Table of Contents

Go Back

SD Model of Economic Growth with Environmental Aspects[1]

P. Bartoszczuk

System Research Institute of the Polish Academy of Science

Newelska 6, Warsaw

Abstract

Our objective is to foster the understanding of the economic, natural, and social components - that make up the global system. We apply system dynamics modeling methodology. We investigate five major trends of global concern: rapid population growth. Industrialization, deteriorating environment and depletion of non-renewable resources. We list the important and causal relationships among the levels and trace the feedback loop structures. In describing an economic and environmental model we focus on the relations among income, pollution, and non-renewable resources. This paper yields insight into the possibilities for replacing non- renewable fossil fuels with more renewable ones. Next, we present the simulation runs of the model, conducted with the help of existing system dynamics modeling tools.

Keywords: *economic model, environmental systems, non-renewable resources, simulation*

1. Introduction

This paper examines the possible impact of economic development on environmental quality. Certain plausible assumptions about the response of some variables are made. We present different possible scenarios, including irreversible decrease of non-renewable resources. The paper consists of 5 chapters including introduction. We present opinions on the influence of economic development on environment, with the stress on the Club of Rome ideas in the chapter 2. In chapter 3 we describe relations in our model, and we present the results of our simulations and conclusion in chapters 4 and 5.

2. The different viewpoints on growth and environment

In the debate over growth and environment, we have two views: optimistic and pessimistic. Proponents of optimistic view argue that continued economic growth will produce less polluted, and more resource rich world (Ophardt, 1997). Beckermann (1999) claims that growth is beneficial due to supporting social improvement. Stiglitz (1996) suggests that the

[1] This paper was presented at System Dynamics Congress in Oxford in July 2004.

elasticity of substitution between two inputs: capital and resources is sufficiently large with new technologies. Lovejoy (1996) imply that technology can change substitution over time so there is less scarcity. Mikesell (1995) emphasizes the lack of evidence that growth leads to lower productivity.

Some other researchers indicate that for a specific kinds of environmental problems the relation between income and the level of environmental pressure shows an inverted U curve (Arrow, at al. 1995; de Bruyn and Heintz, 1999; Dinda, 2001; Grossman and Krueger, 1995). The conclusion of those studies can be criticized on several grounds. Results obtained from cross-section data cannot be translated to future time-series for specific countries. Moreover, empirical studies only focus on particular aspects of environmental pressure not related to the carrying capacity natural resilience of ecosystems.

Overall, optimists view two things: (1) the elasticity of substitution between an essential resource and capital is greater than 1, and (2) technology will increase the productivity of resources faster than their exhaustion. The empirical literature provides a mixed and partial picture. While some studies yield substitution elasticities greater than unity (a necessary condition for economic growth models to generate sustainable paths) for metal: steel, copper and aluminium (Brown and Field, 1979), others suggest that for scarce materials like beryllium elasticity is close to zero (Deadman and Turner, 1988).

Pessimists claim that sustainability recognizes that without intervention the global environment will not be able to provide a reasonable standard of living (Helm, 2000). Malthus (cited by Solow (2000)), was the first who pointed out the possibility of growing relative scarcity of natural resources. The authors of ‘The Limits to Growth’ Report continue to argue that economic growth must be lowered along with other changes (Meadows, 1972). The analyses in the report did draw public awareness to the need for saving and conserving the environment and natural resources (Hayami, 1997). Daly (1996) suggested that renewable resources should be used in amount no greater than the rate of regeneration.

Club of Rome Report emphasised the examples of exponential growth: world population has been growing exponentially since the beginning of industrial revolution. In 1991 annual growth rate was estimated as 1.7%, which means a doubling time of 40 years. Also world production, relative to the base of 1963 year show clear exponential increase, as well. The concentration of carbon dioxide in the atmosphere has risen from 290 parts per million in the last century to over 350 parts per million and will continue on its exponential growth path. According to Intergovernmental Panel on Climate Change (IPCC), atmospheric CO2 concentrations by 2100 will be in the range of 650 to 970 ppm. The increased atmospheric concentrations of CO_2 and other greenhouse gases (GHG) trap more of the earth's heat, causing temperatures to rise. As a result, it is predicted that the global average surface temperature can rise between 1.4 and 5.8 degrees Celsius between 1990 and 2100, an unprecedented rate of increase. These in turn are responsible for melting ice, rising sea levels, and a greater number of more destructive storms.

