Economic Sustainability and Scarcity of Natural Resources: A Brief Historical Review

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1. Introduction

A widely used Finnish textbook on high school biology includes a section on sustainable development and a comparison between ecology and economics (Valste et al. 1993). The message is as follows:

> "As a science economics is older than ecology. At the time of the earliest economists there were no scarcities of natural resources. This is still reflected in present day economic planning. By contrast, ecology cannot accept the idea of unlimited resources. In addition, from the economic point of view a time horizon of 10 years is long while in ecology it is extremely short."

Thus the comparison suggests that economics tends to apply short time horizons and the assumption of limitless natural resources. Besides the fact that this rather common view (see e.g. Begon 1996, p. 666) makes it somewhat difficult for an economist to discuss with people concerned about sustainable development, it raises an interesting issue. Since economic factors may have a strong influence on environmental decisionmaking and more generally on social development, and since many argue that this influence may be too strong, it is important to be aware of how economists understand natural resource scarcity and sustainability of economic growth. In the following, my aim is to evaluate economics in this respect and simultaneously present some basic empirical facts on how the scarcity of natural resources has evolved during the last century.

2. The First Debate: The British Classical Economists

In 1798 Thomas Malthus published his well known essay on the principles of population. Malthus argued against theories raised by the growth optimists and some philosophers of his time (like the French philosopher Nicolas de Condorcet) who believed that the human mind and technological development would solve all obstacles to future progress and economic growth. Malthus believed instead that the human race would always breed until the limits of natural resources are met, and at that equilibrium societies are characterized by misery, starvation, and a subsistence level of wages.

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Technological development only produces a short-term increase in well-being until the limits are again met. Long-term development would be possible only if mankind makes the moral decision not to breed during economically stable times when wages exceed the subsistence level. However, Malthus deemed this impossible.

Other classical economists were not as pessimistic. For example, John Stuart Mill (1862) emphasized that while the limited quantity of natural resources could in principle constrain increases in production, this limit had not yet been reached and would not be reached in any country over any meaningful time frame. Mill based his argument on future developments in agricultural knowledge and because social institutions and increases in economic welfare may slow down population growth. An interesting feature in Mill's thinking was the argument that the quality of living space is an important part of economic well-being. According to Mill, a world where the environment is used completely for industrial and agricultural purposes is not an ideal world.

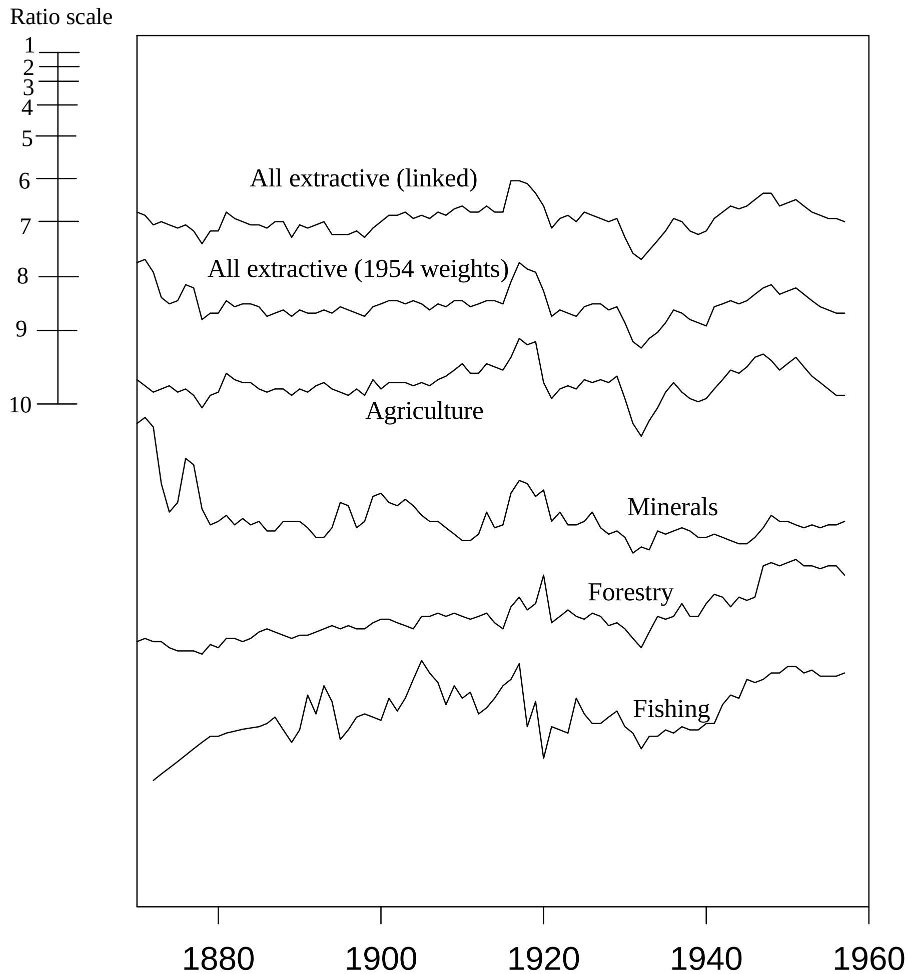
3. The Second Debate: The U.S. Conservation Movement (1890-1920) and the Studies by Hotelling (1931) and Barnett & Morse (1963)

