous or endogenous, have objective functions that should be maximised subject to a set of constraints. None of these models include parameters for emergent realities. Time irreversibilities 2 and 3, as defined in section 3.4.4, are not included in current endogenous growth models. Time is treated as being symmetrical.

Sengupta (1998), however, did include evolutionary dynamics in his discussion on new growth theory. The sources of complexity and chaos have to be included in models on evolutionary economic systems. In the case of chaotic, unstable dynamics, the growth models have to account for some kind of positive feedback behaviour (see Arthur 1989). According to Sengupta (1998:208), this recognition makes the more conventional methods of econometric equilibrium modelling totally useless.

In summary, endogenous environmental growth models have the potential to include environmental concerns and technological progress, representing the two Arrows of Time in one model. However, based on the results of a recent thesis on this topic (Vellinga 1999), the conclusion is that binding conclusions on the opportunity cost of environmental preservation cannot be made at this stage. In the endogenous environmental growth models too many ecological complexities are specified **ex ante** with no adequate underlying ecological modelling results. The potential for mitigation of environmental degradation through technological progress, invention and innovation is also not clear from the modelling results. These models do not describe patterns of development, but are still rooted in the tradition of formulating an objective function subject to a set of constraints. If chaotic dynamics are included in growth models, conventional equilibrium-orientated models are deemed to be useless.

Limits to growth?

The discussion on environmental growth theories and models has not answered the question on how economic growth could be sustainable. Another part of the debate in need of analysis is the actual discussion on the limits to growth. The specified environmental growth models are generally as good as the **ex ante** specifications, which in turn are based on great scientific uncertainties. Whether there are limits to growth is not an output of these models, but an **ex ante** specification of these models themselves. Can anything more specific be said on the question whether there are limits to growth? In the analysis of the current debate it is suggested that, firstly, the definition should change from growth to development. Secondly, biophysical, social and ethical limits on growth need to be placed in perspective. Thirdly, the key arguments for rejecting the **limits to growth hypothesis** need to be scrutinised.

Growth and development

The post-war debate about the limits to economic growth was initiated by Carson's *Silent Spring* (1962) and perpetuated by the Club of Rome Report (Meadows *et al.* 1972) and oil shocks in the 1970s. Earlier critics of economic growth were Hirsch (1976), Scitovsky (1976), Schumacher (1973) and Mishan (1971). Although economic growth remained one of the most important economic indicators in the years to come the critics were not silenced. For more recent critiques on economic growth, see Daly (1996) and Ayres (1995). The main advocacy is that there has to be a shift of attention from economic growth as such to a focus on the components of economic growth and how it has an impact on social and physical environment. Economic growth is not a good in itself, but only a means that would lead to an improvement of human well-being (Zolotas 1981:188).

The focus should shift from economic growth to development – a shift towards improvements in the quality of life (Cairncross 1995:13; Meadows, Meadows & Randers 1992:246). This point was emphasised by the Bruntland Commission in 1987 when the phrase sustainable development was popularised (World Commission on Environment and Development 1987). Another point made by Cairncross (1995:16) is that prospering countries' economic activities are based more on relatively cleaner services: finance, entertainment and transport. According to Cairncross, this is no argument to encourage limitless growth, but to move toward sustainable development as a measure of prosperity. The real objective should be to strive for green growth (Cairncross 1995:17).

It is especially in the literature on development economics that the terms growth and development were separated (Thirlwall 1994). Development models have moved away from growth alone to incorporate equity and later environmental concerns. The latest development model is that of sustainable development, a concept discussed in Chapter 4.

The definition of development should not be confined to a more thorough interpretation of only the First Arrow of Time as ecological approaches to economic growth are portraying. Sengupta (1998:182) pointed out that economic development is also a discontinuous process activated by the spark of innovations in technology and organisational dynamics; thus, not a steady state, in either economic or ecological terms, but a development characterised by changing realities and diversity. The Second Arrow of Time cannot be ignored in sustainable development models.

