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MACROECONOMIC CONSEQUENCES OF INRODUCINIG TAXES ON CARBON DIOXIDE EMISSION IN POLAND

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Scanning Policy Scenarios for the Transition to Sustainable Economic Structures

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1. Introduction

For a couple of decades ecological issues struggled for recognition and equality among the economic sciences and for twenty years or so they have constituted their integral part. Initiated by the Report of Rome, the process of informing the society about the scale of potential worldwide environmental dangers resulted in a plenty of international initiatives aiming at reducing or even diverting the adverse tendencies in devastation of nature. This is so because an innate feature of ecological processes is their supranational character making them inappropriate be treated solely as domestic problems of individual countries.

Development of theoretical foundations of environmental management led to elaboration of the concept of *sustainable growth*, according to which the economic development of present generations should not proceed at the expense of the future generations' right to satisfy their needs. In particular, this means that the future economic growth of the world must not lead to wasteful exploitation of the existing natural resources and, what is more, it should keep natural environment in sound condition (see e.g. T. Bańkowski [2004]). Not abiding by the principles of sustainable growth might even endanger further existence of humanity (see e.g. A. Budnikowski [1994]).

Among the issues being in the center of interest to ecological economics a special priority is given to air pollution. This is because of a global character of this phenomenon as well as because of the scale of potential threat resulted from the greenhouse effect (see e.g. B. Bolin et al [1986]). It follows from various researches (see e.g. W. R. Cline [1991]) that the main reason why the greenhouse effect is taking momentum is the increasing concentration of carbon dioxide in the Earth's atmosphere caused by emission of greenhouse gases, GHG, due to man's economic activity.

In order to counteract or at least considerably limit the adverse consequences of the greenhouse effect, the OECD countries, being major emitters of GHG, agreed in the so called Kyoto Protocol (see e.g. M. Sadowski [1999]) to reduce their CO_2 emissions in line with the Protocol's schedule. For transition economies the year 1988 was appointed the base year, whereas for the others: the year 1990. For computation simplicity the emission of GHG other than carbon dioxide (among which methane and nitrous oxide in the first place) has been expressed in CO_2 equivalent. Thus, further on in the paper emission of all GHG will be associated with CO_2 emission only.

Poland, being a signatory to the agreement, committed herself to reduce her emission by the year 2010 to the level of 94% if compared to the base 1988 year. It follows from the latest investigations (see M. Sadowski [1999], M. Sadowski, Olecka A. [2001] or El Raey et al [2003]) that Poland should not have much difficulty in reaching that target, even if no additional measures were undertaken to facilitate this task. However, bearing in mind the fact that Poland might largely benefit from the mechanism of the word emission trading scheme proposed in Kyoto, as well as the priority given to ecological issues in the EU, it might be of much both academic and political interest to analyze possible ways of accelerating the reduction in CO_2 emission.

From among available instruments of ecological policies (see e.g. Famielec [2000]), it is the economic ones that are of the highest effectiveness due to their superiority over direct regulations (see e.g. M. Sadowski, Olecka A. [2001]). In turn, most popular economic instrument, so far successfully implemented in some highly-developed countries (see e.g. J. Norregaard, Reppelin-Hill V. [2000]), are taxes imposed on carbon dioxide emission.

The paper is an attempt to quantify the possible macroeconomic consequences of introducing CO2 taxes in Poland by means of a modified version of a W8D-2002 econometric model of the Polish economy (see W. Welfe et al [2004]).

In section 2 analytical tools and methodology of the research are reported. Section 3 describes assumptions of the BAU scenario and its results. Section 4 presents assumptions of alternative simulation variants along with the results and their interpretation. Section 5 concludes.

2. Methodology

In order to quantify the influence of carbon taxes upon major economic indicators, it is necessary to possess a proper analytical tool that would allow for the simultaneity between CO_2 tax rates, volume of emission and economic activity. Any other analysis that would ignore such simultaneity would be at best incomplete.

So far, no investigations into so defined a problem have been carried out in Poland. The existing attempts in this respect are limited only either to qualitative elaborations (see e.g. M. Cygler et al [1998]), or to construction of purely theoretical models (see Posłuszny K. [1992]) or, finally, only to some selected aspects of the problem, not accounting for the simultaneity (see e.g. M. Plich [2000]).

A *top-down* methodology implemented in the research is based, first of all, on modelling economic processes by means of time series econometric methods. The only exception is an equation generating volume of carbon dioxide emission, whose parameters have been calibrated. The main analytical tool of the analysis is a modified model of the national economy of Poland: W8D-2002.

2.1 Initial version of the W8D-2002 model: economic aspects

Model W8D-2002 is the latest version of a family of W8 models (see Welfe W., Welfe A., Florczak W., [1996], Florczak W., [1999], Welfe W. (ed.), [2001]), constructed at the Department of Econometric Models and Forecasts, University of Lodz, Poland. It is a one-sector econometric model, explaining basic macroeconomic mechanisms typical of transition economies (see Welfe W. (ed.), [2004]). The model contains blocks of equations accounting for both long-term supply-side production factors (human capital, total factor productivity, potential output, ratio of capacity utilization) and demand conditions of Poland's socio-economic growth.

Specifications of particular equations of the W8D-2002 rest on the extensive macromodelling experience described both in the world and in the Polish literature on the subject (see e.g. Bodkin et al [1991], Dreze et al [1990], Whitley [1994], W. Welfe [1992], W. Welfe, A. Welfe [2004]). They allow for particular mechanisms with respect to producers and state institutions existent in the Polish economy in the transition period.

Basic equations of the model (production function, consumer and investment demand functions, formation of human capital, price and wage equations, etc.) are stochastic. Consequently, to get sufficiently long and coherent time series, one had to construct a homogenous data base (see W. Florczak [2003]).

Parameters of individual equations were estimated on the basis of annual frequency data covering, in general, 41 observations (the years 1960-2000). Information on the majority of financial entries have been available only since the early or even mid 90s. In such a case proper estimates were obtained by means of calibration rather than estimation.

Due to the fact that the estimation sample covered various economic regimes, in which the economy of Poland used to function during the last 40 years, numerous parameters were made vary by means of appropriate interaction variables or piece-wise regression. The estimates obtained for given parameters differ then within particular sub-periods, describing the diversified intensity, with which regressors affect individual regressands. In extreme cases, a given explanatory variable may be present in one regime, whereas absent in another (this is often the case in numerous equations regarding price incentives in the W8D-2002 model).

Model W8D-2002 contains the following blocks of equations, distinguished for essential and technical reasons:

a) domestic final demand,
b) foreign trade by national accounts,
c) production factors and their productivity,
d) human capital,
e) outlays on research and development,

f) employment

g) wages, incomes and prices,

h) financial flows,

i) state budget,

j) balance of payments.

Model W8D-2002 in its simulation versions includes 216 equations, of which 80 are stochastic, and 136 identities. The model is strongly simultaneous and dynamic, with a lot of feedbacks. Its prologue block contains 24 equations, simultaneous block: 98, and epilogue block: 94 equations. There are 8 feedback variables in the model.

