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The purpose of this publication is to present the information technology (IT) tools and techniques that have been developed at the Systems Research Institute of Polish Academy of Sciences in Warsaw (IBS PAN) and at the German Institute for Landscape System Analysis in Müncheberg (ZALF) in the area of applications of informatics in environmental engineering and environment protection. The papers published in this book were presented in the form of extended summaries during a special workshop organized by IBS PAN in Szczecin in September 2006 together with the conference BOS'2006 organized jointly by IBS PAN, University of Szczecin, and the Polish Society of Operational and Systems Research. In the papers the problems of mathematical modeling, approximation and visualization of environmental variables are described. Moreover, some questions concerning the environmental economy are also presented.

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CHAPTER 3

Environmental Economy

KYOTO PROTOCOL INDUCED LONG TERM TECHNOLOGICAL CHANGE

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Abstract: *The paper presents an analysis of an impact of implementation of the Kyoto protocol on the technological change in a small economy. Internalization of the environmental costs causes extra charges or benefits related to the trade in the emission permits. One sector optimization model has been developed assuming the optimum behavior of economic agents. The optimum solution consists of the optimal choice between the competing technologies. Two simulation scenarios differing in the level of permit prices, used as the model parameters, were analyzed.*

Keywords: Greenhouse gases, Kyoto Protocol compliance, induced technological change.

1. Introduction

Following the early models for analyzing the greenhouse gas (GHG) emission impacts and climate policy effects, like Global2010 (Manne & Richels, 1992) or DICE (Nordhous, 1994), many their modifications and particular modeling solutions has been proposed. Especially DICE model enjoyed a broader attention and many of its revisions has been proposed (e.g. Nordhous & Boyer, 1999; Pizer, 1999; Keller at al., 2004). The Dice model is a dynamic growth model that relates economic activity and climate change in the global scale. Thus, the model combines both a traditional macroeconomic sector and a climate sector, using simplified equations for some basic variables. It contains a utility function to be maximized and over a dozen side conditions, some being difference equations and other algebraic equations coupling variables through different definition and balance relations. Due to its simplicity, many important parameters are included in the model coefficients and some other as exogenous variables, like, for example, the production technology.

However, in the climate modeling policy technology change is a crucial factor, as it may enable the economic growth combined with GHGs reduction. Classic approach to model the technology change is to consider research nad development (R&D) sector (e.g. Roberts, 1964; Nahorski & Ravn, 2000), as well as more recently modeled related phenomena like knowledge dissemination and spillover (e.g. Allen, 1977; Jaffe at al., 2002) and learning (Riahi at al., 2004). In most considerations these models are endogenous. Only recently the problem of induced R&D has found more attention (Aghion & Howitt, 1998; Goulder & Schneider, 1999; Hart, 2004).

In Goulder & Schneider (1999) the knowledge of abatementin the consecutive period increases as the result of R&D in the previous period. A cost minimizing firm chooses the optimal level of abatement and R&D in each period.

In Hart (2004) the skilled labour is allocated between production vintages and two forms of research, an ordinary one and an environmentally oriented. A planner, a market or a regulator may control switch of labour between the vintages and different types of research.

Quite straightforward approach is presented in Riahi at al. (2004) where over 400 technologies in 11 world regions are chosen to optimize the criterion. Costs of technologies are assumed to decrease over time as experience is gained. For this, a learning by doing model, proposed by Wright (1936) is adopted. In this model the cost of unit production decreases exponentially with the production scale. This idea is applied to model cost of production of spreading technologies.

Our approach is different. We are not interested in detailed modeling of the R&D sector. We neither consider the global scale. The model presented in this paper is aimed at the analysis of the adjustment of a small country economy to the introduction of the rules agreed upon in the Kyoto Protocol. The role of those rules is to internalize costs of greenhouse gas emission abatement. This aim is performed by the introduction of emission norms and emission permits as well as the trade in those permits. Trade provides financial gains for countries emitting below the limit and enables countries with excessive emissions to buy necessary permits. The imposition of the emission limits is a stimulus for emitters to change production technology to the less polluting ones. In this paper the term "adjustment of a small country economy to the introduction of the Kyoto Protocol rules" means change of the technology. In earlier study, Gadomski, Nahorski (2005), a small mid-term macroeconomic model developed for analysis of the technological change has been presented. In this paper research is aimed at the answering question: what is the technological adjustment in the long-term framework.

