POLISH ACADEMY OF SCIENCES
Systems Research Institute

DEVELOPMENT OF METHODS AND TECHNOLOGIES OF INFORMATICS FOR PROCESS MODELING AND MANAGEMENT

Editors:

Jan Studzinski
Olgierd Hryniewicz

DEVELOPMENT OF METHODS AND TECHNOLOGIES OF INFORMATICS FOR PROCESS MODELING AND MANAGEMENT

Polish Academy of Sciences • Systems Research Institute

Series: SYSTEMS RESEARCH
Vol. 50

Series Editor:
Prof. Jakub Gutenbaum

Warsaw 2006

DEVELOPMENT OF METHODS AND TECHNOLOGIES OF INFORMATICS FOR PROCESS MODELING AND MANAGEMENT

Editors:

Jan Studzinski
Olgierd Hryniewicz

This publication was supported by Polish Ministry of Science and Higher Education

This book consists of papers describing applications of informatics in process modeling and management and in environmental engineering. Problems presented in the papers concern development of methods supporting process management, development of calculation methods for process modeling and development of technologies of informatics for solving some problems of environmental engineering. In several papers results of the research projects supported by the Polish Ministry of Science and Higher Education are presented.

Paper Reviewers:
Prof. Olgierd Hryniewicz
Dr. Jan Studzinski

Text Editor: Anna Gostynska

Systems Research Institute of Polish Academy of Science
Newelska 6, PL 01-447 Warsaw

Section of Scientific Information and Publications
e-mail: biblioteka@ibspan.waw.pl

ISBN 83-894-7507-3
9788389475077
ISSN 0208-8029

CHAPTER 3

Tools of informatics in environmental engineering

CAN GREENHOUSE GAS EMISSION PERMITS SCHEME INDUCE TECHNOLOGICAL CHANGE?

Jan GADOMSKI, Zbigniew NAHORSKI
Systems Research Instytut, Polish Academy of Sciences
<Jan.Gadomski; Zbigniew.Nahorski@ibspan.waw.pl>

Abstract: *In the paper we analyze influence of implementation of the greenhouse gas emission permit scheme on change of technology. Two technologies are considered. One is emitting more but is cheaper. Another is more expensive but emits less. Results of numerical simulations using a macroeconomic model and optimal choice are presented. Dependence of solutions on permit price and length of the decision horizon is discussed.*

Keywords: Greenhouse gases emission abatement, emission permits trade technological change, macroeconomic modeling.

1. Introduction

A proposed remedy for undesirable climate change, believed to be related to excessive emission of greenhouse gases, is inclusion of cost of ecological damages abatement in the costs of production. This initiative was undertaken by a group of countries in the Kyoto Protocol where limits of emissions were agreed upon for each signing party. To mitigate the expenditures the Protocol provides for so called flexible mechanisms, which include among others trading of greenhouse gas emission permits. Kyoto Protocol regulation introduces costs of global public goods, so far considered to be free. An expected result of this mechanism should be the change of production technologies, and in fact consumption, to those more friendly for the environment.

In the economic literature the technology change is usually modeled as an exogenous variable or as a result of an exogenous model of research and development (Roberts, 1964; Nahorski & Ravn, 2000) as well as of related phenomena, like knowledge dissemination and spillover (Allen, 1977; Jaffe et al., 2002) or learning (Riahi et al., 2004). For example, such exogenous solutions were used in most models for analysis impacts of greenhouse gases emissions on climate change (Manne & Richels, 1992; Nordhaus, 1994; Nordhaus & Boyer, 1999; Pizer, 1999; Keller et al., 2004). The problem of tax-induced technology change was considered only recently (Goulder & Schneider, 1999; Hart, 2004; Riahi et al., 2004).

However, another important question in the case of change of technology is, if and on what conditions the regulations admitted in the Kyoto Protocol will bring expected results. This paper tries to answer this question.

The subject of our consideration is the economy of a small country adjusting itself to conditions caused by introducing emission limits. By a small country we mean here not its territory but influence of the country economy, and its adjustment, on the price of emission permits on the international market.