The Conservation Movement, with U.S. president Theodore Roosevelt among its leaders, was a highly successful political ideology in the United States between 1890 and 1920. According to its doctrines, economic growth has clear physical boundaries that cannot be avoided by technological development. Too rapid use of nonrenewable resources was considered a major threat to future generations. It was argued that the lower the use of nonrenewable resources, the better. Economic competition and monopolies were seen as major enemies to the wise use of natural resources, which was defined in physical and ethical terms. Government control of natural resources was deemed desirable. Needless to say, many of the ideas being discussed in the present-day debate on nature conservation and sustainability were conceived during this period.

Partly as a reaction to the Conservation Movement, an economist, Harold Hotelling, published a study "The Economics of Exhaustible Resources" in 1931. In this study he constructed a theoretical model in which social well-being from nonrenewable resources was maximized over an infinitely long period; he then showed that in a market economy, profit maximizing mining firms would extract nonrenewable resources at the "socially optimal rate." This conclusion is widely accepted among economists, but it is surprising for those who have taken the position that competition and the market economy will always lead to short-run profit maximization and rapid exhaustion of nonrenewable resources.

Thirty years later there were data available for studying the question of natural resource scarcity empirically (Figure 1). In the study *Scarcity and Growth*, two U.S. economists (Barnett and Morse 1963) collected price and cost time series data on minerals, agriculture, and renewable resources. Their purpose was to test whether the hypothesis of increasing natural resource scarcity obtains empirical support. The results were quite surprising: for agriculture and minerals, price and production costs had fallen or remained constant within the period from 1870 to 1957. Only the price level in forestry had shown an upward trend. According to the study, these findings can be explained by technological development, which produces substitutes for scare resources, decreases extraction costs of minerals, and thus expands the size of economic reserves. In general, the authors strongly questioned many of the basic premises of the conservation movement as well as the pessimistic Malthusian view.

Figure 1. Trends in natural resource prices relative to other prices in United States 1879-1957



Source: Barnett and Morse (1963).

4. The Third Debate: The *Limits to Growth* Report for the Club of Rome

Only nine years after the study by Barnett and Morse, a group of scientists from the Massachusetts Institute of Technology (MIT) published the *Limits to Growth* report for the Club of Rome (Meadows et al. 1972). This study sold nine million copies in 29 languages. It was based on new digital computers and on a modeling method called “system analysis.” The study presented a large new type of model in order to predict the future development of five global variables: population, food, industrialization, nonrenewable resources, and pollution. The prediction of the study was highly pessimistic: The future world population level, food production, and industrialization would first grow exponentially but then collapse during the next century. The collapse follows because the world economy will reach its physical limits in terms of nonrenewable resources, agricultural production, and excessive pollution. The study also predicted that eleven vital minerals could be exhausted before the end of this century. Among these were copper, gold, lead, mercury, natural gas, oil, silver, tin, and zinc.