The most important macroeconomic simultaneous relationships existent in the model on its demand-side are as follows:

1) between consumption, production and employment: the so called consumption multiplier. Wages, salaries and social benefits shape real incomes of households. The incomes determine private consumption that, in turn, further co-determines final demand and GDP. An increase in GDP translates, with some lag, into an increase in demand for labour force. Consequently, employment rises, which under fixed prices leads to additional increment in households' incomes;

2) between budget expenditures, production and employment: the so called fiscal multiplier. An increase in budget expenditures leads to an increment in social benefits, owing to which the consumption multiplier initiates;

3) between investment outlays and production: the so called accelerator principle. An increase in the investment demand entails an increment in the final demand and, consequently - if there are free capacities - in GDP. The increase in GDP leads, in turn, to an additional growth in investment as the former is one of the determinants of the latter;

4) between prices and wages: the so called inflationary spiral. An increase in nominal wages causes an increment in unit costs, which leads to a growth in inflationary processes.

Of the supply-side feedbacks leading to a rise in potential production the most important are the following:

5) between gross investment outlays (including FDI) and fixed assets;

6) between absorption of imported R&D and total factor productivity;

7) between domestic outlays (from the budget and from private means) on R&D and total factor productivity;

8) between budget expenditures along with households' outlays on tertiary education and formation of human capital.

2.2 Modified version of the W8D-2002 model: ecological aspects

Elaborated for the purpose of analyzing long-term macroeconomic policy scenarios for Poland, the W8D-2002 model - in its initial version - did not use to treat ecological issues. In order to enrich its application capability by ecological aspects so as to enable analyses of the effects of introduction of taxes upon CO_2 emission, the model had to be properly extended and modified. To this end, a key equation generating carbon dioxide emission was introduced into the model, whereas equations generating budget revenues and prices were altered to allow for the economic effects of carbon taxes.

Initially, to be in line with the methodology implemented while constructing the W8D-2002 model, an attempt was undertaken to explain CO_2 emission within an econometric framework. However, due to an abrupt decline in Poland's CO_2 emission in the 90s caused by rapid adjustments on both the demand and supply sides, as well as relatively short sample, this attempt fell flat. The obtained estimates proved unrealistic to hold in the future. Thus, an alternative approach taken consisted in imposing realistic estimates upon parameters under interest. It has been assumed that the emission volume is a function of the following explanatory variables :

a) overall economic activity, measured by means of GDP; under *ceteris paribus*, implicitly presuming no technological progress, the elasticity of the emission with respect to GDP equals 1;
b) technological progress, approximated in model W8D-2002 by total factor productivity (TFP); its elasticity with respect to the emission has been assumed to equal -1;
c) taxes imposed on the GHG in zloties per ton of emission; their elasticity with respect to the emission has been calibrated at the level of –0,2 (see Atkinson J., Manning N., [1995]).

In such a defined relation GDP represents a reduced form of demand for carbon dioxide emission (with the missing link being demand for energy), assuming *ceteris paribus* no changes in technologies. This gap is filled by TFP which directly accounts for the effects of technological progress, making implicitly CO_2 and energy intensity decrease in time. Finally, tax rates moderate the demand for energy consumption and, consequently, carbon dioxide emission. The scale of reduction depends here upon the size of carbon tax rates.

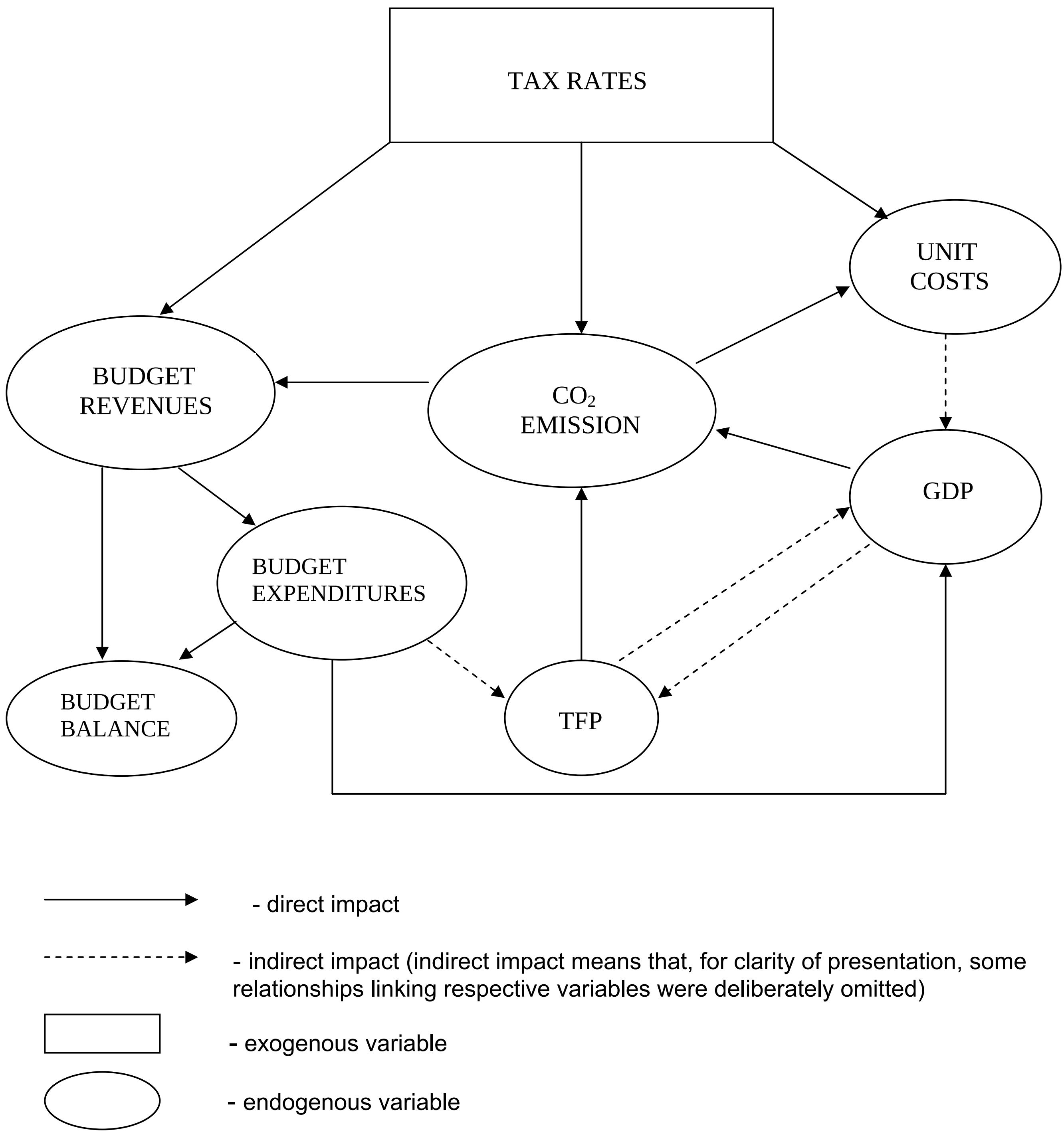
To close to the ecological loop in the W8D-2002 model, another two equations were also modified:

(i) state budget revenues due to carbon taxes (tax rate x CO_2 volume) fed the state budget revenues;
(ii) unit costs of CO_2 emission fed the general unit costs. The influence of carbon taxes upon the general price level is proportional to the tax rates and the emission size.

