DOI: 10.5604/01.3001.0014.1209

PRZEGLĄD STATYSTYCZNY
R. LXIII – ZESZYT 3 – 2016

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ASSESSMENT OF THE IMPACT OF THE REDUCTION OF THE GASEOUS EMISSIONS ON GROWTH IN POLAND. ASSUMPTIONS AND PRELIMINARY RESULTS

1. INTRODUCTION

The presented research addresses the course of economic transformations induced by the technology conversion forced upon a country by the policy of the abatement of the greenhouse gases emission (GHG).

Most research on this topic present in the literature has been performed using Computable General Equilibrium (CGE) models. In the Polish case such models are, for example, the PLACE model, see Antoszewski et al. (2015), Boratyński (2012), Roberts (1994), and others.

The development of CGE models involves large teams and detailed structure of the models. However, not all research is concerned with very detailed questions and not all assumptions of the research using the CGE models are relevant. For example, the energy sector does not adhere to the model of the perfect competition, on which CGE models are based. A monopoly (or oligopoly) can operate in the range of technical inefficiency. Such a situation is not accounted for in the model of perfect competition. This is why the neoclassical production functions such as, for example, Cobb-Douglass or CES, commonly used in the CGE modelling, cease to be adequate for this task. Moreover, a significant part of the energy sector consists also of the integrated networks (electricity), where it is necessary, out of the strategic reasons, to maintain larger reserves of the unused production capacities than it is common in other sectors. This also makes simplification assumptions applied in the CGE models hard to accept.

Far-reaching simplification commonly used in CGE models is micro-rationality of producers, who maximize profits and are not concerned with market shares or other long-term factors affecting the behavior of firms. Macroeconomic policy in these models is expressed in the values of such parameters as the turnover, personal and corporate taxes, custom duties, interest rates etc. This property makes it possible to investigate the response of the national economy, or more economies linked via economic exchange, to different variants of the economic policy.

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Another problem concerning common assumptions of the CGE models is that there exists a continuum of available technologies. We doubt that, because it is hard to imagine a complex technology combining, for example, the nuclear technology and the renewable one. These technologies coexist, but develop separately and remain separated.

As to the utilization of the production capacities; reserves of unused capacities persists in long periods. This feature is common not only in the network monopolies.

The above discussion indicating some weaker aspects of the CGE modelling does not dismiss this technique but it shows that there is still space for other approaches.

In this paper we propose a method based on the simpler model, and thus much less work-intensive, able to generate no-nonsense results. This model has been developed in the Systems Research Institute of the Polish Academy of Sciences and evolved from an earlier version with the addition of a separate energy sector; see Gadomski et al. (2014).

The concept of the proposed model is based, contrary to that of CGE models, on the assumption of the macroeconomic rationality and a perfect ability of the macroeconomic policy to pursue its goals by optimal allocation of resources. Such approach provides a benchmark. Similarly to CGE models, all changes preserve sectoral equilibria in real terms at every step, without assuming that prices clear the markets. Quantitative equilibria are maintained in such a way that surpluses/deficits of the domestic markets are cleared via the foreign trade. Producers react to the changes in demand by increasing utilization rates of the production capacities and by increasing production capacities, by purchases of the investment goods. In the long run, without the technical progress, the sector output structure and the country's GDP are determined by the amount of the final allotted amount of the emission allowances. This is equivalent to the zero growth economy. In the presence of favorable technical changes, such as a beneficial evolution of the technological parameters or the emergence of a new economically more efficient technology, economy would start growing with the rate determined by the improvement of the relevant parameters.

Following this introduction, the paper is divided into three sections. The first one describes the method of analysis including the construction of the model. The next section describes the simulation results, and the final one contains conclusions.

2. METHOD OF ANALYSIS

The process of the macroeconomic technological conversion is analyzed with the support of the macroeconomic long-term model embracing four production sectors, each having a limited number of available production technologies. The sectors exchange their products at both the domestic and international markets. The focus is on modelling a small-country economy, a price-taker of international prices. The analysis is simplified by assuming that a change in emission levels does not affect productivities of the production factors. It is an optimization model, and its result indicates a perfect reaction of the national economy to the changes in its conditions/

rules. In the variant considered in this investigation, the overall economic goal of the national economy is the maximization of the present value of the total consumption over the whole simulation period.

In developing this model we do not point to tools and channels of the economic policy. Instead, this model is to serve as a benchmark showing ideal, but feasible in real terms, long-term behavior.

Two options are considered: an economic development without impediment to growth in the form of the emission limits, and another one with the emission limits imposed. It is reasonable to consider, in both options, the impact of the long – term technical progress expressed by evolving values of the parameters that define a given technology.

