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Abstract

The paper presents an attempt to analyze an impact of introducing the emission norms and trade in permits for the greenhouse gas emissions (implementation of the Kyoto protocols) on the economic growth in a small economy (illustrated on the case of Polish economy). The endogenization of the environmental costs causes extra charges or benefits related to the trade in the emission permits. In order to analyze the impact of the imposed regulations on the economic growth a one sector optimization model has been developed. The finite horizon optimization problem is considered. The zero end-point constraints on the net import and foreign debt have been adopted. The optimal solution consists of the optimal choice between the competing technologies, and investing the revenues gained at the beginning of the permit trading. Two simulation scenarios were performed, which differed in the level of permit prices, used as the model parameters.

1. Introduction

Introduction of the greenhouse gases emission limits and trade in emission permits has been intended to influence the economic policies of participating countries and the calculus of the economic agents by accounting for the extra gains or costs related to the emission levels. This way emissions exceeding the limits cause extra cost while unused limits provide financial gains. Hence, there is a benefit for the relatively more efficient (in terms of emission) economies on the one hand and a stimulus for excessively polluting ones to control the emissions on the other hand. Solution to this problem is a mix of the decisions concerning the output, balance of payments, investment and a choice of the production technology.

The technological transition caused by limiting the emission and charging for the excessive pollutant emission should not be confused with the technical change, which is commonly associated with the desirable changes[1] in the production processes. In the problem being analyzed here, desirable changes in the abatement of the pollutant emission are connected with the mostly inevitable decrease of the productivity of capital, thus deteriorating direct economic efficiency.

The common tool for the analysis of the changes in the production processes is the production function. In most cases in the macroeconomic modeling these changes are assumed to be disembodied technical changes, see for example (Nordhaus W. and J. Boyer, 1999). However, imposing the emission limits forces the economic agents to switch from the commonly acquired capital goods to those, which cause less pollution. In this very case it is necessary to employ models with embodied technical change. On the other hand, the length of the time-period under consideration makes it necessary to employ both categories of the technical changes: embodied and disembodied ones.

The analysis presented here intends to capture the impact of implementation of the Kyoto Protocol (1998) on economic growth. The solution to this problem includes

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[1] Conventionally it is assumed that such changes are capital- and/or labor- and/or materials/energy- saving ones.

substitution of already installed more polluting technology[2] by less emitting one, however costlier. This change is an effect of endogenization of environmental costs, which before the implementation of the Kyoto protocol were just externalities. This problem can be associated with the ongoing discussion on the technological progress curves (Ang B.W. 2004, MacKenzie J.J. 2003, Riahi K. et al., 2004), as well as on scenarios and modeling of future national emissions (Kaivo-oja J. and J. Luukkanen , 2004, MacKenzie J.J., 2003, Manne A. and R. Richels 2004, McKibbin W.J. and Wilcoxen P.J. 2004).

However, the approach adopted here is different[3]. A small economy is being represented by a simple optimization model. Its aim is to provide an explanation of the processes of the long-term technological transition caused by imposing the emission limits. Attention is being focused on the propagation of change via the exchange of capital, the rate of which depends on the depreciation and investment rates. In such an approach the short term adjustments are omitted. It is assumed that the latter are not related to the proper technological changes but to the short-term measures aimed at achieving the short-term goals.

The model is an optimization one. In the opinion of the authors the optimum economic policy is hardly implemented; however the results of the model can be treated as a benchmark helping in answering the question: what would be performance of an economy, if it behaved optimally. Any non-optimum attempt would yield worse results with respect to the chosen criterion.

In Section 2 the elements of the model are presented, namely models of technology, production, emission and foreign trade. Section 3 includes the simulation results and final remarks.

2. Technology, output, emission and foreign trade

The output of the model is measured in two ways, by the gross output and the final product. The former is employed because it includes the usage of the intermediary goods, production of which overwhelmingly contributes to the pollutant emissions. The latter is necessary in order to comply with the convention. All economic variables in the model are expressed in real terms.