With such modifications ready, the new version of the W8D-2002 model is well suited to successfully perform the simulations envisaged in the investigation, i.e. to quantify the possible effects of introduction of taxes on CO_2 emission upon the Polish economy.

To give a gist of how the model performs (in its ecological part), let us take advantage of the following scheme:

Scheme 1. The ecological feedback in the W8D-2002 model



On the basis of the above, one is able to trace all the main simultaneous linkages between imposition of carbon dioxide taxes and economic activity. The scheme depicts the main determinants of the simulation results. It follows from the graph that the taxes set into motion two opposing forces influencing the general performance of the Polish economy.

Firstly, on the side of non-financial corporations the carbon taxes lead to an increase in PPI, which in turn translates into a rise in CPI. Consequently, there follows a decline in real disposable income of households, resulting in a drop of GDP.

Secondly, the taxes feed the state revenues, which, if recycled, favourably affect GDP via public expenditure. However, if the revenues due to the carbon taxes are not recycled, then there remains active only the first loop.

The mechanisms depicted in scheme 1 set into motion all the other feedbacks existent in the W8D-2002 model so that the effects of introducing taxes on CO_2 emission can be observed not only for GDP but also for other crucial macroeconomic variables such as e.g. unemployment rate, inflation, budget balance, etc.

3. Assumptions and results of a forecast of Poland's economic growth to the year 2025[1]

Basic forecast assumptions concern, first of all, investment ratios in GDP, investment outlays by the enterprise and by the public sectors, size of subsidies from the EU funds, as well as foreign direct investments. In particular, it was assumed that the share of total investment outlays in GDP would increase from ca 20% in 2004, through 25% in 2010, up to 26% in 2025. The rates of growth of investment outlays will exceed 10% in the first years after Poland's accession into the EU, i.e. in the years 2005-2007, whereas afterwards they are decreasing regularly to reach 5% in the year 2010 and to stabilize at that level in the years to follow.

The outlays are assumed to enable a far going reconstruction of industry and technical infrastructure, especially in export branches, which will induce an improvement in industrial quality as well as in effectiveness of production factors, leading to a higher competitiveness of Polish commodities. This will produce favourable conditions to sustain high rates of growth of exports that will be only slightly decreasing from the initial 9% to 7% at the end of the forecasting horizon.

The above-mentioned assumptions determine implicitly trajectories of growth of final demand. They also affect the dynamics of investment outlays and, consequently of fixed assets and employment/unemployment.

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[1] An exhaustive coverage of both the assumptions and outcomes of the baseline forecast presented here can be found in W. Welfe, Florczak W., Welfe A, [2004], pp. 15-61.

Another group of assumptions refers to the dynamics of the other factors of growth. It was presumed that an active policy of growth would be pursued, which will be manifested by the increasing shares of domestic outlays on R&D in GDP, from 0.67% in 2004 r., through nearly 1% in 2010 r., 1.5% in 2015 r., 2% in 2020 r., to finally 2.5% in the year 2025. Human capital is also supposed to be on the increase due to higher outlays, of order 8-10% (current prices), on tertiary education, whose shares in GDP will rise from 1.38% in 2004, through 1.5% in 2010 r., up to 1.9% in the year 2025. As a result of these tendencies, there will follow a considerable increment in TFP, and consequently, in production capacities and potential GDP.

Mechanisms determining rates of inflation will not change. Only world trade prices are of exogenous character and are supposed to increase smoothly at 4% pace per annum. Basic interest rates will stay at similar levels to those in the EU, i.e. at ca 4%.

Successive governments are supposed to pursue moderate pro-growth policies to sustain high rates of economic growth. No fiscal expansion is envisaged in the forecast. To prevent from possible crisis in public finances, budget deficits will be curbed, which means cuts in public expenditures. Money policy is supposed to be neutral, which is reflected by constant real interest rates.

As far as the emission of carbon dioxide is concerned, no taxes on CO_2 emission are introduced into the baseline forecast. The emission is thus only a function of general economic activity (approximated by GDP) and technological progress (approximated by TFP).

All the above assumptions, supplemented by projections on demographic development of Poland (total number of population, people at productive age, etc.) and on external conditions (world trade volume, world prices) based on international forecasts of the world's economic development taken from the Project LINK sources, after having been translated into the internal language of the SIMPC simulation programme, have generated outcomes reported in table 1 and in figures 1-4.

Within the whole forecast horizon ca 4% rates of growth of labour productivity can be observed, which under the average 5% rates of growth of GDP results in a slow decline in the rate of unemployment. The latter decreases from 20% in 2004 to almost 10% in the year 2025, being thus still relatively high.

Inflation remains low – even by European standards – not exceeding 3%. It is thus considerably lower than the world prices increment, which results in real appreciation of the zloty. As a result, the purchasing power of average wages, expressed in hard currencies (USD, Euro), is increasing much faster than on the domestic markets.

There follows an improvement in effectiveness of management and in the quality of commodities produced in Poland, which is implicitly expressed by high rates of growth of TFP. As a result, irrespective of the real appreciation of the zloty, the rates of growth of exports are higher than those of imports, which leads to favourable tendencies in the trade balance and in the balance of payments.

In the period under consideration Poland undergoes deep technological changes, taking advantage of the effects of the increased domestic outlays on R&D and of higher absorption of imported advanced technologies. Consequently, the rates of growth of the CO_2 emission will be significantly lower than those of GDP, even if no additional governmental initiatives are undertaken.

The forecast covering the next 20 years is quite optimistic. The average rates of GDP growth, that initially exceed 5%, stabilize at 4% in the last 15 years. These rates are higher than those projected for the pre-enlargement EU, where they oscillate between 2 and 3%. This means that the economic gap between Poland and the other countries is going to gradually diminish. This remark holds also for the per capita GDP as Poland's population increment in the period under investigation will be marginal, if not negative.

The above-presented forecast of a long-run economic development of Poland, that assumes no introduction of CO_2 taxes, will be a benchmark for further analyses, in which macroeconomic consequences of imposing such taxes will be analyzed and the effects of various directions of redistribution of the budget revenues due to the taxes will be investigated.

4. Macroeconomic consequences of introducing taxes on carbon dioxide emission

The investigation into the effects of the introduction of CO_2 taxes on the emission volume itself and on the general economic activity is carried out through observing absolute or/and relative deviations from the baseline forecast presented in the previous section, in which no such taxes were existent. Three simulation scenarios are subject to the investigation. Their assumptions are as follows:

a) scenario 1, *no recycling*: no re-investing of additional budget revenues due to the carbon taxes[2];
b) scenario 2, *lump-sum recycling*: re-investing of the additional budget revenues in line with the existent structure of budget expenditures;
c) scenario 3, *re-investing in R&D*: re-investing of the additional revenues in outlays on research and development activities, which means changing the existing structure of the budget expenditures.

