GOSPODARKA NARODOWA

p-ISSN: 0867-0005
e-ISSN: 2300-5238

1(297)/2019, 9–45

www.gospodarkanarodowa.sgh.waw.pl

DOI: 10.33119/GN/105510

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# Assessment of Energy-Related Technological Shocks Within a CGE Model for the Polish Economy[1]

**Abstract**: Despite the increasing popularity of computable general equilibrium (CGE) models in energy-economy-environment analyses, Polish data still provide a modest disaggregation of energy-related sectors. Hence, CGE modellers need to disaggregate corresponding products and industries on their own – to not only obtain more detailed insights, but also avoid the problem of an "aggregation bias". The aim of this paper is to test for such a bias in Poland's case using a small open economy, CGE model called GEMPOL, with an in-house split of energy sectors. Three alternative versions of the model are calibrated and solved. The first version includes energy sectors in their original breakdown. The second version includes their in-house split, with particular values of Armington elasticities derived directly from "parent" sectors. In the third version, Armington elasticities are increased in order to reflect the higher degree of international competition for smaller sub-products. Through a simulation shock, imposed under comparative-statics mode, an exogenous energy efficiency improvement is modelled. Finally, the results obtained from all the variants of the model are compared. It turns out that the simulation results produced by both aggregations and all three specifications of the model are similar from the macroeconomic perspective, but they vary significantly between different aggregations at the sectoral level.

**Keywords**: computable general equilibrium, aggregation bias, energy efficiency

**JEL classification codes**: C68, D58, Q43

Article submitted July 26, 2018, accepted for publication January 16, 2019.

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[1] The views expressed in this paper are solely those of the author.

## Introduction

Energy efficiency, defined as a quantity of output produced from a given amount of energy inputs[2], is commonly perceived as a key factor of economic and social development. Therefore, a comprehensive understanding of all of its benefits is of great importance [IEA, 2014]. Previous research on the consequences of decreasing energy intensity, i.e. improving the energy efficiency of the economy, focused on measuring direct savings related to decreased energy use and reduced expenditures on energy products. In a broader sense, the direct and indirect economic benefits of this are much greater [ENE, 2012], but their scale is commonly underestimated [Ecofys, 2013]. Recently, there has been a growing understanding of the need to depart from such a narrow approach towards the identification and quantification of a wide spectrum of multiple socio-economic benefits resulting from lower energy intensity. Energy savings themselves are not the only or most important outcome of energy efficiency improvements. According to the International Energy Agency (IEA), there are five main areas in which the impacts of energy efficiency improvements should be assessed [IEA, 2014]: *macroeconomic development*, *public budgets*, *health and well-being*, *industrial productivity*, and *energy delivery*. The availability of adequate techniques of economic modelling makes it possible to properly assess the first, second and, to an extent, fourth areas. These aspects can be jointly defined as the macroeconomic, sectoral and fiscal effects of a decreased energy intensity of an economy.

As observed by Greening *et al.* [2000], prices in an economy are subject to numerous and complex adjustments due to energy efficiency changes. Therefore, only an analytical approach based on general equilibrium theory is capable of providing a full and reliable quantification of such impacts. Improvements in energy intensity spill over to the entire economy through a series of adjustment mechanisms that influence the prices and quantities of production in individual industries and the consumption of various products. The heterogeneity in energy intensities, substitution possibilities within production functions and demand elasticities in various sectors of the economy [Allan *et al.*, 2006] result in asymmetric reactions of particular prices to changes in energy efficiency, which calls for the inclusion of a sectoral dimension to the analytical framework. For these reasons, computable general equilibrium (CGE) models constitute the most adequate tool to estimate the economy-wide consequences of energy intensity changes that impact almost all areas of economic activity [Allan *et al.*, 2006, 2007]. It is noteworthy that CGE models are commonly used not only for impact assessments of energy efficiency changes, but also to evaluate other climate- and energy-related issues [Allan *et al.*, 2007].

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[2] Energy efficiency constitutes a reciprocal of energy intensity, which equals the amount of energy used per unit of output. Hence, energy intensity improvements are equivalent to energy intensity declines.

Bureau and Salvatici [2003] as well as Lloyd and Maclaren [2004] noted, however, that one of the main disadvantages of the CGE framework is its insufficient sectoral dimension. As argued by Grant *et al.* [2006] and Alexeeva-Talebi *et al.* [2012], excessive aggregation misses important details and insights on product specificity (unobserved heterogeneity) at the sectoral level and may lead to model misspecification. Narayanan *et al.* [2010] associated this unobserved heterogeneity with variations in the structural characteristics of the omitted subsectors (e.g. factor and energy intensity, trade openness) as well as with the fact that various policies and shocks are often heterogeneous at low levels of disaggregation. Hence, simulation results obtained from an over-aggregated CGE model may turn out to be biased [Alexeeva-Talebi *et al.*, 2012]. The "aggregation bias" for particular variables is defined as the difference between their values obtained from a more aggregated model and their values from a more disaggregated model, re-aggregated back to the default sectoral breakdown [Caron, 2012]. Among the various elements of the bias, the issue of "false competition" in foreign trade is particularly notable. This involves a situation in which various countries compete with their products at more disaggregated levels, but not with respective product aggregates, as could be suggested by simulation results obtained from over-aggregated CGE models. This aspect is also important for single-country models due to Armington's [1999] formulation of foreign trade mechanisms.

Another potential solution to the problem of an aggregation bias is the use of a combined partial equilibrium/general equilibrium (PE/GE) framework in which certain subsectors are derived from the default aggregation of the GE model, but their functioning is reflected only by PE adjustments [Narayanan *et al.*, 2010]. In this context, bottom-up partial equilibrium models provide more disaggregation than their top-down (computable) general equilibrium counterparts, but at the cost of lacking internal consistency and missing comprehensive economy-wide effects of analysed policies and/or shocks [Grant *et al.*, 2006]. Against this backdrop, the conclusion seems to be legitimate that disaggregated CGE models outperform the combined PE/GE framework because they can fully capture economy-wide effects and inter-sectoral linkages. However, the existing literature on providing a comprehensive, more detailed sectoral disaggregation within a "full" CGE model and measuring the aggregation bias is limited and comprises research conducted by Alexeeva-Talebi *et al.* [2012] and Caron [2012]. However, neither of these studies focused directly on splitting energy-related sectors, but rather energy-intensive, industrial sectors within the Global Trade Analysis Project (GTAP) database [Rutherford, 1998]. The authors of both these studies agreed that the aggregation bias at the sectoral level is remarkable and that macroeconomic variables are mostly unaffected by the level of model aggregation. Hence, sectoral biases seem to cancel out at the level of the entire economy. Grant *et al.* [2006] obtained similar conclusions for their comparison of an aggregated CGE model with a combined PE/GE model that included a far richer disaggregation of dairy sectors. Hence, if a researcher is solely interested in the macroeconomic impacts of given policy changes and/or exogenous shocks, the use of a CGE model with a modest sectoral disaggregation may be sufficient [Alexeeva-Talebi *et al.*, 2012]. In addition, the range and standard deviation of changes in various sectoral variables increase with the detail of model disaggregation [Alexeeva-Talebi *et al.*, 2012; Caron, 2012].

In Poland's case, despite the increasing popularity of computable general equilibrium (CGE) models used in climate and energy research, appropriate data, namely input-output tables and supply and use tables, provide rather modest disaggregation of energy-related sectors. This problem in particular concerns fossil fuels (hard coal, lignite, natural gas, and crude oil) as well as electricity and heat. Hence, CGE modellers are left with the need to perform a disaggregation of corresponding products and industries on their own—not only to obtain more detailed insights, but also to avoid the problem of an aggregation bias.

Against this backdrop, the aim of this paper is to assess the sign and magnitude of such a bias in the case of energy-related products and industries within Poland's economy. The analysis is based on a small open economy, CGE model called GEMPOL (*General Equilibrium Model for Poland*) that contains an in-house split of fossil fuel and energy sectors.

The paper is structured as follows: after the introduction in section 1, section 2 briefly traces the disaggregation of energy-related products and industries; section 3 discusses the main features and characteristics of the model GEMPOL; section 4 describes the modelling exercise and the simulation details; section 5 presents the obtained results; while section 6 concludes.

## Disaggregation of energy-related products and industries

The main data source for calibrating the model GEMPOL is symmetric supply and use tables (SUTs) for Poland as of 2010, based on the ESA 2010 methodology. They contain detailed information on the cost structure, intermediate and final demand, foreign trade, factor incomes and tax payments for 77 products and 77 industries.

An important drawback of Polish SUTs, however, is excessive aggregation of energy-related commodities and industries:

- hard coal and lignite are aggregated into *Coal and lignite* (CPA/NACE 05);
- crude petroleum, natural gas, metal ores and other mining are aggregated into *Crude petroleum and natural gas, metal ores, other mining and quarrying* (CPA/NACE 06–09);
- electricity generation and distribution, gas distribution and heat are aggregated into *Electricity, gas, steam and air conditioning* (CPA/NACE 35).

Such an aggregation most probably stems from the fact that the Central Statistical Office (CSO) does not split double-digit CPA/NACE codes into smaller subgroups (the case of CPA/NACE 05 and 35). This is in part due to "statistical secrecy" resulting from a small number of entities in these segments of the

Polish economy. Too few companies are in operation for the statistical office to single out all the individual codes within the CPA/NACE 06–09 aggregate[3]. As a consequence, publicly available data does not make it possible to track in sufficient detail changes in output and trade patterns in individual fossil fuel and energy sectors, or changes in the use of energy-related products in all sectors of the economy. In fact, such a disaggregation is desirable and necessary for CGE-based analyses to be conducted with respect to energy-related research areas. In order to overcome this obstacle, it is necessary to increase the level of detail in the sectoral disaggregation of the default supply and use tables through a unique in-house disaggregation of the above-mentioned products and industries.

**Table 1. Disaggregation scheme for energy-related commodities and industries**

| Commodities/industries in supply and use tables *(CPA 2008/NACE Rev 2)* | Commodities/industries after disaggregation |
|---|---|
| *Coal and lignite (05)* | Hard coal |
| | Lignite |
| *Crude petroleum and natural gas, metal ores, other mining and quarrying (06-09)* | Crude petroleum |
| | Natural gas |
| | Metal ores, other mining and quarrying products |
| *Electricity, gas, steam and air conditioning (35)* | Electricity |
| | Transmission, distribution and trade of electricity |
| | Distribution and trade of gas fuels |
| | Heat (steam and hot water) |

Source: Own elaboration based on Antoszewski [2016].

For the purpose of the performed disaggregation[4], it was essential to extensively use a variety of data sources: auxiliary supply and use tables from the CSO [2014] that contain a disaggregation of the product CPA 35 as well as ARE [2011], CSO [2012], IGSMiE PAN [2013], IEA [2015], and Eurostat [2016], complemented by some ad-hoc expert assumptions. In order to ensure consistency between various data sources and to construct internally coherent and fully balanced, disaggregated supply and use tables, the RAS procedure [EC, 2014], based on minimum entropy techniques[5], was extensively utilised.

3 "Statistical secrecy" requires that in order for a given figure to be published, it must comprise at least three entities.