As is now clear, these predictions have failed. One example is shown in Figures 2a-c which depict the actual development of oil production and remaining oil reserves. Due to new discoveries and technological change, the level of proven reserves has increased in spite of the fact that oil production has also increased. Figure 2c shows that the static reserve index, calculated by dividing existing reserves by annual production, has increased as well. It follows that such an index cannot be used for predicting resource scarcity. To see this, note that in 1934 the index for copper was 40 years, indicating that reserves would be exhausted by 1974. However, in that year the index had risen to 57 years. According to the Hotelling model mentioned earlier such an index might well increase or stay approximately constant forever as reserves and production change proportionately. Nevertheless, in environmental and energy discussions these indexes are still frequently used.

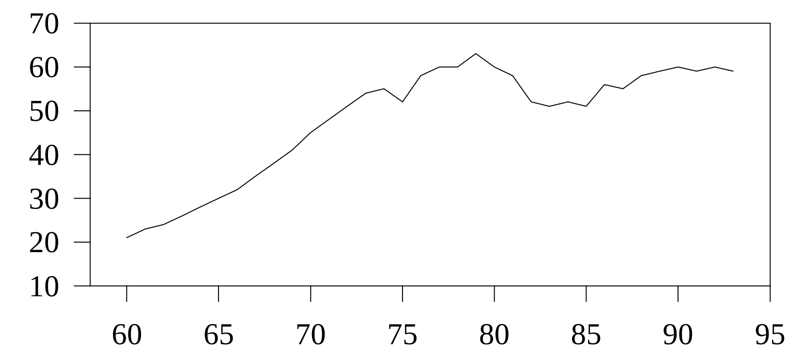
In 1992 the *Limits to Growth* authors published a slightly modified version of the model (Meadows et al. 1992). Economists have strongly argued against both of these studies. One problem with these models is that they are not based on any specific statistical data. Instead the model builders rely on their own intuition of how, for example, population growth depends on other variables. Thus there is a tendency to overlook scientific work in many fields of social sciences and economics. Among other problems, the studies neglect the price system and dynamics of the market economy and thus have strong Malthusian tendencies. In 1977 the United Nations asked the Nobel Prize winning economist Wassily Leontief to carry out a study on whether natural resources will be exhausted before the end of the century. Leontief applied equally pessimistic assumptions as the *Limits to Growth* authors except he took into account that demand may respond to higher prices. According to his results, only two minerals were in danger of being exhausted (Leontief 1977).

5. The Fourth Debate: “Pre-Sustainability” Research in Economics, from 1974 Onwards

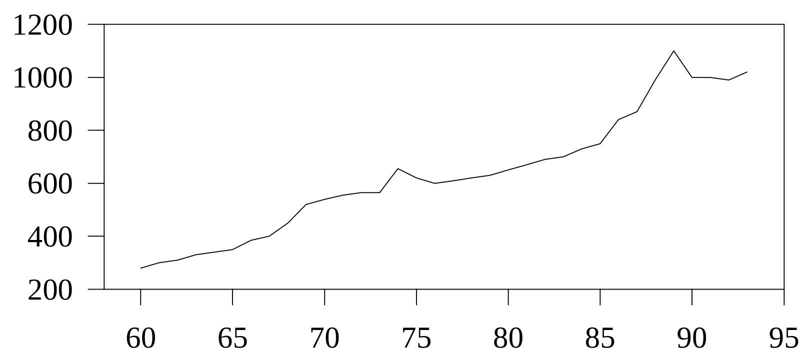
One year after publication of the *Limits to Growth* report, oil prices rose about threefold over a very short time. This caused the first energy crisis. There were very few then who questioned the view that the world was entering a future of increasing scarcity of energy and natural resources. Perhaps the most well known work of this time is the 1974 economic growth and nonrenewable resource model of Partha Dasgupta and Greffrey Heal. These economists ask whether an economy can maintain a positive consumption level forever, given that there is no technical development and that the production of commodities is possible only by using limited nonrenewable resources like oil. This is clearly a question of sustainability. According to their analysis it is possible to maintain a positive