As opposed to the earlier papers on induced technologies change, like Goulder & Schneider (1999) or Hart (2004), which consider GHG tax as the driving force of technology change, in our paper this role is taken by the tradable permits, in accordance with the Kyoto protocol declaration.

In order to make results of the analysis more communicative it is assumed that producers choose between two technologies, which correspond to two distinct generations of capital: a cheaper (not accounting for the charging for the GHG emissions) one, but less capital intensive, and a more expensive one, more capital intensive, however less polluting. The model in question is an optimizing one. It describes the behavior of an economy provided economic agents have perfect knowledge about the future and that their goal functions are explicit and identical.

2. Model formulation

In this model output Q_t in year t is determined by the following relationship:

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

where $Q1_t$ denotes output produced by the capital belonging to the more polluting capital, and $Q2_t$ output produced by the capital belonging to the less polluting capital.

Output $Q1_t$ is determined by the following equation:

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

where $PK1$ denotes the average productivity of the more polluting capital, and where $K1_t$ denotes amount of the more polluting capital at the beginning of year t.

Similarly, output $Q2_t$ is determined by the following equation:

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

where $PK2$ denotes the average productivity of the less polluting capital, and where $K2_t$ denotes amount of the less polluting capital at the beginning of year t. In this study productivity of both categories of capital are assumed to be different and constant.

Changes in the levels of the capital stocks of the more polluting and the less polluting capital are described respectively by the following equations:

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

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

where $I1_t$ and $I2_t$ denote respectively the investment in the more polluting and the less polluting technology, δ stands for the depreciation rate so that $\delta K1_t$ and $\delta K2_t$ denote depreciated (decommissioned) capital representing corresponding technologies.

Both $I1_t$ and $I2_t$ are decision variables.

Production causes emission E_t, which is the following function of the unit emission coefficients $\mu 1$ and $\mu 2$ associated with each technology and respective outputs $Q1_t$ and $Q2_t$.

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

It is assumed that the emission norm N_t, set for a country in a year t, follows the following expression:

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

where N_{t_0} denotes the emission in the initial year, φ denotes the projected percent decrease of the emission norm with per annum decrement of r percent. N_t converges to $N_{t_0}(1 - \varphi)$.

A benefit / cost of unused / excessive gas emissions is determined by the following expression:

$$P_t (N_t - E_t)$$

where P_t denotes the unit permission price in the year t. When the emission norm is not exceeded, the above expression represents a gain or an extra charge otherwise. This expression affects foreign assets:

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

where F_t denotes the level of foreign assets at the beginning of year t, X_t and M_t are respectively export and import in year t. Both X_t and M_t are decision variables.

Note that the foreign assets can be negative. In that case they are interpreted as debt. Foreign assets / debt generate revenue / cost consisting of the principal F_t / T_d (where T_d denotes the average number of yearly installments) and interest $F_t\, i_t$ (where i_t denotes the interest rate on assets / debt).

Disposable product Y_t in year t is determined by the output, net import and revenues from assets (if positive) or servicing of debt (if negative):

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

Consumption is determined as residual of the disposable product diminished by the investment:

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

3. Optimization problem formulation

The aim of the policy in the period t, $t = t_0+1,..,t_0+T$, is to maximize the discounted sum of disposable income over the assumed period T:

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

over the following variables:

* amount of investment I_t in each period t, $t = t_0+1,...,t_0+T$, consisting of the decisions on the structure of investment: $I_t = I1_t + I2_t$
* import M_t in each period t, $t = t_0+1,...,t_0+T$
* export X_t in each period t, $t = t_0+1,...,t_0+T$.

Equations from (1) to (10) constitute equality constraints. There are also inequality constraints, which have been introduced on the basis of simple economic rules.

Inequality constraints

Minimum consumption (securing social stability):

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

(c_{min} is the minimum value of the average propensity to consume).

Minimum investment (enforcing investment rate not smaller than the one providing simple capital reproduction):

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

Balance of payment stability constraint:

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

where DR_{max} stands for the maximum value of the admissible debt-to-GDP ratio.

Border constraints

End period constraint 1:

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

End period constraint 2:

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

The last two end-period constraints provide the balance conditions at the end of the period, thus imposing the time limit (k years) for the use of the balance of payments as a buffer in pursuing adjustment policy.