In the first option we assume that the economy described by the model develops along the long-term growth path using a single technology in each sector, maintaining in all sectors both domestic and external equilibria. The rate of growth is determined by the propensity to invest. This type of growth is characterized by constant proportions of the sectors' outputs, fixed assets, balances of foreign trade, and a certain rate of the utilization of the production capacities. The concept of the long-term equilibria allows another assumption: constant proportions of prices and their real values.

A variant of this option with evolving technology parameters is also worth considering. However, one should be aware that in certain cases there may emerge a possibility of rising economic competitiveness of technologies, which previously did not exist.

In the second option the sectors come across the emission limits, which force adoption of cleaner, previously unconsidered, economically inefficient technologies. Technology conversion influences both levels as well as the output and costs structures. Consider a case without the long-term technological progress. If economic agents are able to coordinate their activities in order to pursue the common goal of welfare/consumption maximization, then after the adjustment period, economy attains a new steady state and the equilibrium at the level determined by the admissible emission level and the structure of the foreign excha nge.

Also in this option a variant with evolving technology parameters can be considered. Such a solution considerably complicates the analysis, therefore it is reasonable to consider only simple hypotheses, such as, for example, one with gradually improving technology parameters reflecting a long-term technical progress.

Model

The letter t, $t = t_0,\ldots,T$, denotes the year. The numbering of years starts with the year 2010, so that t_0 corresponds to the year 2010. The following convention of indexing the model parameters has been applied in this paper: The letter $i = M, E, C, I$, denotes the sector, the letter $j = 1, 2, 3$, denotes technology. M stands for the sector producing non-energy intermediate inputs used in all producing sectors, E denotes the sector producing energy used in all producing sectors as well as the consuming sector,

C stands for the sector producing consumption goods consumed by households and the public sector, and I denotes the sector producing the investment goods supplying the stocks of fixed assets in the production sectors. It is assumed that the number of the available technologies is limited to two in the sectors M, C, I, and three in the energy sector E.

Technology of production

Technology of production in all sectors is described by the following set of parameters in i-th sector, $i = M, E, C, I$; in j-th technology, $j = 1, 2, 3$; in year t, $t = 1,\ldots,T$:

γ_{ijt} – productivity of fixed assets in year t in i-th sector and j-th technology, it is assumed that in the long term in each year the technical progress increases the productivity of the fixed assets by a constant ratio r_γ:

$$\gamma_{ijt} = \gamma_{ijt_0}(1 + r_\gamma)^{t-t_0};$$

where γ_{ijt_0} denotes productivity of the fixed assets in the year t_0;

δ_{ij} – depreciation rate of fixed assets in i-th sector and j-th technology;

α_{ij} – use of goods produced in sector M in producing the unit of the gross product of the i-th sector and j-th technology;

β_{ij} – use of goods produced in sector E in producing the unit of the gross product of the i-th sector and j-th technology;

μ_{ijt} – emission per unit in producing the gross product of the i-th sector and j-th technology in year t, it is assumed that in the long term in each year the technical progress decreases the unit emission by a constant ratio r_μ:

$$\mu_{ijt} = \mu_{ijt_0}(1 + r_\mu)^{t-t_0}.$$

where μ_{ijt_0} denotes unit emission in the year t_0, while r_μ denotes the rate of the decrease of the emission unit.

In the current version of the model in all non-energy production sectors (M, C, I) two competing technologies are assumed: the old one, economically more efficient but emitting more GHG, and the costlier but cleaner one. In the energy sector E three technologies are available: the old one, economically more efficient but emitting more GHG; the costlier but cleaner one; and the preferred one, the cleanest of them all but economically inefficient (of which the second can be interpreted as modernized conventional technology, and the latter can be interpreted as renewable energy).

Production capacity

Production capacity defined as the potential gross output Q_{ijt} of the sector i, $i = E, M, C, I$; using j-th technology, $j = 1, 2, 3$; in the year t, $t = 1,\ldots,T$; is described by the following one factor production function:

$$Q_{ijt} = \gamma_{ijt} K_{ijt-1}, \tag{1}$$

where K_{ijt} stands for stock of the fixed assets in sector i and j-th technology at the beginning of the year t. In this paper, the potential gross output (1) will be also called the production capacity of the j-th technology in the sector E in year t.

Actual gross output X_{ijt} cannot exceed the production capacity

$$0 \leq X_{ijt} \leq Q_{ijt}, \quad j = 1, 2, 3; \ t = 1,\ldots,T, \tag{2}$$

and it can be expressed in the following form:

$$X_{ijt} = \varphi_{ijt} Q_{ijt}, \quad j = 1, 2, 3; \ t = 1,\ldots,T, \tag{3}$$

where φ_{ijt} stands for the coefficient of the production capacity utilization in the i-th sector, $i = E, M, C, I$; using j-th technology, $j = 1, 2, 3$; in year t, assuming values from the range [0;1]. (In particular, $\varphi_{ijt} = 0$ indicates fully idle capital and $\varphi_{ijt} = 1$ represents full utilization of the production capacity of j-th technology in i-th sector in the year t).