Figure 2. Development of oil production and reserves

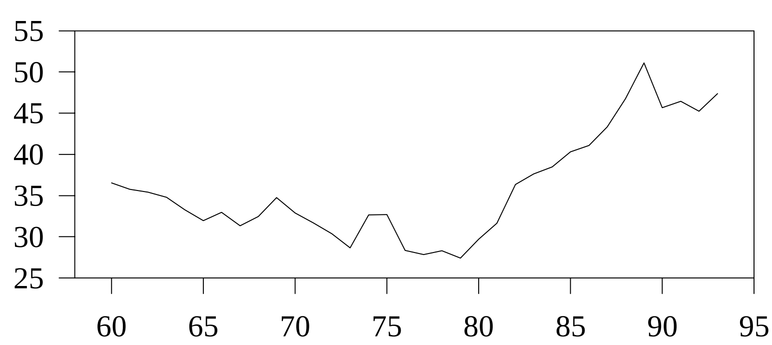
World Crude Oil Production in Million Barrels per Day



World Proven Oil Reserves in Billion Barrels



Reserves to Production Ratio, years



Data source: Middle East Oil and Gas, OECD (1995).

consumption level forever only if capital can be substituted for nonrenewable resources without technical difficulties. If the substitution possibilities are limited, future consumption per capita must finally fall to zero. Many environmental economists have taken the position that only the latter case is in line with physical laws. Within this framework it is argued that even continuous technological change (that does not violate physical laws) will not change the pessimistic outcome (Toman et al. 1995; Gross and Veendorp 1990; Anderson 1987).

Another interesting result of this research is that even in cases where it would be possible, in principle, to maintain positive consumption forever and thus achieve sustainable development, the market system may lead to an outcome where consumption per capita in the long run falls to zero. This unfortunate outcome occurs if consumers are not willing to continuously save a high enough proportion of their income to invest in capital, or if population growth is too rapid.

Since the study by Dasgupta and Heal and other similar studies on natural resource scarcity (Solow 1974, Stiglitz 1974), research in this area has evolved in several directions. One line of discussion has taken seriously the possibility that market economies may not lead to sustainable outcomes even if it is technically possible. Studies in this field have shown that sustainable development may be possible if the economy invests all of its economic surplus or profits from using nonrenewable resources in capital accumulation (Hartwick 1977). In a market economy, governments would have to create an incentive for this using taxation or other methods. For example, it is sometimes argued that the Norwegian policy not to consume but instead invest a high proportion of their oil income resembles the Hartwick policy. However, the Hartwick rule requires a very high savings rate, well above what is observed or what we would expect to see.

Another line of research includes renewable resources, like solar and wind energy, in models of long-run economic growth. This changes the pessimistic outcome noted above. The economy first uses up its nonrenewable resources and simultaneously invests in some revolutionary technology that decreases the cost of using renewable energy (Dasgupta and Stigliz 1981). When nonrenewable resources are used up, there is a switch to the use of renewable energy sources. However, adding pollution problems like carbon dioxide accumulation to the models implies that the shift to the renewable noncarbon energy technology should occur earlier, even when the market price of the new technology is above the direct cost of using fossil fuels (Tahvonen 1997).

A third line of research continues to study natural resource scarcity empirically. Now that the first and second energy crises are historical events, it has become clear that they did not have very much to do with the long-run scarcity of natural resources. When oil prices spiked, companies were willing to take on the risk of exploring for oil in new regions. Oil was found from the North Sea, Mexico, and Venezuela. Whatever market power OPEC possessed collapsed because it was not able to prevent the entry of new oil producers (Salo and Tahvonen 2000). As a consequence the present real price of oil returned to approximately at the same level as before the energy crises (Figure 3).

Against this evidence, one is forced to conclude that the basic economic prediction has failed. It has been much too pessimistic. There are several different explanations for this. Nonrenewable resource prices may decline if markets are not able to anticipate new discoveries and new substitutes for those resources that are becoming more scarce. Another important reason for the declining resource prices is continuous technical progress in nonrenewable resource extraction (Tahvonen and Salo 2000).

Figure 3. Development of Crude Oil Real Price

Source: Energy Information Administration (1996).