The concept of technology in the model is associated with the technological parameters of the capital assets. The technology vector T is defined below;

$$T_t = T[\, a,\, \delta,\, \gamma_t,\, PK^*_t,\, \mu^*_t,], \qquad (1)$$

where:

a - share of the intermediate consumption, constant coefficient;

δ - depreciation rate, constant coefficient;

PK^*_t - average productivity of capital,

γ - a long-term rate of the overall productivity growth,

μ^*_t - average unit emission.

The parameter a stands for the intensity of material inputs. Denoting by Q_t the gross output in the year t, to be specified later, the intermediate consumption used by the production sector can be expressed by the following expression:

$$a\, Q_t.$$

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[2] Being in fact a mixture of a set of technologies, such as the nuclear, wind, etc.

[3] It can be considered as an extension of the question addressed in (Horabik J. and Z. Nahorski, 2003)

The stock of the fixed assets is described by the commonly employed relationship:

$$K_t = K_{t-1} + I_t - \delta K_{t-1} = (1 - \delta) K_{t-1} + I_t, \tag{2}$$

where I_t denotes investment in the year t while K_t denotes the stock of the fixed assets at the end of the year t. The investments made in a given year increase the stock of the fixed assets in the succeeding year.

The fixed assets are not assumed to be homogenous. This means that the fixed assets in the stock can belong to two generations of fixed assets (characterized by different technology vectors (1)). Values of parameters PK^*_t and μ^*_t, which represent the mean values of the productivity of capital and the unit emission, respectively, depend on the structure of the stock of fixed assets.

In order to describe the process of determining PK^*_t and μ^*_t, the following model is proposed below. As both these parameters will be described by the similar model, it is assumed that ρ_t represents the marginal value of a variable of interest, while ρ^*_t represents the mean value of that variable of the entire fixed capital.

Assume that agents invest I_t in the year t in such a way that in the year t an amount $I1_t$ is being invested in the technology 1 and $I2_t$ in the technology 2, and, of course, $I_t = I1_t + I2_t$. Under these assumptions the marginal value in the year t can be expressed by the following formula:

$$\rho_t = (I1_t \, \rho^1 + I2_t \, \rho^2) / I_t, \tag{3}$$

which is the weighted average of the values ρ^1 and ρ^2 with weights being the shares of respective technologies in the investment made in the year t.

The mean value ρ^*_t evolves in time according to the following equation[4]:

$$\rho^*_{t+1} = (1 - \lambda_t) \, \rho^*_t + \lambda_t \, \rho_t, \tag{4}$$

where the time-varying coefficient λ_t denotes the share of the fixed assets obtained from the investment in the year t in the total amount of the fixed capital at the end of the year t:

$$\lambda_t = I_t \, / \, K_t \, . \tag{5}$$

Variable λ_t, equation (5), is positive (or equal to 0, if there is no investment) and smaller than 1 (or equal to 1, if the end period stock of the fixed assets were entirely created by investment from the year t). It follows from equation (4), that the average value ρ^*_{t+1} is unchanged when there is no investment, while ρ^*_{t+1} assumes the marginal value ρ_t, if the entire stock of the fixed assets is created in the previous year.

The above described property of equation (4) is important as it provides adequate description of the process of change of the technological parameters, which is usually distributed in time and its rate depends on the rate of investments[5].

The gross output in year t, Q_t, is determined by the following production function[6]:

$$Q_t = PK^*_t \, K_{t-1} \, (1+\gamma)^{t-t_0}, \tag{6}$$

By substituting PK^*_t for ρ^*_t, the dynamics of PK^*_t is given by equation (4).

Production causes emission E_t, which is the following function of the output and the average unit emission μ^*_t of the installed capital assets:

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[4] This model was proposed in (Gadomski 2003).

[5] This modeling solution contributes also to the reduction of the dimension of the optimization problem.

[6] Production function (6) does not account for the impact of the labor on the output.

$$E_t = \mu^*_t Q_t. \tag{7}$$

The dynamics of μ^*_t is described by an equation based on (4). In this model the emission is associated solely with the production rate and not with other factors such as, for example, consumption.

