Summary

The paper investigates an adjustment of the economy to the instruments of the pollution limiting policy. To adapt to the tighter limits, the enterprises have to replace cheaper, more polluting technology by a cleaner, more capital-intensive one. In the long run the economic growth helps in achieving the emission limits by improving emission intensity of production. Such effects are caused by the technical progress associated with the R&D efforts and also by learning of the economic agents. Our attention was focused on duration of the transition process with respect to the viable investment rates in the parts of the economy. In order to investigate the above mentioned adjustment, a three-sector model has been used, with sectors producing, respectively, intermediary goods, consumer goods, and capital goods. The aim was to study the changes of the sector structure and behavior of sectors during the period of technology conversion. The output of each sector is determined by the demand for its product. Demand for the product of a sector is a sum of demands generated in all sectors. Firms in each sector choose between available technologies, to fulfill the emission limits. In the long-term, the economy achieves a growth rate related to the rate of reduction of emission intensity. All calculations have been performed using the data for Poland.

Keywords: emission limits, macroeconomic structure, technology change, technical progress.

1. Introduction

Emission limits agreed upon by intergovernmental agreements such as the European Union Directives are main tools of controlling the greenhouse gas pollution. The limits concern total country emissions and determine minimum shares of output from preferred technologies in total supply (from the renewable sources, for example). The technology structure of production is a result of adjustment of the economic agents at the microeconomic level to the tools of the macroeconomic policy. This paper aims at tracing consequences of such limits for the economic growth of a small country economy.

Following the early models for analyzing the greenhouse gas (GHG) emission impacts and climate policy effects, like Global2010 [12] or DICE [16], many their modifications and particular modeling solutions has been proposed. Especially DICE model enjoys broader attention and many of its revisions has been proposed [9, 17]. 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. In modeling the climate policy the technology change links the economic growth with GHGs reduction.
Classical approach of modeling the technology change is to consider research and development (R&D) sector [8, 14], as well as such phenomena like the knowledge dissemination and spillover [1] and learning [19].

Impact of R&D on environment has found more attention in Goulder & Schneider [7] and Hart [9]. In Goulder & Schneider [7] the knowledge in the consecutive period increases as a result of R&D activity in the previous period. In Hart [9] a planner, a market or a regulator controls allocation of labor between the vintages and different types of research; the skilled labor is allocated between generations of capital and two forms of research, an ordinary and an environment friendly one. Conway et al. [3] also discuss the reallocation of human capital. Pareto [18] studies effects of effluent taxes on firms’ allocation of resources to cost- and emission-reduction R&D.

A straightforward approach is presented in Riahi at al. [19] 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, and the learning-by-doing model, proposed by Wright [20], is adopted. In this model the average production cost decreases exponentially with the production scale.

We follow a different approach\(^9\). The model used in this paper is aimed at the analysis of the adjustment of a small country economy to the emission limits determined by the European Union Directives. Our approach to the technical progress is based on the observation that it is hardly predictable, difficult to control and considerably contributes to the uncertainty in the long-term decision making. In this approach attention is focused on the problem: what is the technological adjustment in the long-term framework.

In order to analyze this problem the three-sector macroeconomic model with two competing/coexisting production technologies in each sector has been used [6]. The aim of the model is to analyze different scenarios of economic growth, emissions limits, as well as technical progress. In our approach producers choose between distinctive technologies, which correspond to distinct generations of capital: (i) the cheapest dirtiest (“old”) one and at the same time the least capital intensive, (ii) the cleanest but the most expensive one.

Three sectors have been distinguished: M - producing goods used as material inputs (raw materials, energy, and the production and infrastructure services), C – producing consumption goods and services, and I – producing investment goods. The public sector has been included in the consumption sector. Such a division aims at capturing production structure of the economy in terms of main macroeconomic categories.

The model does not account for the impact of polluting emissions on the technology parameters. All categories are presented in real terms.

We focus on the long-term path omitting the short- and mid-term business cycle fluctuations, and therefore the model is the long-term one and follows the equilibrium path. All sectors are in the equilibrium of the Keynesian type in every period, so that the utilization of the production capacity at the technology level, as well as the sector and economy as a whole, varies and can be far from the full one. Allocation between sectors is unconstrained.