Adjustment of economy to emission permits scheme is analyzed using simple, one-sector optimizing model, proposed by Gadomski (2003) and applied in Gadomski & Nahorski (2005). The only criterion in the economy is maximization of production. All firms have the same decision horizon and choose from two possible technologies. One of them, used earlier, is less capital intensive but has higher emission. Another one is emitting less but is more capital intensive.

An important assumption is lack of technological progress, which is equivalent to assuming lack of growth. It allows for analyzing a decision problem which converges to equilibrium. Another assumption is connected with emission of greenhouse gases. It is assumed that emission depends on production but does not depend on its structure. This is a strong assumption, as it means that production of investment or consumption goods of the same value causes equal emission of greenhouse gases.

The assumptions taken are quite simplifying ones. They appear, however, not to undermine usefulness of the model. If a simple model with well understandable construction does not give an expected solution, than suspicions may arise that in a much more complicated economic reality a chance of achieving this solution will be small.

2. Formulation of a model

Output Q_t produced in the year t is determined by the following relationship:

$$Q_t = Q1_t + Q2_t, \tag{1}$$

where $Q1_t$ denotes output produced in the year t with capital representing the first technology and $Q2_t$ denotes output produced in the year t with capital representing the second technology.

Outputs $Q1_t$ and $Q2_t$ are determined by the following equations:

$$Q1_t = PK1 * K1_t \tag{2}$$

$$Q2_t = PK2 * K2_t \tag{3}$$

where $PK1$ denotes the productivity of capital representing the first technology, while $PK2$ denotes the productivity of capital representing the second technology,

$K1_t$ stands for the capital representing the first technology at the beginning of the year t, and $K2_t$ is the capital using the first technology at the beginning of the year t.

Changes in the capitals representing both technologies are described, respectively, by the following equations:

$$K1_{t+1} = K1_t + I1_t - \delta K1_t = (1 - \delta)\, K1_t + I1_t, \tag{4}$$

$$K2_{t+1} = K2_t + I2_t - \delta K2_t = (1 - \delta)\, K2_t + I1_t, \tag{5}$$

where $I1_t$ and $I2_t$ denote investment in the capitals representing the first and the second technology, respectively, and coefficient δ stands fort the depreciation rate. Expressions $\delta K1_t$ and $\delta K2_t$ denote depreciation of both categories of capitals, respectively. As it is easy to notice in equations (4) and (5), the capitals are being increased by the investments and decreased by capital depreciation, which is proportional to the amount of capital at the beginning of the year. This means that no accelerated decommissioning of capital is assumed in this model.

Output causes emission E_t, which is a function of the unit emission coefficients $\mu 1$ and $\mu 2$, associated respectively with the first and second technologies and outputs $Q1_t$ and $Q2_t$:

$$E_t = \mu 1\, Q1_t + \mu 2\, Q2_t \tag{6}$$

Each country is being allocated with the prescribed emission limit. It is assumed that the international regulatory body sets the initial emission limit N_{t_0} for the year t_0 and the percentage emission reduction φ with regard to that initial value. The evolution of the emission limit is determined by the following relationship:

$$N_t = N_{t_0} \{1 - \varphi (1 - e^{-r(t-t_0)})\}, \tag{7}$$

where r denotes the yearly rate of decrease of the emission limit. It is easy to notice that N_t converges to N_{t_0} $(1 - \varphi)$.

Benefit/cost from sale/purchase of unused limits is presented by the following expression:

$$P_t (N_t - E_t)$$

where Pt stands for the price of the emission permit in the year t. Whenever this expression is positive, then it increases the foreign assets F_t. Otherwise those assets are being decreased. Thus,

$$F_{t+1} = F_t (1 - 1/T_d) + (X_t - M_t) + P_t (N_t - E_t), \tag{8}$$

where T_d denotes the average term of loans, F_t stands for the amount of the foreign assets at the beginning of the year t, and X_t and M_t are respectively export and import in the year t. Whenever the foreign assets are positive, they are interpreted as assets generating interest i_tF_t (variable i_t represents the interest rate in year t); while negative ones are interpreted as a debt with due interest i_tF_t. Apart from interest, the foreign assets are also serviced with the payment of the principal F_t/T_d. That servicing increases/decreases the disposable product Y_t in the year t:

$$Y_t = Q_t + (M_t - X_t) + F_t\,(1/\,T_d + i_t\,). \tag{9}$$

Consumption C_t in the year t is determined as the residual:

$$C_t = Y_t - I_t\,. \tag{10}$$

Consmption is also determined by the constraints mentioned in the sequel.

3. Optimization problem

The aim of the decisions made in years t, $t = t_0+1,..,t_0+T$, is maximization of the discounted sum of disposable products:

$$\max\ \{S = \sum_{t\ =t_0+1}^{t_0+T} Y_t(1+i_t)^{-(t-t_0)}\ \} \tag{11}$$

with respect to:

- Investments $I1_t$ in the capital using the first technology in the years t, $t = t_0+1,...,t_0+T$
- Investments $I2_t$ in the capital using the second technology in the years t, $t = t_0+1,...,t_0+T$
- Imports M_t in the years t, $t = t_0+1,...,t_0+T$
- Exports X_t in the years t, $t = t_0+1,...,t_0+T$.

Equations from (1) to (10) are the equality constraints.

Inequality constraints

Minimum consumption (a social stability requirement):

$$C_t \geq c_{min}\, Y_t, \tag{12}$$

where c_{min} is the minimum admissible consumption rate.

Minimum investment (simple reproduction):

$$I_t \geq \delta K_{t-1} \tag{13}$$

Balance of payments stability:

$$|F_t\,| \leq DR_{max}\, Y_t, \tag{14}$$

where DR_{max} is the maximum value of the debt-to-GDP ratio.

Order conditions

End-point constraint 1:

$$F_t = 0, \text{ for } t \geq t_0 + k;\ 1 < k \leq T \tag{15}$$

End-point constraint 2:

$$X_t - M_t = 0, \text{ for } t \geq t_0 + k;\ 1 < k \leq T. \tag{16}$$

The last two constraints are aimed at achieving equilibrium of the balance of payments in the last period. Parameter *k* stands for the assumed number of years, which are necessary for the operation of the technological change.

For the simulation experiments the model was calibrated on the Polish data. The starting year is 2001 and the basic parameters were estimated on the basis of the data from 1995-2000.

Capital in the technology 1, $K1_{2001} = 1732\ 10^9$ PLN.

Capital in the technology 2, $K2_{2001} = 0$ PLN.

Productivity of capital in the technology 1, $PK1 = 1.007$.

Productivity of capital in the technology 2, $PK2 = 0.80$.

Unit emission in the technology 1, $\mu 1 = 1$.

Unit emission in the technology 2, $\mu 2 = 0.75$.

The initial emission, $E_{2001} = 1.456 \cdot 10^8$ tC.

The initial emission norm, $N_{2001} = 3.734\ 10^8$ tC, φ=10%,

The foreign assets, $F_{2001} = 0$.

Two scenarios have been analyzed based on different prices of the emission permits: the low-price scenario named Scenario LP and the high price scenario named Scenario HP. The low price is assumed to be equal to 60 PLN/tC while the high price equals 600 PLN/tC. In both scenarios the interest rate and discount rate are equal to 3%. Moreover in both scenarios parameter *k* is equal to 26 years.

In the research described here, the time horizon of the decision making is assumed to be practically infinite. This constitutes the fundamental difference from the earlier results, see Gadomski & Nahorski (2005), where the time horizon was equal to 20 years. The model converged well.

4. Results

A common element of results obtained with the use of both scenarios is immediate choice of the second, less emitting technology in all years. This result confirms the efficacy of the trade in the emission permits as a tool for curbing of the negative impact of production on the environment.

