Optimisation of consumption with emission[1]

Pawel Bartoszczuk
System Research Institute of the Polish Academy of Science
Newelska 6, Warsaw, Poland
Tel. 48 228373578 ext. 477
Email: bartosz@ibspan.waw.pl

Abstract

Our objective is to conduct simulations with economic –environmental model. 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, consumption, emission, and damage. This paper yields insight into maximization of welfare. Next, we present the simulation runs of the model, conducted with the help of existing system dynamics modeling tools.

Keywords: economic model, environmental systems, optimisation, simulation

1. Introduction

This paper examines the possible impact of economic development and maximization of welfare on environmental quality. 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 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.

---

[1] This paper was presented at System Dynamics Congress in Boston in July 2005.

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 CO_2 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.

3. The analysis of main relations

First, we consider macroeconomic relations with capital, income, consumption, and savings (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 (equation 1). Subtracting consumption from income yield investments. Saving can be changed into investments goods like raw materials, thereby increasing capital stock.
Our goal is to maximize consumption per labour force (equation 2)

$$\max \sum_{t=2001}^{t=2020} c_{pt} \frac{1}{(1+r)^t} \tag{1}$$

where: c_{pt} is consumption per labor force in time t (C_t/L_t), t-time, r-discount rate.
Labor force is given by equation 2, where. g is increase rate of labor force.

$$L_{t+1} = L_t\ (1+g) \tag{2}$$

We assume the stock of capital is increased by new investments and decreased by depreciation. The stock of capital is given by equation (3):

$$K_{t+1} = K_t\ (1-\delta) + I_t \tag{3}$$

where: δ is depreciation rate, K_{t+1} is capital in time $t+1$, K_t is capital in time t.
Production is given by Cobb-Douglas formula with technological progress (equation 4).

$$Y_t = e^{\gamma t}\ K_t^{\alpha} L_t^{1-\alpha} \tag{4}$$

where γ-is coefficient of technological progress, K_t - is capital in time t, L_t- is labour force.
From the data from Polish economy (1990 prices) we calculate the coefficients of Cobb-Douglas function: $\alpha = 0{,}2830$ (1,4842), and coefficient of technological progress: $\gamma = 0{,}044$ (5,7558).

Next, let us assume that production activities generate as by-product industrial emissions, represented for example 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 fossil fuels that causes an emission of carbon dioxide and eventually environmental damage: global warming. Emissions of pollutants are proportional to the output and decreased by emission abatement (equation 5). Emission abatement *(ER_t)* is determined by optimization.

$$E_t = 0{,}5 * Y_t - ER_t \tag{5}$$

Emission of pollution leads to environmental damages and we assume that those damages are linearly dependent on the emission (see equation 6)

$$ED_t = 0{,}1 * E_t \tag{6}$$

In Poland environmental damages equals 10% of total output.
The output is either consumed *(C_t)*, invested in the new capital *(I_t)* or spend for emission reduction *(ER_t)*. Environmental damage *(ED_t)* decrease the output, which can be used for consumption (equation 7)

$$Y_t = C_t + I_t + ER_t + ED_t \tag{7}$$

where ER_t-is emission reduction, ED_t-is environmental damage.
Next, consumption per worker is given by (equation 8):

$$c_t = \frac{C_t}{L_t} \tag{8}$$

Number of working force is calculated by optimization. The main relations described above are presented on the Figure 1.

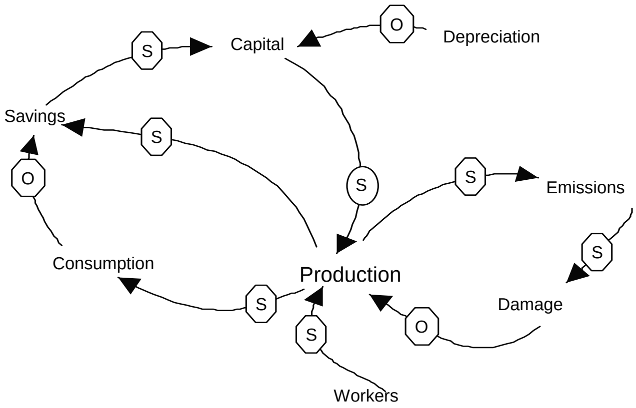

Figure 1.Reinforcing loop between capital, income and consumption, and balancing loop between emission, damage and output. *S*- change in the same direction and *O*- change in the opposite direction.

4. The results of simulation.

We distinguish two scenarios in our simulation: (1) without emission constraint, and (2) with emission constraint.