We propose gradation of the technology choice dynamics and change, by distinguishing the following approaches to the impact of the technical change/progress: basic, moderate and comprehensive. The basic approach is static; only a given number (restricted to two) of not

\(^9\) This paper is a continuation of an earlier study, [5], [6].
evolving technologies is available. Such an attitude makes it possible to analyze economic structure during the unrestricted growth and after the imposition of the emission limits.

In the moderate approach, there are also two available technologies at the sector level; however, their parameters evolve because of the long-term technical improvement. As the evolution is hard to capture, adopting the simplest assumptions concerning the future seems relevant. Thanks to such an attitude, it is possible to analyze economic structure after the imposition of the emission limits in the presence of the technical improvements and in the absence of qualitative changes. In the comprehensive approach, the number of available technologies is greater and their parameters evolve. However, we do not consider such an attitude at this stage of our research, as it would require too many assumptions concerning future technologies.

The model developed is an optimization one. We are fully aware that even in the centrally planned economies there was nothing like optimum path. In this case, however, solution of the optimization problem can be interpreted as reference performance of the economy in certain conditions, assuming the economy as a whole behaves optimally. Moreover, one has to remember that in this context optimality is conditioned by the fact that production capacities are assessed at their average values and not maximum ones.

The main difference between this study and the former ones is in employing regularization in the optimization algorithms. This was found to be necessary, as the previous results revealed excessive volatility of main decision variables, namely investment in particular technologies, which is completely unfeasible in the world of real economies.

2. Model and its properties

Technology is a way of production using specific techniques, capital assets and production procedures. We assume that, both at the micro as well as the macro levels, one can distinguish reasonably small number of “pure” technologies and that any “real” technology can be represented as the linear combination of the pure ones. In particular, for example, a requirement of certain share of the renewable technologies in total output can also be presented as separate technology. Therefore we consider just two distinctive technologies.

Supply

Technology in any sector is described by the following set of parameters:

- \( \gamma_{ijt} \) - productivity of capital in the \( i \)-th sector, \( i = M, C, I \); using the \( j \)-th technology, \( j = 1, 2 \); in the year \( t \), \( t = 1, \ldots, T \);
- \( \delta_{ijt} \) - depreciation rate of capital in the \( i \)-th sector, \( i = M, C, I \); using the \( j \)-th technology, \( j = 1, 2 \); in the year \( t \), \( t = 1, \ldots, T \);
- \( \alpha_{ijt} \) - intensity of usage of goods produced in the sector \( M \) in production of the \( i \)-th sector, \( i = M, C, I \); using the \( j \)-th technology, \( j = 1, 2 \); in the year \( t \), \( t = 1, \ldots, T \);
- \( \mu_{ijt} \) - unit emission in the \( i \)-th sector, \( i = M, C, I \); using the \( j \)-th technology, \( j = 1, 2 \); in the year \( t \), \( t = 1, \ldots, T \).

Potential gross output \( Q_{ijt} \) produced in the \( i \)-th sector, using \( j \)-th technology, in year \( t \), equals:

\[
Q_{ijt} = \gamma_{ijt} K_{ijt}, \quad i = M, C, I; \quad j = 1, 2; \quad t = 1, \ldots, T,
\]
where $K_{ijt}$ stands for the stock of the capital in the $i$-th sector and using the $j$-th technology at the beginning of the year $t$. In (1) we assume that the labor is abundant so that it does not act as a barrier to growth. In this paper, the potential gross output is interpreted as the full production capacity.