The ‘Limits to growth’ study made a valuable contribution to our knowledge on sustainable development in bringing the implications of unbounded growth at a time when the environmental capacity was often thought to be unlimited. The nature of the policy prescription of the World3 arises from the way the resources sectors have been modelled. The stocks of these resources have outflow, but not inflow, which causes collapse, since the outflow continue with production.

Acharay and Saeed (1996) modified the “Limits” model first to accommodate the model variety. The modified model generated the behaviour similar to the original model under realistic assumptions, although it contained latent structure for arriving at robust equilibrium. When run for longer time, Model “Limits to growth” spell doom, even when their policy recommendation are applied. Hayes (1993) claimed that that policies, which seem to ensure sustainable future could only postpone collapse until middle of next century.

The resources ecosystem of the earth is a relatively small subsystem within the universe and it derives its energy from sun. Most resource policies currently we use fall into reactive category. Implementation of reactive policies requires powerful exogenous intervention. Corrective policies aimed at improving market mechanisms attempt to ensure efficient use of resources. We must emphasize that market mechanism assure only intra-temporal efficiency of resources and they cannot address the issue of inter-temporal equity. Market economy claims that restoring resources for futures makes sense only when the expected resource' future price is increasing at a rate that is at least equal the market rate of interest. Therefore, market mechanisms always favour present use of resources over future one (Saelid, 1996) Understanding the fact that markets may fail to allocate resources properly also favour public intervention to slow down and stretch out the exploitation of resources pool. The model, however, rules out any inputs into global resource system. One could say that the fixed stocks take into account the ultimate available resources, including sun energy, but the time frame of such stocks would be extremely long. We have attempted in this paper to add green energy, which can replace fossil fuels. This kind of policy is implemented after 2016 year.

3. The analysis of main relations

First, we consider macroeconomic relations with capital, income, consumption, and savings, which can be found in many macroeconomic books (Solow, 2000). Capital is accumulated by the amount of investment and decreased by depreciation in a specified time unit, like one year. We assume all production comes about as a function of capital and labour. The consumption per capita is minimum from consumption per capita and substantial level of consumption. Subtracting consumption from income yield savings. Saving can be changed into investments goods like raw materials, thereby increasing capital stock. At equilibrium, investments have to be equal to saving otherwise output would not be sold out completely or would be in short supply. To warrant a non-negative amount of saving, the saving function is maximum from zero and the difference between output and consumption.

Each year the population is increased by the total number of births that year and decreased by the total number of deaths that that year. Number of working force is proportional to the population. Some relations described above are presented on the *Powersim* diagram (Figure 1).

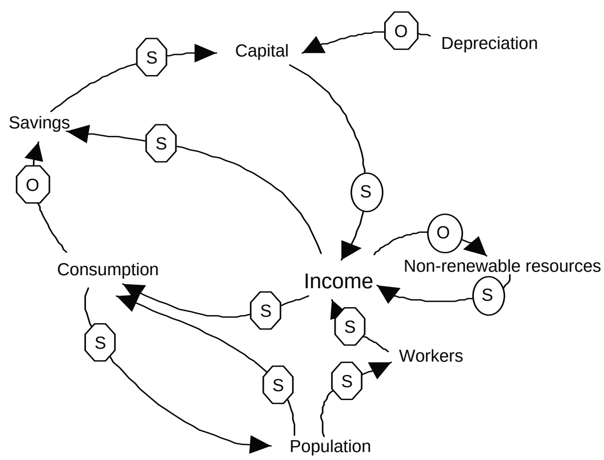

Figure 1.Diagram with reinforcing loop between capital and income and consumption, and balancing loop between Non-renewable resources and income. *S*- change in the same direction and *O*- change in the opposite direction.