Total actual output of the i-th sector, $i = E, M, C, I$; is the sum of outputs produced using available technologies:

$$X_{it} = X_{i1t} + X_{i2t} + X_{i3t}, \quad t = 1,\ldots,T. \tag{4}$$

Stock of the fixed assets K_{ijt} using j-th technology, $j = 1, 2, 3$; in the i-th sector, $i = E, M, C, I$; at the end of year t is given by the relationship:

$$K_{ijt} = K_{ijt-1}(1 - \delta_{ij}) + I_{ijt}, \quad j = 1, 2, 3; \ t = 1,\ldots,T, \tag{5}$$

where I_{ijt} denotes investment in the j-th technology, $j = 1, 2, 3$; in the i-th sector, $i = E, M, C, I$; in the year t. (Note that the term $K_{ijt-1}\delta_{ij}$ denotes depreciation of the capital in i-th sector). For simplicity one year lag between the investment and its contribution to the stock of fixed assets is assumed.

Production of the i-th sector using j-th technology in year t causes the emissions S_{ijt} of GHG:

$$S_{ijt} = \mu_{ijt} S_{ijt}, \quad i = E, M, C, I; \ j = 1, 2; \ t = 1,\ldots,T. \tag{6}$$

The total emission of GHG by the i-th sector in the year t equals:

$$S_{it} = S_{i1t} + S_{i2t} + S_{i3t}, \quad i = E, M, C, I; \ t = 1,\ldots,T. \tag{7}$$

Gross income GI_t is defined as the sum of incomes generated in the sectors E, M, C and I:

$$\begin{aligned} GI_t = {} & [1-(\alpha_{E1}+\beta_{E1})]X_{E1t}+[1-(\alpha_{E2}+\beta_{E2})]X_{E2t}+[1-(\alpha_{E3}+\beta_{E3})]X_{E3t}+ \\ & +[1-(\alpha_{M1}+\beta_{M1})]X_{M1t}+[1-(\alpha_{M2}+\beta_{M2})]X_{M2t}+ \\ & +[1-(\alpha_{C1}+\beta_{C1})]X_{C1t}+[1-(\alpha_{C2}+\beta_{C2})]X_{C2t}+ \\ & +[1-(\alpha_{I1}+\beta_{I1})]X_{I1t}+[1-(\alpha_{I2}+\beta_{I2})]X_{I2t}. \end{aligned} \tag{8}$$

Each year country is endowed with certain number N_t of the emission permits and its trajectory is determined by the following relationship:

$$N_t = f_N(t, N_{td}), \quad t = 1,\ldots,T, \tag{9}$$

where N_{td} denotes the yearly number of the emission permits in the last considered period. Two variants of the function N_t considered in this paper are presented in figure 1d. The mild variant assumes decreasing numbers of the emission permits till 2030, after which it attains steady value of 57% of the 2005 emission level, and the restrictive variant with decreasing numbers of the emission permits till 2050, after which it attains steady value of 45% of the 2005 emission level.

Disposable income DI_t equals the defined above gross income GI_t, decreased/ increased by the debt servicing/income from foreign assets:

$$DI_t = GI_t - r \cdot D_{t-1} + P(N_t - S_t), \tag{10}$$

where:
r – interest rate;
D_t – foreign debt (if positive)/ foreign assets (if negative) at the end of the year t:

$$D_t = D_{t-1} - (F_{Et} + F_{Mt} + F_{Ct} + F_{It}), \tag{11}$$

where P stands for the price of the emission permit, N_t denotes the number of the emission permits in the year t, defined above, and S_t denotes actual total emission:

$$S_t = S_{Et} + S_{Mt} + S_{Ct} + S_{It}. \tag{12}$$

Trade balance of all sectors (the sum in parentheses in (11)) increases debt if it is negative; and decreases debt if it is positive. Negative debt is interpreted as foreign assets, which in the year t generate an income equal to $- r \cdot D_{t-1}$. Note also that the excessive emission above the number of the emission permits has to be purchased in the international market at the emission unit price P, thus decreasing disposable income. In the opposite situation a country's disposable income is supplemented by the sale of the excessive emission permits in the international market.

Below, the balance equations for each sector are presented. The left hand sides of these equations denote domestic supply and the right hand sides represent domestic demand supplemented by the balances of foreign exchange in given good.