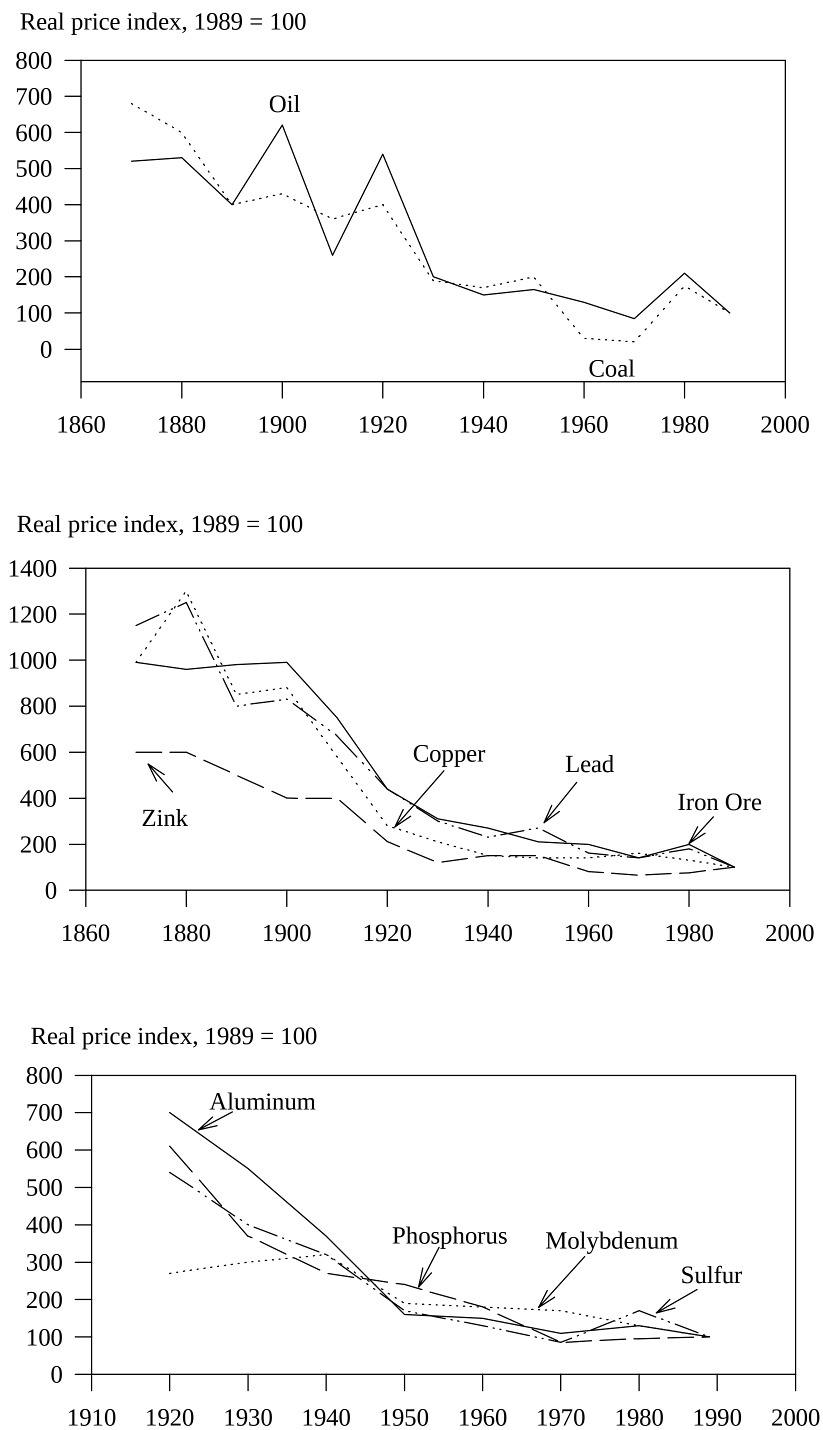
But economists should also evaluate the basic assumptions in their models more critically. The most simple and frequently used economic model in this context, the "cake eating" model, assumes that resources can be fully depleted physically. Many geologists view physical resource exhaustion as an impossibility since rising cost from declining resource availability will stimulate substitution. Nevertheless, this assumption is still included in many more complicated resource economic models.