4 A preliminary version of this split was prepared by Antoszewski [2016].

5 As described by EC [2014]: *"The RAS […] is a well-known method for data reconciliation. Its aim is to achieve consistency between the entries of some nonnegative matrix and pre-specified row and column totals. […] Mathematically, RAS is an iterative scaling method whereby a non-negative matrix is adjusted until its column sums and row sums equal to some pre-specified totals. It multiplies each entry in one row or column by some factor that is chosen in such a way that the sum of all entries in the row or column becomes equal to its target total. This operation is first applied*

A similar approach was taken by Alexeeva-Talebi *et al*. [2012] and Caron [2012]. A detailed description of the in-house disaggregation of energy-related products and industries is provided in Annex 2.

As a result, the above-mentioned procedures made it possible to obtain symmetric supply and use tables, distinguishing between 83 products and 83 industries thanks to disaggregating the three above-mentioned energy-related sectors into nine smaller sub-groups (see Table 1 for more details).

## Analytical toolbox – CGE model GEMPOL

GEMPOL (*General Equilibrium Model for Poland*) is a single-country CGE model of the Polish economy, calibrated to the 2010 supply and use tables [CSO, 2014], with their initial inclusion of 77 products and 77 industries. The unique in-house disaggregation makes it possible to increase the number of products and industries to 83 and to split labour into three skill groups: high- (*HS*), medium- (*MS*) and low-skilled (*LS*)[6]. The model also contains a relatively rich representation of direct and indirect taxes, including VAT, excise duties, other taxes and subsidies on products, producer taxes levied on industries, as well as income taxes levied on labour and capital. Although recursive-dynamic in origin, for the purpose of this paper the model is run in comparative-statics mode, since the time paths are not of central role for this analysis. GEMPOL takes certain assumptions that are standard for a vast majority of CGE models: constant returns to scale, perfect competition, and nested production structure. The model was coded in GAMS/MPSGE software [Rutherford, 1999] and is solved as a mixed complementarity (MCP) problem.

For the sake of transparency of this analysis, GEMPOL was aggregated from 83 to 31 products and industries, which included merging numerous agriculture and service sectors of lesser importance in the context of the researched problem (see Table 8 and Table 9 in Annex 1).

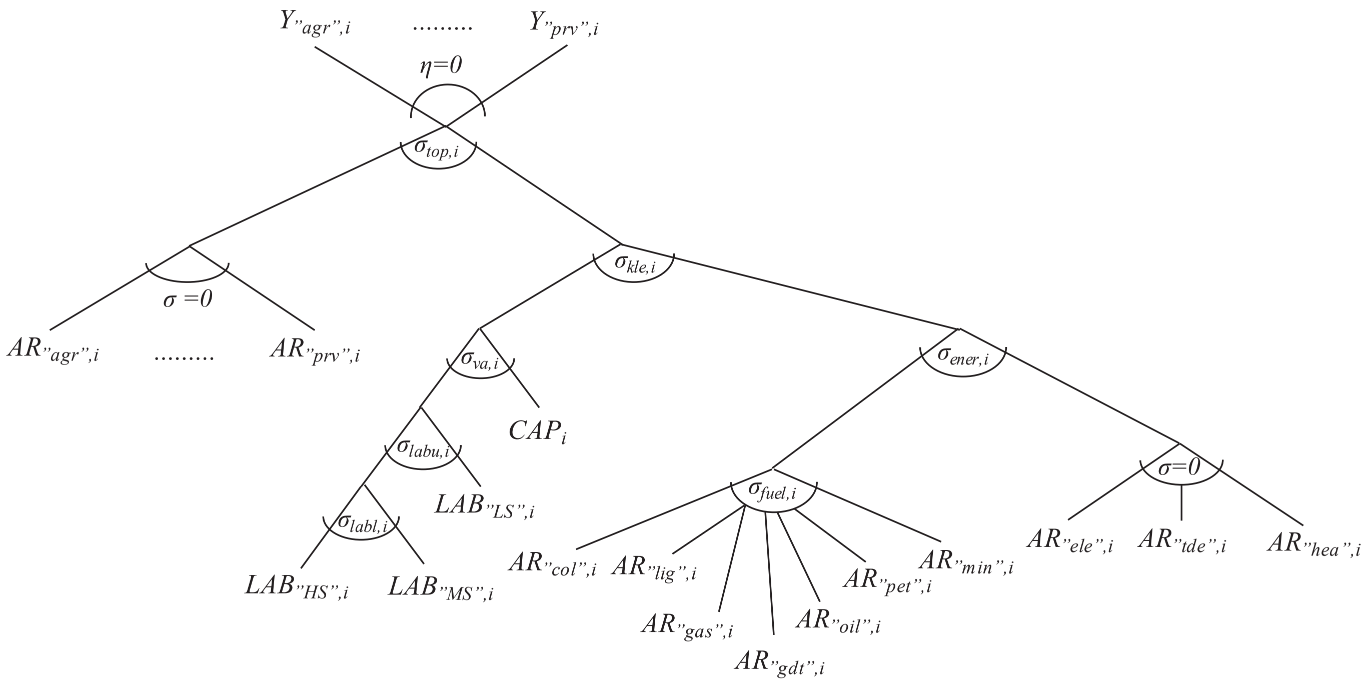
### Nesting structures

The empirical literature does not offer any definite suggestions with respect to an "optimal" nesting structure of production functions within a CGE model [Allan *et al*., 2006; van der Werf, 2008]. Therefore, the nesting scheme applied in the model GEMPOL was derived from Beauséjour *et al*. [1995] and Rutherford [2010].

*to all rows of the matrix. As a consequence the matrix becomes consistent with all target row totals. Then, the columns are made consistent with their required totals. As a result consistency is achieved with the column totals, but the constraints on the row totals may be violated again. The rows and columns are adjusted in turn, until the algorithm converges to a matrix that is consistent with all required row and column totals."*

6 This split was performed based on *WIOD Socio Economic Accounts 2013* [Timmer *et al*., 2015].

**Figure 1. Nesting structure of production function for industry *i***




* Annex 1 provides explanation of the acronyms used.

Source: Own elaboration based on Beauséjour *et al*. [1995] and Rutherford [2010].

All domestic industries share the same production function structure (see Figure 1). At the top nest, they combine fixed proportions of non-energy materials (all intermediate products except for fossil fuels, metal ores, electricity and heat) with the labour-capital-energy composite[7]. This composite consists of the value added and energy composites. The former consists of the labour composite – made up of low-skilled labour and the composite of medium- and high-skilled labour[8], in after-tax value – and capital (in after-tax value). The latter consists of the electricity-heat composite as well as the fossil fuels and metal ores composite (hard coal, lignite, natural gas, gas distribution, crude oil, refined petroleum, metal ores, other mining and quarrying). The electricity-heat composite is a product of electricity, its distribution and heat, combined in fixed proportions. A multi-production of various goods and services by all industries, but with a fixed structure consistent with the base year, modelled via a zero elasticity of transformation, is also captured.

Domestically produced goods are combined with imported products (including import tariffs), creating the Armington [1969] composite, which is then augmented, in fixed proportions, with trade and transport margins[9]. This composite is then combined with excise duty and other product taxes, corrected by product subsidies. Subsequently, such an aggregate, after including the Value Added Tax, is divided between the domestic demand and exports, which is reflected by the constant elasticity of transformation (CET) function with a product-uniform, unitary elasticity of transformation.

In addition, the domestic sources of final demand include households and the government. These agents bear both consumption and investment expenditures. The nesting structures of the consumption functions of households (see Figure 2) and the government (see Figure 3) are similar to the previously described industrial production functions. At the top nest, non-energy materials[10] (all intermediate products except for fossil fuels, metal ores, electricity, heat and related) are combined with the energy composite. This composite consists of the electricity-heat composite and of the fossil fuels and metal ores composite (hard coal, lignite, natural gas, gas distribution, crude oil,

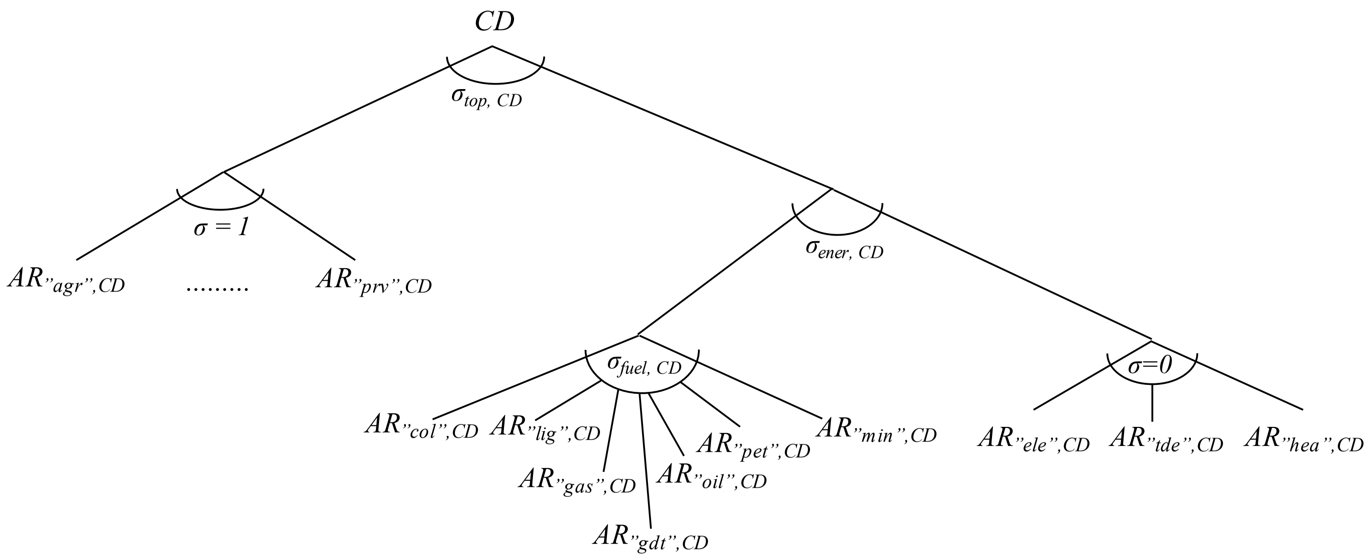
7 It must be stressed that all the materials that appear in the production function are expressed in purchaser's prices, i.e. including margins, taxes and subsidies. Technically, margins, taxes and subsidies are levied on the values of particular products in basic prices at an earlier stage, with the use of additional nested "production" functions. A similar approach was applied to the taxation of labour and capital and to the combination of domestic and imported products. Due to the limited space, such graphs have not been presented here.

8 Such a nesting scheme for labour is related to the fact that, from the viewpoint of the education level, high- and medium-skilled labour as defined in *WIOD Socio Economic Accounts* are much more similar to each other than to low-skilled labour.

9 Under the aggregation of the model GEMPOL, trade margins stem solely from the product *Sale and repair services of motor vehicles and motorcycles, wholesale and retail trade services* (trd), while transport margins constitute a Leontief combination of the products *Transmission, distribution and trade of electricity* (tde) and *Transport (land, pipeline, water, air)* (trn).

10 For household consumption, this composite aggregates non-energy products with the Cobb-Douglas function, while for government consumption the Leontief function is used.