Biophysical limits

Biophysical limits are discussed in six sections: first the scarcity of resources and assimilative capacity of the environment, second the law of entropy, third the sun's external energy, fourth entropy and technological progress, fifth, the boundaries of entropy and sixth, ecological interdependence.

The scarcity of natural resources and the assimilative capacity of the environment

A discussion on the limits of growth needs a definition of the concept of scarcity. According to neoclassical theory scarcity can be defined as a shortage at a given price (Jones & Hollier 1997:37). Scarcity is relative and will be rectified through the market mechanism (Randall 1987:29). Absolute scarcity, however, refers to depletion of resources or limited availability of ecosystem services. No price is able to increase the supply of depleted resources.

In the early 1970s the notion of absolute resource scarcity was brought to the world's attention through the Club of Rome Report (Meadows *et al.* 1972). It resulted in a debate between pessimistic and optimistic views about natural resource availability. Pessimists emphasise the physical exhaustion of non-renewable resources and the failure of renewable resources to meet an increasing world demand. Optimists have long pointed out that the resource base was steady and healthy and that prices would take care of relative scarcity (Barnett & Morse 1963). Smith (1979) re-examined the Barnett-Morse analysis and found that the basic trend of decreasing mineral scarcity between 1870 and 1957 could not be refuted. However, the strong underlying assumption in these studies was that the increasing scarcity of raw materials would be reflected in the increasing real costs of obtaining them (Randall 1987:26).

This analysis says nothing about environmental damage to the ecosystem due to resource extraction and processing (Randall 1987:28). In recent decades it has become evident that environmental damage can undermine economic growth as well. These costs are of three kinds: costs to human health; costs in lost productivity; and costs due to the loss of intangibles such as existence values (Cairncross 1995:11). Examples are air poisoning, traffic congestion and the word-wide loss in bio-diversity.

Another approach, especially perpetuated by the endogenous growth theorists and models, is to see resources as a combination of knowledge. Technological advancements and perfect substitution are able to continuously outrun DD&PW. In this approach biophysical limits are perceived to be a function of information, or human know-how, thereby implying that the limits to growth are found within man's limited know-how and his institutions (Ranson 1979:664-665). In this viewpoint, the short supply of resources can therefore be mitigated by learning (Dunn 1971), behavioural change and substitution. The underlying idea is a belief in human creativity, positive information and optimum resource use ad infinitum. Scarcity is seen as only the result of a lack in human innovation.

The debate is far from resolved. Being an optimist or a pessimist does not take away the fact that large uncertainties about future resource supplies and demands make it dangerously simple to extrapolate past trends into the future (Fisher & Peterson 1977:712). In the same vein would it be unwise to ignore useful contributions from technological progress and increasing-returns-to-scale because of positive knowledge externalities. It has been pointed out in section 3.5.1 that modern endogenous growth theories have not been able to integrate environmental concerns and the promise of technological progress and positive feedback into one model.

The law of entropy

Entropy increases when natural resources are extracted and/or waste accumulates. Entropy would not be so limiting if natural resources and the assimilative capacity were infinite, but there are good indications that both are finite (Daly 1996:33). When these limitations prove to be true, the only plausible way will be to mitigate entropy. The question is whether the law of entropy is binding for all resources at all scales. Is it a general rule, thereby excluding all approaches other than the ecological economic approach, or are there production and consumption scales where this law is not that binding, or perhaps even not binding at all? In answering this question the discussion centres around solar energy, the boundaries of entropy and ecological interdependence.

Solar energy

It cannot always be assumed that the limitations of the entropy law can be passed on to higher scales without any inflictions on the scale under observation. Even the assumption that the sun will always provide external energy, still does not mitigate the law of entropy, unless all economic activities on earth are based on solar energy. When energy from the outside flows into a system to raise it to a higher energy state, the reaction is endothermic (Smith 1996:169). The idea that the loss of useful energy can be compensated for by an endothermic, useful energy supply from the sun is flawed. The argument goes that the sun will absorb the amount of increased disorder and it will not be inflicted on the terrestrial environment or possibly onto life-support systems. The question is whether this external solar energy is useful within the current economic system. The current institutional structure places limits on the conversion from solar energy to useful energy.