Actual gross output $X_{ijt}$ in the $i$-th sector, $i = M, C, I$; using the $j$-th technology, $j = 1, 2$; in the year $t, t = 1,..,T$; accounts for the fact that production capacity is hardly ever fully used:

$$X_{ijt} = \lambda_{ijt} \gamma_{ijt} K_{ijt}, \quad i = M, C, I; \quad j = 1, 2; \quad t = 1,..,T,$$

(2)

where $\lambda_{ijt}$ stands for coefficient of the production capacity utilization in the $i$-th sector, $i = M, C, I$; using the $j$-th technology, $j = 1, 2$; in year $t$, assuming values from the range $[0;1]$, in particular 0 indicates fully idle capital and 1 represents full utilization of the production capacity. Coefficient $\lambda_{ijt}$ can be only roughly estimated, therefore the equation (2) is necessary. Total actual output of the $i$-th sector is the sum of the outputs produced using both technologies:

$$X_{ij} = X_{ij1} + X_{ij2}, \quad i = M, C, I; \quad t = 1,..,T.$$

(3)

Capital stock $K_{ijt}$ in the $i$-th sector, $i = M, C, I$; using the $j$-th technology, $j = 1, 2$; in the year $t, t = 1,..,T$; is given by the standard relationship:

$$K_{ijt} = K_{ijt-1} + I_{ijt-1} - \delta_{ijt} K_{ijt}, \quad i = M, C, I; \quad j = 1, 2; \quad t = 1,..,T,$$

(4)

where $I_{ijt}$ denotes investment in the $i$-th sector, $i = M, C, I$; using the $j$-th technology, $j = 1, 2$; in the year $t, t = 1,..,T$; and the term $\delta_{ijt} K_{ijt}$ denotes depreciation of the capital in the $i$-th sector, $i = M, C, I$; using the $j$-th technology, $j = 1, 2$; in the year $t, t = 1,..,T$. Investment outlays in (4) are assumed to be non-negative, which means that capital decreases without investment because of physical depreciation only; we do not assume other ways of removal of the capital assets (early decommission). Note that there is only one year lag between the investment and its contribution to the stock of fully operational capital.

Production of the $i$-th sector using $j$-th technology causes emission $E_{ijt}$ of greenhouse gases:

$$E_{ijt} = \mu_{ijt} X_{ijt}, \quad i = M, C, I; \quad j = 1, 2; \quad t = 1,..,T,$$

(5)

where $\mu_{ijt}$ denotes emission per unit of actual output in the $i$-th sector, $i = M, C, I$; using the $j$-th technology, $j = 1, 2$; in the year $t, t = 1,..,T$. Emission $E_{it}$ of the $i$-th sector is equal:

$$E_{it} = E_{i1t} + E_{i2t}, \quad i = M, C, I; \quad j = 1, 2; \quad t = 1,..,T,$$

(6)

and the total emission is the sum:

$$E_t = E_{M1} + E_{C1} + E_{I1}, \quad t = 1,..,T.$$

(7)

Demand

Having in mind equation (3), supply of the sector $M$ equals the sum of the consumptions of these goods and services in all sectors:

$$X_{Mt} = \alpha_{M1t} X_{M1t} + \alpha_{M2t} X_{M2t} + \alpha_{C1t} X_{C1t} + \alpha_{C2t} X_{C2t} + \alpha_{I1t} X_{I1t} + \alpha_{I2t} X_{I2t}, \quad t = 1,..,T.$$

(8)
where $\alpha_{ijt} X_{ijt}$ denotes consumption of goods and services produced by the sector $M$ in the $i$-th sector, $i = M, C, I$; using the $j$-th technology, $j = 1, 2$; in the year $t$, $t = 1, \ldots, T$.

Output of the goods and services supplied by the sector $C$ equals the sum of their consumptions $C_t$ in all sectors:

$$X_{C1} = X_{C1t} + X_{C2t} = C_{M1t} + C_{M2t} + C_{C1t} + C_{C2t} + C_{I1t} + C_{I2t}, \quad t = 1, \ldots, T;$$

where $C_{ijt}$ denotes consumption demand in the $i$-th sector, $i = M, C, I$; using the $j$-th technology, $j = 1, 2$; in the year $t$, $t = 1, \ldots, T$; while $C_{it}$ stands for the consumption demand of the $i$-th sector, $i = M, C, I$; in the year $t$, $t = 1, \ldots, T$.