The balance equation of the E sector is expressed by the following equation:

$$X_{E1t} + X_{E2t} + X_{E3t} = \beta_{E1t}X_{E1t} + \beta_{E2t}X_{E2t} + \beta_{E3t}X_{E3t} + \beta_{M1t}X_{M1t} + \beta_{M2t}X_{E2t} + \\ + \beta_{C1t}X_{C1t} + \beta_{C2t}X_{C2t} + \beta_{I1t}X_{I1t} + \beta_{I2t}X_{I2t} + \rho_t\lambda DI_t + F_{Et}, \quad (13)$$

where the term

$$\beta_{E1t}X_{E1t} + \beta_{E2t}X_{E2t} + \beta_{E3t}X_{E3t} + \beta_{M1t}X_{M1t} + \beta_{M2t}X_{E2t} + \beta_{C1t}X_{C1t} + \\ + \beta_{C2t}X_{C2t} + \beta_{I1t}X_{I1t} + \beta_{I2t}X_{I2t}$$

denotes consumption of energy in year t in the sectors M, E, C, I; using all technologies available in those sectors, and the term F_{Et} stands for the net balance of the foreign trade of the sector E (if $EXP_{Et} - IMP_{Et} = F_{Et} \geq 0$, then export EXP_{Et} exceeds import IMP_{Et} in the foreign trade of goods produced by the sector E, and if $F_{Et} < 0$ then import IMP_{Et} exceeds export EXP_{Et} in the foreign trade in energy). The term $\rho_t DI_t$, $0 < \rho_t \leq 1$, denotes part of the disposable income DI_t in the year t designed for the purchases of the consumption goods, of which $\lambda\rho_t DI_t$ stands for the part of the total consumption expenditures directed for the purchases of energy. Note that the part $(1 - \rho_t)DI_t$ of the disposable income equals the total investment expenditures. Coefficient ρ_t is not a constant as it depends on the propensity to invest. Constant coefficient λ, $0 < \lambda \leq 1$, denotes assumed constant share of the energy expenditures in the total consumption expenditures.

Supply of goods produced by the sector M is supplemented by import, while some part of its output can be directed to export. The gross output of the sector M is distributed in the way expressed by the following balance equation:

$$X_{Mt} = \alpha_{M1}X_{M1t} + \alpha_{M2}X_{M2t} + \alpha_{E1}X_{E1t} + \alpha_{E2}X_{E2t} + \alpha_{E3t}X_{E3t} + \\ + \alpha_{C1}X_{C1t} + \alpha_{C2}X_{C2t} + \alpha_{I1}X_{I1t} + \alpha_{I2}X_{I2t} + F_{Mt}, \\ t = 1,\ldots,T; \quad (14)$$

where the term

$$\alpha_{M1}X_{M1t} + \alpha_{M2}X_{M2t} + \alpha_{E1}X_{E1t} + \alpha_{E2}X_{E2t} + \alpha_{E3t}X_{E3t} + \alpha_{C1}X_{C1t} + \\ + \alpha_{C2}X_{C2t} + \alpha_{I1}X_{I1t} + \alpha_{I2}X_{I2t}$$

denotes consumption of the non-energy intermediate inputs in year t in the sectors M, E, C, I, and F_{Mt} stands for the net balance of the foreign trade of the sector M

($EXP_{Mt} - IMP_{Mt} = F_{Mt} \geq 0$ means that export EXP_{Mt} exceeds import IMP_{Mt} in the foreign trade of goods produced by the sector *M*, and when $F_{Mt} < 0$, the opposite).

Supply of goods produced by the sector *I* is supplemented by import, while some part of its output can be directed to export. The gross output of the sector *I* is distributed as described by the following balance equation:

$$X_{It} = I_t + F_{It}, \quad t = 1,\ldots,T; \tag{15}$$

where the term I_t

$$I_t = (1-\rho_t)DI_t = I_{M1t} + I_{M2t} + I_{E1t} + I_{E2t} + I_{E3t} + I_{C1t} + I_{C2t} + I_{I1t} + I_{I2t}$$

denotes total investment in the sectors *M*, *E*, *C*, *I*, and all technologies in year *t*, and F_{It} stands for the net balance of the foreign trade of the sector *I* (if $EXP_{It} - IMP_{It} = F_{It} \geq 0$, export EXP_{It} exceeds import IMP_{It} in the foreign trade of goods produced by the sector *I*, and if $F_{It} < 0$, the opposite).

Supply of goods produced by the sector *C* is supplemented by import, while some part of its output can be directed to export. The balance equation of the sector *C* is as follows:

$$X_{Ct} = \rho_t \cdot (1-\lambda) \cdot DI_t + F_{Ct}, \quad t = 1,\ldots,T; \tag{16}$$

showing that the domestic supply (left-hand side of the above equation) of the non--energy consumption goods is equal to the demand generated by the part of the disposable income directed at purchasing non-energy consumption goods and the balance of the foreign trade in those goods (right hand side of the equation (16)). It is worth noting that the variable ρ_t can be interpreted as the propensity to consume. The term F_{Ct} stands for the net balance of the foreign trade of the sector *C* (if $EXP_{Ct} - IMP_{Ct} = F_{Ct} \geq 0$, export EXP_{Ct} exceeds import IMP_{Ct} in the foreign trade of goods produced by the sector *C*, and if $F_{Ct} < 0$, the opposite).