[2] Which is tantamount to breaching the direct link between the budget revenues and budget expenditures, presented in scheme 1. Thus the additional revenues due to CO_2 emission do not feed the economy on the demand side, leading only a decrease in the state budget and, consequently, in the public debt.

Table 1
Average rates of growth of basic macro-categories in sub-periods in the years 2005–25

Variable	2005-07	2008-10	2011-15	2016-20	2021-25
Final demand, GDP					
Final demand	5,02	3,45	3,74	3,93	3,92
Private consumption	3,60	2,65	3,36	3,78	3,57
Public consumption	2,20	2,25	2,53	2,54	2,49
Gross investment outlays	11,21	6,12	5,23	4,88	5,18
Net exports by national accounts	61,25	24,67	11,92	10,64	10,13
GDP	5,42	3,83	3,99	4,20	4,24
Exports by national accounts	8,72	7,44	7,52	6,67	6,50
Imports by national accounts	7,88	6,80	7,27	6,41	6,23
Share of exports in GDP*	41,72	47,40	59,30	66,01	72,97
Share of invesment outlays in GDP*	21,90	23,77	25,29	25,63	26,16
Production factors and their efficiency					
Fixed assets in machinery equipment	4,66	5,54	5,64	5,54	5,45
Fixed assets over labour ratio	0,88	1,57	2,41	3,37	4,20
Fixed assets over output ratio	-0,90	1,56	1,59	1,30	1,17
Labour productivity	4,21	2,64	3,67	4,28	4,12
Employment	1,16	1,16	0,31	-0,08	0,12
Unemployment rate*	17,63	15,80	12,74	10,30	9,87
Potential output technological progress					
Potential output	3,28	4,11	4,84	5,17	5,20
Capacity utilization ratio	75,21	75,46	72,66	69,32	65,98
Human capital	0,37	0,40	0,35	0,25	0,35
TFP	1,01	1,43	1,94	2,51	2,87
Domestic outlays on R&D	5,21	5,52	5,73	5,82	5,80
Share of domestic outlays on R&D in GDP*	0,80	0,99	1,39	2,01	2,51
Share of outlays on education in GDP PKB*	4,48	4,54	4,63	4,53	4,26
Share of outlays on tertiary education in GDP*	1,46	1,54	1,56	1,75	1,92
Wages, incomes, money market					
Average nominal wages	2,42	2,34	2,78	3,44	3,66
Real incomes	3,61	3,09	3,32	3,65	3,65
Unit costs	1,39	2,68	2,69	2,30	2,68
GDP deflator	2,05	2,06	2,51	2,29	2,46
Deflator of private consumption	2,20	2,31	2,59	2,59	2,77
Exchange rate PLN/USD	-0,01	-0,98	-0,40	-0,56	-0,41
Exchange rate / GDP deflator*	1,80	1,64	1,42	1,23	1,07
Share of budget balance in GDP*	-3,08	-2,70	-2,34	-2,15	-2,10
Share of public debt in GDP*	46,10	41,87	34,25	27,88	23,17
Interest rate*	3,61	3,74	4,27	3,68	3,63
Share of current balance in GDP*	-0,85	0,07	1,61	2,61	3,52
Share of FDI in GDP*	4,03	4,58	5,01	4,54	3,99
CO_2 emission					
Emission of carbon dioxide	4,49	2,45	2,06	1,68	1,35
Tax rate per one ton of CO_2 emission (in zloties)	0	0	0	0	0

* - at the end of period

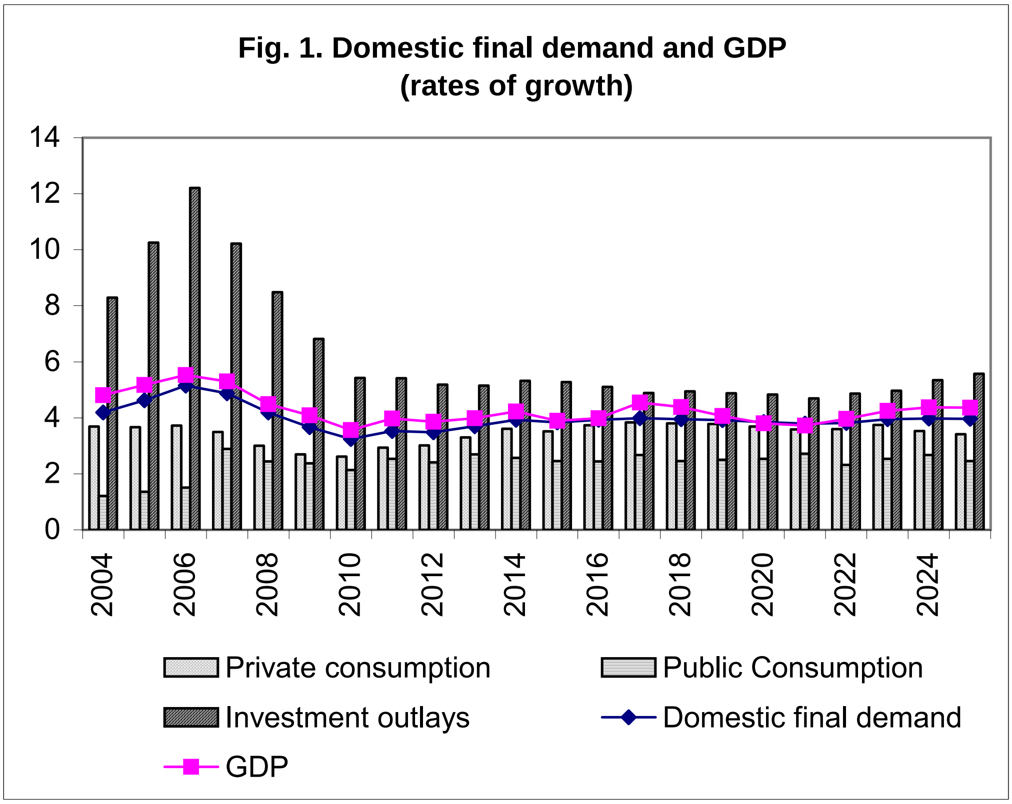


Fig. 1. Domestic final demand and GDP
(rates of growth)
14
12
10
8
6
4
2
0
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Private consumption
Public Consumption
Investment outlays
Domestic final demand
GDP