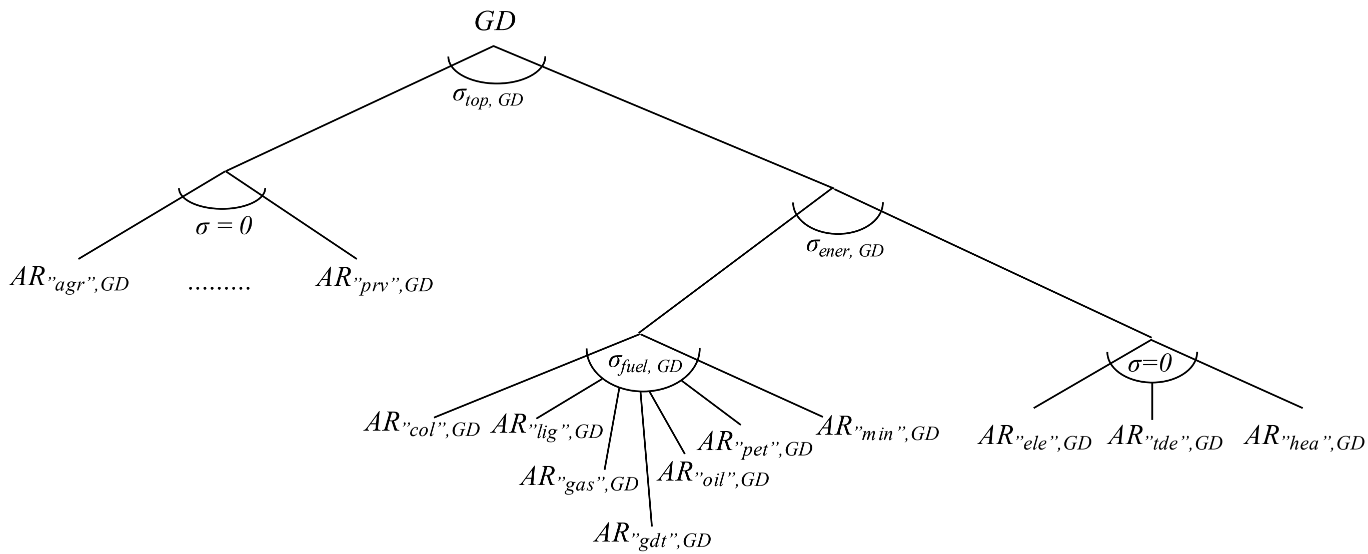
**Figure 2. Nesting structure of household consumption**




* Annex 1 provides explanation of the acronyms used.

Source: Own elaboration based on Beauséjour *et al.* [1995] and Rutherford [2010].

**Figure 3. Nesting structure of government consumption**




* Annex 1 provides explanation of the acronyms used.

Source: Own elaboration based on Beauséjour *et al*. [1995] and Rutherford [2010].

refined petroleum, metal ores, other mining and quarrying). The electricity-heat composite is a product of electricity, its distribution and heat, combined in fixed proportions.

Besides, both private and public investment sectors aggregate purchased products with the Leontief function, thus creating the composites of private and public investment.

In contrast with the production function structures, a vast majority of the substitution elasticities are industry- and product-specific (see Table 6 in Annex 1). However, the issue of Armington elasticity values for the more disaggregated sub-products, whose derivation was described in section 2, must be carefully taken into account. As underlined by Alexeeva-Talebi *et al*. [2012] and Caron [2012], the model's disaggregation implies a definition of the more homogenous goods that are closer substitutes than the more aggregated commodities. Hummels [2001], Balistreri and McDaniel [2002] as well as Grant *et al*. [2006] argued that, with a more detailed sectoral disaggregation of the model, greater substitutability between domestic and imported goods should be expected[11]. This would call for an increase in Armington elasticities for detailed sub-products, as compared to their "parent" counterparts. This issue is important because Armington elasticities play a key role in determining the results of CGE-based analyses [Hillberry, Hummels, 2013]. As no appropriate estimates for such detailed, independently derived sub-sectors are available, all the substitution elasticities for each disaggregated product and industry were directly taken from their "parent" counterparts. Still, a sensitivity analysis should also be conducted of the simulation results with respect to the assumed elasticity values, especially the Armingtons. This issue is discussed in section 4.

As most CGE models, GEMPOL distinguishes between the two main economic agents: households and the government. Households constitute an aggregate comprising all consumer groups, hence the commonly used term "representative household". The government comprises the whole public finance sector: the state budget, local government budgets, the social security system, and other budgetary units. The representative household derives income from labour and private capital remuneration, social transfers and public debt interest. It purchases consumption and investment goods and pays taxes on products, producers and factors of production. Meanwhile, the government derives income from public capital remuneration, taxes on products, producers and factors of production. It purchases consumption and investment

[11] To illustrate this, let us consider the following example. For a given branch of the economy, it is more difficult to change the proportions of domestic and imported inputs of manufacturing products in the broad sense than in the case of more specific goods such as non-metallic minerals, in response to relative price changes at home and abroad. This results from the fact that in the former case it would be necessary to apply significant changes to the domestic-imported structure of a much larger fraction of the overall value of intermediate inputs within a given branch. From a technical and economic viewpoint, such a process would be difficult to conduct. Consequently, this calls for a lower elasticity value in the former case.

goods and incurs expenses on social transfers and public debt interest. The difference between government expenditures and revenues constitutes the budget deficit. Notably, the shares of the private and public sectors in capital stock ownership are exogenously fixed at values consistent with the model's base-year calibration.

## Closure and *numeraire*

For the purpose of this analysis, the model is closed using comparative-statics mode suited for long-term scenario analysis. Table 2 provides a brief description of individual elements of the closure.

**Table 2. Model's closure**

| Dimension | Characteristics |
|---|---|
| Labour | Fixed labour stock: mobile between industries, but immobile between skills. No unemployment. Market equilibrium guaranteed by adjustments of an industry-uniform and skill-specific real wage. |
| Capital | Capital stock fixed, but mobile between industries. Market equilibrium guaranteed by adjustments of an industry-uniform real capital rental rate. |
| Productivity | Fixed productivity of production factors and intermediate inputs. Simulation scenarios capture exogenous productivity shocks. |
| Trade | Fixed real trade balance. Market equilibrium guaranteed by real exchange rate adjustments. |
| Investment | Real private and public investment proportional to real private and public consumption respectively. |
| Government | Endogenous real government consumption. Real government investment proportional to real government consumption. Fixed real expenditure on social transfers and debt service, fixed real budget deficit. |

Source: Own elaboration.

Labour is mobile between industries, but immobile between skill levels, which implies an industry-uniform, but skill-specific real wage rate. The total labour stock is fixed at its benchmark level. Capital is mobile between industries, which implies an industry-uniform capital rental rate. The total capital stock is fixed at its benchmark level. Productivity is exogenous, i.e. the initially calibrated values of the technology parameters are determined by the base year situation of the economy. This, however, makes it possible to simulate the impacts of various productivity shocks on the economy. The small open economy (SOE) assumption implies no impact by the domestic economy on world prices and the country's ability to import and export infinite product quantities for a given level of world prices. The trade balance is fixed in real terms, i.e. adjusted by real exchange rate changes. Among the final demand components, both private and public consumption are fully endogenous. Real private and public consumption determine the dynamics of private and public investment respectively. Hence, it is investment that determines the required level of savings (*investment-driven closure*), and not the reverse. Government expenditure on social transfers and debt interest as well as the budget deficit are fixed in real terms, i.e. adjusted by household consumption price changes. This implies a stability of the fiscal policy parameters (i.e. tax and subsidy rates) at a level consistent with the baseline calibration of the model.

In addition, a reference price (*numeraire*), against which all changes in the remaining prices are interpreted, needs to be chosen. In the case of the model GEMPOL, the price of household consumption, i.e. the consumer price index (CPI), acts as a *numeraire*. This also implies that all the price changes within the model should be perceived in real terms, i.e. after correcting for inflation.

## Simulation scenarios

Prior to scenario formulation, the model was calibrated to two alternative datasets with various aggregation levels. The first dataset includes an in-house disaggregation of all the energy sectors described in section 2, combined with an aggregation of the numerous agriculture and service sectors for the sake of compactness. Hence, this version of the model (**GEMPOL 31a**) distinguishes between 31 instead of 83 products/industries that are technically available in the full-fledged model. The second dataset includes energy-related sectors as broken down originally by the CSO. This, in combination with an aggregation of the numerous agriculture and service sectors, makes it possible to distinguish between 25 products/industries (**GEMPOL 25**). The nesting structure in GEMPOL 25 is the same as in GEMPOL 31a (presented in section 3): the commodities *col* and *lig* are aggregated into single product *col*, commodities *gas*; *oil* and *min* are aggregated into single product *min*; while commodities *ele*, *tde*, *gdt* and *hea* are aggregated into single product *ele*. The particular elasticities for GEMPOL 25 are aggregated[12] as weighted averages of the corresponding sub-sector elasticities from GEMPOL 31a, with the weights derived from the base-year economic flows constituting the output of the nest with a given elasticity[13]. As previously suggested, the simulations performed in this study include a sensitivity analysis with respect to the values of the Armington elasticities for the disaggregated sub-products. Therefore, another version of the model, with disaggregated energy products (**GEMPOL 31b**), was calibrated. For this specification, the Armingtons, by default "inherited" from the respective aggregate products in GEMPOL 25, were multiplied by a factor of 1.31. This number constitutes a ratio of the mean Armington elasticity, estimated

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12 The need for an aggregation of the elasticity values stems from the fact that, within the model GEMPOL 25, both energy-related products and industries are subject to aggregation, whose scheme is presented in Table 1. Hence, it was also necessary to aggregate the values of all the sector-specific substitution elasticities within the production functions of the energy-related industries, as well as the Armingtons for the energy-related sectors in order to ensure coherence with the less detailed level of disaggregation.

13 In particular, this procedure is consistent with the CES function approach and was directly derived from the *gtapaggr* utility, which constitutes a part of the GTAP database [Rutherford, 1998].

from more disaggregated sectoral data, to the mean estimate from the more aggregated data at the sectoral level, estimated by Hummels [2001]. Such an approach was initially demonstrated by Caron [2012].