Next, we add to our model fossil fuels. As the world's population and capital grow, the demand for fuels will increase accordingly. The amount of non-renewable resources (fossil fuels) consumed each year can be found by multiplying the output (income) by usage rate. As population becomes wealthier, it tends to consume more resources per person and year. That input of natural resources to production decreases with time due to application of new technologies enabling effective use of non-renewable fossil fuels. In turn, demand for fossil fuels depends on demand for energy minus green energy generation. Non-renewable fossil fuels can be replaced with alternative energies generated by wind, hydrogen, solar cells and geothermal sources. Such alternative energies are in turn assumed to be generated by alternative renewable sources. The accumulation of the green capital is done through green investment. The green investment is assumed to decrease the amount of savings so that a level of consumption is not relinquished and only the conventional amount of investment on fossil fuels becomes a trade-off with green investment. This is a novelty from the traditional approach, where substitutes were subtracted out of the output, and accordingly capital accumulation began to decline with less amount of savings and investment.

Next, we have to distinguish renewability from recyclability. Renewability is related with reproducibility of natural resources themselves. For instance, fossil fuels, once consumed, cannot be reproduced, while rangelands, croplands and fisheries could be repeatedly produced (and used) as well as sources of wind energy (Yamaguchi, 2002). On the other hand, recyclability is related with the re-use of the products of natural resources. For instance, metals from minerals, trees and papers could be repeatedly used, while electricity by any source, as well as meat from rangelands, grains from croplands and fish from fisheries, cannot be re-used. Whenever these distinctions are made, natural resources are more completely classified into four groups as it is presented in Table 1.

<table>
<tr><th></th><th>Non-renewable sources</th><th>Renewable sources</th></tr>
<tr><td rowspan="2">Non-Recyclable products once consumed</td><td rowspan="2">Fossil fuels energies
Nuclear energy</td><td>Wind/Solar Hydrogen energies Geothermal)</td></tr>
<tr><td>Rangelands, Croplands, Fisheries</td></tr>
<tr><td>Recyclable products as sources</td><td>Minerals</td><td>Forest, Water</td></tr>
</table>

Table 1

Distribution of products and sources in our model (Yamaguchi, 2002)

Finally, let us assume that production and consumption activities generate as by-products industrial wastes, represented here by carbon dioxide. The increased amount of atmospheric carbon dioxide has a considerable influence on the growth paths, since the economy heavily depends on the use of non-renewable fossil fuels that causes an emission of carbon dioxide and eventually global warming. This impact can be analyzed by setting a positive level of carbon contribution to the fossil fuels productivity in the model (Yamaguchi, 2002).

4. The results of simulation.

We considered two possible scenarios of development. In the first scenario we assume that at least 50% energy will come from fossil-fuels, while in second scenario this amount will be at least 10 percent (similarly to Yamaguchi (2001). The rest of energy will be from renewable sources. The results of our simulation show that in the coming decades, after initial increase, we can expect decline in non-renewable resources-fossil fuels, industrial production and in population. In the first scenario, after 300 years of our simulation 50% of resources are depleted. At the outset, after an initial increase of output (income), we observe its decrease after 100 years of our simulation, and our economy presents overshoot and collapse behavior (Figure 2). Following 250 periods of simulation, investment equal zero, and all the production is consumed. Production is lower due to higher costs of exploring fossil fuels. In the second scenario depletion rate of fossil fuels is lower than in a first scenario (–0,3 % versus –0,4, but resources are stabilized), and overshoot and collapse behavior will not occur and only 35% of resources are depleted.

