Intertemporal hybrid modeling of energy policy in Poland: how to avoid biased results

by

Olga Kiuila (Dr hab.)*

1) Senior Economist, STATEC, National Institute of Statistics and Economic Studies, Grand Duchy of Luxembourg
2) Assistant Professor, University of Warsaw, Poland

Jan Hagemejer (Dr)

1) Senior Economist, National Bank of Poland
2) Assistant Professor, University of Warsaw, Poland

Grzegorz Poniatowski (PhD candidate)

1) Senior Economist, CASE – Center for Social and Economic Research, Warsaw, Poland
2) Research Assistant, Warsaw School of Economics, Poland

Maciej Sobolewski (Dr)

1) Assistant Professor, University of Warsaw, Poland
2) Research Fellow, CASE – Center for Social and Economic Research, Warsaw, Poland

* corresponding author: STATEC, 13 Rue Erasme, 1468 Luxembourg, Grand-Duché de Luxembourg,
ph. +352 621 619 652, kiuila@yahoo.com

Abstract

In the coming decades the energy sector in Poland will undergo a substantial transition towards low carbon usage which will have a preponderant impact on the economy. Several modernization scenarios for energy policy are currently being discussed and not yet concluded. The main objective of the paper is to provide a tool that allow to simulate such scenarios and to show the impact into the whole economy by accounting for complex set of linkages between energy sector and other parts of economy. Those scenarios should assume, in different proportions, increasing use of nuclear energy, renewable sources and natural gas in exchange for reduction of carbon.

Energy is a crucial economic input circulating in the economy, widely utilized as production factor and consumed in different forms by households. For this reason, any changes in energy will have a preponderant impact on the entire economy, thus partial equilibrium modeling is not sufficient. Currently there is no appropriate research tool in Poland which could accommodate complex structure of different energy sources and wide linkages of the energy sector to assess economy-wide impacts of the energy policy in longer horizon for Poland. We propose a hybrid general equilibrium modeling that incorporates energy technologies (bottom-up approach) directly into macroeconomic structure (top-down approach). By accounting for wide adjustments in the economy, while controlling for all major constraints - such as energy balance and available capital stock - the model can give a unique and detailed insight into the future shape of energy sector and low carbon economy in Poland.

Based on the model outcomes we can state that simulation results can be very much biased even if the model is properly calibrated. We present several issues that should prevent modelers to supply results to policy-makers without careful tests. The immediate source of “strange” results is wrong model design to study specific topics. The lack of formal tests to validate computable general equilibrium models should not be a pass for unreasonable results. Our study helps to understand the source of selected “strange” results.

Keywords: computable general equilibrium modeling, dynamics, energy technologies

JEL: C61, C68, D58, Q43.

1. Introduction

The Polish energy sector is dominated by electricity produced from bituminous coal and lignite (above 80%). These two types of energy sources have been developed due to substantial resources of coal that Poland possesses. Some other sources of electricity production are oil, gas, hydro, wind, biomass, solar and photovoltaic. In recent years the sector has been changing towards more renewable resource with diminishing dependence of coal. The total production of energy in Poland in 2007 was 159 TWh (ARE 2013) and worth 5136 mio EUR (URE 2008).

Transitioning towards a low carbon economy has been considered as one of the most important and inevitable challenges for many developing economies. Poland is an extreme case in terms of its reliance on fossil fuels in electricity generation. Despite this fact and despite the substantial economic impact that such a transition may cause, empirical studies on the impacts of energy transition on the Polish economy is rather scarce. In contrast, in the literature there is a broad range of studies that uses different quantitative approaches to simulate environmental policy changes and understand mechanisms driving the macroeconomic effects.

The theme of the economic impacts of energy transition in Poland is carefully investigated by the World Bank (2011). The goal of the study is to document the economic impacts of the transition required by the EU abatement rules. It uses a comprehensive methodological approach, which compiles four complementary and interlinked models: marginal abatement cost curve, multi-region CGE model, a large-scale multi-sector DSGE model and road transport model . The DSGE model with an incorporated marginal abatement cost curve serves to simulate economy-wide impact of emissions reduction. The CGE model complements the analysis in global context, i.e. by simulation spillover effects to and from international markets. Transport sector model is used to simulate the impacts of different economic assumptions delivered by micro abatement cost curve on the transport market. One of the findings of the study is that Poland has a lot of space for cutting its greenhouse gas emissions, i.e. by almost one third by 2030, at an average cost of 10 to 15 EUR per ton of carbon dioxide equivalent abated. According to the study, the reduction would have a negative impact on GDP, in average of 1pp lower growth by 2030 each year. The impact of the transition on GDP is consistently negative but declining, and already close to zero in 2030. Moreover, the study finds that onshore wind and small hydropower plants are most efficient in terms of the metric of GDP growth. Nuclear power offers the most significant abatement potential but remains an impediment for growth in longer term.

Bukowski and Kowal (2010) employ the above DSGE model to derive macroeconomic effects of continuation of current policies, trends and convergence process in terms of GHG abatement. In addition, the impact of 120 mitigation levers identified in the bottom-up sectoral analysis by McKinsey (2009) is simulated. From the wide set of levers the authors derive the optimal scenario, i.e. the combination of levers minimizing loss function. The loss function expresses the deviation of the reduction from the target value and increase in costs relatively to the reference scenario. The optimal scenario envisages significant growth of nuclear capacity (up to 19% of energy mix in 2030) and onshore wind (up to 14% in 2030). These growth is accompanied by a large drop of conventional coal (from 81% to 44%) and decrease in small-hydropower plants.