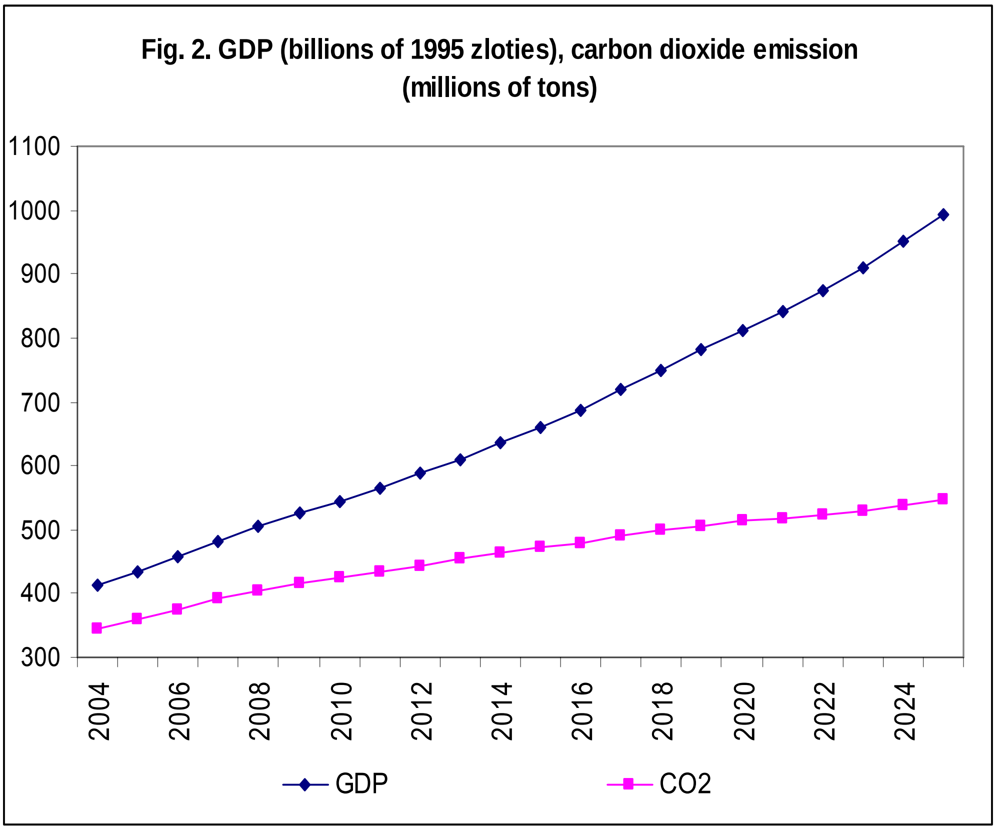


Fig. 2. GDP (billions of 1995 zloties), carbon dioxide emission
(millions of tons)
1100
1000
900
800
700
600
500
400
300
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
GDP
CO2

Fig. 3. Shares of exports, imports and investment outlays in GDP (in %)

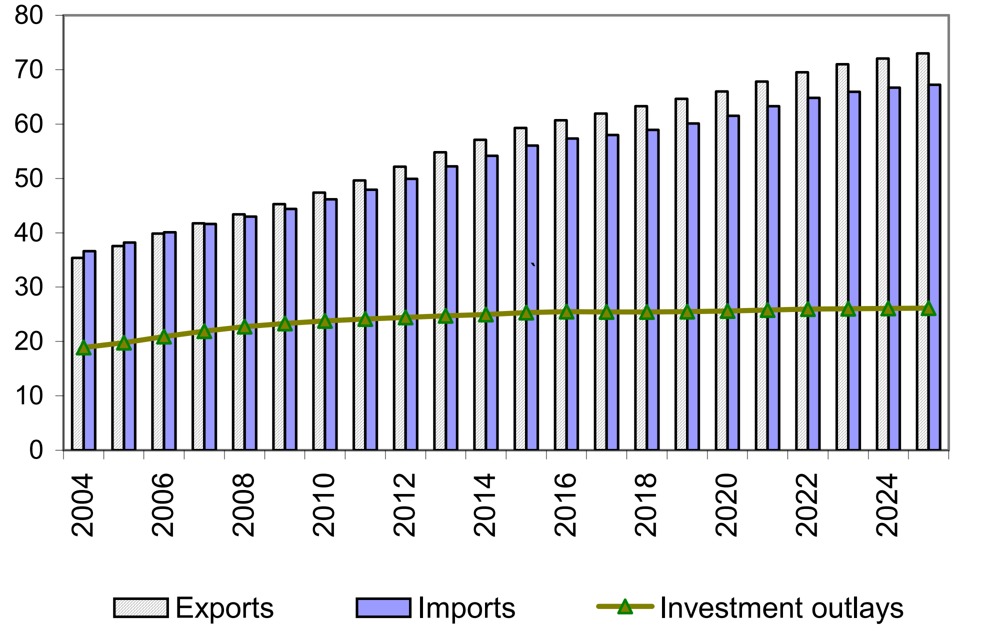
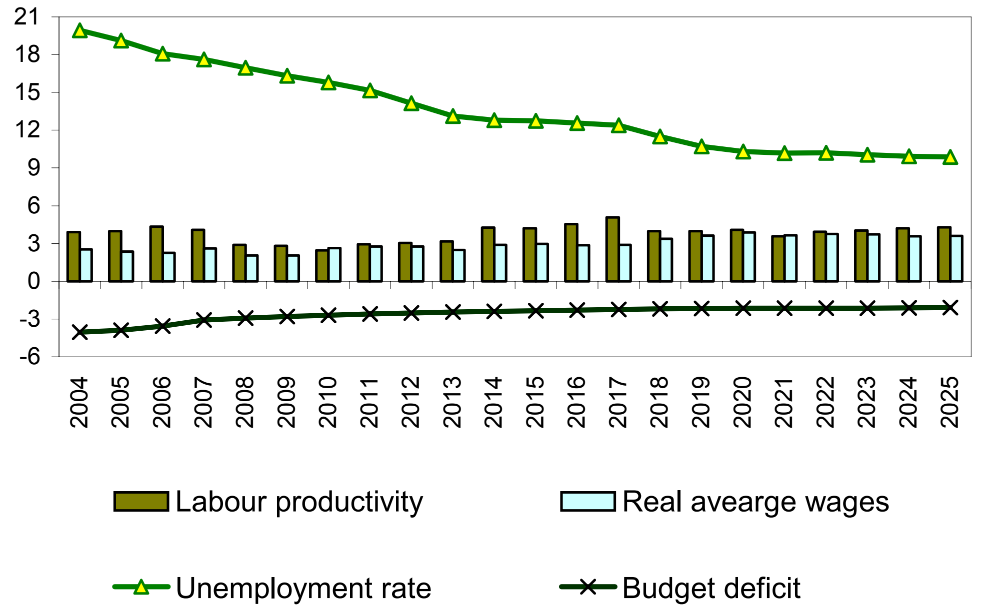


Fig. 4. Labour productiity, budget deficit, inflation, and unemployment rate



In all the simulation variants it was presumed that the taxes would be introduced in the year 2005 at the level 20 zloties per one ton of emission, whereas in the following years they would be raised gradually, in a linear way, by another 20 zloties a year, so that in the year 2025 they would reach 420 zloties per ton[3] (being equivalent to ca. 100 Euros).