The results of first simulation show that in the coming decades, we can expect increase in capital, industrial production and in labor force. After 30 years of our simulation, the labor is increasing with exogenously given growth rate from the value 17 million people in 2001 to 23 millions in 2020, i.e. for 27% (figure 2). At the outset production increases for 18%. In the first scenario emission of pollutants are increasing from 30,3 thousands in initial year to the level 35,8 thousands in 2020 year (i.e. for about 17%). The cost of emission reduction is zero since abatement is not applied here. As a result, production is completely allocated to investments in capital and consumption. From the other side, production is decreased by higher environmental degradation. Environmental damages increase from initial value 3,0 to 3,6 thousands in the last period of our simulation (figure 3). Total consumption increases from 50000 in 2001 to the level 61000 in year 2020. Investments equals depreciation-about 6700, due to condition that depreciated capital must be replaced by new one. The consumption per worker coefficient decreases from the level of 3,07 w 2001 year to 2,93 in 2020, as labor force increases.

In the second scenario emission of pollutants is increasing from 30,2 thousands in 2001 to 33,0 thousands in 2011 and is fixed on that level as emission constraint is introduced to the model (figure 4). Damages, which are proportional to the emission, increase from the level 3,0 thousands to the level 3,3 thousands in 2011, and are fixed later. Emission constraint causes increase of emission reduction cost. Emission reduction equals zero until 2011 year, when it starts growing from 188 to 2822 at the end of our simulation. As a result, the cost of emission reduction increase from 0 in 2011 to the level 5645 in 2020 (figure 5).

In the second scenario consumption increases from 50000 in 2001 o to 55930 in 2011 and stays on that level until the end of simulation: 2020. Investments equals depreciation -around 6700, due to constraint in our model. Production increases from the level 60461 in 2001, to 71645 (figure 4). Labor force increases from 16 millions in 2001 to 22 millions in 2020, similar to the first scenario (figure 4). The output increase rate is lower than in first scenario, due to higher costs of abating pollution. After 30 years of our simulation environmental damages increase for about 10% (figure 5).

Coefficient of consumption per worker decreases by 18%, from the level 3,07 in 2001 to 2,52 in 2020, as labor force exogenously increases (figure 6). The coefficient of consumption to production increases initially from the value of 0,84 to 0,9 in 2011, and then decreases to the value of 0,75 (figure 7).

5. Conclusion

The results of simulation support view that economic growth may lead to deterioration in the environment. Economic growth leads to increase of pollution, and higher emissions may decrease output and lead consequently to a decrease in consumption. Second scenario requires that some capital have to be sacrificed to emission abatement. Imposing the emission limits in that scenario requires the economic agent to switch from the commonly acquired goal to more environmentally friendly.

Therefore, emphasis on sufficiency, equity and quality of life rather than quantity of output is necessary. Moreover, comprehensive revision of existing policies in rational consumption is necessary

To accomplish this goal, we have to follow Brown (2001), who shows how to change the economy and reduce emissions. In that new economy, wind farms replace coal mines, and hydrogen-powered fuel cells replace internal combustion engines