Apart from these two compound studies, there are several smaller studies touching upon certain aspects of energy transition in Poland. Bukowski (2013) raises a wide range of aspects in that regarding links between the energy sector and economy, energy efficiency perspective, energy security and political issues around climate policy. The conclusion from the study is that resistance to transitioning of the energy sector creates a risk to the Polish economy of lagging behind highly developed economies and falling into middle income trap. Taking courageous, systematic and coordinated modernization activities, according to the study, is the only reasonable way to maintain competitiveness of the economy in the next decades. Properly designed climate policy (comprising of ecological education, active labor market policies, public support for innovations), is an opportunity to build the foundations of a modern, ecological, highly developed economy. Specific actions should involve energy management projects enabling for better utilization of installed capacity in power plants, promotion of low-emission means of transport, popularization and subsidizing of electromobility, proper allocation of funds infrastructure.

Kassenber and Sniegocki (2015) take narrower approach and draw scenario for the impact of energy transitioning only on the labor market. According to them, public policy in Poland should focus on providing the efficient reallocation of labor and capital in the direction of industries that could ensure sustainable development taking into account environmental and resource constraints. One of the methods to achieve such goal is investment in technologies with high development potential and proper tax and subsidies policy. The green tax reform should lead to increase of the fiscal burden on companies that use scarce natural resources and pollute the environment. The government should also reduce tax rates on labor and secure competitiveness of Polish energy intensive industries.

Kiuila et al. (2016) focus on another important aspect of climate policies concerning Poland, namely the effects of unilateral actions at the EU level. The authors, using static CGE framework, assess the EU unilateral carbon abatement commitments for 2020. Unilateral actions may appear to be counter-productive because a large part of emissions may be offset by an increase in emissions in non-EU Member States. More stringent abatement commitments by the EU lead to higher carbon leakages but also results in higher welfare losses at the EU level. As a result, only global actions prove to be efficient, whereas any regional policies prove to be insufficient.

Poland faces unique challenges in its energy transition. Nevertheless, there are many countries that are going or will inevitably go through energy transition sharing with Poland similar concerns. Gonseth and Vielle (2012) model the impacts of change on the energy sector in Switzerland. The article discusses the impact of climate change on energy policy and the economy in Switzerland. The analysis uses a CGE model and focuses on both the demand side and the supply side. According to the authors, climate change will significantly reduce heating costs and improve the conditions for the use of renewable energy sources. As a result of climate change, reducing the costs of production and increased consumption of goods not related to the production chain of the energy sector. As a result of climate change by 2050, the Swiss economy will gain 704 million USD and CO2 emissions will be reduced by 2.6%.

Some other compound quantitative studies in recent years were focused on energy transition in the US. Mattoo et al. (2009) present the results of the impact of different scenarios for emission reduction on the economy of the United States in 2020 based on CGE analysis. Reducing emissions by 17% between 2005 to 2020 would result in a loss of 4% of GDP. Furthermore, increased competitiveness of carbon-intensive India and China may require an increase in import tariffs up to 20%. As a result, US export's fall from 21% to 16%.

A wide range of studies, instead of simulating the effects of specific reforms and policies, focuses on the methodology for energy reforms assessments. Along these lines, Bohringer and Loschel (2006) analyse the usability of CGE modelling in the sustainability impact assessments, i.e. the ability of CGE models to provide the comprehensive impact assessment of policy changes on the economic, environmental and social indicators. They provide a survey of the CGE models existing in the literature to construct an overview of the coverage of the three types of indicators. The results suggest that the while the majority of the models provide very good coverage of the economic indicators, the ability to assess the changes in environmental indicators and social indicators is considerably lower. In the case of the latter, it is partially due to a lack of precise definition and measurement.

Bohringer and Rutherford (2008) present a model combining the advantages of top-down models (general equilibrium) and bottom-up (partial equilibrium), i.e. hybrid modeling. The market equilibrium is formulated as mixed complementarity problem. The complementarity approach allows to exploit the advantages of each model type – technological details of bottom-up models and economic richness of top-down models – in a single mathematical format. Bottom-up models of the energy system may impose a large number of bounds on decision variables. These bounds introduce unavoidable complexity in the integrated complementarity formulation as they must be associated with explicit price variables in order to account for income effects. Mixed complementarity approach allows to achieve it in a simple way.

Two different methods of integrating bottom-up and top-down approach in the modelling of the economic effects of environmental reforms are studied by Kiuila and Rutherford (2013). Bottom-up abatement cost is implemented into top-down modeling using two methods. "Economy-wide" method treats an abatement sector as a unique set of technologies for all sectors, while "sector-specific" approach distinguish between different abatement possibilities for each sector. The study proves that both (hybrid and the traditional) CGE modelling approaches yield similar results if the calibration process is precisely executed. Furthermore, simulation experiment proved that the emission permits are equivalent to carbon taxation when no transaction costs are considered. However, market for emission permits creates a transaction cost which results in a deadweight loss higher than carbon taxation.