Post Industrial Revolution economic systems are in general heavily dependent on exhaustible fossil fuels (Norgaard 1988). This implies that the second law of thermodynamics is essential to the understanding of the present-day economy. Fossil fuels embody a high level of useful energy, but entropy increases when it is burnt to release waste energy in the form of heat and emissions. The increased disorder is reflected through the effects of emissions. The possibility that these emissions could threaten life-support systems cannot be ruled out. As pointed out in chapter 1, the evidence on human and ecological vulnerability to the enhanced greenhouse effect is accumulating.

Technological progress and entropy

Neoclassical economists tend to ignore the notion of entropy and treat technology as a changing ratio between capital and labour (Mansfield 1988). From an institutional viewpoint, Khalil (1997:943) argues that both the neoclassical and ecological economic approaches fail to accord technology and institutions their proper role. Technological innovation is a function of a particular institutional regime (Khalil 1997). Better institutions would increase society's pool of knowledge and increase their ability to mitigate the entropy and other limits to growth. Ecological economists are quick to point out that gain in knowledge and technology can only be seen as prevention of any unnecessary deterioration of the environment (Georgescu-Roegen 1976:19). Technological advancement can only make throughput more efficient, but cannot mitigate entropy. The appropriate course of action therefore is to minimise environmental problems, not maximise growth. Cook (1982:194) states the ecological economic position clearly: What does it matter that human ingenuity may be limitless, when matter and energy are governed by other rules than information? The logical extension of this argument is that the earth will ultimately move to a point of no return if some fundamental shifts are not made.

The boundaries of entropy

Entropy is a natural law and cannot be fully mitigated. The question remains whether entropy can be mitigated within certain predefined boundaries. How can growth otherwise occur in a system of continuous entropy? Some answers lie in the constraints of time and space. A spatial mitigation of entropy given a certain period of time might be achievable. Entropy measures the stochastic nature or the state of disorder within a predefined system. Biological growth in essence means a decrease in entropy, but at the expense of higher entropy in its surroundings.

This necessitates another question: Can entropy be mitigated on earth with increased disorder in other areas such as outer space? The only two foreseeable ways of achieving this would be to use the sun as an external source of energy and to export pollution & waste into space. The former is technologically possible to some extent, but lacks institutional and market support. The latter would be theoretically possible given a cost-efficient institutional structure to support the transformation into space. It can be cautiously concluded that therefore the law of entropy is binding. Space and time are limiting factors in the development of the two Arrows of Time (Boulding 1981: 29).

Boulding (1981:29) recognises that …*[a potential crisis] all depends on the extent to which an increase in know-how can push back the limits of materials and energy, by finding new sources and new forms.* The point is neither an earth flowing into the bathtub, nor the ability of technology and institutions to overcome this. The focus is limited to softening the impacts of entropy. The central arguments are: first, how long the sun will continue to supply energy to the earth and its inhabitants and second, how this energy is converted to overcome the increasing entropy in other sources. Georgescu-Roegen's pessimism might be true if mankind does not learn how to draw on alternative forms of energy. In this case the thermodynamic imperative is applicable: *Act so as to create the minimum amount of entropy* (Dyke 1994:235). Such action would, per definition, include technological progress and innovations.

Ecological interdependence

The extraction of natural resources and the resulting pollution and waste can have an effect on a particular ecosystem, but many indirect effects on interconnected ecosystems. This magnifies the uncertainty factor in using natural and environmental resources considerably (Gowdy 1994:89). Gowdy (1994:89) mentions the example of sea-otters being hunted to extinction, which led to an increase in sea urchins which in turn resulted in kelp forests being destroyed, and all creatures depending on them. Humans are dependent on ecosystems for their life support. This critical natural capital cannot be used for production and consumption. The existence of critical natural capital places an absolute biophysical limit on economic growth.