Similar to Caron [2012] as well as Alexeeva-Talebi *et al*. [2012], the counterfactual scenario implemented in this paper has been stylised to illustrate the problem of the aggregation bias for a particular kind of economic shock. The simulation exercise performed in comparative-statics mode includes an exogenous, one-step improvement in the energy efficiency of industrial production or final consumption, modelled as a positive, sector-specific (for particular industries, households and the government), fuel-uniform technological shock. The size of this shock is the 2010–2030 change in sectoral energy intensity derived from the *EU Reference Scenario 2016 – Energy, transport and GHG emissions – Trends to 2050* [EC, 2016]. In the case of all the industries, the simulation shock reflects the expected energy efficiency improvement of production in particular branches, i.e. a decrease in energy intensity due to technology improvement, not as a result of changes in the structural composition of the economy. Hence, this shock consists of an increase in the productivity of using fossil fuels, electricity and heat as intermediate inputs, i.e. decreases in the use per unit of goods produced by a given industry. In the case of households and the government, the size of the simulation shock reflects the expected energy efficiency improvement of private and public consumption respectively. Hence, this shock is equivalent to an increase in the "efficiency" of consuming fossil fuels, electricity and heat as final demand components, i.e. decreases in the use per unit of aggregate private and public consumption goods. The products whose productivity increases are: *Hard coal* (col), *Lignite* (lig), *Natural gas* (gas), *Crude petroleum* (oil), *Metal ores, other mining and quarrying products* (min), *Coke, refined petroleum products* (pet), *Electricity* (ele), *Transmission, distribution and trade of electricity* (tde), *Distribution and trade of gas fuels* (gdt), and *Heat (steam and hot water)* (hea). The simulated productivity shock is uniform across all the energy-related products used, in the form of either intermediate or final demand, by a given sector of the economy, but its scale is user-specific. Such an approach stems from the availability of appropriate projections, but it is also the most common in the empirical literature [Allan *et al.*, 2006]. In addition, no energy efficiency improvement has been assumed in the energy-related industries themselves. As noted by Allan *et al*. [2007], there are arguments that such industries already operate closely to the "thermodynamic limits", which makes them unable to increase their production volume, keeping the amount of energy-related products used at the current level – see Table 7 in Annex 1 for more details of the size of the simulation shocks. Notably, in the case of the model GEMPOL 25, which is less detailed with respect to energy sectors, no aggregation of the simulation shock is needed because these industries do not face any energy efficiency improvement in the counterfactual scenario.

These three alternative versions of the model, namely GEMPOL: 25, 31a and 31b, were subsequently solved. Afterwards, a re-aggregation was performed of the results obtained from the more detailed models (GEMPOL 31a and 31b) to the sectoral scheme consistent with GEMPOL 25 (see Table 8 and Table **9** in Annex 1) in order to provide a comparability of the results and to allow for identification and quantification of the aggregation bias.

It must also be stressed that the potential difference between the results obtained from the two model versions – GEMPOL 31a and 31b, as well as the aggregation bias measured against the GEMPOL 25 version, stems not only from the multiplication of the Armington elasticity values by a uniform factor of 1.31, but also from their default level. In order to address this issue, a robustness check was also performed with respect to the default Armington elasticity values. This sensitivity analysis included a multiplication of the initial values by a factor of two, with a subsequent repetition of the simulation exercise[14].

## Results

Table 3 presents the impact of an improved energy efficiency on selected macroeconomic and fiscal variables under both aggregations and three specifications of the model, as well as the aggregation bias, defined as a percentage difference between the values obtained from the aggregated (GEMPOL 25) and from one of the disaggregated (GEMPOL 31a or 31b) versions of the model. In general and unsurprisingly, a positive technological shock in the form of improved energy efficiency has a favourable impact on the economy – with respect to variables such as output, GDP, consumption, investment and foreign trade. Still, several outcomes require a more in-depth explanation. The relatively low increase in real public consumption results from a relatively strong upswing in its price. Nominal government consumption rises much stronger, similar to the increase in nominal budget revenues. Gross output rises significantly weaker than the GDP because improved energy efficiency leads to a reduced "energy" share of intermediate use, combined with an increased role for value added and "non-energy" intermediate use within total production costs. As a result, an increase in the economy-wide, total intermediate demand turns out to be significantly weaker than in the case of final demand[15]. Almost parallel changes in the volumes of exports and imports result from the adopted closure of the model, i.e. the exogeneity of the real trade balance.

14 The robustness check does not include the case of decreasing default values of Armington elasticities. This results from the fact that the initial values of the Armingtons used in the model GEMPOL (see Table 6) are already close to the lower bound of a wide range of values available in the empirical literature – see for example Rutherford [1998], Saito [2004], and Németh *et al.* [2011].

15 The Gross Domestic Product equals the sum of the final expenditures in the economy, while gross output comprises both the intermediate and final expenditures.

Notably, changes in tax revenues show an interesting pattern. Budget revenues from excise tax, import tariffs and other product taxes exhibit a drop due to decreased demand for and (consequently) output of energy-related products whose productivity increases. However, VAT revenues increase as a consequence of a higher level of overall economic activity, induced by the technological shock. All the macroeconomic variables show a similar pattern of changes under both model aggregations, i.e. GEMPOL 25 vs. GEMPOL 31a/31b. In general, the overall aggregation bias turns out to be negative, i.e. the overly aggregated model (GEMPOL 25) under-predicts the changes in particular macro-variables due to improved energy efficiency, as compared to the more disaggregated versions (GEMPOL 31a/31b). Still, the negative aggregation bias does not exceed 1%, with the upper bound marked by excise tax revenues. Hence and similar to Caron [2012] and Alexeeva-Talebi *et al*. [2012], the macroeconomic bias is limited. In addition, the difference in the bias with respect to the Armington elasticity values is negligible, with the bias being slightly more negative for higher elasticities (i.e. GEMPOL 31b).

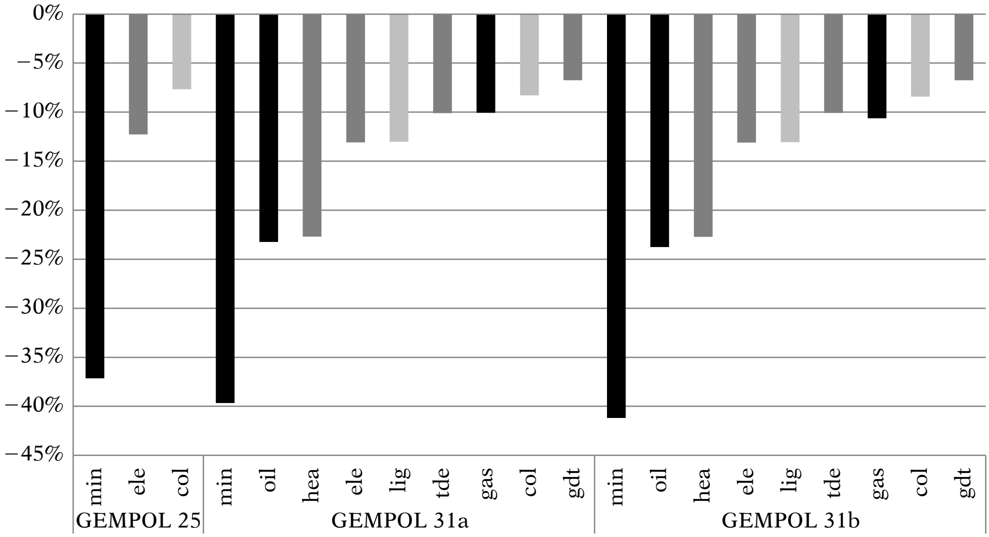
**Table 3. Measures of aggregation bias for the simulated shock at the macroeconomic level (in %)**

| | % change vs. BAU | | | Aggregation bias | |
|---|---|---|---|---|---|
| | GEMPOL (25) | GEMPOL (31a) | GEMPOL (31b) | GEMPOL (31a) | GEMPOL (31b) |
| Real GDP | 4.22 | 4.24 | 4.25 | –0.02 | –0.03 |
| Private consumption | 4.33 | 4.33 | 4.33 | 0.00 | –0.01 |
| Public consumption | 3.59 | 3.68 | 3.69 | –0.09 | –0.09 |
| Private investment | 4.33 | 4.33 | 4.33 | 0.00 | –0.01 |
| Public investment | 3.59 | 3.68 | 3.69 | –0.09 | –0.09 |
| Exports | 2.40 | 2.12 | 2.18 | 0.27 | 0.21 |
| Imports | 2.28 | 2.02 | 2.08 | 0.26 | 0.20 |
| GDP deflator | 0.57 | 0.66 | 0.66 | –0.09 | –0.09 |
| Nominal GDP | 4.82 | 4.93 | 4.94 | –0.11 | –0.12 |
| Output | 2.63 | 2.59 | 2.61 | 0.04 | 0.02 |
| Value Added Tax | 0.07 | 0.11 | 0.13 | –0.04 | –0.06 |
| Excise tax | –4.12 | –3.32 | –3.30 | –0.83 | –0.85 |
| Import tariffs | –0.31 | –0.23 | –0.19 | –0.08 | –0.12 |
| Other product taxes | –4.01 | –4.09 | –4.06 | 0.08 | 0.06 |

Source: Own elaboration.

However, the magnitude of the reactions induced by the improvement in energy efficiency and their heterogeneity under various aggregations of the model, are far more pronounced for the sectoral variables. This is especially visible in the case of all the industries subject to the disaggregation process. Their production volumes fall sharply as they produce large quantities of fossil fuel- and energy-related products. Since the productivity of such commodities shows a large increase, the intermediate and final demand for them in all branches of the economy, households and the government is reduced. Within each of the three industrial groups that were disaggregated from the default breakdown, as in GEMPOL 25, the range of sub-industry output changes is quite large. However, the impact of the Armington elasticity values (i.e. the difference between GEMPOL 31a and 31b) on output reactions is negligible (see Figure 4).

**Figure 4. Gross output changes for the disaggregated sub-industries due to the simulated shock**

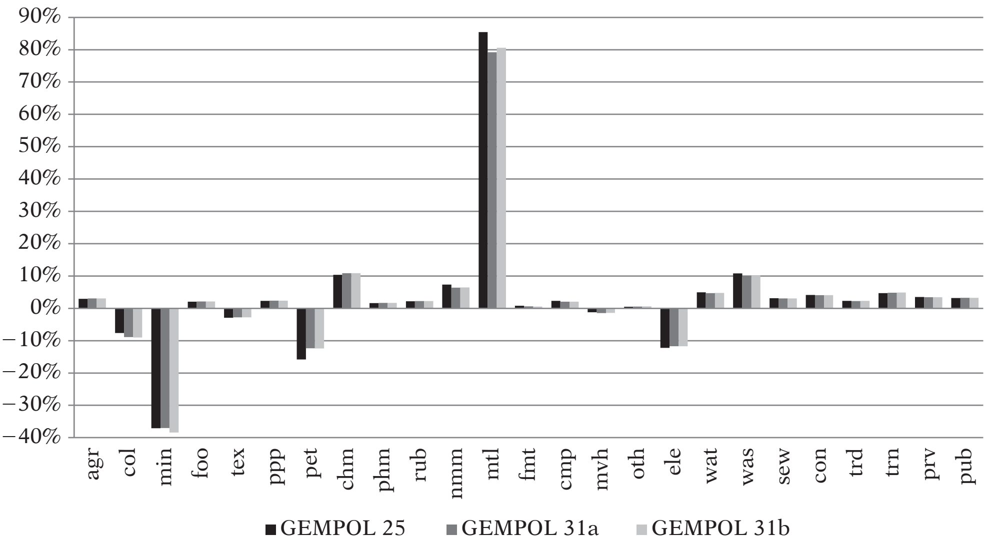



Source: Own elaboration.

Notably, heterogeneous changes in the output volume in response to the improved energy efficiency under various aggregations of the model can also be observed for industries not subject to the in-house split (see Figure 5). This in particular refers to energy-intensive industries such as *Coke, refined petroleum* (pet), *Non-metallic minerals* (nmm) and *Basic metals* (mtl). In fact, these branches of the economy, in which energy inputs constitute a key part of intermediate demand, are the main "winners" when there is an energy efficiency improvement and a consequent increase in the productivity of energy-related products. The impact of varying Armington elasticity values (i.e. the difference between GEMPOL 31a and GEMPOL 31b) on output in these industries is less pronounced.