Burnieaux and Martins (2012) study the mechanisms of carbon leakages using bi-regional general equilibrium model. The first region is under emission restrictions, while the second one is without restrictions. Electricity can be produced through consumption of coal, oil or renewable sources. The three most important observations of the article resulting directly from the sensitivity analysis are: (i) carbon leakages to a small extent depends on Armington flexibility (i.e. elasticity of substitution between domestic and imported products), (ii) the most important parameter for carbon leakage is the price elasticity of supply for coal (iii) and the importance of the functional form and parameters of production (i.e. high inter-factor and inter-fuel substitution elasticities can generate large carbon leakages even when the supply of coal is elastic). It is one of the strange results that could be found in the literature.

As could be observed in the literature reviewed above, the leading approach to modelling changes in energy mix is CGE. It does not mean that this is the best approach. Bottom-up modeling is more precise for technologies analysis, but it usually fails to show the macroeconomic impact as well and the effects on factor reallocation between different non-energy sectors of production. (see Bohringer and Rutherford (2008)). As shown among others in Bhattacharyya (1996) and Bohringer and Loschel (2006), modelling approaches using general equilibrium may differ significantly. Difference between the models lies, among others, in disaggregation of sectors and products, number of nests, dynamic properties, functional forms of particular functions and methods for including environmental and energy component. The choices regarding the structure of the model are important for the accuracy of the results. However, well-designed CGE models are a very powerful tool for simulating the effects of environmental reforms (see e.g. Bohringer and Loschel (2006)). In particular, studying the effects transitioning towards a low carbon economy in Poland using well developed methodology is necessary, as corresponding literature is rather scarce.

The outline of the paper is the following. In the Section 2 we present the general structure of the model, discuss some important issues related to data, and emphasize the role of the capital. As we show in Section 4, capital is one of the sources of troubles in dynamic modeling. Section 3 explains how capital markets interacts in the model. Using several simulations we have compared results of ten model versions in Section 4 to explain the complexness of the energy policy simulations. The last section concludes.

2. Model

Energy is a crucial economic input circulating in most economies, widely utilized as a production factor and consumed in different forms by households. Due to inter-sectoral linkages and the wide impact of energy-related policies on the remaining sectors and all economic agents, general equilibrium modelling is an appropriate tool to assess energy and environmental policy scenario. However, the comprehensive economic toolset to analyze the energy issues in the Polish economy has not been present in the literature. We fulfil this research gap by building a fully dynamic computable general equilibrium model that takes into account the complex structure of different energy sources.

Polish economy is represented in the model by 21 sectors, i.e. the whole economy was aggregated to those sectors based on input-output accounts for 169 sectors in 2007:

- 4 fuel sectors (coal, gas, crude oil, oil)
- 3 energy sectors (electricity production, electricity distribution, heating)
- 6 transportation sectors (motor vehicles production, other transport equipment production, cars service, passenger land transportation, other passenger transportation, freight transportation)
- 2 food sectors (agriculture and food industry)
- 6 other sectors (mining and metals, chemical, engineering, other production, construction, research, other service).

The original data are carefully analysed in order to precisely reflect the structure of the economy, otherwise the results of simulation would be biased. For example, the original data exclude motorcycle from production of motor vehicles, but they include it into servicing of motor vehicles. We take the effort to make it consistent by excluding servicing of motorcycles from service of motor vehicles. The better alternative would be to include production of motorcycles into production of motor vehicles, but we do not have disaggregated data for production of motorcycles.

Final demand is represented by households, investors, and government. There is one representative household that maximize lifetime utility subject to the lifetime budget constraint. The top tier utility function is the intertemporal CES function over all the (infinite number of) years of household life. The instantaneous (period-level) subutilty is of the CES type and covers all consumption goods, services and energy directly consumed by the households. The budget constraint involves the stream of all lifetime factor earnings.

Households supply labor (L) and capital (K). Capital can be either bought or rented (see next Section), but labor can be rented only. Investors supply capital (capital service) to producers, while households supply capital (capital stock) to investors. Capital stock (K) and capital service (KD) denote two different but interrelated concepts of capital:

$$KD = K*d + KF$$

where d is depreciation rate of capital, d*K is physical capital, KF is financial capital. Thus capital service is just the volume of gross operating surplus. Capital service is derived from the stock of capital installed, while capital stock is defined based on profit-maximizing behavior of economic actors. National accounts do not account for the capital stock directly, but the value of fixed capital consumption ($RK*K*d$) and net operating surplus ($RK*KF$) using the following accounting

$$PKL*KL = PL*L + RK*KD$$

where RK is price for capital service, PKL*KL is the (nominal) value added aggregate. Thus total factor earnings are attributed to labor and capital earnings. Capital earnings are the stream of payments for capital services (which alternatively can be expressed as the value of capital stock exactly equal to the discounted stream of all capital earnings). Capital services encompass the return on financial capital (firm profit) and the return on physical capital (consumption of fixed capital). While constant returns to scale assure zero profit, the national accounts data include firms profit. The usual approach in CGE models, in order to solve the problem of non-zero profit in data, is to aggregate profit (RK*KF) with capital depreciation (RK*K*d) and to treat it as a value of capital flow (RK*KD). Another reason for doing this aggregation is that quality of capital data is usually poor, then it is better to have aggregated values (i.e. gross operating surplus) rather than disaggregated (i.e. net operating surplus and depreciation).