Evolution of output in both scenarios is depicted in Figure1. Development of production in Scenario LP can be divided into two sub-periods. In the first sub-period the output reaches climax in 2012, then there occurs the decrease. In the Scenario HP the output increases till 2006. In the next period, similarly as in the Scenario LP, the production stabilizes on the long-term steady state level.

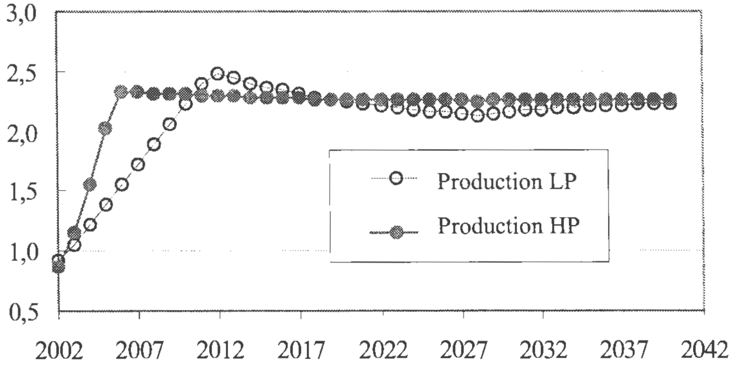

Figure 1. Evolution of production, in 10^{12} PLN, in Scenarios LP and HP.

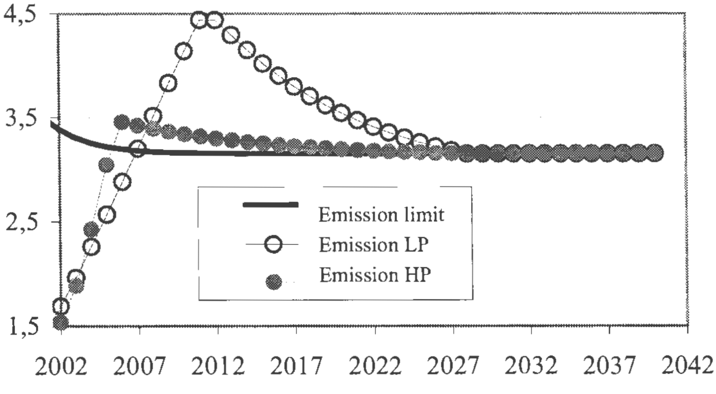

Figure 2. Emissions in Scenarios LP and HP.

Evolution of emissions related to the production is depicted in Figure 2. The emissions only partially follow those of production, as presented in Figure 1, as the average production emissivity decreases as a result of stopping investments in more emitting capital of the old technology and investing only in the less emitting new one. This way the first technology assets gradually deplete. In both scenarios emissions overshoot the limits and then stabilize in the equilibrium. A bigger overshoot happened for the Scenario LP.

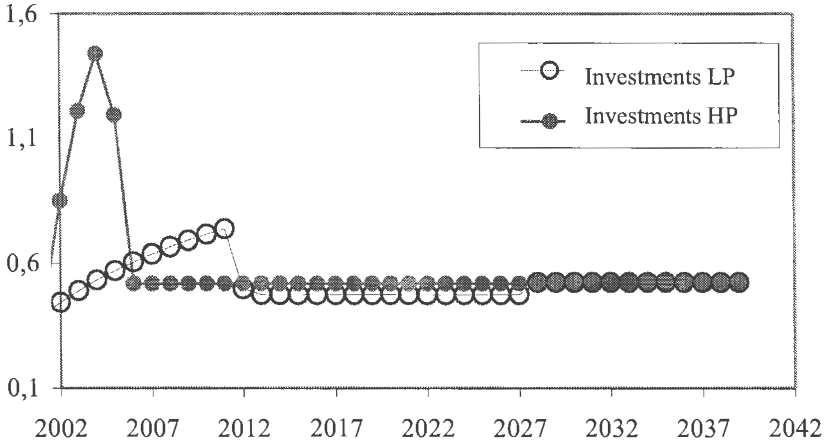

Figure 3. Investments in Scenarios LP and HP, in 10^{12} PLN.