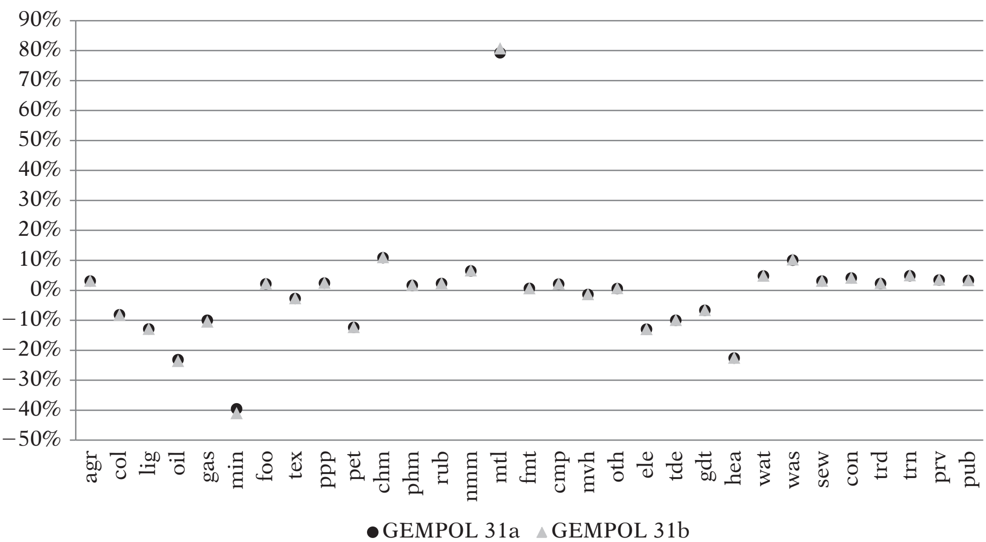
In fact, sectoral reactions to the simulated shock are similar for both specifications of the model with broader sectoral disaggregation and different Armington elasticity values (GEMPOL 31a and 31b). Figure 6 illustrates this observation for sectoral output volumes. Such an outcome proves the relative robustness of the results with respect to the Armington elasticity values for the derived sub-products and, as a consequence, a similar magnitude of the aggregation bias against the more aggregated specification (GEMPOL 25).

**Figure 5. Gross output changes for "parent" industries in all specifications of the model**




Source: Own elaboration.

**Figure 6. Gross output changes by industry based on the disaggregated model with default (GEMPOL 31a) and increased (GEMPOL 31b) Armington elasticities for energy-related products**

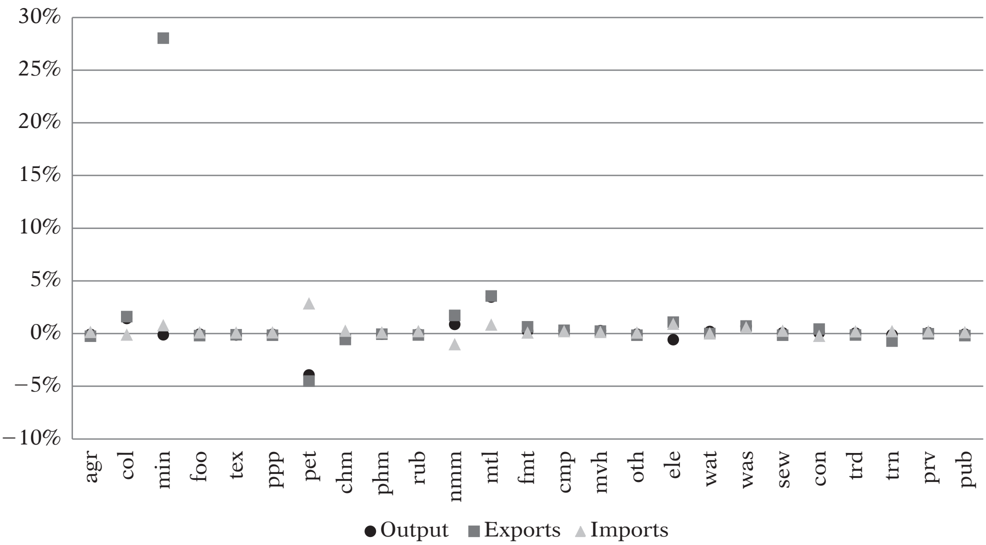



Source: Own elaboration.

Therefore, a detailed description of the aggregation bias for only one of these specifications – namely GEMPOL 31a – seems to be justified. In most cases, the aggregation bias for the sectoral activity variables does not exceed

±1%. However, there are notable exceptions in several cases, for which a much more pronounced bias is observed (see Figure 7). This mainly refers to the exports of *Crude petroleum and natural gas, metal ores, other mining and quarrying* (min) and, to a much lesser extent, to the output and exports of energy-intensive sectors such as *Coke, refined petroleum* (pet), *Fabricated metals* (mtl), and *Non-metallic minerals* (nmm). For these last three sectors, an interesting pattern arises. The excessively aggregated model overestimates the output and export gains in the sectors *mtl* and *nmm* (positive bias), but underestimates them in the sector *pet* (negative bias). In contrast, the import decline is slightly overestimated for the sector *nmm* (negative bias), but is underestimated for the sectors *pet* and *mtl* (positive bias).

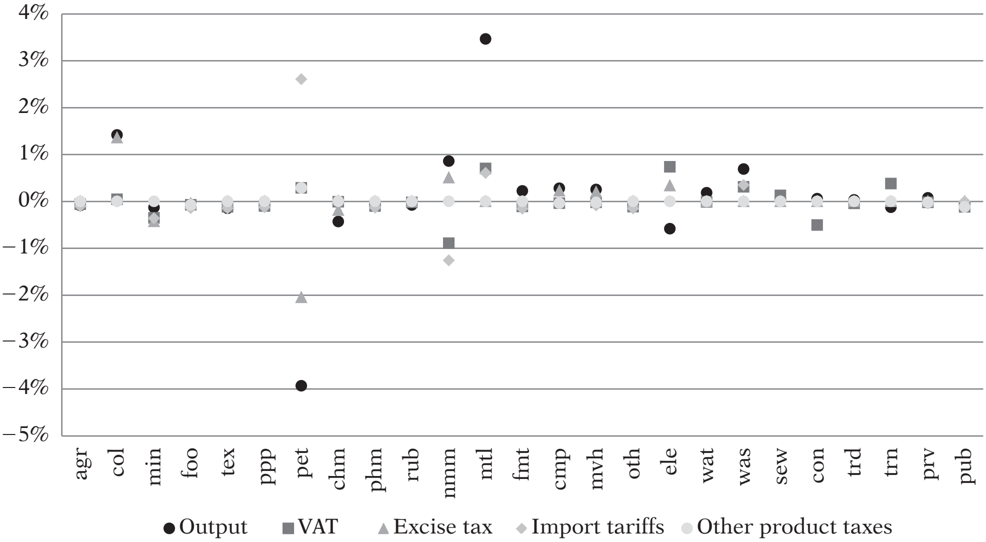
**Figure 7. Measures of sectoral aggregation bias for the simulated shock – activity variables (GEMPOL 31a)**




Source: Own elaboration.

Unlike with the activity measures, the aggregation bias for the sectoral tax variables is much less pronounced, especially in comparison with gross output (see Figure 8). In a vast majority of the cases, the bias falls within the range of ±1%. Notably, the direction of the aggregation bias for particular tax categories in a given sector is not necessarily consistent with the sign of the real output bias for several reasons. Firstly, certain taxes (VAT, import tariffs, and other product taxes) are levied on nominal, not on real output – hence, they also depend on the price levels. Secondly, taxes such as import tariffs are levied directly on imports, whose share within domestic output may change. Thirdly and most importantly, the particular taxes are levied on products, while real gross output changes are observed at the industry level. Such a distinction results from the possibility of producing multiple products within each industry, consistently with the supply and use tables used in the model's calibration. Those several exceptions for which the aggregation bias falls outside the range of ±1% include excise tax for *Coke, refined petroleum* (pet), import tariffs for *Other non-metallic minerals* (nmm) – negative bias, excise tax for *Hard coal* (col), and import tariffs for *Coke, refined petroleum* (pet) – positive bias.

**Figure 8. Measures of sectoral aggregation bias for the simulated shock – tax variables (GEMPOL 31a)**




Source: Own elaboration.

Table 8 and Table 9 in Annex 1 contain detailed results on the simulation impacts and aggregation bias for particular variables, not only for the model version with the default Armington elasticity values (GEMPOL 31a), but also for the version calibrated to the increased Armingtons for the disaggregated sub-products (GEMPOL 31b). As previously suggested, these results do not differ significantly between both versions of the model.

As the initial values of particular variables differ considerably between sectors, it is worthwhile to express the sectoral aggregation bias in absolute terms, i.e. in millions of PLN. Table 10 contains the absolute values of the sectoral aggregation bias for particular variables. It turns out that the sectoral pattern of the aggregation bias does not change dramatically in comparison with the bias measured in relative terms, though with several notable exceptions. A low positive aggregation bias in relative terms for the output of *Market services* (prv) is accompanied by a substantial positive bias in millions of PLN. A huge positive aggregation bias in relative terms for the exports of *Metal ores, other mining and quarrying* (min) is far less remarkable in absolute terms. A positive aggregation bias for the imports of *Computer, electronic and optical products, electrical equipment, other machinery and equipment* (cmp) is low in relative terms, but high in absolute terms.

Table 11 and Table 12 present the results of the sensitivity analysis conducted with respect the default values of the Armington elasticities ("doubled Armingtons" scenario). It is apparent that the uniform multiplication of all the default Armington elasticity values by a factor of two slightly increases the magnitude of either positive or negative aggregation bias for particular variables with respect to the initial specification of the model (see Table 3 and Table 9). Moreover, the differences in the sectoral aggregation bias between the model specifications GEMPOL 31a and 31b increase to a limited extent, but with some notable exceptions. These include the output and exports of *Metal ores, other mining and quarrying* (min) and *Basic metals* (mtl) and the imports of *Hard coal* (col), *Metal ores, other mining and quarrying* (min) and *Electricity* (ele). Notably, for the imports of *Electricity* (ele), the sign of the aggregation bias differs between the alternative specifications of GEMPOL 31a and 31b.

## Summary and conclusions

The aim of this paper was to estimate an "aggregation bias" in the CGE framework resulting from an excessive aggregation of energy-related products and industries (hard coal, lignite, natural gas, crude oil, electricity, heat) in Polish supply and use tables. Such an assessment was performed based on a small open economy, CGE model called GEMPOL (*General Equilibrium Model for Poland*) – containing a unique in-house split of energy-related sectors. Three alternative versions of the model were subsequently calibrated and solved. The first version included sectors in the original breakdown provided by the statistical office. The second version included an in-house split, with particular values of Armington elasticities derived directly from the "parent" sectors. In the third version, the elasticities were increased by a uniform factor in order to reflect the higher degree of international competition for smaller sub-products than in the case of their respective aggregates. The simulation shock, imposed under the comparative-statics mode, consisted of an exogenous improvement in energy efficiency, modelled as a positive, sector-specific (for particular industries, households and the government) and fuel-uniform technological shock. The aggregation bias for particular variables was defined as the difference between their values obtained from the original, more aggregated model (version 1) and their values from a more disaggregated model (version 2 or 3), re-aggregated back to the default sectoral breakdown after the calibration and solution.