The outcomes of the simulation experiments, allowing for the above-mentioned assumptions, are reported in table 2 and in figures 5-8.

An analysis of the obtained results indicates a high effectiveness of the taxes as an economic instrument to reduce the volume of carbon dioxide emission. In all the variants there follows a considerable drop in emission as compared to the baseline forecast, so that the volume of emission is practically frozen at the level of the year 2005 (300-350 million tons in the whole forecast horizon). In general, one may thus state that the directions of redistribution of the additional budget revenues do not markedly affect the volume of emission itself (see fig. 5). The latter seems to depend mainly on the size of the taxes and their distribution in time. On the other hand, the directions of redistribution fundamentally influence the other macro-categories, among which a large diversification can be observed across individual variants.

And so, in scenario *no recycling* there follows the deepest decline in the overall economic activity (up to 6% as compared to the baseline forecast; see figure 6), which results both from the highest inflation of all the variants and from the lack of feeding the economy with the additional budget revenues. On the other hand, this scenario is characterized by a fast balancing of the state budget so that in the course of time even a budget surplus appears (of 3% in GDP; see figure 8). As a result, additional means can be spent on reducing the public debt.

The unemployment rate in the *no recycling* variant is, during the first 10 years of the forecast, higher than in the baseline solution, whereas in the next years: practically at the same level as in the forecast. This is caused both by a decline in aggregate demand and by a decrease in labour productivity. Initially, the drop in the labour productivity is deeper than that of GDP but later on this situation is inverted. All in all, one can state that in the long-run the considerable reduction in the CO_2 emission is not paid for by high social cost in the form of the increased unemployment rate (see fig. 7).

[3] Both the starting year of introducing the taxes, suggested in the research, as well as their size are of discretionary nature. Taking another starting year would result only in changing the time distribution, whereas imposing other rates would lead only to some re-scaling of the effects of introduction of the carbon taxes. All in all, this would not enrich the analysis by qualitative dimension and that is why such additional variants were not taken into account in the presented investigation.

Table 2. Annual average rates of growth (if not indicated otherwise) of some selected macro-categories in sub-periods in the years 2005-2025 (real 1995 prices) and percentage deviations from the baseline forecast; simulation results obtained by means of the modified W8D-2002 model of the Polish economy

Variable		Years				
		Scenario	2005-2010	2011-2015	2016-2020	2021-2025
Carbon dioxide emission	annual average rates of growth	forecast	3,42	2,06	1,68	1,35
		no recycling	-1,38	0,54	1,29	-0,09
		lump-sum recycling	-1,07	0,35	0,91	0,05
		re-investing in R&D	-0,68	-0,23	0,57	0,75
	% deviations at the end of period	no recycling	-27,19	-33,34	-34,68	-38,88
		lump-sum recycling	-25,84	-32,52	-35,15	-39,02
		re-investing in R&D	-23,57	-32,26	-36,23	-38,14
GDP	annual average rates of growth	forecast	4,59	3,99	4,20	4,24
		no recycling	3,58	4,21	5,03	3,67
		lump-sum recycling	3,98	4,14	4,73	3,91
		re-investing in R&D	4,99	4,04	4,44	4,50
	% deviations at the end of period	no recycling	-4,95	-4,66	-0,73	-2,77
		lump-sum recycling	-2,80	-2,53	0,05	-1,12
		re-investing in R&D	3,18	3,40	4,48	5,90
Exports	annual average rates of growth	forecast	8,10	7,52	6,67	6,50
		no recycling	8,06	7,53	6,69	6,48
		lump-sum recycling	8,07	7,53	6,68	6,49
		re-investing in R&D	8,66	8,23	7,08	6,88
	% deviations at the end of period	no recycling	-0,17	-0,14	-0,06	-0,12
		lump-sum recycling	-0,12	-0,10	-0,04	-0,07
		re-investing in R&D	2,63	5,94	8,16	10,12
R&D Expenditures	annual average rates of growth	forecast	11,75	11,20	11,94	8,62
		no recycling	11,64	11,23	11,96	8,64
		lump-sum recycling	11,74	11,11	11,84	8,54
		re-investing in R&D	24,55	9,14	8,94	6,74
	% deviations at the end of period	no recycling	-0,59	-0,46	-0,35	-0,28
		lump-sum recycling	2,06	1,62	1,15	0,75
		re-investing in R&D	98,95	83,19	59,31	45,24
TFP	annual average rates of growth	forecast	1,24	1,94	2,51	2,87
		no recycling	1,20	1,86	2,45	2,81
		lump-sum recycling	1,27	1,98	2,55	2,90
		re-investing in R&D	1,85	2,46	2,61	2,77
	% deviations at the end of period	no recycling	-0,20	-0,57	-0,88	-1,14
		lump-sum recycling	0,19	0,41	0,62	0,77
		re-investing in R&D	3,18	6,09	6,83	6,37
Labour productivity	annual average rates of growth	forecast	3,31	3,67	4,28	4,12
		no recycling	3,20	3,69	4,16	3,89
		lump-sum recycling	3,29	3,78	4,29	4,03
		re-investing in R&D	3,99	4,39	4,53	4,09
	% deviations at the end of period	no recycling	-0,61	-0,55	-1,02	-2,14
		lump-sum recycling	-0,07	0,44	0,57	0,14
		re-investing in R&D	3,69	7,53	9,00	9,03
Unemployment rate	level at the end of period	forecast	15,80	12,74	10,30	9,87
		no recycling	19,37	16,41	10,13	10,39
		lump-sum recycling	18,03	15,39	10,88	11,03
		re-investing in R&D	16,26	16,32	14,40	12,88
GDP deflator	annual average rates of growth	forecast	2,11	2,51	2,29	2,46
		no recycling	3,00	2,64	2,44	2,66
		lump-sum recycling	2,97	2,60	2,35	2,52
		re-investing in R&D	2,69	2,24	2,28	2,50
	% deviations at the end of period	no recycling	4,97	5,82	6,52	7,65
		lump-sum recycling	4,84	5,51	5,76	6,12
		re-investing in R&D	3,43	2,08	1,90	2,07
State budget balance (% share in GDP)	level at the end of period	forecast	-2,70	-2,34	-2,15	-2,10
		no recycling	1,07	2,32	3,33	2,92
		lump-sum recycling	-3,19	-2,96	-2,82	-2,75
		re-investing in R&D	-3,14	-2,93	-2,79	-2,72
Public debt (% share in GDP)	level at the end of period	forecast	41,87	34,25	27,88	23,17
		no recycling	29,73	14,53	1,54	-5,61
		lump-sum recycling	42,72	36,08	29,97	26,20
		re-investing in R&D	41,05	35,50	29,94	25,56