The efficiency of the market mechanism seems to be one reason why nonrenewable resources have been saved from exhaustion. Environmental economists have emphasized that it is not possible to rely on the same argument with respect to pollution and many common property renewable resources like open sea fisheries (Clark 1976). Economically efficient long-term policy requires government control in the form of environmental taxation, for example.

6. New Economic Growth Models

As economists have studied past developments in natural resource scarcity, it has become clear that theories neglecting technological change have always failed. However, it has been difficult to include technical change in a satisfactory fashion in economic theories of growth. Up to the mid-1980s technological change was taken as being exogenous—not explained in the model. During the last ten

Figure 4. Development of some nonrenewable resource prices.



Source: Nordhaus (1992).

years economic theories of growth have dramatically changed. In so-called “endogenous growth theory” technological development is considered a continuous progress that originates from innovations made in firms and can be speeded up by government investments in research and development projects and in general education (Barro and Sala-I-Martin 1995). From the point of view of sustainable development these models have an interesting feature: long-run consumption per capita simply grows without bound (see also Baumol 1986). How can this be possible in a finite world with finite natural resources?

It may be argued that economists should more carefully consider the physical and material basis of these models. It is impossible to find natural resources in the indexes of books on new theories of economic growth. It is easy to find theories in which variables resulting physical substances increase exponentially without limit. This may be as misleading as the *Limits to Growth* modeling. In some models natural resources have been included but the authors seem to not be aware of the work done in natural resource economics.

However, these new theories also force us to discuss more carefully the material content of economic growth. From an economic point of view there is no sense in measuring growth as an increase in output in terms of material units like kilograms. Instead economic growth increases the net value of annual production. This value obtains its content from supply and demand for all goods and services and fundamentally from the preferences of all consumers in the society. The value of production may not be directly related to the use of natural resources, and consumption and production measured in physical units. Some theoretical growth models make this very clear in the sense that they specify growth as an increase in the quality of commodities, while production and consumption in terms of material units remain constant. There should not be any direct environmental reasons to oppose this type of qualitative growth. From this point of view arguing against economic growth for environmental reasons is a conceptual confusion. It is sensible to oppose polluting emissions and excessive use of natural resources but not economic growth. However, for similar reasons there is no sense in arguing that economic growth will automatically solve any environmental problems.

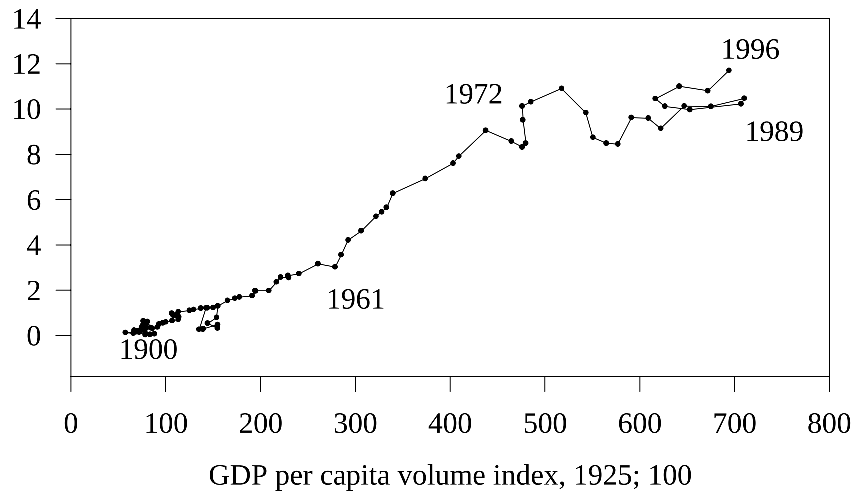
Recent research has considered this issue empirically by studying whether the material content of production and consumption increases or decreases with per capita GDP in various countries (Schmalensee et al. 1998). According to theoretical models, per capita emission levels should start to decrease at some level of per capita GDP. The hypothesis has obtained some support, for example in the case of city air pollutants. The following graphs (Figure 5) show the development of per capita carbon emissions related to per capita GDP growth in the United States and Finland. It must be emphasized that although the growth of per capita emissions has peaked in some countries in the Organization for Economic Co-Operation and Development (OECD), these emission levels are still very high compared to those in many developing countries.