Households and the public sector belong to the same sector called the consuming sector, where decisions being made concern: utilization of the production capacities in sectors and technologies; distribution of the disposable income between consumption and investment; technology choice; and the role of the foreign trade. Constant proportion between the household and public consumption is assumed.

Decision variables of the model include: the actual gross outputs in sectors and technologies; investment in the capital assets in sectors and technologies; and the foreign trade balances of all production sectors:

$$\begin{aligned} &X_{E1t}, X_{E2t}, X_{E3t}, X_{M1t}, X_{M2t}\, X_{C1t}, X_{C2t}\, X_{I1t}, X_{I2t}, I_{E1t}, I_{E2t}, I_{E3t}, \\ &I_{M1t}, I_{M2t}\, I_{C1t}, I_{C2t}\, I_{I1t}, I_{I2t}, F_{Et}, F_{Mt}, F_{Ct}, F_{It}. \end{aligned} \tag{17}$$

The inequality constraints are as follows.

Non-negative outputs and investments:

$$X_{E1t}, X_{E2t}, X_{E3t}, X_{M1t}, X_{M2t}\ X_{C1t}, X_{C2t}\ X_{I1t}, X_{I2t}, I_{E1t}, I_{E2t}, I_{E3t},$$
$$I_{M1t}, I_{M2t}\ I_{C1t}, I_{C2t}\ I_{I1t}, I_{I2t} \geq 0. \tag{18}$$

Note that the foreign trade balances $F_{Et}, F_{Mt}, F_{Ct}, F_{It}$ can be either positive or negative.

Propensity to invest, defined as a ratio $I_t \,/\, DI_t$, cannot exceed the maximum propensity to invest:

$$I_t \,/\, DI_t \leq \sigma_{I\,/\,DI}, \tag{19}$$

where $\sigma_{I\,/\,DI}$ denotes the maximum value of the investment to income ratio.

The above constraint reflects social resistance to the exceedingly high propensity to invest. The propensity to consume ρ_t is also constrained from beneath:

$$\rho_t \leq \sigma_{cons\,/\,DI}, \tag{20}$$

where coefficient $\sigma_{cons\,/\,DI}$ denotes the minimum value of the consumption to income ratio.

Another set of constraints deals with the feasible shares of foreign trade in the output of sectors. The following constraints:

$$\sigma_{IMP\,/\,X} \leq \frac{IMP_t}{X_t} \leq \sigma_{IMP\,/\,X},\ j = M,\ E,\ C,\ I; \tag{21}$$

$$\sigma_{EXP\,/\,X} \leq \frac{EXP_t}{X_t} \leq \sigma_{EXP\,/\,X},\ j = M,\ E,\ C,\ I; \tag{22}$$

impose maximum proportion of import and export respectively, in the national supply of the given product, where coefficients $\sigma_{IMP\,/\,X}$ and $\sigma_{EXP\,/\,X}$, $j = M, E, C, I$; denote respectively the maximum ratio of import and export of a given product to its national gross output.

The following two constraints:

$$-r^{(-)}_{INV\,i\,j} \leq \frac{I_{i\,j\,t} - I_{i\,j\,t-1}}{I_{i\,j\,t-1}} \leq r^{(+)}_{INV\,i\,j},\ j = 1,\ 2,\ 3;\ j = M,\ E,\ C,\ I; \tag{23}$$

$$-r^{(-)}_{cons} \leq \frac{\rho_t DI_t - \rho_{t-1} DI_{t-1}}{\rho_{t-1} DI_{t-1}} \leq r^{(+)}_{cons}, \tag{24}$$

limit relative increases and decreases of investments in sectors and total consumption, respectively, where parameters $r^{(-)}_{INV\,i\,j}$ and $r^{(+)}_{INV\,i\,j}$ stand for the lowest and highest admissible rate of increase of the investment in technology j, j = 1, 2, 3; $i = M, E, C, I$; while $r_{cons}^{(-)}$ and $r_{cons}^{(+)}$ denote the lowest and highest admissible rate of the consumption change respectively. In particular, the constraint (24) reflects social sensitivity to the changes in consumption and a possible resistance to them.