Based on the obtained results, several conclusions can be drawn. Changes in individual variables, both macroeconomic and sectoral, show sign-coherent reactions, but of different magnitude, to the simulated shock under both aggregations and all three specifications of the model. An over-aggregation of energy products and industries within the model GEMPOL generates a slightly negative "aggregation bias" at the macroeconomic level. This implies an underestimation of the economy-wide benefits of the higher energy efficiency, but of a negligible scale and within the margin of tolerance. This bias is however much larger at the sectoral level, which suggests that both positive and negative sectoral biases tend to cancel out. Moreover, not only the fossil fuel and energy sectors, i.e. those subject to the in-house disaggregation, but also the other energy-intensive products and industries are to some extent affected by the aggregation bias. For both disaggregated specifications of the model, simulation results at the sectoral level turned out to be quite robust with respect to the assumed Armington elasticity values for the derived sub-products. Summing up, it is clear that the issue of an aggregation bias must not be ignored in CGE-based, sectoral impact assessments, especially in the area of energy efficiency.

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## Annex 1

**Table 4. Commodities in the model version used in this paper**

| Ver. 25 | Ver. 31 | Description | CPA 2008 |
|---|---|---|---|
| agr | agr | Products of agriculture, hunting, forestry, fish and other fishing products | 01, 02, 03 |
| col | col | Hard coal | 05 |
| | lig | Lignite | 05 |
| min | gas | Natural gas | 06–09 |
| | oil | Crude petroleum | 06–09 |
| | min | Metal ores, other mining and quarrying products | 06–09 |
| foo | foo | Food products, beverages, tobacco products | 10, 11, 12 |
| tex | tex | Textiles, wearing apparel | 13, 14, 15 |
| ppp | ppp | Paper and paper products, printing and recording services | 17, 18 |
| pet | pet | Coke, refined petroleum products | 19 |
| chm | chm | Chemicals and chemical products | 20 |
| phm | phm | Pharmaceutical products | 21 |
| rub | rub | Rubber and plastic products | 22 |
| nmm | nmm | Other non-metallic mineral products | 23 |
| mtl | mtl | Basic metals | 24 |
| fmt | fmt | Fabricated metal products | 25 |
| cmp | cmp | Computer, electronic and optical products, electrical equipment, other machinery and equipment | 26, 27, 28, 33 |
| mvh | mvh | Motor vehicles, other transport equipment | 29, 30 |
| oth | oth | Wood and products of wood, furniture, other manufactured goods | 16, 31, 32 |

| | | | |
|---|---|---|---|
| ele | ele | Electricity | 35 |
| | tde | Transmission, distribution and trade of electricity | 35 |
| | gdt | Distribution and trade of gas fuels | 35 |
| | hea | Heat (steam and hot water) | 35 |
| wat | wat | Natural water, water treatment and supply services | 36 |
| was | was | Waste collection, treatment and disposal services, materials recovery services | 38 |
| sew | sew | Sewerage, remediation services | 37, 39 |
| con | con | Constructions and construction works | 41–43 |
| trd | trd | Sale and repair services of motor vehicles and motorcycles, wholesale and retail trade services | 45–47 |
| trn | trn | Transport (land, pipeline, water, air) | 49, 50–51 |
| prv | prv | Market services (private sector) | 52–53, 55, 56, 58, 59, 60, 61, 62, 63, 64, 65, 66, 68, 69, 70, 71, 72, 73, 74, 75, 77, 78, 79, 80, 81, 82, 90, 91, 92, 93, 94, 95, 96, 97–98 |
| pub | pub | Non-market services (public administration, national defence, education, human health, social works) | 84, 85, 86, 87–88 |

Source: Own elaboration.

**Table 5. Industries in the model version used in this paper**

| Ver. 25 | Ver. 31 | Description | NACE Rev 2 |
|---|---|---|---|
| agr | agr | Crop and animal production, hunting, forestry and logging, fishing and aquaculture | 01, 02, 03 |
| col | col | Agglomeration of hard coal | 05 |
| | lig | Agglomeration of lignite | 05 |
| min | gas | Mining of natural gas | 06–09 |
| | oil | Mining of crude oil | 06–09 |
| | min | Other mining | 06–09 |
| foo | foo | Manufacture of food products, beverages and tobacco products | 10, 11, 12 |
| tex | tex | Manufacture of textiles and wearing apparel | 13, 14, 15 |
| ppp | ppp | Manufacture of paper and paper products, printing and reproduction of recorded media | 17, 18 |
| pet | pet | Manufacture of coke and refined petroleum products | 19 |
| chm | chm | Manufacture of chemicals and chemical products | 20 |
| phm | phm | Manufacture of pharmaceutical products | 21 |
| rub | rub | Manufacture of rubber and plastic products | 22 |
| nmm | nmm | Manufacture of other non-metallic mineral products | 23 |
| mtl | mtl | Manufacture of basic metals | 24 |
| fmt | fmt | Manufacture of metal products | 25 |

| Ver. 25 | Ver. 31 | Description | NACE Rev 2 |
|---|---|---|---|
| cmp | cmp | Manufacture of computer, electronic and optical products, electrical equipment, machinery and equipment | 26, 27, 28, 33 |
| mvh | mvh | Manufacture of motor vehicles, trailers and semi-trailers and other transport equipment | 29, 30 |
| oth | oth | Manufacture of products of wood, cork, straw and wicker and furniture, other manufacturing | 16, 31, 32 |
| ele | ele | Electricity generation | 35 |
| | tde | Electricity transmission and distribution | 35 |
| | gdt | Production and distribution of natural gas | 35 |
| | hea | Production and distribution of heat (steam and hot water) | 35 |
| wat | wat | Collection, purification and distribution of water | 36 |
| was | was | Waste collection, treatment and disposal activities, materials recovery | 38 |
| sew | sew | Sewerage and remediation activities | 37, 39 |
| con | con | Construction | 41–43 |
| trd | trd | Wholesale and retail trade | 45–47 |
| trn | trn | Transport | 49, 50–51 |
| prv | prv | Market services (private sector) | 52–53, 55, 56, 58, 59, 60, 61, 62, 63, 64, 65, 66, 68, 69, 70, 71, 72, 73, 74, 75, 77, 78, 79, 80, 81, 82, 90, 91, 92, 93, 94, 95, 96, 97–98 |
| pub | pub | Non-market services (public administration, national defence, education, human health, social works) | 84, 85, 86, 87–88 |

Source: Own elaboration.

**Table 6. Values of substitution elasticities by product/industry and production function nest – disaggregated version of the model (GEMPOL 31a)**

| | σ(top) | σ(armi) | σ(kle) | σ(va) | σ(labu) | σ(labl) | σ(fuel) | σ(ener) |
|---|---|---|---|---|---|---|---|---|
| agr | 0.76 | 0.79 | 0.21 | 0.15 | 0.14 | 0.05 | 0.70 | 0.60 |
| col | 0.48 | 0.37 | 0.21 | 0.00 | 0.32 | 0.01 | 0.15 | 0.15 |
| lig | 0.48 | 0.37 | 0.21 | 0.00 | 0.32 | 0.01 | 0.15 | 0.15 |
| gas | 0.48 | 0.37 | 0.21 | 0.00 | 0.32 | 0.01 | 0.15 | 0.15 |
| oil | 0.48 | 0.37 | 0.21 | 0.00 | 0.32 | 0.01 | 0.15 | 0.15 |
| min | 0.48 | 0.37 | 0.21 | 0.00 | 0.32 | 0.01 | 0.90 | 0.80 |
| foo | 0.52 | 0.61 | 0.39 | 0.44 | 0.08 | 0.55 | 0.90 | 0.80 |
| tex | 0.72 | 0.88 | 0.39 | 0.10 | 0.02 | 0.66 | 0.90 | 0.80 |
| ppp | 0.86 | 0.81 | 0.32 | 0.35 | 0.00 | 0.41 | 0.90 | 0.80 |
| pet | 0.84 | 1.13 | 0.49 | 0.19 | 0.00 | 0.59 | 0.10 | 0.20 |
| chm | 0.98 | 0.96 | 0.25 | 0.43 | 0.11 | 0.65 | 0.90 | 0.80 |
| phm | 0.98 | 0.96 | 0.25 | 0.43 | 0.11 | 0.65 | 0.90 | 0.80 |

| | σ(top) | σ(armi) | σ(kle) | σ(va) | σ(labu) | σ(labl) | σ(fuel) | σ(ener) |
|---|---|---|---|---|---|---|---|---|
| rub | 0.84 | 1.10 | 0.64 | 0.42 | 0.00 | 0.56 | 0.90 | 0.80 |
| nmm | 0.98 | 0.96 | 0.52 | 0.42 | 0.04 | 0.42 | 0.90 | 0.80 |
| mtl | 0.92 | 0.93 | 0.35 | 0.14 | 0.00 | 0.46 | 0.90 | 0.80 |
| fmt | 0.92 | 0.93 | 0.35 | 0.14 | 0.00 | 0.46 | 0.90 | 0.80 |
| cmp | 0.97 | 0.51 | 0.73 | 0.29 | 0.06 | 0.38 | 0.90 | 0.80 |
| mvh | 0.71 | 1.26 | 0.46 | 0.18 | 0.11 | 0.40 | 0.90 | 0.80 |
| oth | 0.81 | 0.76 | 0.56 | 0.16 | 0.08 | 0.41 | 0.90 | 0.80 |
| ele | 0.87 | 0.61 | 0.08 | 0.31 | 0.35 | 1.25 | 0.20 | 0.20 |
| tde | 0.87 | 0.61 | 0.08 | 0.31 | 0.35 | 1.25 | 0.00 | 0.20 |
| gdt | 0.87 | 0.61 | 0.08 | 0.31 | 0.35 | 1.25 | 0.10 | 0.90 |
| hea | 0.87 | 0.61 | 0.08 | 0.31 | 0.35 | 1.25 | 0.10 | 0.90 |
| wat | 0.87 | 0.61 | 0.08 | 0.31 | 0.35 | 1.25 | 0.40 | 0.30 |
| was | 0.87 | 0.61 | 0.08 | 0.31 | 0.35 | 1.25 | 0.40 | 0.30 |
| sew | 0.87 | 0.61 | 0.08 | 0.31 | 0.35 | 1.25 | 0.40 | 0.30 |
| con | 0.81 | 0.89 | 0.34 | 0.18 | 0.00 | 0.00 | 0.90 | 0.80 |
| trd | 0.79 | 1.00 | 0.38 | 0.27 | 0.00 | 0.21 | 0.40 | 0.30 |
| trn | 0.89 | 0.39 | 0.06 | 0.15 | 0.01 | 0.00 | 0.10 | 0.20 |
| prv | 0.76 | 0.82 | 0.24 | 0.26 | 0.08 | 0.02 | 0.40 | 0.30 |
| pub | 1.00 | 1.04 | 0.19 | 0.11 | 0.23 | 0.48 | 0.40 | 0.30 |
| CD | 0.93 | n/a | n/a | n/a | n/a | n/a | 0.40 | 0.30 |
| GD | 1.00 | n/a | n/a | n/a | n/a | n/a | 0.40 | 0.30 |

Source: Own elaboration based on Antoszewski [2017], Antoszewski *et al*. [2014], and McKibbin, Wilcoxen [1999].