Economic growth leads not only to the depletion of fossil fuels, but also to increase of pollution and wastes, together with global warming. As the resources continues its inevitable decline, the input rate of fossil fuels declines due to autonomous technological progress. Further, we allow for the non-renewable resource to be substituted by green capital, from 2016 year, but in first scenario, even with that energy our resources are depleted. This result should not be surprising, and we must remember that the amount of green energy is proportionate to the savings. Since the savings are lowered as a result of lower economic output, renewable resources will be depleted when consumption is bigger than zero.

Population is increasing until 2050 year in first scenario or 2075 year in the second scenario and than starts to decline (Figure 2 and 3). Population growth is significant initially due to increase of output. Consumption or erosion of the carrying capacity by the population could create a negative feedback, which will limit growth. When resources over period of our simulation are abundant, positive growth dominates and the system grows exponentially. As the economy grows, resources are more depleted. In the future the negative loop gradually gain in strength, and at some point, population falls.

In the second scenario population starts to grow again, after years. It is due to increasing consumption and increasing green energy generation.

5. Conclusion

The results of simulation support view that growth may lead to the exhaustion of natural resources and deterioration in the environment. A depletion of non-renewable resources leads to higher prices of those resources, may decrease output and lead consequently to a decrease in population. We can circumvent such depletion of non-renewable resources and stay within a limit of resource availability by limitation the inefficient use of fossil-fuels, and common application of renewable sources of energy. Moreover, comprehensive revision of existing policies in rational consumption is necessary. Therefore, emphasis on sufficiency, equity and quality of life rather than quantity of output is necessary.

Particular interest should be put on the influence of technological progress on effective consumption of non-renewable resources and productivity of production factors. It is essential to implement renewable sources of energy, like biomass, together with less capital-consuming technology. The renewable energy will protect us from global warming. To accomplish this goal, we have to follow Brown (2001), who shows how to change the economy. In that new economy, wind farms replace coal mines, hydrogen-powered fuel cells replace internal combustion engines and cities are designed for people, not for cars.

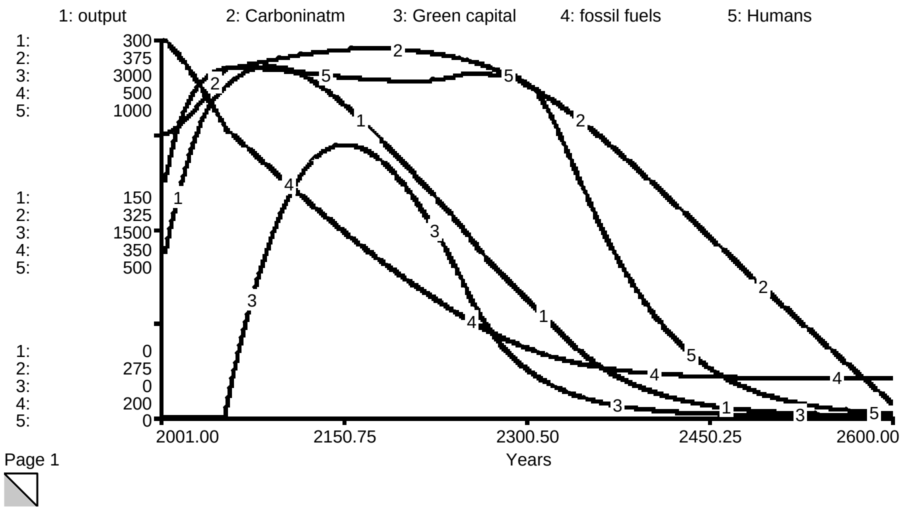

Figure 2a. Results of our simulation-pessimistic scenario, at least 50% of the energy is coming from fossil fuels: production (output). carbon in atmosphere, green capital, fossil fuels, population (humans).