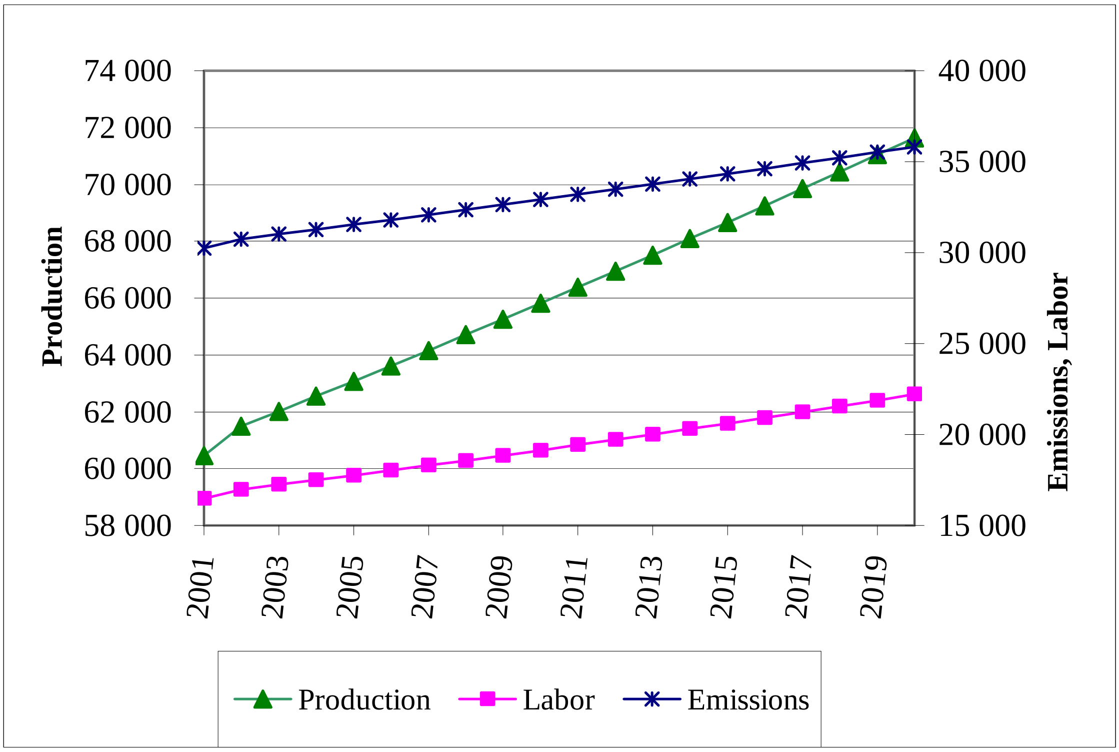

Figure 2 Results of simulation in the first scenario (no emission constraint). Emissions, labor force and output.

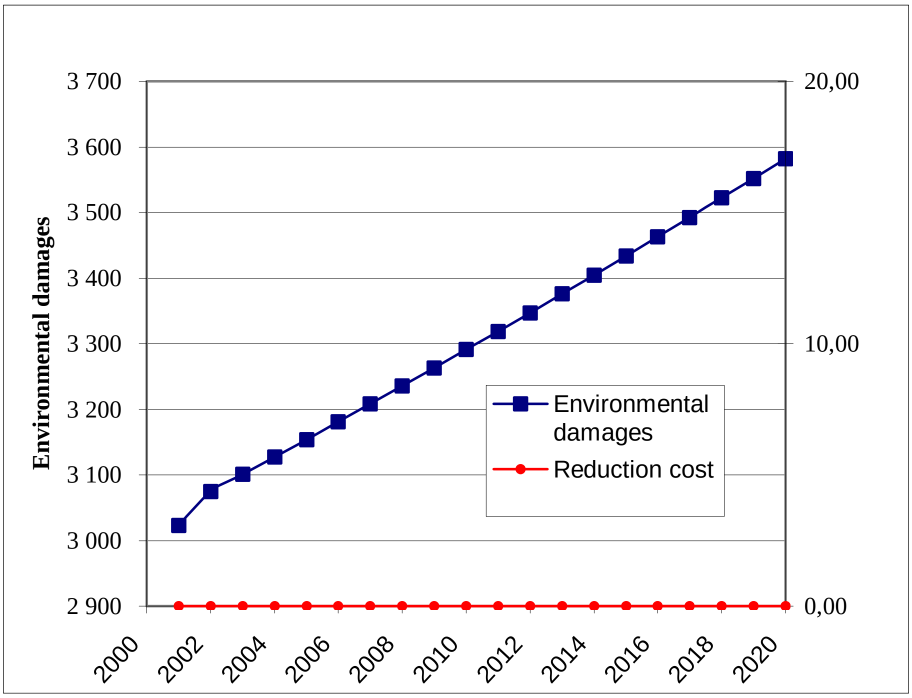

Figure 3. Simulation results-first scenario. Environmental damages and reduction cost.