Moving from capital stocks to capital services, the common assumption is that capital services provided during a given period should be proportional to the stock:

$$KD_t = K_t(r + d)$$

where K*r=KF is financial capital and K*d is physical capital. Note that physical capital is a stock (wealth perspective), while financial capital is a flow (production perspective). The return to capital (RK*KD) must be sufficient to cover dividends (RK*K*r) and depreciation (RK*K*d) according to market clearing condition.

Demand has been set endogenously for all production factors. The model assumes lack of mobility of capital and labour. Each sector uses production of other sectors and its own, which altogether forms indirect demand. In addition to intermediate and private final demand, the model distinguish public demand created by government. There are three main sources of public income:

- income tax covers labour tax only (PIT, social security payments by employers and employees)
- taxes on products cover
    - net taxes on electricity paid by households (VAT, excise, other)
    - net taxes on electricity paid by firms (excise, other)
    - net taxes on fuel (VAT, excise, other)
    - net taxes on other energy products paid by households (VAT, excise, other)
    - net taxes on other energy products paid by firms (excise, other)
    - net taxes on newly purchased cars (VAT, excise, other)
    - net taxes on other products paid by households (VAT, excise, other)
    - net taxes on other energy products paid by firms (excise, other)
- taxes on production (incl. emission taxes)

Redistribution of income is done via transfers. We classify them into three groups:

- social benefits (incl. unemployment benefits)
- pension benefits (incl. income for retired persons)
- other transfers

Another important property of the model is detailed representation of electricity production, i.e. we use a hybrid general equilibrium modeling that incorporates energy technologies (bottom-up approach) directly into macroeconomic structure (top-down approach). The electricity sector is decomposed to several subsectors utilizing different energy sources and producing different types of energy using different technologies:

- coal – 91%
- gas – 3%
- oil – 1.6%
- biomass and waste – 1.6%
- hydro – 1.4%
- wind – 0.3%
- other (mostly from processed gas like LPG) – 1%

There are two additional technologies (nuclear and solar) that participate in electricity supply in Poland for less than 1%, but this electricity comes only from import.

This approach allows to capture substitutability between different inputs and measures crowding out effects. Several linkages between energy sector and the rest of economy are taken into consideration. Similarly to capital or labor, energy enters production functions in industrial sectors directly as a production factor and also indirectly in form of transport services for raw materials. In case of households, energy consumption enters utility function through housing and transport services. However, produced electricity (based on above technologies) is supplied only to a single sector (electricity distribution) because nobody except this single sector should buy electricity directly from producers. This means that neither households nor other agents can buy electricity directly from electricity producers, except sector of electricity distribution.

Finally, we simplified the model by excluding international trade, unemployment and other important elements that we plan to include in a future. Following Bohringer and Rutherford (2008), we have applied mixed complementarity approach.

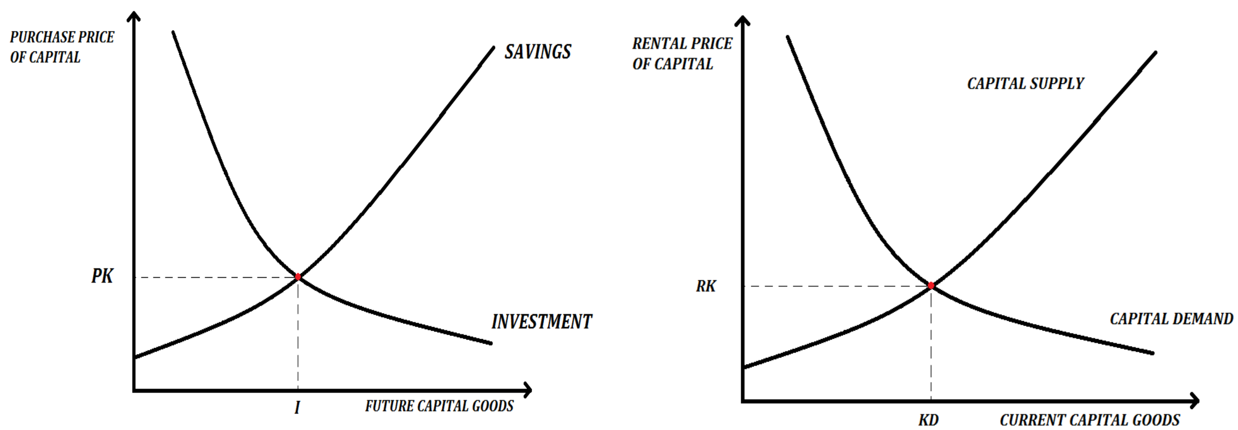
3. Dynamics and capital formation

The model is able to simulate the effects of dynamic shocks introduced into the economy, resulting from the implementation of different scenarios such as changes in taxation, emission quotas, or production capacity investments both in the energy sector and elsewhere. The main problem with dynamic models is distinguish between two capital markets: capital purchase versus capital renting. The lack of formal tests to validate computable general equilibrium models implies that seemingly good structure of a model may contain flaws that lead to unreasonable results.