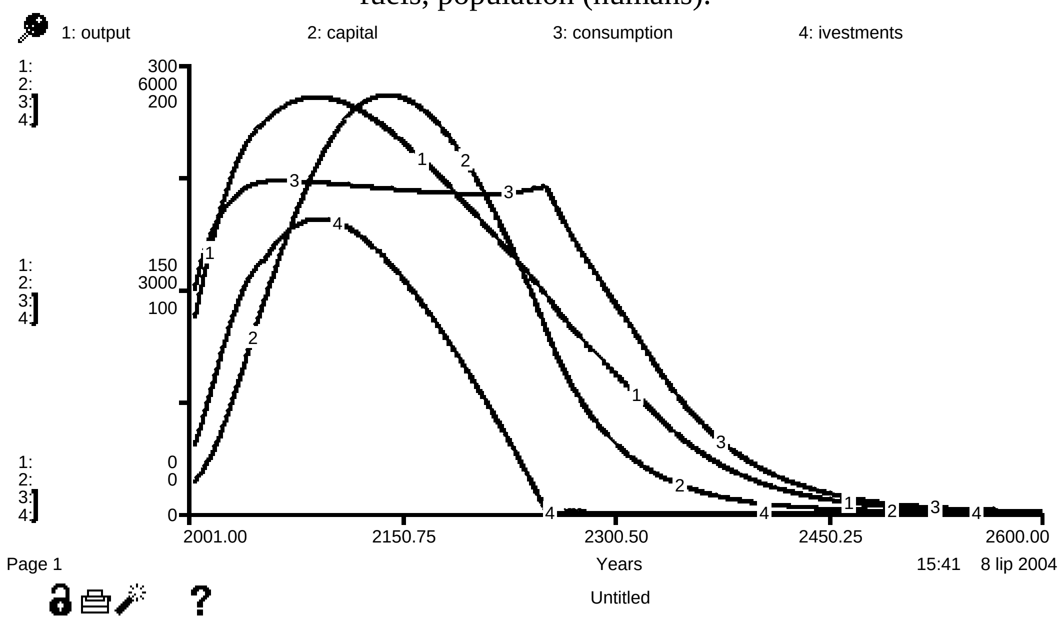

Figure 2b. Pessimistic scenario: output, capital, consumption and investments.

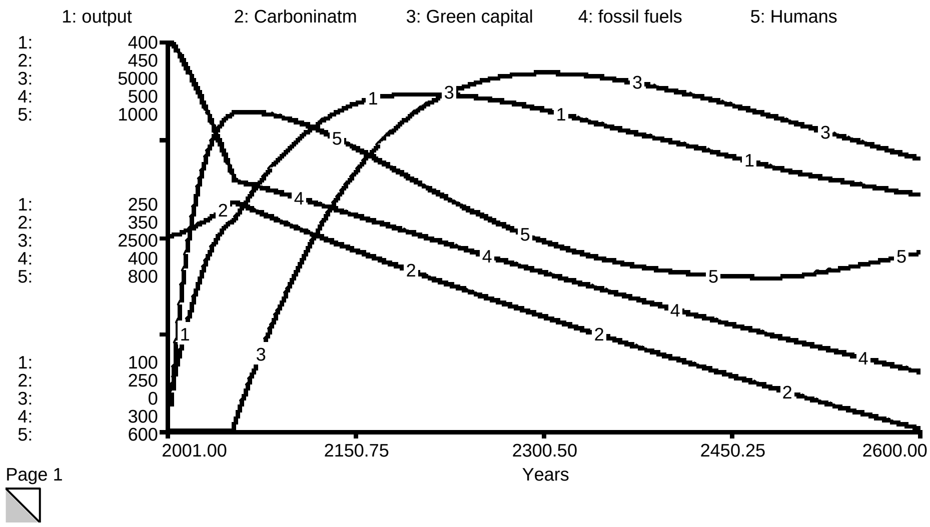

Figure 3a. The results of our simulation- optimistic scenario: at least 10% of the energy is coming from fossil fuels: production (output), carbon in atmosphere, green capital, fossil fuels, humans