7. Interpretations and Conclusions

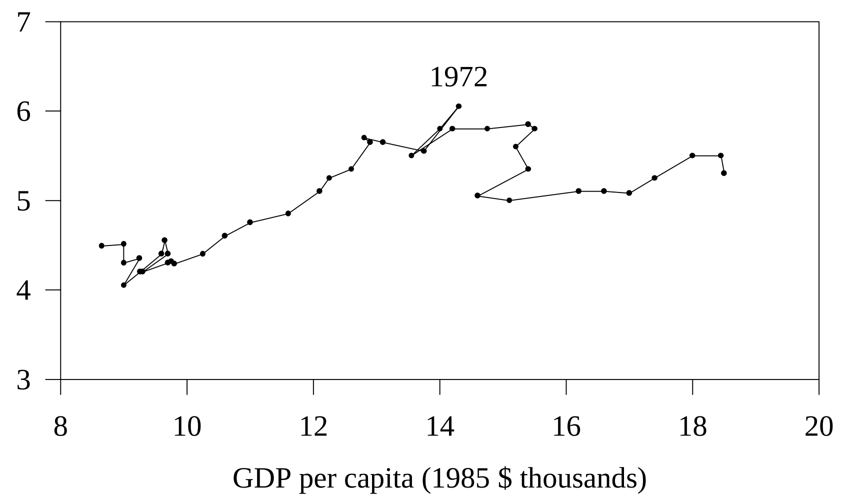
For interpretation purposes let us assume a hypothetical situation where a green politician wants to argue against a plan for using part of the natural environment for production purposes. If the green ideology is based on Malthus and limits to growth views she is somewhat in trouble because she must admit that not using the environment may cause reductions on citizens’ well-being. If she instead

Figure 5. Income carbon dioxide relations

Carbon emissions (tonnes) per capita, Finland



Carbon emissions (tonnes) per capita, U.S.A.



Source: Authors calculations based on Finnish statistics, Schmalensee et al. (1998).

refers to the more recent and optimistic studies on growth and natural resources, she can simply argue that recent economic research shows that the physical limits to natural resource supply do not cause any serious effects on economic growth. This is because growth depends more strongly on technical development, education, and economic policy, for example. Thus she may argue that preserving that part of the environment for future generations cannot cause any serious slowdown in conventional economic growth.

Many years ago, Aristotle wrote that it is possible to reach a satisfactory level of income by a "natural means of livelihood." He claimed that capital accumulation is ethically problematic and not at all necessary for a good human life since it leads to confusion between ends and means. It also leads to bad economics, Aristotle argued, since unlimited growth becomes a value in itself. He argued that it is more valuable to aim at a moderate standard of living and concentrate on more valuable things in life such as politics and philosophy. These ideas belong to perhaps the first wave of criticism of growth in western civilization (Aristotle 1972, Väyrynen 1993). However, we know for sure that besides some local erosion problems, sustainable development was not in danger at that time. Aristotle was highlighting a more fundamental criticism of growth, independent of any environmental problems. It seems that this ideology is today more or less hidden in the attitudes of many people toward economic growth, technological development, and scarcity of natural resources. However, stating it more explicitly might help to clarify the discussion.

Finally we could go back to the high school biology text and try to reformulate the section on sustainable development and the reference to economics. Perhaps it might then read something like this:

> In economics concerns about sustainable development, increasing scarcity of natural resources, and pollution problems go back about two hundred years. During this time many pessimistic economic predictions have failed. Among these is the view of the British classical economist Thomas Malthus (1766-1834) that per capita food production will always eventually collapse to the lowest possible subsistence level due to scarcity of agricultural land. The pessimistic predictions might have failed because the concern has forced people to react in time and develop better technologies and social institutions. From the economic point of view the most serious environmental problems are related to cases where the market mechanism does not work, such as in the cases of pollution and common property open sea fisheries. In the coming years the problems may take completely new and surprising forms, and anticipating them and reacting accordingly will require unbiased and open-minded cooperation between different sciences such as ecology and economics.

References

Anderson, C. 1987. The production process: Inputs and wastes. *Journal of Environmental Economics and Management* 14:1-12.