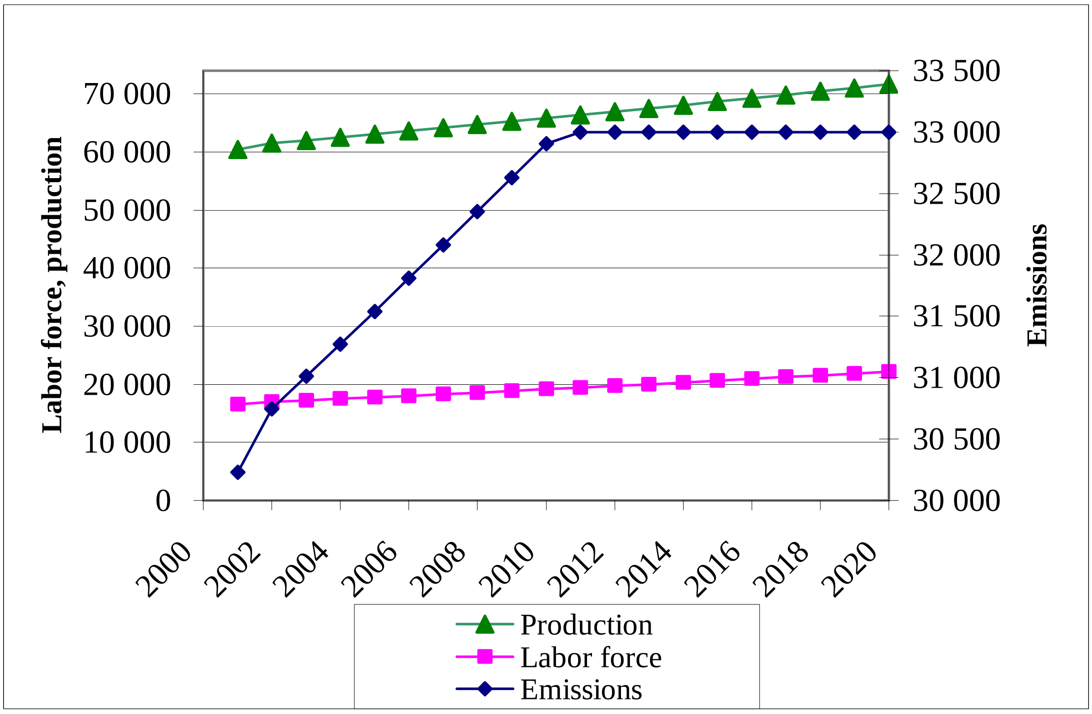

Figure 4. Simulation results-second scenario. Emissions, production and labor force.

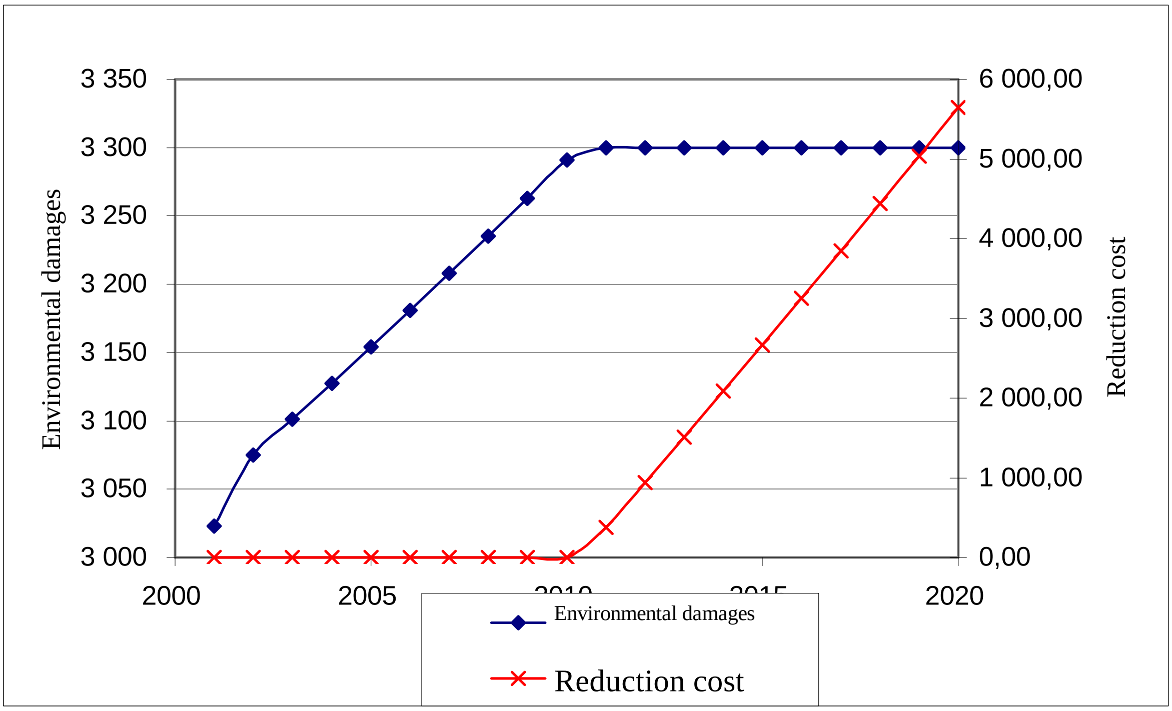

Figure 5. Simulation results-second scenario. Environmental damages and reduction cost.