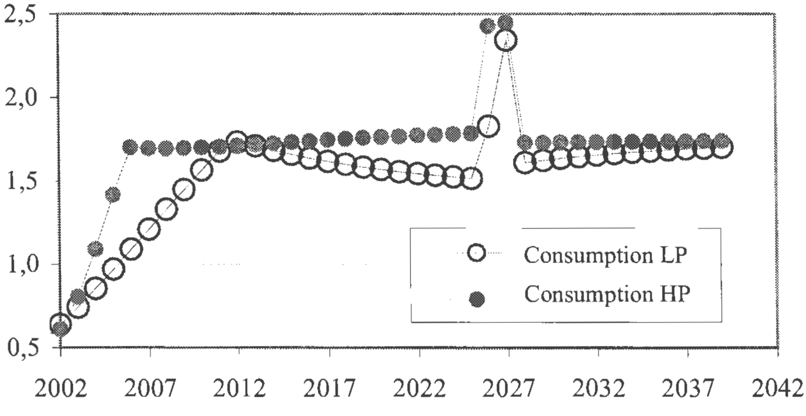

Figure 4. Change of consumptions in Scenarios LP and HP, in 10^{12} PLN.

The investments obtained from computations for both scenarios are presented in Figure 3. High values of investments in the Scenario HP are concentrated in four initial years of simulation. In the rest of the period they take the values of simple reproduction, i.e. the minimal values of the constraint (13). The cumulative investment for the Scenario HP in the full simulation period is bigger than the cumulative investment in Scenario LP in the same period. In the Scenario LP the investments take the minimal values from 2011.

Consumptions in both analyzed variants are depicted in Figure 4. The cumulated consumption is mach bigger in the Scenario HP, because of bigger prices of emission permits for this case. It makes possible not only to spend more on consumptions but also, as mentioned earlier, on investments, which results in a quicker achievement of equilibrium conditions. Visible jump in consumption in 2026 and 2027 is connected with the sale of the foreign assets in these years, see Figure 5.

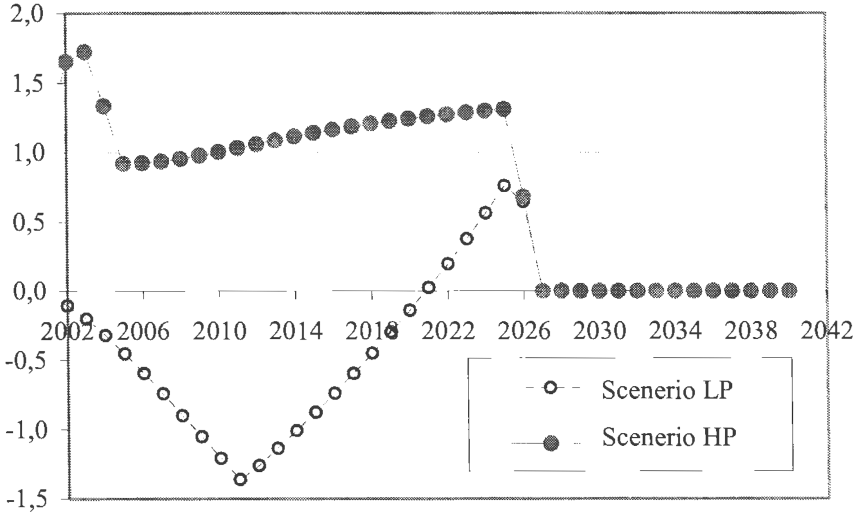

Figure 5. Net foreign assets in Scenarios LP and HP, in 10^{12} PLN.

From evolution of foreign assets for the Scenario LP presented in Figure5 it results that in the early period the foreign debt raises in order to gain means for investments. The debt is repaid in 2021. In the Scenario HP the change of technology is fully financed by selling the spare emission permits.

5. Conclusions

The results obtained from simulation and optimization support the idea of introduction of emission permits trade as an efficient tool to limit emissions of greenhouse gases. In both analyzed scenarios the ecologically better technology was chosen. As possible to predict, higher prices of permits let the countries with beneficial starting conditions to change quicker the production technology.