In the simulations the Polish economy data were used. It was assumed that the emission norms are valid bounds on emissions in every year. In the consequence, emission permits were also assumed to be traded on the yearly basis. Initial conditions for the model were set for 2001, and parameters characterizing the Polish economy were estimated on the data from 1995 to 2000.

Capital assets $K_{2001} = 1732\ 10^9$ PLN.

Average productivity of the capital $PK^* = 1.007$.

Average unit emission $\mu^* = 1$.

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

Productivity of the capital in the technology 2, $PK2 = 0.\ 80$.

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

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

Emission, $E_{2001} = 1.456 \cdot 10^8$ tC.

Emission norm, $N_{2001} = 3.734\ \ 10^8$ tC, φ=10%, .

Debt, $D_{2001} = 0$.

As this analysis has been focused on the technological change, no autonomous technical progress has been assumed. Both considered scenarios are based on different prices for the unit emission assumed to be constant over the entire simulation period: the first one assuming the low price (60 zł/tC), denoted as LP, and the second assuming the higher price (600 zł/tC), denoted as HP. In both scenarios the interest rate i is constant and equal 3% serving also as the discounting factor. An important feature of both simulation scenarios is that Poland is at the initial period a beneficiary of the trading in emission permits as Polish economy emits greenhouse gases below assigned emission norm.

4. Simulation results

Simulations based on both considered scenarios have one element in common: in both cases the less polluting, but more capital intensive technology were chosen. This confirms that the introduction of the trade in emission permits is a factor contributing to the desired technological change.

A comparison of outputs in both scenarios is depicted in Figure 1.

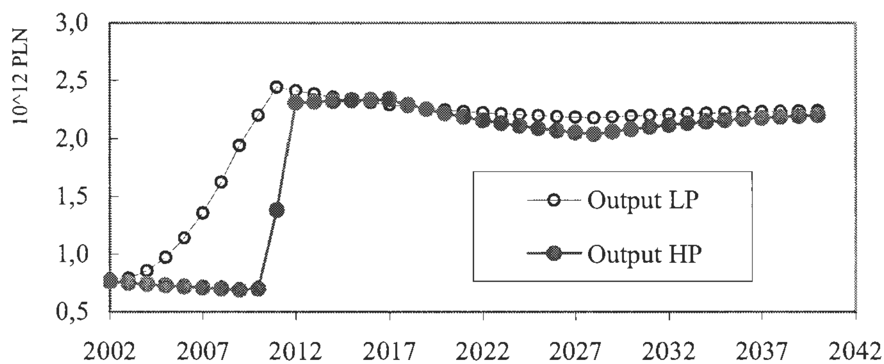

Figure 1. Output in scenarios LP and HP.

Emissions generated in both scenarios are shown in Figure 2. It can be noticed that emission replicates the evolution in output despite the technology change which occurred at the very beginning of the simulations. (That change obviously causes decrease of the effective unit emission). After ten years the emissions in both scenarios exceed the emission norms, however that happens sooner, what is another paradox, in the case of Scenario LP. From year 2017 on the emissions in both scenarios converge from above to the assigned emission norm.

The optimal paths of investment is presented in Figure 3. It is worth noticing that only in two years, e.g. 2010 and 2011 investment in Scenario HP exceeds that of the Scenario LP. Total investment outlays in Scenario HP are considerably smaller than those in Scenario LP mainly because until year

2009 investment in the former scenario was determined by the minimum constraint.

Evolution of consumption in both scenarios is shown in Figure 4. Scenario HP is in this respect absolutely superior; it enables much higher consumption. Similarly as in the case of the output and investment, the final level of consumption is considerably lower than the highest one attained in year 2017 (Scenario LP) and year 2012 (Scenario HP).

Evolution of consumption in both scenarios is shown in Figure 4. Scenario HP is in this respect absolutely superior; it enables much higher consumption. Similarly as in the case of the output and investment, the final level of consumption is considerably lower than the highest one attained in year 2017 (Scenario LP) and year 2012 (Scenario HP).