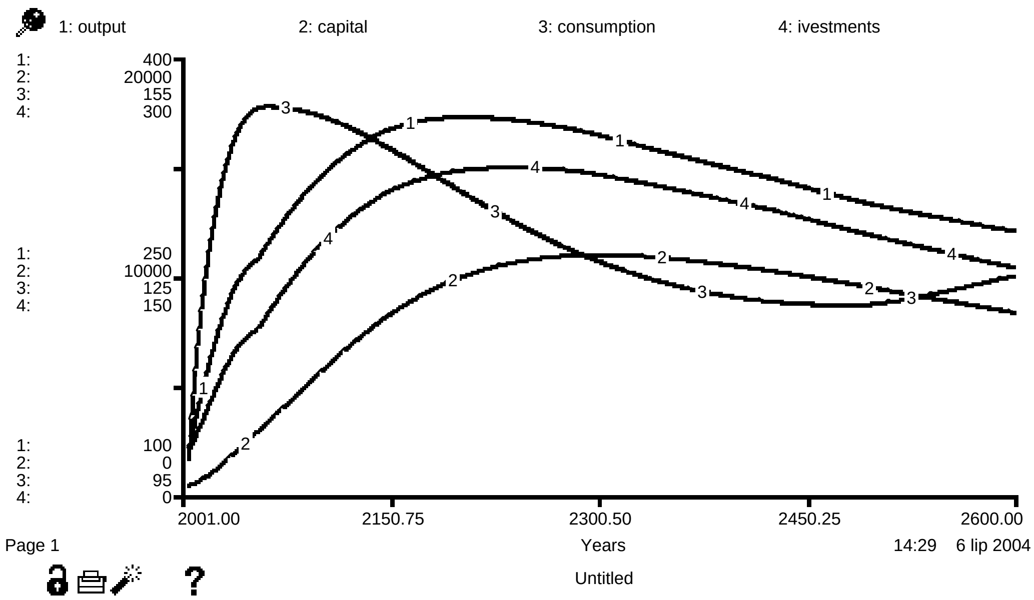

Figure 3b. The results of our simulation-optimistic scenario, at least 10% of the energy is coming from fossil fuels: output, capital, consumption and investments.

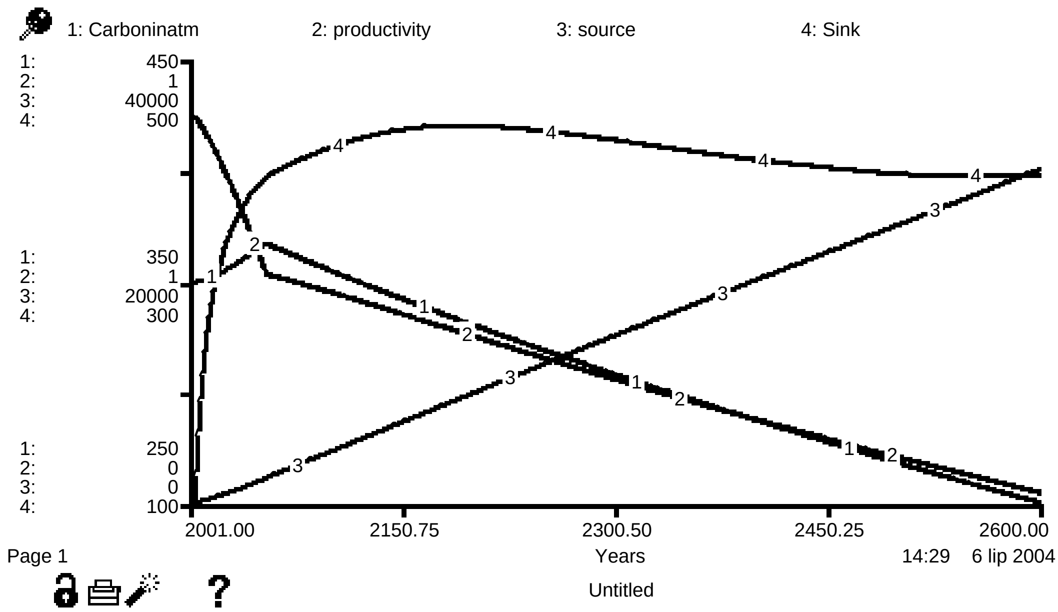

Figure 3b and 3c. The results of our simulation-optimistic scenario: carbon in atmosphere, productivity, source, sink of pollutants (dumping and garbage.