**Table 7. Index of energy intensity changes in particular branches of the economy (BAU = 1)**

| | GEMPOL 25 | | GEMPOL 31 |
|---|---|---|---|
| agr | 0.77 | agr | 0.77 |
| col | 1.00 | col | 1.00 |
| | | lig | 1.00 |
| min | 1.00 | gas | 1.00 |
| | | oil | 1.00 |
| | | min | 1.00 |
| foo | 0.88 | foo | 0.88 |
| tex | 0.90 | tex | 0.90 |
| ppp | 0.65 | ppp | 0.65 |
| pet | 0.87 | pet | 0.87 |
| chm | 0.69 | chm | 0.69 |
| phm | 0.69 | phm | 0.69 |
| rub | 0.69 | rub | 0.69 |

| | GEMPOL 25 | | GEMPOL 31 |
|---|---|---|---|
| nmm | 0.72 | nmm | 0.72 |
| mtl | 0.61 | mtl | 0.61 |
| fmt | 0.61 | fmt | 0.61 |
| cmp | 0.87 | cmp | 0.87 |
| mvh | 0.87 | mvh | 0.87 |
| oth | 0.87 | oth | 0.87 |
| ele | 1.00 | ele | 1.00 |
| | | tde | 1.00 |
| | | gdt | 1.00 |
| | | hea | 1.00 |
| wat | 0.87 | wat | 0.87 |
| was | 0.87 | was | 0.87 |
| sew | 0.87 | sew | 0.87 |
| con | 0.85 | con | 0.85 |
| trd | 0.61 | trd | 0.61 |
| trn | 0.70 | trn | 0.70 |
| prv | 0.61 | prv | 0.61 |
| pub | 0.61 | pub | 0.61 |
| CD | 0.63 | CD | 0.63 |
| GD | 0.63 | GD | 0.63 |

Source: Own elaboration.

**Table 8. Sectoral impacts of the simulated shock for the disaggregated versions of the model GEMPOL (% changes vs. BAU)**

| | GEMPOL 31a | | | | | | | GEMPOL 31b | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes |
| agr | 3.0 | 0.2 | 5.6 | 2.5 | n/a | 1.5 | n/a | 3.1 | 0.3 | 5.5 | 2.5 | n/a | 1.5 | n/a |
| col | –8.2 | –13.4 | –5.0 | –5.1 | –7.6 | n/a | n/a | –8.3 | –13.3 | –4.1 | –5.0 | –7.5 | n/a | n/a |
| lig | –12.9 | n/a | n/a | –11.0 | –12.9 | n/a | n/a | –13.0 | n/a | n/a | –11.1 | –13.0 | n/a | n/a |
| oil | –23.2 | n/a | –21.6 | –24.5 | –21.6 | –24.6 | n/a | –23.7 | n/a | –21.6 | –24.5 | –21.6 | –24.6 | n/a |
| gas | –10.0 | n/a | –7.7 | –10.5 | –8.1 | –11.2 | n/a | –10.6 | n/a | –7.5 | –10.5 | –8.1 | –11.2 | n/a |
| min | –39.6 | –41.9 | –16.0 | –4.8 | –24.1 | –19.2 | n/a | –41.1 | –41.6 | –13.3 | –4.8 | –24.0 | –19.2 | n/a |
| foo | 2.1 | –1.7 | 5.1 | 2.9 | 2.6 | 1.0 | 2.9 | 2.1 | –1.6 | 5.1 | 2.9 | 2.6 | 1.0 | 2.9 |
| tex | –2.8 | –2.6 | 3.6 | 0.7 | n/a | –0.4 | n/a | –2.8 | –2.6 | 3.6 | 0.8 | n/a | –0.4 | n/a |
| ppp | 2.4 | 0.7 | 4.9 | 1.6 | n/a | 0.8 | n/a | 2.4 | 0.7 | 4.9 | 1.6 | n/a | 0.8 | n/a |
| pet | –12.4 | –6.7 | –17.4 | –15.5 | –9.4 | –20.6 | –15.5 | –12.4 | –6.6 | –17.4 | –15.5 | –9.4 | –20.6 | –15.5 |

| | GEMPOL 31a | | | | | | | GEMPOL 31b | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes |
| chm | 10.9 | 6.7 | 3.2 | 0.3 | 5.5 | –0.8 | n/a | 10.9 | 6.8 | 3.2 | 0.4 | 5.6 | –0.8 | n/a |
| phm | 1.7 | 1.7 | 6.1 | 3.3 | n/a | 2.0 | n/a | 1.7 | 1.7 | 6.1 | 3.3 | n/a | 2.0 | n/a |
| rub | 2.2 | 1.0 | 4.7 | 1.2 | n/a | 0.7 | n/a | 2.3 | 1.0 | 4.8 | 1.2 | n/a | 0.7 | n/a |
| nmm | 6.4 | 5.3 | 4.6 | 1.8 | 5.6 | 0.6 | n/a | 6.5 | 5.4 | 4.6 | 1.8 | 5.6 | 0.6 | n/a |
| mtl | 79.2 | 34.8 | 10.3 | 7.0 | n/a | 6.0 | n/a | 80.6 | 35.1 | 10.5 | 7.3 | n/a | 6.0 | n/a |
| fmt | 0.6 | 3.7 | 4.1 | 0.8 | n/a | 0.1 | n/a | 0.6 | 3.8 | 4.2 | 0.8 | n/a | 0.1 | n/a |
| cmp | 2.1 | 0.9 | 3.6 | 0.8 | 2.9 | –0.4 | 0.8 | 2.1 | 1.0 | 3.6 | 0.9 | 2.9 | –0.4 | 0.9 |
| mvh | –1.4 | –2.0 | 3.2 | –0.8 | 0.6 | –0.8 | –0.8 | –1.4 | –1.9 | 3.2 | –0.8 | 0.6 | –0.8 | –0.8 |
| oth | 0.6 | –2.7 | 4.3 | 1.5 | n/a | 0.3 | n/a | 0.6 | –2.6 | 4.3 | 1.5 | n/a | 0.3 | n/a |
| ele | –13.0 | –17.0 | –8.5 | –11.4 | –12.5 | n/a | n/a | –13.0 | –16.9 | –7.3 | –11.4 | –12.5 | n/a | n/a |
| tde | –10.0 | n/a | n/a | –8.1 | –9.5 | n/a | n/a | –10.0 | n/a | n/a | –8.1 | –9.5 | n/a | n/a |
| gdt | –6.7 | –7.2 | –4.2 | –6.8 | –5.9 | n/a | n/a | –6.7 | –7.2 | –3.7 | –6.8 | –5.9 | n/a | n/a |
| hea | –22.6 | n/a | n/a | –15.2 | –17.4 | n/a | n/a | –22.6 | n/a | n/a | –15.2 | –17.4 | n/a | n/a |
| wat | 4.7 | n/a | n/a | 6.3 | n/a | n/a | n/a | 4.8 | n/a | n/a | 6.3 | n/a | n/a | n/a |
| was | 10.1 | 7.9 | 10.1 | 6.4 | n/a | 5.8 | n/a | 10.2 | 8.1 | 10.2 | 6.5 | n/a | 5.8 | n/a |
| sew | 3.1 | –2.3 | 6.9 | 5.0 | n/a | n/a | n/a | 3.1 | –2.3 | 6.9 | 5.0 | n/a | n/a | n/a |
| con | 4.1 | –0.2 | 7.5 | 3.8 | n/a | n/a | n/a | 4.1 | –0.1 | 7.5 | 3.8 | n/a | n/a | n/a |
| trd | 2.3 | –3.0 | 7.9 | 3.7 | n/a | n/a | n/a | 2.3 | –2.9 | 7.9 | 3.7 | n/a | n/a | n/a |
| trn | 4.8 | 9.6 | 2.5 | –4.3 | n/a | n/a | n/a | 4.9 | 9.7 | 2.5 | –4.3 | n/a | n/a | n/a |
| prv | 3.4 | –0.6 | 7.0 | 3.7 | n/a | 2.9 | 3.7 | 3.4 | –0.6 | 7.0 | 3.7 | n/a | 2.9 | 3.7 |
| pub | 3.3 | –4.7 | 12.4 | 7.7 | n/a | n/a | 7.7 | 3.3 | –4.7 | 12.4 | 7.7 | n/a | n/a | 7.7 |

Source: Own elaboration.

**Table 9. Measures of sectoral aggregation bias for the simulated shock (in %)**

| | GEMPOL 31a | | | | | | | GEMPOL 31b | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes |
| agr | –0.1 | –0.3 | 0.1 | –0.1 | n/a | –0.1 | n/a | –0.1 | –0.3 | 0.1 | –0.1 | n/a | –0.1 | n/a |
| col | 1.4 | 1.6 | –0.2 | 0.0 | 1.4 | n/a | n/a | 1.5 | 1.5 | –1.1 | 0.0 | 1.3 | n/a | n/a |
| min | –0.1 | 28.0 | 0.7 | –0.4 | –0.4 | –0.4 | n/a | 2.2 | 27.5 | 0.3 | –0.3 | –0.4 | –0.4 | n/a |
| foo | –0.1 | –0.2 | 0.1 | –0.1 | 0.0 | –0.1 | –0.1 | –0.1 | –0.3 | 0.1 | –0.1 | –0.1 | –0.1 | –0.1 |
| tex | –0.1 | –0.1 | 0.1 | –0.1 | n/a | –0.1 | n/a | –0.2 | –0.2 | 0.0 | –0.1 | n/a | –0.1 | n/a |
| ppp | –0.1 | –0.2 | 0.1 | –0.1 | n/a | –0.1 | n/a | –0.1 | –0.2 | 0.1 | –0.1 | n/a | –0.1 | n/a |