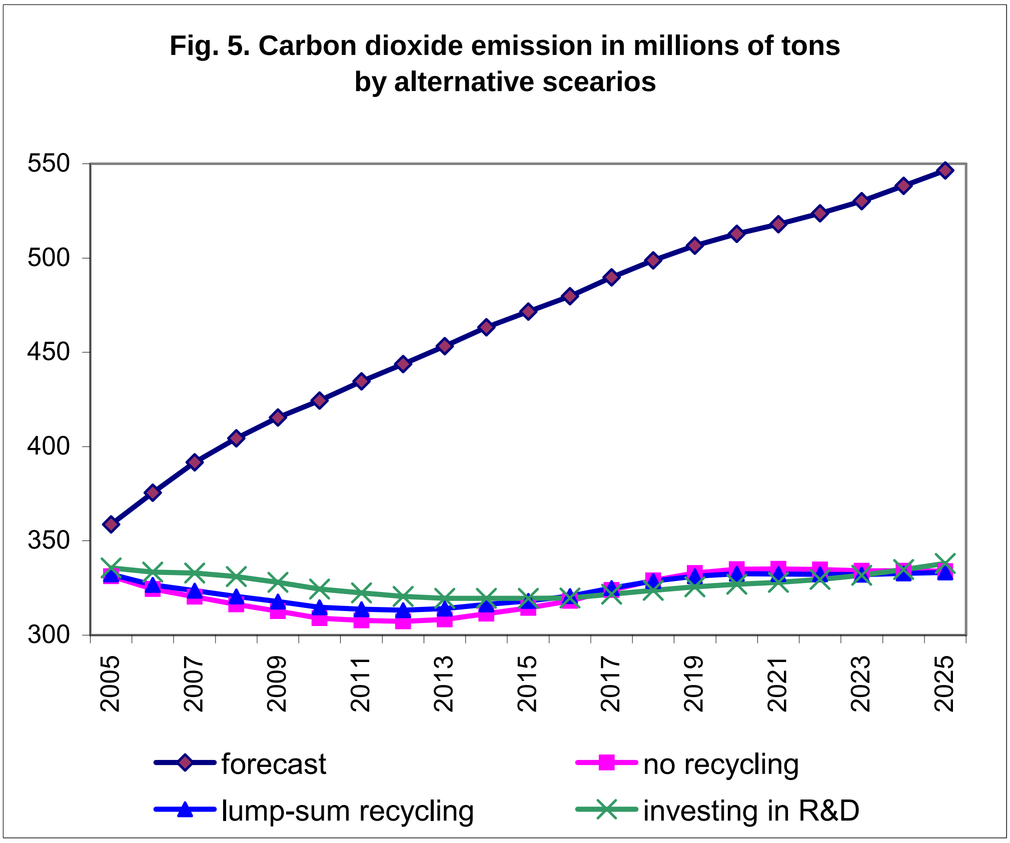


Fig. 5. Carbon dioxide emission in millions of tons
by alternative scearios
550
500
450
400
350
300
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
forecast
no recycling
lump-sum recycling
investing in R&D

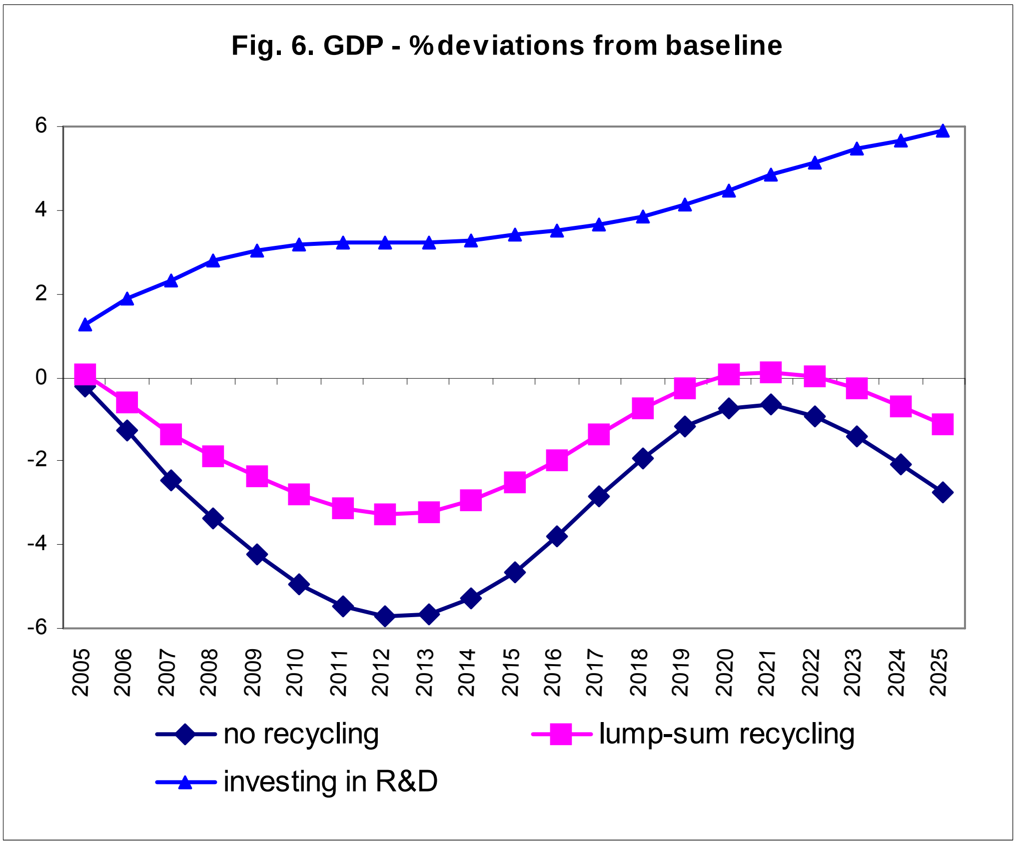


Fig. 6. GDP - %deviations from baseline
6
4
2
0
-2
-4
-6
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
no recycling
lump-sum recycling
investing in R&D