The following constraint reflects policy decisions concerning the desired share of a certain technology in the total output of a certain sector. In the current version of the model this constraint is the consequence of the requirement that in the energy sector the share of the renewable technology should be at least equal to 20% from the year 2030:

$$\frac{X_{E3t}}{X_{E1t} + X_{E2t} + X_{E3t}} \geq 20\%;\ t \geq 2030. \tag{25}$$

The last constraint limits the possibility of the excessive debt/credit relative to gross income

$$-0.60 \cdot GI_t \leq D_t \leq 0.60 \cdot GI_t. \tag{26}$$

Macroeconomic goal of economic development

The overall goal of the economic development, which is considered in this paper, is maximization of the discounted future consumption given by the following expression:

$$PVC = \sum_{t=t_0}^{T} \rho_t DI_t (1 + r_d)^{-(t-t_0)} \tag{27}$$

subject to the constraints (1)–(26), where r_d denotes the discounting rate and $\rho_t DI_t$, $t = t_0, t_0+1, t_0+2, \ldots, T$, denote future consumption rates (note that the total consumption in the year t is equal to $\rho_t DI_t$).

Another tool worth considering is the multicriteria optimization, which aims at the harmonization of two conflicting objectives: maximization of the discounted future consumption and minimization of the cumulated GHG emissions. Such an approach was applied in Gadomski et al. (2016), and is suitable in the negotiations or training.

Data

In order to perform computations it was necessary to transform available data into a relevant form. The main source of the data was the Head Statistical Office (2011).

The method of reaggregation of the original input-output table was as follows. The energy sector E has been created by aggregating the following products: (i) Coal and lignite; (ii) Crude petroleum and natural gas; (iii) Coke, refined petroleum products; (iv) Electricity, gas, steam and air conditioning. Product of the sector E is interpreted further as the energy produced for the needs of the sector E and all other sectors, as well as tradable goods in the foreign trade. Products of other sectors were classified respectively as: M – the non-energy intermediary inputs in other production sectors, C – non-energy goods used in the consuming sector (consisting of households and the public sector), and I – investment goods serving for creation of the fixed assets exploited in the production sectors. The structure of the end uses of goods served also as a structure for decomposition of exports and imports of the original sectors. The new sectors were obtained by summing up all similarly classified parts of the original sectors; the same procedure was used in determining the exports and imports of the new sectors.

The initial values of variables were taken from the reaggregated input-output table and data concerning fixed assets.

In particular, the productivities of the fixed assets were estimated on the basis of the input-output data and the additional assumption that the utilization rates in sectors equaled 90%.

3. SIMULATION RESULTS

Two types of the simulation scenarios have been considered. The first one, called the static one, is based on the assumption that the number of available technologies in each sector is given and that they do not evolve. The second type is also based on the assumption that the number of available technologies in each sector is given and that there exists a technical progress, which improves technology parameters.

In each type of the simulation scenario two variants are considered. The first one (mild variant) assuming that the number of the emission allowances from the year 2030 on settles at the level of 57% of the initial emission level in 2010. The second (restrictive variant) assumes further reduction of the number of allowances from the level of 57% of the initial emission level in 2010 achieved from 2030 to 2050, when it settles at the level of 45% of the 2010 level.

Static scenarios

In all simulation scenarios a simplifying assumption has been adopted that before 2010 only old technologies had been in use so that the choice of technology starts in 2010. Also the initial level of foreign debt has been assumed to be equal to zero (simulation results were insensitive to that quantity). In all variants, solutions of the model converged to the steady state so that it was sufficient to present the development of variables till 2070.

The development of GDP, consumption, investment and emissions paired with relevant allowances are presented in figure 1.

In all sectors but sector I (having negligibly low emissions in both technologies), new technologies replaced old ones in the investment outlays. It is necessary to note that in the energy sector the most expensive technology has been chosen (the one interpreted as the renewable). This can be explained by the severity of the end-period emission constraints. However, because of the volatility of supply from this source of energy, it is worth considering additional constraint setting the maximum share of the third technology in the total energy output.

A necessity to adjust to the lowest emission levels at the end period forces the economic system to cumulate consumption at the beginning period, figure 1, panel (b), with the similar impact on investment, figure 1, panel (c), and GDP, figure 1, panel (a). As a result, after the initial growth period lasting to 2013, there comes recession and then stagnation, both determined by the low admissible level of emission.

Having in mind that the commented results were based on the assumption of fixed price relation and the absence of the technical progress, these results indicate that in such conditions it would be more effective to build considerable surplus in foreign trade, figure 4b, supporting the level of consumption in the end period.

As could be expected, investment and foreign exchange are the most volatile variables with variability concentrated in the beginning period.

The results described above explain the behavior of the economic system without the technical progress.