References

ACHARYA R., SAEED K., An Attempt to operationalize recommendations of 'Limits to growth' study to sustain the future of mankind, System Dynamics Review, Vol. 12, no 4., 281-301, **1996**.

ARROW, K. et al. , Economic growth, carrying capacity and the environment. *Science*, Vol. 268, pp. 520-521, reprinted in *Ecological Economics*, Vol.15, pp. 91-95, **1995.**

BECKERMANN W., A pro-growth perspective, in: Handbook of environmental and resource economics, ed. J. C. J.M van den Bergh, Edward Elgar, Cheltenham UK, Northampton MA, USA, **1999**

BROWN G. M. and B. FIELD, The adequacy of measures for signaling the scarcity of natural resources, in U.K Smith (ed.), Scarcity and Growth Reconsidered, Baltimore, MD: Johns Hopkins University Press, pp. 218-248, **1979**

BROWN L., Eco-Economy, Norton&Company, New York, **2001**

De BRUYN S. M. and R.J. HEINTZ, The environmental Kuznets Curve hypothesis, in: Handbook of environmental and resource economics, ed. J. C. J.M van den Bergh, Edward Elgar, Cheltenham UK, Northampton MA, USA, **1999**

DALY, E.H,. Beyond growth, Beacon Press, Boston, **1996**

DEADMAN D., R.K. TURNER, Resource conservation sustainability and technical change, in RK Turner (ed.), Sustainable Environmental Management: Principles and Practise, London : Belhaven Press, pp. 67-100, **1988**

DINDA, S., COONDOO, D. and M. PAL, Air quality and economic growth: an empirical study, *Ecological Economics*, Vol. 34, pp. 409-423, **2000**

GROSSMAN, G. M., KREUGER, A., Economic Growth and the Environment, *Quarterly Journal of Economics*, Vol. 110, No. 2, pp. 353-377, **1995.**

HAYAMI, Y., *Development economics from the poverty to the wealth of nations*, Clarendon Press, Oxford, England, **1997.**

HELM, D., Objectives, Instruments and Institutions in Environmental Policy, Oxford: Oxford University Press, **2000.**

LOVEJOY, D., Limits to growth*?, Science and Society 60 (3), 266-278,* **1996**.

MEADOWS, H. D., et al., *The Limits to Growth. A report for the Club of Rome. Project on the predicament of mankind*, Universe Books, New York. **1972.**

MIKESELL R.F., The limits to growth a reappraisal, *Resources Policy* 21 (2), 127-131. **1995.**

OPHARDT C., Human society and environmental impacts global collapse or sustainable future ? (http://www.elmhurst.edu/~chm/onlcourse/chm110/labs/limits.html), **1997.**

SOLOW, R., *Growth theory. An exposition*, Oxford University Press, Oxford. **2000**

STIGLITZ, J.E, A neoclassical analysis of the economics of natural resources. In: Smith, V.K. (Ed.), Scarcity and growth reconsidered. Resources for the future, Baltimore, pp. 36-66, **1979.**

WOODWELL J.C, *A simulation model to illustrate feedbacks among resource consumption, production and factors of production in ecological-economic systems, Ecological Modelling, 112*, 227-247, **1998.**

YAMUGUCHI, K. *A step-by step system dynamics modeling of sustainability*. in: Proc. of International Conference of the System Dynamics Society, Atlanta, US. **2001.**

YAMAGUCHI, K, On A System Dynamics Modeling of the Eco-Economy, International Symposium "Scientific Heritage of N.D. Kondratieff in the Context of Development of the Russian and the World Socio-Economic Thought", the Institute of Economics, Russian Academy of Sciences, **2002.**

7/16/2004 12:13 PM