Capital can be either bought or rented (Chart 1). Therefore, implementation of dynamics involves purchase price of new assets (PK) and rental price (RK) of capital. The price for new assets can be interpreted as an investment price deflator:

$$PK_{t+1} = PK_t/(1+r)$$

where one unit of investment in period t produces one unit of capital stock in the next period, r is real interest rate. With perfect foresight (as in the full dynamic models), agents plan future capital use and this implies that current price of output determines the price of investment good and therefore the future price of capital. Market clearing conditions equilibrate the supply (by households) of savings with the demand (by investors) for investment goods (Chart 1a).



(a) investment (future capital) goods (b) capital goods

Chart 1. Capital markets in the model

The rental price is an implicit price that the production company charges itself for assets that it owns (it equals the price that the firm would have to pay to rent an equivalent asset in a competitive market). In other words, the rental price has to be paid for the use of the capital goods by producers:

$$RK_{t+1} = RK_t(1-d)$$

A unit of capital generates less revenue next period because of depreciation (*d*). Market clearing conditions equilibrate the supply (by investors) with the demand (by producers) for capital goods (Chart 1b).

There is a direct relationship between both markets, since purchase price of capital reflects the sum of discounted rental over time:

$$PK_t = RK_t + RK_{t+1}/(1+r) + \cdots$$

This is a definition of spot price of a unit of capital. When expectations are made in current period about the next period, it needs to be discounted by factor 1/(1+r). Investors may also wish to sell the asset after getting paid for rental. So the value of the investors capital stock is:

$$PK_t = RK_t + PK_{t+1}(1-d)$$

This is the inter-temporal arbitrage condition for renting capital. Depending when rental price is paid (beginning or the end of the rental period), this condition could be more complicated. Also depending whether capital stock data represents gross or net stock, including or excluding current investments, at the end or beginning of the period, etc. the above condition may not hold. If we apply wrong formula into the model, the results will not be reasonable.

The households own the initial capital stock. In the subsequent periods capital is formed according to a standard law of motion:

$$K_t = (1-d)K_{t-1} + I_{t-1}$$

where new gross investment (I). This means that future capital is not immediately converted into the capital good, but in the next period because investments require one year to mature. Thus the total capital stock in the current period cannot be augmented through current investments. The decision when to buy the asset is independent from the decision when to rent the asset. If investors are able to rent an equipment immediately, then no mature period is covered by the evolution of capital.

Growth of capital stock is relatively simple process. Growth in sectoral output depends on the growth of both employment and capital stock in that sector. Labour force is assumed to grow at a constant rate (*g)*. Allowing for the labor force to grow with constant capital stock is not a simple boost to growth. In order for new workers to be as efficient as their counterparts, they require either comparable capital to work with or substitution possibility between capital and labor, otherwise the new employee will lag seriously in productivity. The structure of factor employment is constant in the steady state, i.e. the capital to labour ratio does not change. Thus the model has a long run balanced growth path, where all real variables grow at a constant rate equal to the growth rate of population.

$$K_{t+1} = K_t(1+g)$$

where K*g is net investment (net expansion of the capital stock from this year to the next). While some of capital is depreciated, the amount of gross investment (I) required to keep the economy on the balanced growth path is:

$$I_t = K_t(g+d)$$

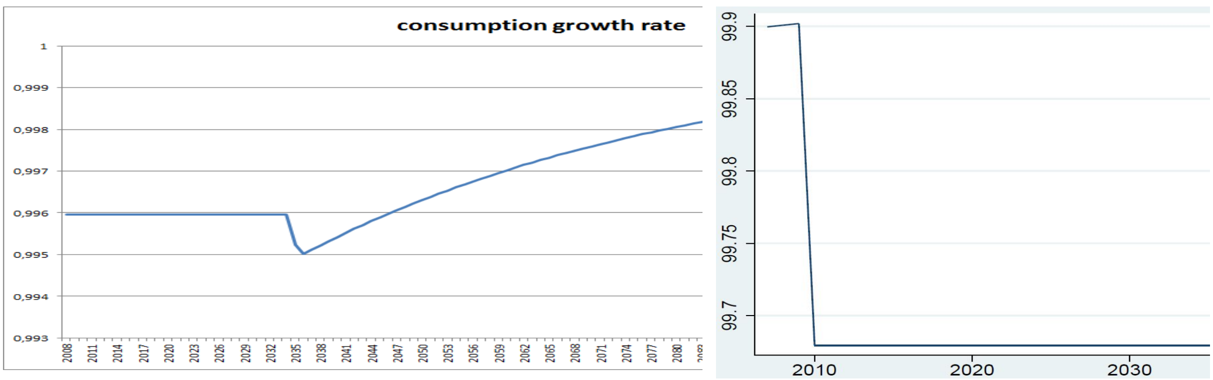
This relationship ensures that economy is on the balanced growth path, but deviations from it in scenarios should be allowed. Sectoral growth rate responds to changes in the marginal productivity of capital due to changes in investment. Readjustment of the capital stock and investments continue until the steady-state is achieved. This is a rule of investments on a steady-state relationship according to the macroeconomic[1] growth model. Net investments (K*g) together with the consumption of goods determine the aggregate income, while gross investments (I) together with consumption of goods determine the output. The division of income between consumption and investment is the fundamental factor determining how fast income will grow from period to period.