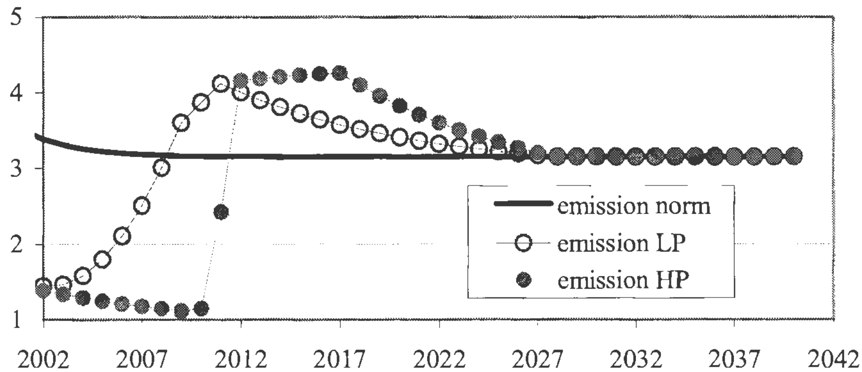

Figure 2. Emissions in scenarios LP and HP.

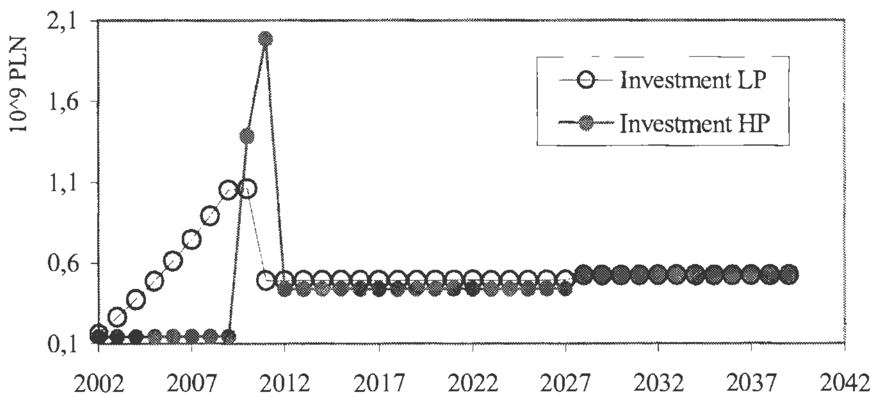

Figure 3. Investment in scenarios LP and HP.

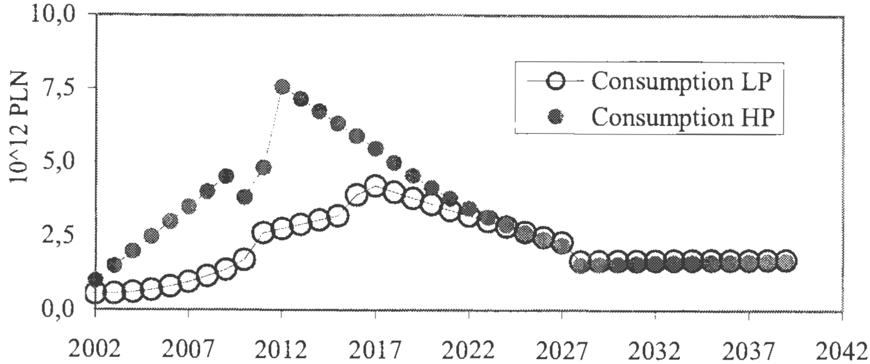

Figure 4. Consumption in scenarios LP and HP.

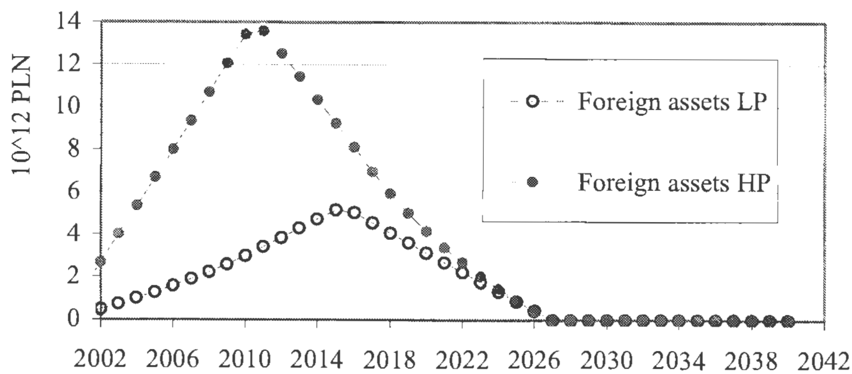

Figure 5. Foreign assets in scenarios LP and HP.