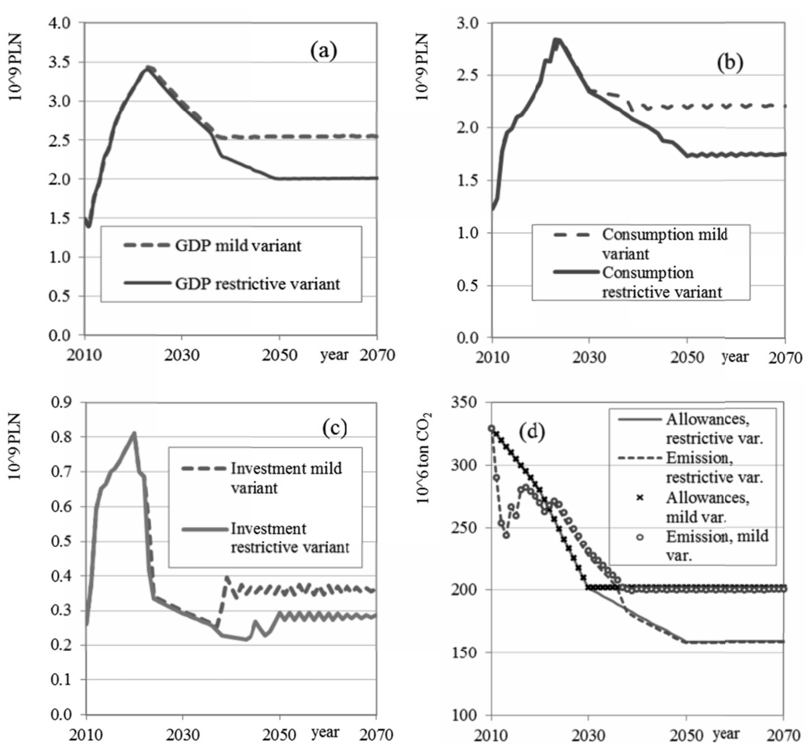

Figure 1. GDP in the mild and restrictive variants, panel (a), consumption in the mild and restrictive variants, panel (b), investment in the mild and restrictive variants, panel (c), emission allowances and emissions in the mild and restrictive variants, panel (d)

Source: own calculations.

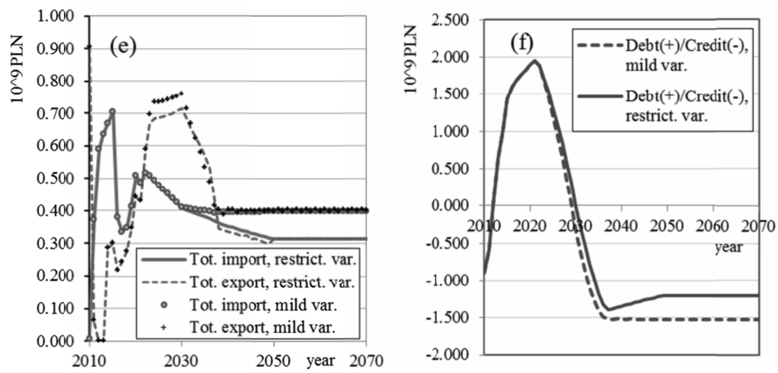

Figure 2. Total exports and imports, left hand panel, debt (if positive) or foreign assets (if negative), right hand panel, in the mild and restrictive variants

Source: own calculations.

4. CONCLUSIONS

Results obtained by the proposed model confirm its applicability in the analysis of the impact of the policy of curbing the GHG emissions on the national economy. This model should not be treated as the substitute but as a supplementary analytical tool used along the CGE models. One has to keep in mind the fact that the results are presented in constant prices, and that exogenous evolution in prices can be considered, given a credible scenario.

The technological conversion significantly affects the sectoral structure of the economy. The development of the shares of the gross output of each sector in the total gross output is presented in figure 3. One can observe that an increased share of the energy sector achieves the second position in the end period (not because of increased production but because of the high cost of the cleaner technologies).

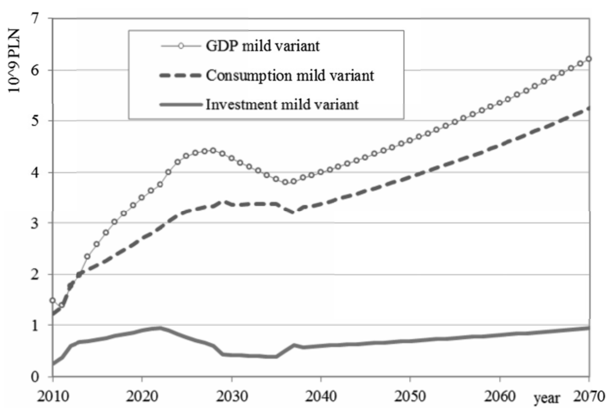

Figure 3. Development of GDP, consumption and investment according to the model with assumed yearly 1.5% decreases of the unit emissions of all technologies, mild variant, constant prices

Source: own calculations.

Economics would remain a dismal science, if the technical progress did not exist. In the presence of the technical progress expressed in the form of yearly 1.5% improvement (decrease) of the unit emission rates, main results with such technical progress accounted for are presented in figure 4.