Fig. 7. Unemployment rate

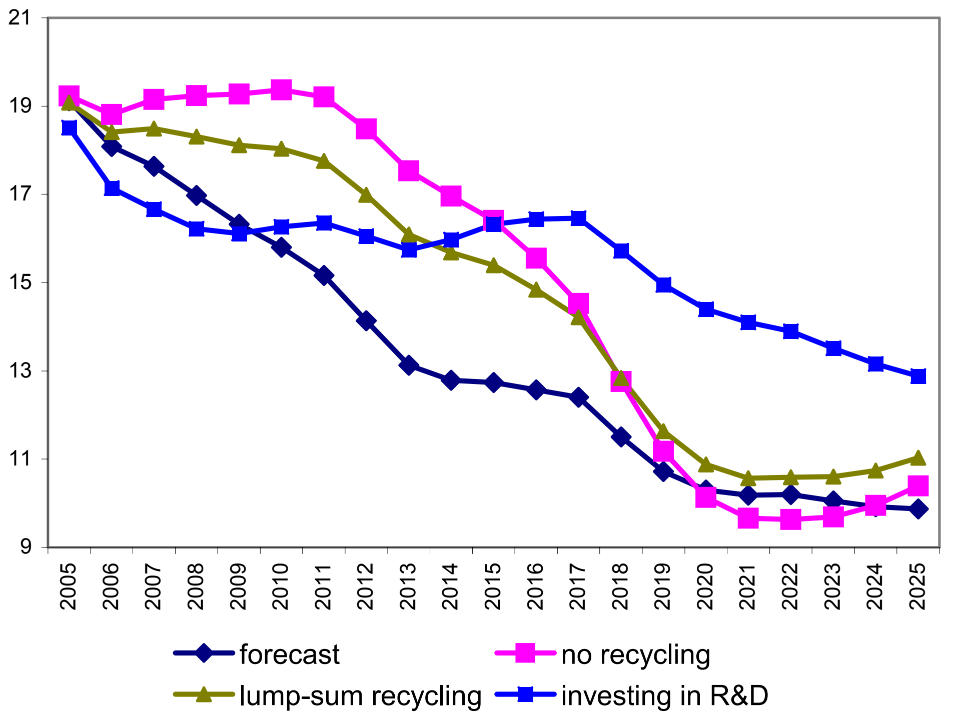
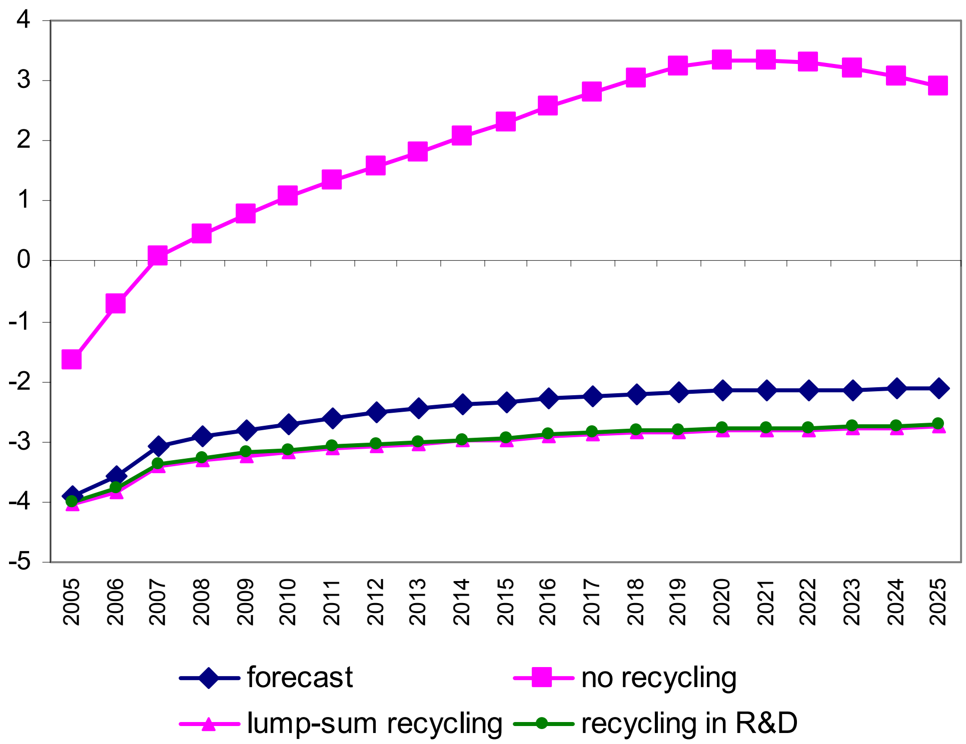


Fig. 8. Budget balance (% share in GDP)



The outcomes of scenario *lump-sum recycling* are close to those obtained in *no recycling*, with the scale of adverse effects being, however, a little lower. On the other hand - due to the initial assumptions – no improvement in the state budget balance or in the public debt can be observed.

Although the economy is fed with the additional revenues, there follows a drop in GDP. It is so because of two reasons: increased inflation and the fact that only a slight part of the additional means is spent on investment ends (no changes is the structure of the budget expenditures were envisaged in this variant). Just like in the previous scenario, the drop in GDP is accompanied by a decline in labour productivity, as a result of which only negligible changes appear on the side of demand for labour force and in the rate of unemployment. On the whole, the social costs of a considerable reduction in the CO_2 emission are not too high, and besides, they are decreasing in the course of time.

Scenario *re-investing in R&D* seems to have generated the most favourable outcomes from the point of view of Poland's long-term economic development. Only this variant is typified by a continuous economic growth as compared to the baseline solution. A marginal rise in the general price level is more than compensated by a higher aggregate demand due to both investment and export increased activities. The latter stems from a higher quality of Polish products (higher TFP). There follows the strengthening of the competitiveness of the Polish economy and transition towards less energy-consuming technologies, which is manifested by a decline in demand for energy, and consequently, a decrease in the CO_2 emission, all this despite a rise in GDP.

The only *fly in the ointment* in the scenario under consideration is its unemployment rate, especially in the last 15 years of the analysis. A radical increase in expenditures on research and development results, initially, in a rise of the aggregate demand in a scale higher than that of labour productivity. As a result, the unemployment rate in the period 2005-2010 is lower here than in the baseline forecast. However, in the years to follow the cumulated effects of outlays on R&D far extend the production capacities and labour productivity, which declines the effective demand for labour force, with the consequent rise in the unemployment rate. Thus in the years 2011-2025 the unemployment rate is in the *re-investing in R&D* scenario higher than in the baseline solution. This should be viewed as a serious social cost in the long-run to be realized while embarking on this variant of reducing the CO_2 emission.

5. Conclusions and final remarks

The simulation analyses presented in the paper, carried out by means of the modified version of the W8D-2002 model of the Polish economy, show that it is possible to significantly reduce the CO_2 emission at relatively low socio-economic costs of introducing appropriate taxes. The costs, meant either as changes in overall economic activity, inflation rate, unemployment rate or public debt, differ both in time and across individual scenarios.

Each of the presented variants has its strong and weak points so that it is difficult to univocally point out at the best one. And so, despite its relatively deep drop in GDP and high increase in prices, the unquestionable advantage of the *no recycling* scenario is a radical improvement in the state of public finances, measured either as a ratio of budget balance or public debt in GDP. On the other hand, scenario *lump-sum recycling* is characterized by lower – if compared to the previous variant – socio-economic costs, without however, any improvement in the field of public finances. Finally, the high dynamics of labour productivity and GDP in the *re-investing in R&D* scenario are offset by a rise in the general level of unemployment. It seems thus that a choice of a particular variant must be subject to a discretional decision in view of the policy maker's preferences with respect to three basic macroeconomic criteria: GDP, inflation, and unemployment rate.

The analyzed scenarios are typified by some extremity in the assumptions about the directions of redistribution of the budget revenues due to the carbon taxes. The outcomes obtained in the scenarios mark only the boundaries of possible macroeconomic changes caused by the suggested scheme and schedule of introducing the taxes on the CO_2 emission. In practice, an implemented variant might be a combination of the above scenarios, whereas any additional/new assumptions concerning both the tax rates and their distribution in time or directions of redistribution of the budget revenues due to the emission, may be subject of an additional research.

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