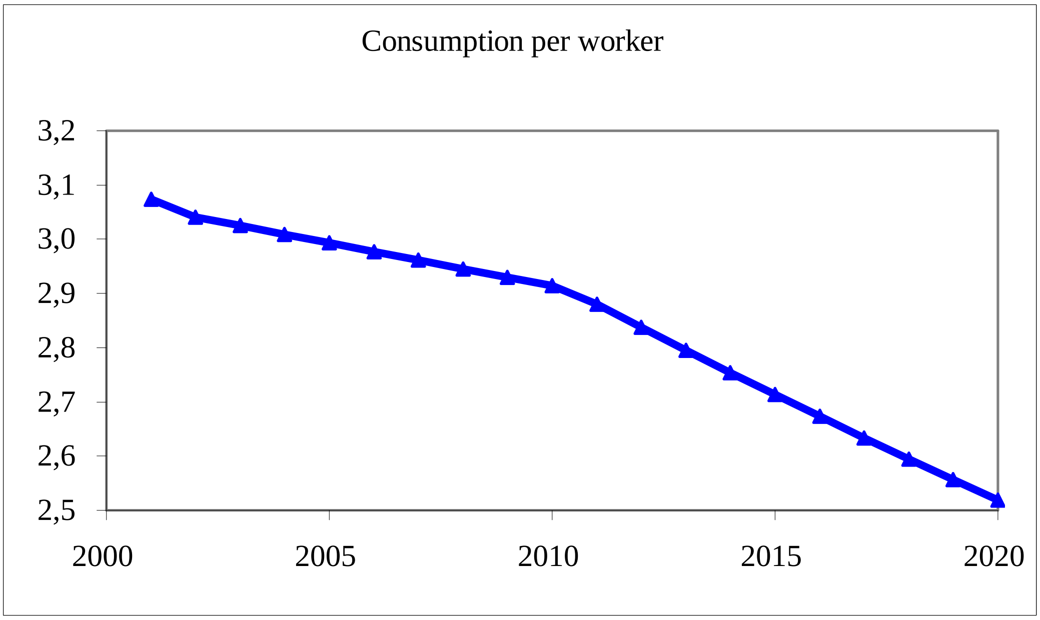

Figure 6. Simulation results-second scenario. Consumption per worker.

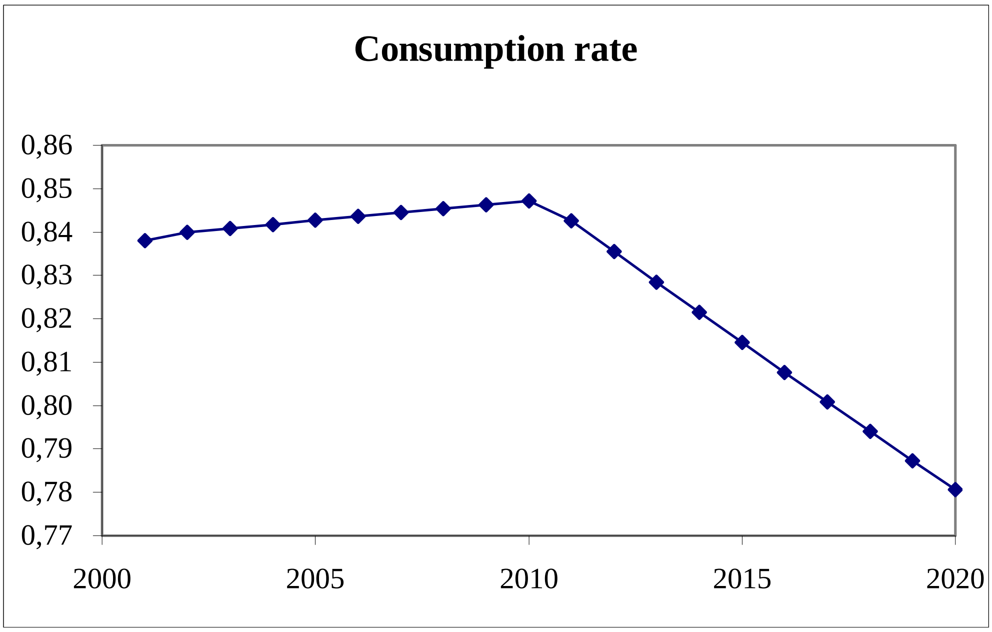

Figure 7. Simulation results-second scenario. Rate of consumption to production

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.**