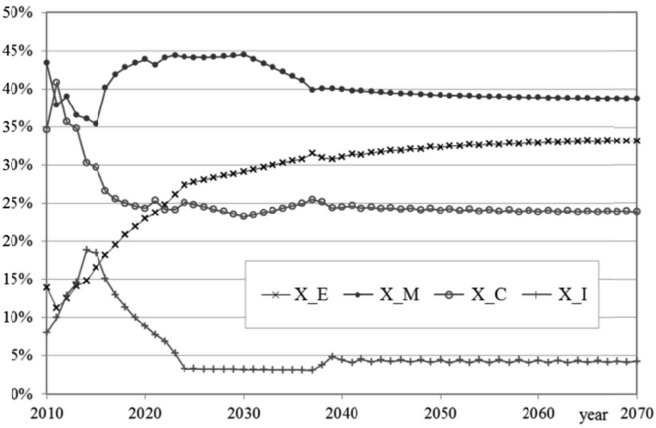

Figure 4. Changing shares of sectors in total output in constant prices
Source: own calculations.

The results presented in figure 4 show that the technical progress slightly extends the initial growth period, however it is also succeeded by a shorter recession period. Its depth is obviously determined by the rate of the technical progress.

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OCENA WPŁYWU REDUKCJI EMISJI GAZOWYCH NA WZROST GOSPODARCZY POLSKI. ZAŁOŻENIA I WSTĘPNE WYNIKI

Streszczenie

W pracy przedstawiono model służący do oceny procesu konwersji technologicznej będącej następstwem ograniczania emisji gazów cieplarnianych. Limity emisji są wprowadzane w celu ograniczenia ocieplenia klimatu, czego skutkiem jest ograniczenie wzrostu gospodarczego. Konwersja technologiczna oznacza wybór czystszych, lecz ekonomicznie mniej sprawnych technologii. W rezultacie, długookresowy wzrost gospodarczy zmienia charakter: ze wzrostu względnie swobodnego ograniczonego przez dostępność czynników produkcji, zasobów oraz tempa postępu technicznego, na wzrost ograniczany ponadto przez dodatkowe ograniczenie – limit emisji. Analizę przeprowadzono przy pomocy modelu opartego na założeniach różniących się od stosowanych w budowie modeli CGE. Model składa się z następujących sektorów: a) konsumujący (obejmujący gospodarstwa domowe i sektor publiczny), b) wytwarzający dobra (z wyłączeniem energii) kupowane przez sektor konsumujący, c) wytwarzający nakłady pośrednie (bez energii) zużywane przez wszystkie sektory produkcyjne, d) wytwarzający energię zużywaną przez wszystkie sektory, e) wytwarzający dobra inwestycyjne kupowane przez wszystkie sektory produkcyjne. Wszystkie sektory produkcyjne realizują wspólny cel maksymalizacji zdyskontowanej wartości konsumpcji dla całego okresu optymalizacji, przy czym wielkości produkcji, inwestycje w poszczególne technologie w sektorach oraz salda wymiany zagranicznej stanowią zmienne decyzyjne. Model jest rozwiązywany jako zadanie optymalizacji liniowej. Rozwiązanie modelu jest traktowane jako wielkość referencyjna, nie obejmuje narzędzi polityki gospodarczej służących realizacji celu.

Słowa kluczowe: modelowanie ekonomiczne, polityka ekonomiczna, zmiana technologii, polityka ochrony środowiska

ASSESSMENT OF THE IMPACT OF THE REDUCTION OF THE GASEOUS EMISSIONS ON GROWTH IN POLAND. ASSUMPTIONS AND PRELIMINARY RESULTS

Abstract

The paper presents a model aimed at assessing the process of technology conversion imposed by limits of the greenhouse gas (GHG) emission. These limits are being introduced in order to stop climate warming, but by themselves they also inevitably curb economic growth. The change signifies choosing cleaner but economically less efficient technologies. In effect, the nature of the long-term economic growth is thus changed from a relatively free growth constrained by the availability of resources, production factors and technical progress, to that codetermined by the new constraint: the emission limit. The analysis is performed by using a model based on assumptions different from those applied in the CGE modelling. The model consists of the following sectors: a) consuming (both households and public); b) producing non-energy goods purchased by the consuming sector; c) producing intermediary non-energy inputs used in all producing sectors; d) producing energy consumed in all sectors; and e) producing investment (capital) goods purchased by all producing sectors. All economic agents pursue a common goal of achieving maximum total discounted consumption over the whole period of analysis, while the outputs in sectors and technologies, investment in sectors and technologies, as well as net foreign trade in sectors are decision variables. The model is solved using linear optimization. The model results constitute a benchmark; no economic tools are indicated for achieving the optimum.

Keywords: economic modelling, economic policy, technological change, environmental policy