There is no incentive for future capital accumulation in equilibrium. If the capital service (KD) in a given sector is positive, then investment should also be positive. There is no possibility for zero investment in a given sector if capital stock is positive in that sector (except zero rate for depreciation and growth) and vice versa. This means that when sector has a positive demand on capital (KD), then this sector should has both, a positive capital stock (K) and positive investments (I). For simplicity, we do not distinguish sectoral capital, except KD, because the model is complicated enough as results of simulation suggests.

4. Simulations

The model allows for evaluating the multidimensional impact of scenarios: shifts in demand for labor and other factors of production, influence into the demand for energy and intermediate and final products, changes in competitiveness of the economy and new structure of investment, changes in production and income distribution. For each of the scenarios the model provide a number of performance measures such as social welfare, the ratio of investment to GDP, and the ratio of investment to employment, which enable to quantify the economic efficiency of different solutions. However, we found that the model does not produce reasonable results and we discuss it in this section.

First problem was related to non-smooth behavior of the variables after any shock. For example, increase of tax on fuels by 20% in a single period - 2035 (Figure 1a) and 2010 (Figure 1b) - implied that private final consumption initially decreased (as expected), but there is no reaction immediately at the first period. Dynamic models assume perfect foresight, i.e. households react immediately to future shock because they know in advance what and when shock will be applied. Thus the model reacts wrong to the tax shock if consumption reacts suddenly instead of smoothly. Also the steady state should imply that consumption would return to balanced growth path, but it is not (see Figure 1).



(a) no return to steady state (b) wrong perfect foresight

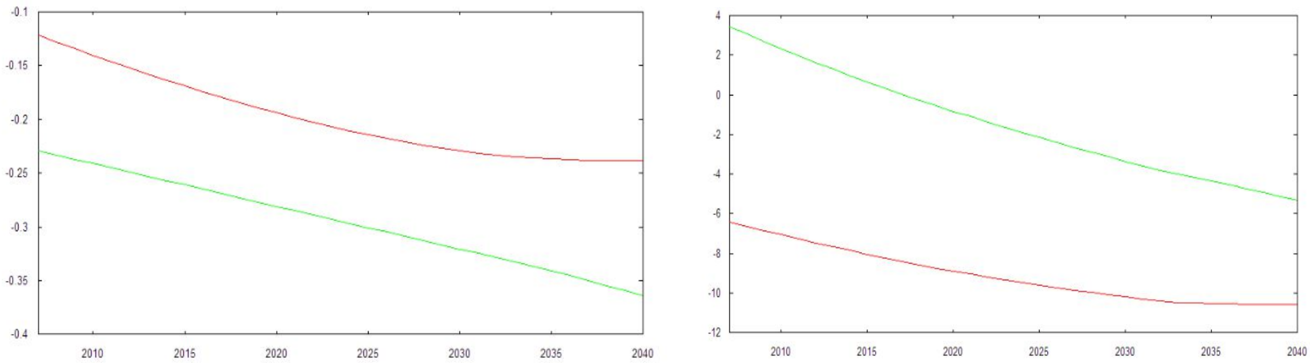
Figure 1. Single-period tax shock on fuels (horizontal line – time, vertical line - % change)

---

[1] Note that CGE models are based on microeconomic foundations.

On the other hand, there is no reaction on producers side except last years. In order to find out the source the problem, we started from changing definition of inputs share in production function. Since we have many taxes and some agents do not pay given tax, the exceptions can be applied in a different way. As a result we can see the considerable change in the results (Figure 2). There is no single-period tax shock in this simulation, but continues shock immediately for the first period. However, inputs share did not solve all problems because consumption still does not return to steady state. Adjustments of parameters like depreciation rate (d) or growth rate (g) also did not help.

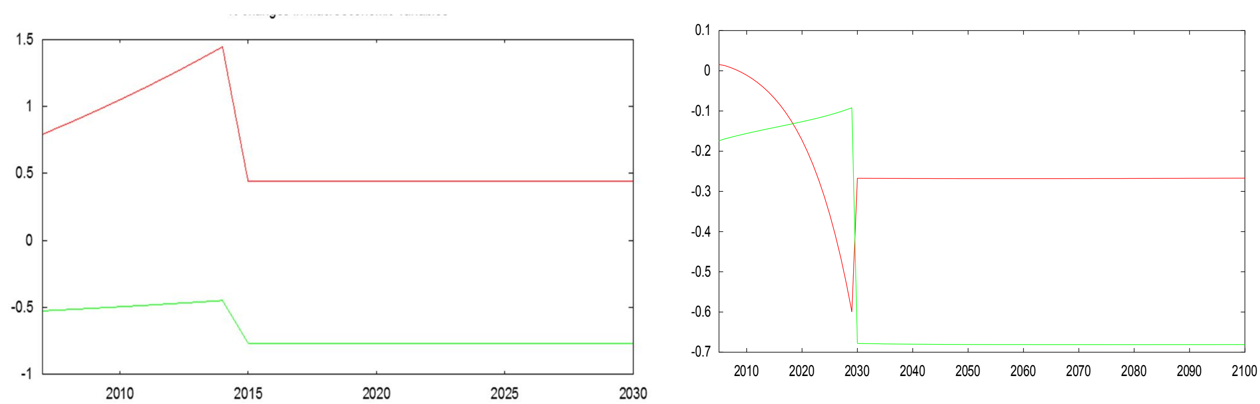
In the next step we have analyzed capital-labor ratio (KD/L) and we have found unproportionaly more capital than labor in the economy. For example, KD/L for electricity sector is 2.8 that means over 70% of capital share in the value added of this sector. It can be explained by capital transfers from the EU and labor emigration. If the economy has too much capital than investments should be huge in order to keep the capital in a steady state. That's why the model could not return to the steady state. In order to solve this problem, we have rescale capital-labor data keeping value-added constant. After rescaling we have obtained KD/L ratio 0.6 instead of original value 1.3 and it helped to keep the variables in a steady state (Figure 3a).