Aristotle. 1972. *Politics, Aristotle in Twenty-Three Volumes*. Vol. XXI. London: Loeb.

Barnett, H., and C. Morse. 1963. *Scarcity and Growth*. Washington, D.C.: Resources for the Future.

Barro, R., and X. Sala-I-Martin. 1995. *Economic Growth*. New York: McGraw Hill.

Begon, M,. C. Harper, and C. Townsend. 1996. *Ecology: Individuals, Populations and Communities.* Oxford: Blackwell Science.

Clark, C. 1976. *Mathematical Bioeconomics: Optimal Management of Renewable Resources*. New York: John Wiley & Sons.

Dasgupta, P., and G. Heal. 1974. The optimal depletion of natural resources. *Review of Economic Studies*, Symposium Issue, 3-28.

Dasgupta, P., and J. Stigliz. 1981. Resource depletion under technological uncertainty. *Econometrica* 49:85-104.

EIA (Energy Information Agency). 1996. *Annual Energy Review*. Washington, D.C.: EIA, U.S. Department of Energy.

Gross, L., and E. Veendorp. 1990. Growth with exhaustible resources and a materials-balance production function. *Natural Resource Modeling* 4:77-94.

Hartwick, J. 1977. International equity and the investing of rents from exhaustible resources. *American Economic Review* 67:972-974.

Hotelling, H. 1931. The economics of exhaustible resources. *Journal of Political Economy* 39: 137-175.

Leontief, W. 1977. *The Future of the World Economy*. New York: Oxford University Press .

Malthus, T. 1798. *An essay on the principle of population as it affects the Future Improvement of Society*. London: Ward Lock.

Meadows, D. H., D.L. Meadows, J. Randers, and W. Behrens. 1972. *The Limits to Growth: A Report for the Club of Rome´s Project on the Predicament of Mankind*. New York: Signet.

Meadows, D. H., D.L. Meadows, and J. Randers. 1992. *Beyond the Limits: Global Collapse or a Sustainable Future*. London: Earthcan Publications.

Mill, J.S. 1862. *Principles of Political Economy*. New York: Appleton.

Nordhaus, W. 1992. Lethal models 2: The limits to growth revisited. *Papers on Economic Activity 2*. Washington, D.C.: Brookings Institute.

OECD (Organization for Economic Cooperation and Development). 1995. *Middle East Oil and Gas*.

Salo, S., and O. Tahvonen. 2000. Oligopoly equilibria in nonrenewable markets. *Journal of Economic Dynamics and Control*, in press.

Schmalensee, R., T. Stoker, and R. Judson. 1998. World carbon dioxide emissions: 1950-2050. *The Review of Economics and Statistics* LXXX:15-27.

Solow, R. M. 1974. Intergenerational equity and exhaustible resources. *Review of Economic Studies, Symposium on the Economics of Exhaustible Resources*, 29-46.

Stiglitz, J. E. 1974. Growth with exhaustible natural resources: efficient and optimal growth paths. *Review of Economic Studies, Symposium on the Economics of Exhaustible Resources,* 123-137.

Tahvonen, O. 1997. Fossil fuels, stock externalities, and backstop technology. *The Canadian Journal of Economics* XXX:855-874.

Tahvonen, O., and S. Salo. 2000. Economic growth and transactions between nonrenewable and renewable resources. European Economic Review, in press.

Toman, M., J. Pezzey, and J. Krautkraemer. 1995. Neoclassical economic growth theory and "sustainability." In *The Handbook of Environmental Economics,* edited by D. Bromley. Oxford: Blackwell .

Valste, J., S. Airamo, M. Holopainen, I. Koivisto, T. Suominen, and P. Viitanen. 1993. *Biologia: Toimiva eliömaailma, Perinnöllisyys ja Evoluutio* (in Finnish). Porvoo: WSOY.

Väyrynen, K. 1993. Ympäristöeettisiä teemoja antiikin moraalifilisofiassa, (in Finnish). In *Ympäristökysymysten yhteiskunnallisia ja eettisiä näkökulmia* (J. Jokisalo and K. Väyrynen, Eds.). Oulu University, Department of Philosophy, Report 25.