The results presented differ qualitatively from those obtained in the earlier simulations with a shorter decision horizon equal to 20 years (Gadomski & Nahorski, 2005). The difference is connected with change of technology in the Scenario LP, with smaller permit price. For this case no change of technology occurred previously. It shows importance of prices and decision horizon for optimal decisions. Lower prices, and therefore lower incentives, and short (myopic) decision horizon are factors fostering undesirable effects – no change of technology.

References

Allen T.J. (1977) *Managing the Flow of Technology Transfer and the Dissemination of Technological Information within R&D Organizations.* MIT Press. Cambridge, MA.

Ang B.W. (2004) Growth curves for long-term global CO2 emission reduction analysis. *Energy Policy*, 32: 1569-1572.

Gadomski J. (2003) Production and the gas emission. Proposed modeling solutions (in Polish: Produkcja a emisja gazów. Propozycja rozwiązań modelowych), SRI PAS Working Paper.

Gadomski J., Nahorski Z. (2005) Impact of charging for pollutant emission on technological change. In: J. Studzinski, L. Drelichowski, O. Hryniewicz (Eds.): *Applications of Informatics in Environment, Engineering and Medicine.* SRI PAS, Warszawa, 71-82.

Goulder L.H., Schneider S.H. (1999) Induced technological change and the attractiveness of CO_2 abatement policies. *Resource and Energy Economics*, 21: 211-253.

Hart (2004) Growth, environment and innovation – a model with production vintages and environmentally oriented research. *Journal of Environmental economics and Management*, 48: 1078-1098.

Jaffe A.B., Newell R.G., Stavins R. (2002) Environmental policy and technological change. *Environmental Resource Economics*, 22: 41-69.

Keller K., Boler B.M., Bradford D.F. (2004) Uncertain climate thresholds and optima economic growth. *Journal of Environmental Economics and Management*, 48: 723-742.

Manne A.S., Richels R.G. (1992) *Buying Greenhouse Insurance.* MIT Press. Cambridge, MA.

Nahorski Z., Ravn H.F. (2000) A review of mathematical models in economic environmental problems. *Annals of Operations Research*, 97: 165-201.

Nordhaus W.D. (1994) *Managing the Global Commons: The Economics of Climate Change.* MIT Press. Cambridge, MA.

Nordhaus, W., Boyer J. (1999) Roll the DICE Again: Warming the World: Economics Models of Global Warming (Internet Edition), Yale University.

Pizer W.A. (1999) The optimal choice of climate change policy in the presence of uncertainty. *Resource and Energy Economics*, 21: 255-287.

Riahi K., Rubin E.S., Taylor M.R., Schrattenholzer L., Houndshell D. (2004): Technological learning for carbon capture and sequestration technologies. *Energy Economics*, 26: 539-564.

Report of the Conference of the Parties on Its Third Session, Held at Kyoto From 1 to 11 December 1997. Addendum. (1998) Document FCCC/CP/1997/7/Add.1.

United Nations Framework Convention on Climate Change (FCCC). http://unfccc.int/index.html.

Roberts E.G. (1964) *The Dynamics of Research & Development*. Harper & Row.

Jan Studzinski, Olgierd Hryniewicz (Editors)

DEVELOPMENT OF METHODS AND TECHNOLOGIES OF INFORMATICS FOR PROCESS MODELING AND MANAGEMENT

The purpose of this publication is to popularize application of informatics in process modeling and management and in environmental engineering. The papers published are thematically selected from the works presented during the conference '*Multi-accessible Computer Systems*' organized by the Systems Research Institute and the University of Technology and Agriculture in Bydgoszcz for several years already in Ciechocinek. Problems presented in the papers concern: development of quality and quantity methods supporting the process management, development of quantity methods for process modeling and simulation, development of technologies of informatics for solving problems of environmental engineering. In several papers results of research projects supported by the Polish Ministry of Science and Higher Education are presented.

ISBN 83-894-7507-3
9788389475077
ISSN 0208-8029