In the greenhouse gas case, bounds on emission growth are imposed only in chosen commitment periods while the path to achieve the bounds is free. Here, however, we assign a path with a constant year decrement r for a smooth transition to the assigned goal. Thus, it is assumed that the emission norm N_t, set for a country in a year t, follows the following expression:

$$N_t = N_{t_0} \{ 1 - \varphi (1 - e^{-r(t-t_0)}) \}, \tag{8}$$

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

Balance of payment of the country depends solely on the trade balance (net import, which can be positive or negative), and the capital outflows related to the repayment of principal (or capital inflows when the country is a net creditor). The net foreign debt D_t of a country at the end of the year t is created by the net import M_t and the due repayment:

$$D_t = D_{t-1} + M_t - D_{t-1} / T_D = D_{t-1} (T_D - 1) / T_D + M_t, \tag{9}$$

where the expression D_{t-1} / T_D indicates that the average debt repayment period equals T_D years. Note that in this model the debt is the real net debt so that it can assume negative values whenever a country becomes a net creditor.

Disposable aggregate supply Y_t accounts for the flows of foreign exchange:

$$Y_t = (1 - a) Q_t + M_t + P_t (N_t - E_t) - D_{t-1} (i + 1/T_D), \tag{10}$$

where P_t denotes the unit gain (when $N_t - E_t \geq 0$) or payment (when $N_t - E_t < 0$) for the excessive emission, and i stands for the real interest rate. The last summand in equation (10) expresses financial flows related to the principal D_{t-1} / T_D and the interest iD_{t-1}on debt D_{t-1}.

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

$$C_t = Y_t - I_t \tag{11}$$

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 production over the assumed period T:

$$\max \{S = \sum_{t=t_0+1}^{T} Q_{t_0} (1+r_d)^{-(t-t_0)} \} \tag{12}$$

where r_d stands for the discount rate[7], over the following variables:

- amount of investment I_t in each period t, $t = t_0+1,\ldots,t_0+T$, consisting of the decisions on the structure of investment: $I1_t$, standing for the investment in the capital representing the older technology, and $I2_t$ being an investment in the capital belonging to the technology with smaller emission ($I_t = I1_t + I2_t$)

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[7] Conventionally the rate used in discounting equals interest rate. Factor $(1 + r)^{-i}$, $i = 1, 2,..,T$, can be also interpreted as a weight attributed to the output in i-th year. In particular, problem with $r<0$ can be interpreted as a case, when later outputs are assigned greater weighs than the earlier ones.

* net import M_t in each period t, $t = t_0+1,\ldots,t_0+T$

Equality constraints

Capital:

$K_t = K_{t-1} + I_t - \delta K_{t-1} = (1 - \delta) K_{t-1} + I_t$, equation (2);

Changes of the marginal productivity of capital in the technology 1 being the result of the disembodied technical progress with average growth rate r_{PK1} :

$PK1_t = PK1_{to} (1 + r_{PK1})^{t-to}$

Changes of the marginal productivity of capital in the technology 2 being the result of the disembodied technical progress with the average growth rate r_{PK2} :

$PK2_t = PK2_{to} (1 + r_{PK2})^{t-to}$

Output:

$Q_t = PK^*_t K_{t-1}$, equation (6);

Marginal productivity of investment:

$PK_t = (I1_t PK1_t + I2_t PK2_t) / I_t$, equation (3);

Average productivity of capital:

$PK^*_t = PK^*_{t-1} + (I_{t-1} / K_{t-1})(PK_t - PK^*_{t-1})$, equations (4) and (5);

Changes of the marginal unit emission in the technology 1 being a result of the disembodied technical progress with the average growth rate $r_{\mu 1}$:

$\mu 1_t = \mu 1_{to} (1 + r_{\mu 1})^{t-to}$

Changes of the marginal unit emission in the technology 2 being a result of the disembodied technical progress with the average growth rate $r_{\mu 2}$:

$\mu 2_t = \mu 2_{to} (1 + r_{\mu 2})^{t-to}$

Marginal unit emission:

$\mu_t = (I1_t \mu 1_t + I2_t \mu 2_t) / I_t$, equation (3);

Average unit emission:

$\mu^*_t = \mu^*_{t-1} + (I_{t-1} / K_{t-1})(\mu_t - \mu^*_{t-1})$, equations (4) and (5);

Emission:

$E_t = \mu^*_t Q_t$. equation (7); equation (3);

Emission norm:

$N_t = N_{t_0} \{ 1 - \varphi (1 - e^{-r(t-t_0)}) \}$, equation (8);

Foreign debt/liability:

$D_t = D_{t-1} + M_t - D_{t-1} / T_D = D_{t-1} (T_D - 1) / T_D$, equation (9);

Disposable aggregate supply:

$Y_t = (1 - \alpha) Q_t + M_t + P_t (N_t - E_t) - D_{t-1} (i + 1/T_D)$, equation (10);

Consumption:

$C_t = Y_t - I_t$, equation (11);

Inequality constraints

Scenario independent inequality constraints.