Output of the goods and services supplied by the sector $I$ equals the sum of demands for these goods in all sectors:

$$X_{I1} = X_{I1t} + X_{I2t} = I_{M1t} + I_{M2t} + I_{C1t} + I_{C2t} + I_{I1t} + I_{I2t}, \quad t = 1, \ldots, T;$$

Decisions

In the short-term, firms maximize profit, but in the long-term the aim of decision-makers is the maximum discounted total consumption in the infinite time horizon:

$$\max \left\{ \sum_{t=1}^{\infty} (\sum_{i=M, C, I} \sum_{j=1, 2} C_{ijt} (i + r)^{-t}) \right\},$$

where $r$ denotes discount rate, subject to the following constraints.

Balance of production (consumption as a residual)

$$C_t = \sum_{M, C, I} \left[ \sum_{j=1}^{2} (1 - \alpha_{ijt}) X_{ijt} - I_{it} \right];$$

Politically safe consumption

$$C_t \geq \eta \sum_{M, C, I} \left[ \sum_{j=1}^{2} (1 - \alpha_{ijt}) X_{ijt} \right];$$

where $\eta$ stands for the minimum consumption rate. This constraint reflects impact of the political resistance to the policy of forced conversion on the one hand, and on the other hand, it imposes policy limits as to the extent of possible sacrifices in consumption.

Emissions satisfy the following constraints:

$$L_t \geq \sum_{i=1}^{5} E_t,$$

10At this point, the limits are the EU (ETS) type. In the essence the EU imposes in the long-run decreasing yearly emissions, with limits diminishing in consequent subperiods determined by the EU directives.
where: $L_1, \ldots, L_N$, are decreasing emissions limits for succeeding $N$ periods, and $L_{N+1}$ is the yearly limit in the $N$-th period.

\[
L_{N+1} \geq E_t, \quad \text{for} \quad t > t_{N+1}.
\]

Regularization constraints:

\[
D_{i,\text{min}} \leq I_{t+i+1} - I_{t+i} \leq D_{i,\text{max}}
\]

where parameters $D_{i,\text{max}}$ and $D_{i,\text{min}}$ denote respectively maximum one-period increase and decrease of investment in given technology and sector.

The most important properties of the model (1)-(18) have been described in [4], with consideration of the following problem: relation between growth and proportions between the sectors in the static approach. These proportions are as follows.

An economy, described by the above model, using single technology in each sector and having no emission limit, growing with the constant growth rate $r$, follows the mid-term growth path maintaining fixed proportions between output of the sectors:

\[
X_{M_1} = \frac{r+\delta_M}{\lambda_M \alpha_M} \frac{r+\delta_C}{\lambda_C \alpha_C} \frac{1-r}{\gamma_M} \frac{1-r}{\gamma_C}.
\]

\[
X_{C_1} = \frac{r+\delta_M}{\lambda_M \alpha_M} \frac{r+\delta_C}{\lambda_C \alpha_C} \frac{1-r}{\gamma_M} \frac{1-r}{\gamma_C}.
\]

Note that equations (20) and (21) together with equation (1) imply adequate proportions of capital in sectors. Note also that whenever such an economy achieves the emission limit, then it can grow at the zero growth rate with the proportions defined by the following equations:
The sets of equations (20) and (21) as well as (22) and (23) are sufficient for the comparative static analysis in the cases of single technology in each sector and/or if there occurs conversion from one technology to another.

3. Simulation results

Initial values were determined for the Polish economy in 2005, while the parameters were roughly estimated using available macroeconomic data from the period 2000-2005. For all scenarios, only two technologies available to each sector are considered: existing or the old one, and new, less polluting, however more expensive. The old technology in the case of Poland is mainly associated with the energy generated by traditional burning of fossil fuels (mostly coal). The new, more expensive technology is a mix of the old one as well as the nuclear energy (not used in Poland) and required by the EU share of the renewable sources. Obviously, no conversion to the cleaner technologies will occur without emission limits. Our aim is to analyze the process of technology conversion in the time and sector structure aspects.

Here, we consider the Moderate Scenario based on the assumption that the productivity of capital in all technologies grows with constant growth rate in response to the demand. Model runs on yearly data and the starting year, numbered 1, is equivalent to the calendar year 2006. A linear programming algorithm is used to solve the optimization problem.