(a) inputs share excl. selected agents (b) inputs share incl. selected agents

Figure 2. Tax shock under different definition of inputs share in production function (green line – private consumption, red line – investment)

Thus the benchmark capital-labor ratio plays crucial role in dynamic models. If the economy has unproportional relationship, the dynamic model will not work properly. While the benchmark investment, capital stock, depreciation ratio and the flow of capital services may reach the standard steady state assumptions, it may not be a sufficient condition to return to the steady state in scenarios. If someone will make a simulation on such model in order to support policy-makers in their decision process, it will not make any sense.

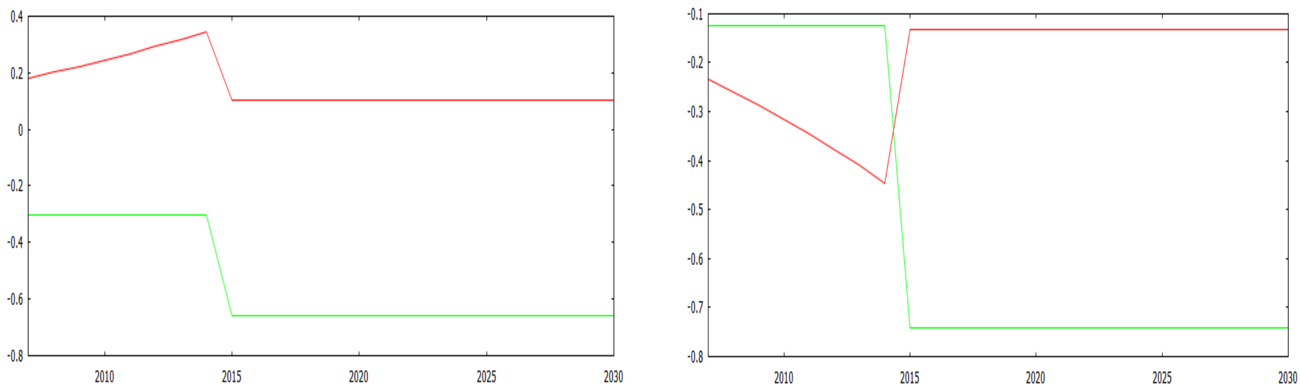


(a) wrong perfect foresight (b) proper perfect foresight

Figure 3. Single-period tax shock under different version of the model
(green line – private consumption, red line – investment)

In order to solve next problem - wrong perfect foresight - we have taken a generic simple dynamic CGE model (Figure 3b) and applied similar shock. The scenario assumed to increase all taxes on products by 5% in 2015. This simple model shows how properly consumption and investments should react, i.e. smooth preparation to the shock and then immediate return to steady state. Unfortunately our model does not show that reaction (Figure 3a). The solution for this problem was found at Figure 4 and 5.

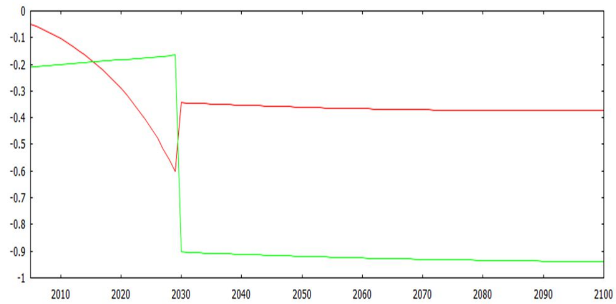
The Figure 3b reveals also that our model (Figure 3a) wrongly simulate reaction of investors. Increase of future consumption tax should not increase investments since household will save less. According to the claasical Ramsey model, households maximize the utility over the whole horizon and this means that they borrow and lend until the model will not reach the final period. Government has more restriction because they have to equilibrate public balance each period. The changes of this public constraint to the behavior similar to households implies improvement in behavior of investors (Figure 4a). Thus the models with public demand could behave badly if the government faces one-period budget constraints. The future improvement (Figure 4b) were obtained by switching from Leontief to CES function of households welfare due to flexibility of leisure-labor choice.