Minimum consumption (securing social stability; too high investment rate can cause social unrest):

$C_t \geq c_{min} Y_t$, (c$_{\min}$ is the minimum value of the average propensity to consume)

Minimum investment (enforcing investment rate greater than that providing simple capital reproduction by a margin rate r_l):

$I_t \geq (1 + r_l) dK_{t-1}$

Balance of payment stability constraint:

$D_t \leq DPR_{max} Y_t$, (DPR_{max} stands for the maximum value of the admissible debt-to-GDP ratio)

Border constraints.

End period constraint 1:

$D_t = 0$, for $t \geq t_0 + k$; $1<k\leq T$

End period constraint 2:

$M_t = 0$, for $t \geq t_0 + k$; $1<k\leq T$.

The last two end period constraints provide foreign exchange balance condition at the end of the period, thus imposing the time limit for the adjustment policy.

4. Simulation results

The data used in the simulations are data describing the Polish economy. In order to present changes and technological adjustment of the economy in the transition period 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 $PK^*_{2001} = 1.007$.

Average unit emission $\mu^*_{2001} = 1$.

Marginal productivity of the capital in the technology 1, $PK1_{2001}= 1.007$.

Marginal productivity of the capital in the technology 2, $PK2_{2001}= 0.\ 80$.

Marginal unit emission in the technology 1, $\mu1_{2001} = 1$.

Marginal unit emission in the technology 2, $\mu2_{2001} = 0.75$.

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

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

Debt, $D_{2001} = 0$.

As in this analysis the interest has been focused on the consequences of the technological change, no autonomous technical progress has been assumed. Both considered scenarios are based on different prices for the unit emission: the first with a low price (60 zł/tC), denoted as LP, and the second with a higher price (600 zł/tC), denoted as HP. Lower price means that a country having a surplus of emission permits is less sensitive to this stimulus on the one hand, but on the other hand receives less from the sale of the emission permits.

The time horizon for optimization was set for 15 years (till 2016), what was the maximum allowed by the used software. In both scenarios the end-point conditions have been set in such a way as to allow the use of the foreign trade and foreign capital flows in the period ending in 2008.

Results

The most important difference between two analyzed scenarios is that in Scenario HP there occurs the immediate switch to the cleaner technology already in the first year, while in Scenario LP no change of technology occurs. The process of growth is in both scenarios supported by the foreign sources; in Scenario LP foreign loans are drawn while in Scenario HP high revenues make it possible to employ them as income generating assets (with one exception in year 2004), Fig. 1.

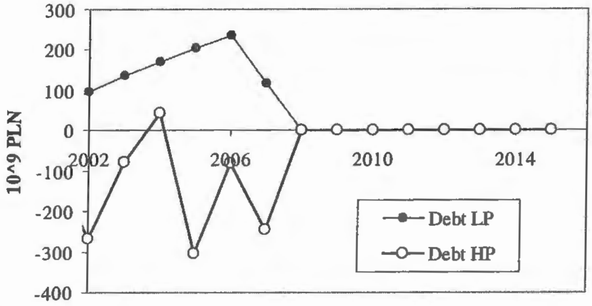

Fig.1. Debt and net foreign assets (minus sign) respectively in Scenarios LP and HP.

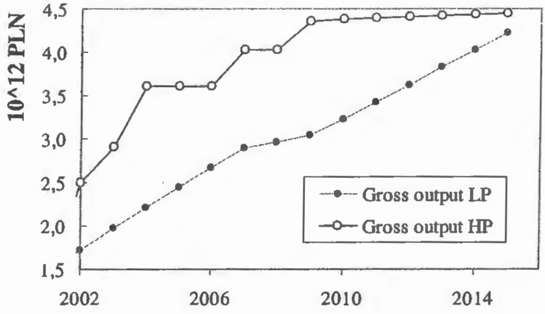

Fig.2. Output in Scenarios LP and HP.