Ethical and social limits

Section 3.4.2 contains a full discussion on ethical and social limits to economic growth.

No limits to economic growth

The denial of limits to growth is central to neoclassical reasoning. The relevance of this basic neoclassical postulate will be discussed, focusing first, on the potential of mitigating limits, second, the benefits of economic growth to welfare and, third, the U-curve hypothesis.

The potential to mitigate limits

Simon and Kahn (1984) claim in their book *The Resourceful Earth* that the nature of the physical world will tolerate a limitless improvement in the economic situation of mankind. Limits could be mitigated relatively easily and after that the economy will be stronger than before. The most prominent mitigation factors are (Jones & Hollier 1997:36-47):

- the problems associated with making accurate estimates of resource availability
- the price mechanism which will be adjusted for resources shortages
- the role of substitution
- the prospects for recycling
- the opportunities for conservation

Without discussing them all, underpinning all these options lies a faith in the ability of markets and technological progress to solve human and resource problems. However, market prices will not dictate the full opportunity cost of loss in complex ecosystems, and technological innovation can only mitigate within predetermined boundaries of space and time and will not be able to circumvent entropy totally. The point is not whether the market and technological progress will be able to circumvent the constraints on economic growth, but where these institutional arrangements are applicable and where they are not.

The benefits of economic growth to welfare

A number of analysts argue that sustained economic growth over the last few decades has brought many benefits to mankind, including increased health, more comfort, better communication and transport, more leisure time, less exhausting and less routine work (Simon & Kahn 1984), and that this situation can easily be extrapolated for future events.

As pointed out by Ayres (1995:122-124) the underlying important question is whether economic growth is necessarily the driver of increased welfare. Science, knowledge and technology generated economic growth – on the contrary: *Quality of life is not totally independent of the price and availability of manufactured goods and infrastructure, but neither is the connection one-to-one as we tend to assume…* (Ayres 1995:124).

The U-curve hypothesis

The U-curve or Environmental Kuznets Curve is *an econometric methodology that assumes that environmental quality or pollutant emissions are correlated with economic growth…This has been interpreted to mean that pollution increases with national industrial and income growth, but once a specific 'turning point' is reached, environmental quality begins to improve as incomes grow further* (Moomav & Unruh 1997:3). The same authors found evidence for decreasing CO_2 emissions per capita for sixteen industrial countries. However, this does not appear to correlate with specific income levels, but to a specific point in time, probably coinciding with a historically exogenous shock to these economies (Moomav & Unruh 1997:26). In another study, Arrow *et al.* (1995) demonstrate that the U-curve only holds for a selected set of pollutants. When pollutants are more aggregated and start to threaten life-support systems and incur social welfare losses the U curve hypothesis is not valid anymore. The focus is not on economic growth, but on the contents of economic growth (Arrow *et al.* 1995:93). This economic growth should be accompanied by institutions that are designed to provide the right incentives for protecting the resilience of ecological systems. Thus, the theory that economic growth will lead to a positive environmental trickle-down effect, should, like the evidence on the trickle-down effect in favour of redistribution in the literature in development economics, be treated at best on a case-by-case basis.

Conclusion

The second law of thermodynamics, or the First Arrow of Time, is binding. Natural and environmental resources are being used and move to higher states of disorder. Biophysical limits are therefore existent in an absolute sense and the thermodynamic imperative is applicable: Act so as to create the minimum amount of entropy. Daly (1996) argues for the limitation of throughput in the economic system.

The limitation of throughput necessitates the recognition of the Second Arrow of Time: technological progress, innovation and growth. However, as Pearce (1998:105) points out, carrying capacity indicators are extremely pessimistic regarding the judgements on technology. Given a particular economic structure, the normative criterion of (technological) efficiency and (biophysical) sustainability are both lacking in their truth-value, and mostly tend to exclude each other at the expense of potential better solutions. Within such a structure indicators should at least take into account both Arrows of Time.