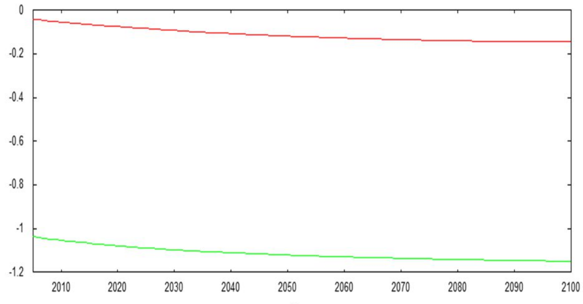
(a) muli-period budget constraint (b) CES welfare function

Figure 4. Tax shock under adjustments in final demand
(green line – private consumption, red line – investment)

Finally, we have applied different approach to natural resources than to other sectors. The initial (above) version assume that production in all sectors except electricity is based on CES structure with differentiated nesting approach. This means that producers has flexibility in changing elasticity of substitution between production factors, but it is limited to some extent. The main problem here is that capital consumed by sectors of natural resources (coal, gas, crude oil) contributes to capital stock. If we exclude this capital from the capital stock, it will not contribute to new investments. The idea is that we cannot increase long-term production of natural resource by simple increase of capital consumption, because the natural resources are limited. We can interpret this capital as a capital rent of natural resources. Its supply is interpreted in the same way as labor supply, i.e. exogenous growth path determines final supply (while other sectors has endogenous capital supply).



(a) single-period tax shock



(b) continuous tax shock

Figure 5. Tax shock under adjustment of capital supply of natural resources (green line – private consumption, red line – investment)

As a result of new treatment for natural resources sectors, the relationship between consumption and investment becomes proper (Figure 5a) in the initial periods. This means that consumption decrease more than investments immediately after households find that the future shock will be applied.

Furthermore, the order of sectors summation versus time summation is important in the multi-sectoral models. The models with sector-specific investments may lead to a uniform investment price even if it was not the modeler's goal. In fact, it is difficult to find a computable general equilibrium model with differentiated sectoral price of investments that would behave properly. We have simplified our model by switching to aggregate investments.

5. Conclusion

The model is built as a system of multiple nonlinear equations that describe the circular flow of goods and services in the economy, taking into account the optimizing behaviors of households (in terms of consumption and supply of production factors) and firms (in terms of production and employment of production factors). Government is included from the point of view of taxes, subsidies, and social transfers. From the economic theory point of view, the models is based on neoclassical assumptions – maximization of consumers' utility, minimization of costs by firms and marginal-cost pricing. By accounting for wide adjustments in the whole economy, while controlling for all major constraints such as energy balance and available capital stock the model gives a unique and detailed insight into the future shape of energy sector in Poland.

We have addressed several issues that could biased the results. First, data should be properly aggregated. Second, capital-labor relationship is important in dynamic modeling. Too much capital will require huge investments, but investment goods cannot be produced without additional labor. Thus unproportioned capital-labor relationship implies that economy cannot achieve a long-term equilibrium (steady-state). Third, capital rent from natural resources should not contribute to total capital stock. Otherwise, perfect foresight by households is biased.

CGE models are usually possessed as a black box because they are very complex. Dynamic CGE models are more complex than static one. Hybrid dynamic CGE models are even more complex. It is not difficult to make a mistake in design of such model. We do not offer the test to validate CGE models, but we help to identify the flaws that may lead to unreasonable results. It will be useless for policy-makers to get biased results. Every model is based on number of assumptions, but if the assumptions are wrongly implemented, there is no return from its complexness. Thus more simple models could be more usefulness. However, policy-makers expect to simulate the economy as close to reality as possible. Modelers will be able to fulfill this task only if the model will not work as a black box for them. Our study helps to achieve it using energy context as an example.

References

Gonseth C., Vielle M. (2012), *Modeling the Impacts of Climate Change on the Energy Sector: a Swiss perspective*, Ecole polytechnique fédérale de Lausanne, EPFL-CONF-177610

Bhattacharyya S.C. (1996), "Applied general equilibrium models for energy studies: a survey", *Energy Economics* 18, p. 145–164

Böhringer C. and Löschel A. (2006), "Computable general equilibrium models for sustainability impact assessment: Status quo and prospects", *Ecological Economics* 60, p. 49-64

Böhringer C., Rutherford T.F. (2008), "Combining bottom-up and top-down", *Energy Economics* 30(2), p 574–596

Bukowski M., red. (2013), *2050.pl podróż do niskoemisyjnej przyszłości*, report 1, Niskoemisyjna Polska 2050

Bukowski M. and Kowal P. (2010). "Large scale, multi-sector DSGE model as a climate policy assessment tool - Macroeconomic Mitigation Options (MEMO) model for Poland," *IBS Working Papers* 3, Instytut Badań Strukturalnych

Burniaux J.M., Martins J.O. (2012), "Carbon leakages: a general equilibrium view", *Economic Theory* 49, p. 473-495

Kassenberg A., Śniegocki A. (2015), *W kierunku niskoemisyjnej transofromacji rynku pracy*, report 6, Niskoemisyjna Polska 2050

Kiuila O., Wójtowicz K., Żylicz T., Kasek L. (2016), "Economic and environmental effects of unilateral climate actions," *Mitigation and Adaptation Strategies for Global Change* 21(2), p. 263-278

Kiuila, O., Rutherford, T.F. (2013), "The cost of reducing CO2 emissions: Integrating abatement technologies into economic modeling," *Ecological Economics* 87, p. 62-71

Mattoo A., A. Subramanian, D. van der Mensbrugghe, J. He (2009), "Reconciling climate change and trade policy", *Policy Research Working Paper* 5123, World Bank

McKinsey & Company (2009), *Assessment of Greenhouse Gas Emissions Abatement Potential in Poland by 2030*, Warsaw

World Bank (2011), "Transition to a Low-Emissions Economy in Poland", *World Bank Other Operational Studies* 10083