Fig.2 ilustrates the obvious superiority of Scenario HP over Scenario LP, as in every year the output of Scenario HP is higher. However, the rate of growth from 2009 to 2015 is close to zero. A similar tendency can be observed in the development in consumption, Fig.3.

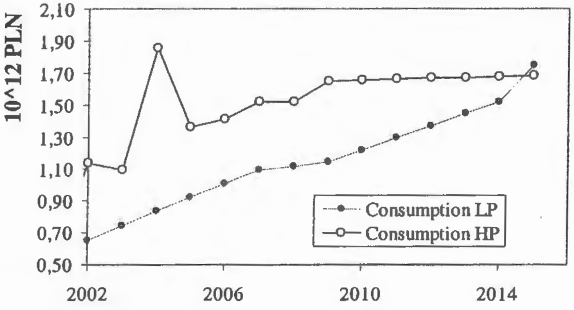

Fig.3. Consumption in Scenarios LP and HP.

Such development of output and consumption in Scenario HP has been made possible due to high revenues from the trade in the emission permits. These revenues in turn have enabled higher investment rates, Fig. 4, in the first half of the period being considered.

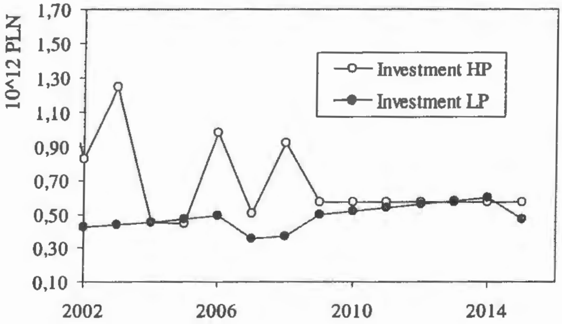

Fig. 4. Investment in Scenarios LP and HP.

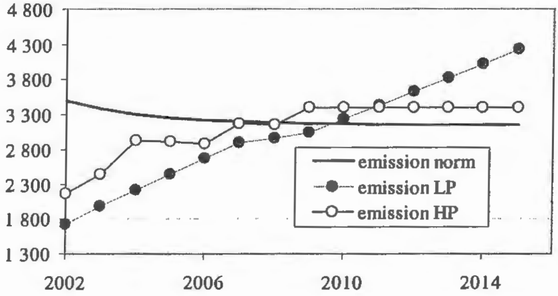

Fig. 5. Emission norm and emissions in Scenarios HP andLP.

Fig.2, Fig.3 and Fig.4 indicate that the trajectories of all three rates depicted in them converge. This common feature is a result of approaching the emission limit, Fig. 5. Despite lower production, the end period emissions in Scenario LP are higher because of two reasons. The first one is a result of unchanged extensively emitting technology. The second reason is an effect of weaker sensitivity of economy to charging for excessive emissions; in the first period lower prices are weaker incentives for the technology change, while in the second period the cost is correspondingly lower allowing for a bigger excess of the emission norm.

Within assumed time-horizon the simulation results reveal a slowdown associated with approaching and/or exceeding the emission norm. The time-horizon is too short for discussing the behavior of the model beyond that time-limit. However, one can suppose that the stop of economic growth is imminent.

5. Conclusions

The performed optimizations allow the following conclusions:

1. A small country endowed with excessive emission permits has mid-term benefits from the emission permit trade. These benefits increase with the price of permits.
2. Introduction of the emission control imposes adjustment. In both scenarios considered it caused increased investment.
3. Adjustment requires a financial effort. In the case of the lower permission prices no change in the production technology occurred; financial means were insufficient to bring the qualitative change. Further economic growth can be determined by the rate of the technical progress.
4. In the case of the higher permission prices most investment was financed by the revenues from the trade in the emission permits. There occurred a change of the production technology; all invested capital belonged to the new less productive but less emitting technology.
5. In both analyzed scenarios the period of a fast economic growth is succeed by the period where further economic growth is determined by the rate of the technical progress.

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