The integration of the two Arrows of Time, namely entropy and innovation, has been attempted in endogenous environmental growth models, but with very binding limitations. These models are no better than their **ex ante** specifications on the complexities of natural phenomena and spatial differentiation (Vellinga 1999). These models cannot answer the question whether economic growth or development is sustainable or not. The debate on the limits of economic growth is one of technological optimism or ecological pessimism: a **pre-analytical** normative choice of criteria that come closest to this analyst's own values.

On a higher level of analysis the informational revolution, as experienced in the last few decades, is seen as a relatively clean engine of economic growth, but still operative within the era of hydrocarbons as a source of energy (Norgaard 1988). The technologies on renewable energy sources are available, but are not supported by institutional structures to make them more widely applicable. Such situations could lead to potentially disastrous situations on a higher scale such as global climate change. To apply the concept of biophysical limits and carrying capacity of ecosystems on an increasingly higher scale can only be done in a careful way. The spatio-temporal boundaries of a system under observation and the linkages with the systems environment are important variables when analysing whether a system has reached its threshold or not. However, the study of entropy on larger scales is extremely complex, as evident from the application of global circulation models (GCMs) for instance. In this line of argument Vollebergh (1999:128) cautioned against the rejection of economic cost analysis in the cases where entropic processes are uncertain.

Neither biophysical, nor economic or technological normative criteria can appeal to truth-values. Therefore the debate on economic growth and development is so divided. One can speak of two camps organised according to their sets of beliefs: the pessimists believing in ecological doom and the optimists believing in technological and economic efficiency. Both camps will find evidence, whether rational or empirical, to fight the opposing camp. However, it should be recognised that the impacts of entropy and innovation differ across spatio-temporal scales, making a case-by-case approach the best way forward.

It is accepted that ethical limits are cutting across all the criteria of efficiency and sustainability. These ethical limits are an important guide in the evaluation of biophysical limits and economic efficiency on a case-by-case basis. Social limits are also relevant, as the promised high level of human happiness has not been achieved through economic growth. Neither can it be believed that a high level of human happiness will be achieved by limiting development in the first place. Van den Noort (1993:9) argues that innovations are needed to sustain development; if one part of the economy collapses, the disaster will have dire consequences on the economy as a whole.

In conclusion, the question whether there are limits to economic growth in itself is too limited. The complexities of the growth debate need to be recognised before choosing a normative point of departure rooted in technological optimism or ecological pessimism. Both entropic and technological processes are complex and uncertain. This means that a choice of one in favour of another should be guided on a case-by-case basis.

CURRICULUM VITAE

Martinus Petrus de Wit was born in 1972 in Pretoria. He matriculated at the Wonderboom High School and graduated with a major in economics at the University of Pretoria in 1992. He completed his Honours in economics at the University of Stellenbosch in 1994 and the equivalent of a Masters in general economics at the Rijksuniversity of Groningen in The Netherlands in 1995. In 1996 he started his career at the South African Reserve Bank and joined the CSIR in 1998. He has published widely in the field of economics and the environment. From his thesis a total of five papers in accredited journals are anticipated, of which two have been published already. He is also the co-founder and executive council member of the Forum for Economics and Environment.

His doctoral thesis entitled **Economic policy making for complex and dynamic environmental problems: a conceptual framework** is of importance to both the academic and the policy maker, since it integrates standard economic theory, environmental problems, systems (or non-linear) theory and the policy-making process. This is the first time that such a link is made between these various research domains. Using systems theory enabled the candidate to develop a conceptual framework for policy making in order to solve complex (i.e. interconnected) and dynamic (i.e. changing over time) environmental problems such as global climate change. This is a unique way of addressing a problem that is of increasing importance to South Africa and for which there is currently no unified policy or policy process in place. This thesis provides the required theoretical and analytical framework to address such problems.