Results show that under given assumptions old technology is immediately abandoned in such a sense that all investment outlays are directed onto the new technologies. Figures 1, 2 and 3 show, respectively, investment in sectors $M$, $C$ and $I$ in new technology. Sector structure of investment is uneven. Fig. 1 shows that in the first period investment is concentrated in sector $M$ and is very intensive, while investment in sector $C$ is postponed for 22 years, Fig. 2, while in sector $I$, Fig. 3, there is no investment in the period between the eighth and thirtieth year.
Fig. 1. Yearly investment in new technology in sector M, in million zlotys

Source: Own computations.

Fig. 2. Yearly investment in new technology in sector C, in million zlotys

Source: Own computations.

Fig. 3. Yearly investment in new technology in sector I, in million zlotys

Source: Own computations.
Changed structure of investments does not reveal whole picture of the behavior of the sectors. The following figures show utilization of the production capacities in the sectors and technologies.

In this aspect the sectors behave differently. While new technology is fully utilized in all sectors, the use of the old one differs, Fig. 5, Fig. 7 and Fig. 9. In the sector M old technology is used marginally and only during first seven years, Fig. 4.

![Fig. 4. Yearly production capacity (solid line) and actual output (dotted line), old technology, in million zlotys, sector M.](image1)

Source: Own computations.

In the sector C old technology is used for the longer time, Fig. 6. In this respect, the sector I behaves in a similar way as the sector M, Fig. 8. It should be noted that the restructuring of the economy is possible on the expense of consumption and is guaranteed by constraint (13).

![Fig. 5. Yearly production capacity (solid line) and actual output (dotted line), new technology, in million zlotys, sector M.](image2)

Source: Own computations.
Fig. 6. Yearly production capacity (solid line) and actual output (dotted line), old technology, in million zloties, sector C

Source: Own computations.

Fig. 7. Yearly production capacity (solid line) and actual output (dotted line), new technology, in million zlotys, sector C

Source: Own computations.

Fig. 8. Yearly production capacity (solid line) and actual output (dotted line), old technology, in million zloties, sector I, in million zlotys

Source: Own computations.
In the analysis of the process of technology conversion, one can distinguish distinct stages. The first one is the period of exploitation of the old technologies. In the second stage, old technology is abandoned while the new one is being intensively introduced. At the third stage the model achieves steady state; it takes approximately 22 years to achieve equilibrium path.

In a series of simulations duration of this period depended on the emission limit; the smaller limit the shorter first period of conversion.
4. Conclusions

It can be stated that technical progress acts as a factor easing constraints determined by the emission limits as it lets the sectors to achieve equilibrium at higher levels of output. Thanks to that, the conversion lasts longer than in the Basic Scenario.

All sectors immediately abandon old technologies; however, investment in the sectors is less intensive. Output is volatile in the sectors $M$ and $C$ while in the sector $I$ for the period of twelve years investment is negligible. Another important feature of this scenario is the way the production capacities are used. In the Moderate Scenario, the sector $M$ at the second stage (years 15-30) does not use full production capacity. (in this paper utilization of production capacity is relative). Completion of the second period of conversion takes in the Moderate Scenario longer than in the basic Scenario – about 30 years. The model reveals considerable dynamic behavior (volatile investment) which is improbable in the real-world economy. This has been corrected to some extent by introducing constraints concerning rates of investment growth.

The above presented results show that economy is not always a dismal science; the technical progress provides hope for the sustainable growth accounting for environmental impact of
economic activity. From the above considerations, it can be concluded that the imposition of the greenhouse gases emission limits can be an effective way of enforcing technology conversion. However, it causes the slow down to the consequent growth rate of the productivity of capital and decrease of the unit emissions. Without the effects of technical progress, economy achieves steady state or the zero-growth equilibrium.

Smaller demand for the output from the old technology can cause drop in the production costs, therefore increasing the competitiveness of the old technology. This so called green paradox cannot be considered within the framework of our paper, as this study has been performed on the basis of assumed constant prices.

Bibliography


Wpływ polityki ograniczania emisji na konwersję technologiczną i strukturę makroekonomiczną

Streszczenie


Słowa kluczowe: ograniczenia emisji, struktura makroekonomiczna, zmiana technologiczna, postęp technologiczny.

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