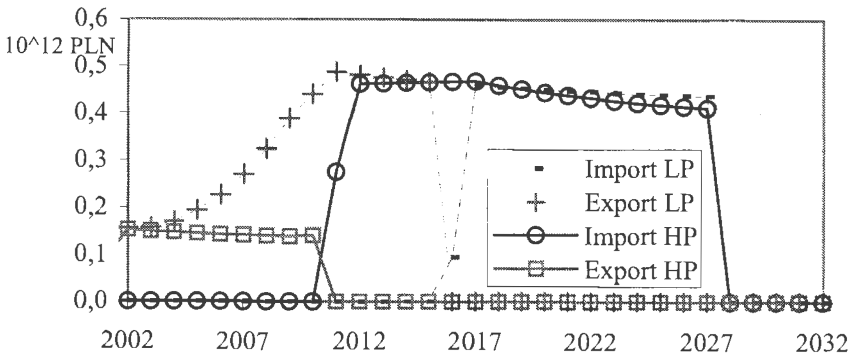

Figure 6. Imports and exports in scenarios LP and HP.

Evolution of consumption in both scenarios is shown in Figure 4. Scenario HP is in this respect absolutely superior; it enables much higher consumption. Similarly as in the case of the output and investment, the final level of consumption is considerably lower than the highest one attained in year 2017 (Scenario LP) and year 2012 (Scenario HP).

In both scenarios there are positive foreign assets. Regarding this the scenarios differ in two elements. The first one is the maximum level achieved by those assets. In Scenario HP the foreign assets achieve in year 2011 the highest level, which is almost three times greater than the highest level achieved in Scenario LP in year 2015. Positive value of the foreign assets indicates that it is profitable to use those assets as a source of income supplementing domestically generated product. Huge amount of foreign assets enables such a high rate of consumption in Scenario HP, Figure 4, despite lower investment. These results provide ground for a hypothesis that the foreign assets are used as means for shifting financial means for later years when discounting coefficient is smaller. Such a hypothesis can be also confirmed by the evolution of imports (e.g. positive net imports) and exports (e.g. absolute value of negative net imports), which is presented in Figure 6.

In the results generated in both scenarios two periods can be distinguished. In the first one a considerable foreign trade surplus occurs contributing to the buildup of the foreign assets. The second period consists in foreign trade deficit enabling usage of the means accumulated in the foreign assets during the first period, what is necessary in order to meet the end point conditions.

5. Conclusions

Results from this simple model confirm that the introduction of the trade in the permits for the gas emissions is an effective tool of curbing greenhouse emissions and stimulating desired technological change. In the analysis an economy without technical progress was considered. Expectedly such assumptions produced the "zero-growth" result: an economy finds its optimum (steady state). In both considered scenarios for all the investment outlays the less polluting, but more capital intensive technology has been chosen.

This is a qualitatively different result from the earlier study (Gadomski, Nahorski, 2005) based on the same model but with the finite time horizon of 20 years. In that study technology change occurred only in the Scenario HP.

Gains from the trade due to the higher prices in Scenario HP are too abundant; the surplus contributes mainly to the high consumption and destabilize production (which even initially decreases) and investment (concentrated in the two year period 2010-2011; beyond that period investment is at its minimum rate). This scenario is economically, socially and politically unfeasible because of the scale of volatility of consumption and investment.

The above presented results make it possible to formulate a hypothesis that there are two factors which can distort technology change: too abundant gains from trade and myopic decision-making.

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Jan Studzinski, Olgierd Hryniewicz (Editors)

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This book presents the papers that describe the most interesting results of the research that have been obtained during the last few years in the area of applications of informatics in environmental engineering and environment protection at the Systems Research Institute of Polish Academy of Sciences in Warsaw (IBS PAN) and at the German Institute for Landscape System Analysis in Müncheberg (ZALF). The papers were presented in the form of extended summaries during a special workshop organized by IBS PAN in Szczecin in September 2006 together with the conference BOS'2006 dedicated to the applications of systems research in science, technology and economy and organized jointly by IBS PAN, University of Szczecin, and the Polish Society of Operational and Systems Research. They deal with mathematical modeling, approximation and visualization of environmental variables and with development of computer aided decision making systems in the area of environmental informatics.

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