| | GEMPOL 31a | | | | | | | GEMPOL 31b | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes |
| pet | –3.9 | –4.5 | 2.8 | 0.3 | –2.0 | 2.6 | 0.3 | –3.9 | –4.6 | 2.8 | 0.3 | –2.1 | 2.6 | 0.3 |
| chm | –0.4 | –0.6 | 0.2 | 0.0 | –0.2 | 0.0 | n/a | –0.5 | –0.6 | 0.2 | 0.0 | –0.2 | 0.0 | n/a |
| phm | –0.1 | –0.1 | 0.1 | –0.1 | n/a | –0.1 | n/a | –0.1 | –0.1 | 0.1 | –0.1 | n/a | –0.1 | n/a |
| rub | –0.1 | –0.1 | 0.2 | 0.0 | n/a | 0.0 | n/a | –0.1 | –0.2 | 0.2 | –0.1 | n/a | 0.0 | n/a |
| nmm | 0.9 | 1.7 | –1.1 | –0.9 | 0.5 | –1.3 | n/a | 0.8 | 1.6 | –1.0 | –0.9 | 0.5 | –1.3 | n/a |
| mtl | 3.5 | 3.6 | 0.8 | 0.7 | n/a | 0.6 | n/a | 2.7 | 3.3 | 0.6 | 0.5 | n/a | 0.6 | n/a |
| fmt | 0.2 | 0.6 | 0.0 | –0.1 | n/a | –0.2 | n/a | 0.3 | 0.6 | 0.0 | –0.1 | n/a | –0.2 | n/a |
| cmp | 0.3 | 0.3 | 0.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.3 | 0.3 | 0.2 | –0.1 | 0.2 | 0.0 | –0.1 |
| mvh | 0.3 | 0.2 | 0.1 | 0.0 | 0.2 | –0.1 | 0.0 | 0.2 | 0.2 | 0.1 | –0.1 | 0.2 | –0.1 | –0.1 |
| oth | –0.1 | –0.2 | 0.0 | –0.1 | n/a | –0.2 | n/a | –0.1 | –0.2 | 0.0 | –0.1 | n/a | –0.2 | n/a |
| ele | –0.6 | 1.1 | 0.9 | 0.7 | 0.3 | n/a | n/a | –0.6 | 1.0 | –0.5 | 0.7 | 0.3 | n/a | n/a |
| wat | 0.2 | n/a | n/a | 0.0 | n/a | n/a | n/a | 0.2 | n/a | n/a | 0.0 | n/a | n/a | n/a |
| was | 0.7 | 0.7 | 0.5 | 0.3 | n/a | 0.3 | n/a | 0.6 | 0.6 | 0.4 | 0.2 | n/a | 0.3 | n/a |
| sew | 0.1 | –0.2 | 0.2 | 0.1 | n/a | n/a | n/a | 0.1 | –0.2 | 0.2 | 0.1 | n/a | n/a | n/a |
| con | 0.1 | 0.4 | –0.3 | –0.5 | n/a | n/a | n/a | 0.0 | 0.4 | –0.2 | –0.5 | n/a | n/a | n/a |
| trd | 0.0 | –0.1 | 0.2 | 0.0 | n/a | n/a | n/a | 0.0 | –0.2 | 0.2 | –0.1 | n/a | n/a | n/a |
| trn | –0.1 | –0.7 | 0.2 | 0.4 | n/a | n/a | n/a | –0.1 | –0.8 | 0.2 | 0.4 | n/a | n/a | n/a |
| prv | 0.1 | 0.0 | 0.2 | 0.0 | n/a | 0.0 | 0.0 | 0.1 | –0.1 | 0.2 | 0.0 | n/a | 0.0 | 0.0 |
| pub | –0.1 | –0.2 | 0.1 | –0.1 | n/a | n/a | –0.1 | –0.1 | –0.2 | 0.1 | –0.1 | n/a | n/a | –0.1 |

Source: Own elaboration.

**Table 10. Measures of sectoral aggregation bias for the simulated shock – in millions of PLN**

| | GEMPOL 31a | | | | | | | GEMPOL 31b | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes |
| agr | –88.2 | –25.8 | 15.4 | –0.9 | n/a | –0.1 | n/a | –105.8 | –29.8 | 16.3 | –1.1 | n/a | –0.1 | n/a |
| col | 325.2 | 57.8 | –7.5 | 0.8 | 0.9 | n/a | n/a | 351.7 | 53.3 | –53.8 | –0.5 | 0.9 | n/a | n/a |
| min | –23.2 | 236.0 | 318.5 | –0.2 | 0.0 | 0.0 | n/a | 383.0 | 232.5 | 149.6 | –0.2 | 0.0 | 0.0 | n/a |
| foo | –120.8 | –100.0 | 18.9 | –13.8 | –12.4 | –0.2 | –0.1 | –148.0 | –118.2 | 19.1 | –16.6 | –16.2 | –0.2 | –0.1 |
| tex | –30.5 | –31.6 | 14.3 | –7.1 | n/a | –0.6 | n/a | –34.5 | –38.1 | 13.0 | –8.5 | n/a | –0.6 | n/a |
| ppp | –33.4 | –20.9 | 10.9 | –1.7 | n/a | 0.0 | n/a | –44.6 | –26.8 | 9.2 | –2.3 | n/a | 0.0 | n/a |
| pet | –2198.6 | –596.7 | 319.2 | 14.2 | –447.7 | 0.2 | 8.8 | –2169.6 | –602.3 | 317.6 | 12.5 | –453.2 | 0.2 | 7.8 |
| chm | –224.1 | –181.2 | 116.8 | –0.3 | –0.3 | 0.0 | n/a | –246.4 | –193.5 | 109.0 | –2.0 | –0.4 | 0.0 | n/a |
| phm | –8.2 | –4.0 | 14.1 | –2.1 | n/a | 0.0 | n/a | –10.7 | –5.4 | 14.7 | –2.5 | n/a | 0.0 | n/a |
| rub | –43.4 | –35.0 | 43.9 | –0.2 | n/a | 0.0 | n/a | –61.8 | –46.8 | 42.1 | –0.6 | n/a | 0.0 | n/a |
| nmm | 387.8 | 178.7 | –83.1 | –16.5 | 0.1 | –0.5 | n/a | 362.2 | 171.2 | –82.2 | –16.8 | 0.1 | –0.5 | n/a |
| mtl | 2271.6 | 1546.7 | 309.8 | 1.0 | n/a | 0.3 | n/a | 1768.2 | 1446.3 | 242.4 | 0.7 | n/a | 0.3 | n/a |
| fmt | 149.0 | 137.2 | 8.8 | –1.2 | n/a | –0.1 | n/a | 171.4 | 125.4 | 6.8 | –1.6 | n/a | –0.1 | n/a |
| cmp | 403.1 | 328.8 | 249.6 | –1.7 | 0.0 | –0.1 | 0.0 | 378.6 | 295.9 | 238.1 | –3.0 | 0.0 | –0.1 | 0.0 |
| mvh | 265.7 | 194.8 | 73.5 | –0.9 | 2.8 | –0.2 | –0.2 | 213.2 | 148.2 | 66.5 | –2.6 | 2.3 | –0.2 | –0.5 |
| oth | –47.9 | –57.9 | 7.4 | –5.6 | n/a | –0.1 | n/a | –67.7 | –74.2 | 5.9 | –7.1 | n/a | –0.1 | n/a |
| ele | –525.1 | 14.4 | 9.0 | 67.6 | 7.8 | n/a | n/a | –518.3 | 13.8 | –5.1 | 66.6 | 7.5 | n/a | n/a |
| wat | 12.6 | n/a | n/a | 0.0 | n/a | n/a | n/a | 10.6 | n/a | n/a | –0.1 | n/a | n/a | n/a |
| was | 114.2 | 35.9 | 11.6 | 0.8 | n/a | 0.0 | n/a | 92.6 | 28.6 | 9.5 | 0.5 | n/a | 0.0 | n/a |
| sew | 5.3 | 0.0 | 0.2 | 0.3 | n/a | n/a | n/a | 5.2 | 0.0 | 0.2 | 0.3 | n/a | n/a | n/a |
| con | 170.4 | 60.6 | –7.4 | –73.0 | n/a | n/a | n/a | 134.9 | 54.8 | –6.9 | –73.5 | n/a | n/a | n/a |
| trd | 126.3 | –0.1 | 3.5 | –1.0 | n/a | n/a | n/a | 17.6 | –0.1 | 3.6 | –1.5 | n/a | n/a | n/a |
| trn | –149.4 | –182.3 | 22.8 | 6.4 | n/a | n/a | n/a | –177.6 | –193.0 | 21.1 | 6.0 | n/a | n/a | n/a |
| prv | 510.9 | –13.2 | 70.4 | –5.0 | n/a | 0.0 | –1.0 | 423.6 | –29.5 | 73.8 | –8.2 | n/a | 0.0 | –1.6 |
| pub | –174.7 | –0.7 | 0.9 | 0.0 | n/a | n/a | –0.6 | –184.5 | –0.8 | 1.0 | 0.0 | n/a | n/a | –0.7 |

Source: Own elaboration.

**Table 11. Measures of aggregation bias for the simulated shock at the macroeconomic level: "doubled Armingtons" scenario (in %)**

| | % change vs. BAU | | | Aggregation bias | |
|---|---|---|---|---|---|
| | GEMPOL (25) | GEMPOL (31a) | GEMPOL (31b) | GEMPOL (31a) | GEMPOL (31b) |
| Real GDP | 4.32 | 4.33 | 4.34 | –0.01 | –0.01 |
| Private consumption | 4.41 | 4.39 | 4.40 | 0.02 | 0.01 |
| Public consumption | 3.76 | 3.83 | 3.84 | –0.07 | –0.08 |
| Private investment | 4.41 | 4.39 | 4.40 | 0.02 | 0.01 |
| Public investment | 3.76 | 3.83 | 3.84 | –0.07 | –0.08 |
| Exports | 3.22 | 2.73 | 2.85 | 0.47 | 0.36 |
| Imports | 3.06 | 2.60 | 2.71 | 0.45 | 0.34 |
| GDP deflator | 0.63 | 0.69 | 0.70 | –0.07 | –0.07 |
| Nominal GDP | 4.97 | 5.05 | 5.06 | –0.07 | –0.08 |
| Output | 2.99 | 2.87 | 2.91 | 0.12 | 0.08 |
| Value Added Tax | 0.30 | 0.27 | 0.31 | 0.03 | –0.01 |
| Excise tax | –3.66 | –2.96 | –2.92 | –0.72 | –0.76 |
| Import tariffs | 0.83 | 0.86 | 0.91 | –0.03 | –0.08 |
| Other product taxes | –3.59 | –3.75 | –3.70 | 0.16 | 0.11 |

Source: Own elaboration.

**Table 12. Measures of sectoral aggregation bias for the simulated shock – in percent: "doubled Armingtons" scenario (in %)**

| | GEMPOL 31a | | | | | | | GEMPOL 31b | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes |
| agr | –0.1 | –0.2 | 0.2 | –0.1 | n/a | 0.0 | n/a | –0.1 | –0.3 | 0.3 | –0.1 | n/a | 0.0 | n/a |
| col | 2.2 | 1.8 | –0.4 | 0.8 | 2.0 | n/a | n/a | 2.4 | 1.5 | –2.3 | 0.6 | 1.8 | n/a | n/a |
| min | –9.9 | 25.1 | 1.6 | –1.2 | –1.0 | –1.1 | n/a | –5.0 | 24.0 | 0.8 | –1.1 | –1.0 | –1.1 | n/a |
| foo | –0.1 | –0.2 | 0.2 | –0.1 | 0.0 | 0.0 | –0.1 | –0.1 | –0.2 | 0.2 | –0.1 | 0.0 | 0.0 | –0.1 |
| tex | –0.4 | –0.1 | 0.2 | –0.1 | n/a | 0.0 | n/a | –0.4 | –0.2 | 0.2 | –0.1 | n/a | 0.0 | n/a |
| ppp | –0.1 | –0.1 | 0.2 | –0.1 | n/a | 0.0 | n/a | –0.2 | –0.2 | 0.2 | –0.1 | n/a | 0.0 | n/a |
| pet | –5.3 | –4.2 | 7.8 | 0.4 | –1.8 | 7.6 | 0.4 | –5.2 | –4.3 | 7.7 | 0.3 | –1.9 | 7.6 | 0.3 |
| chm | –0.9 | –0.6 | 0.6 | –0.1 | –0.2 | 0.4 | n/a | –1.0 | –0.7 | 0.5 | –0.1 | –0.3 | 0.4 | n/a |
| phm | –0.1 | 0.0 | 0.1 | –0.1 | n/a | –0.1 | n/a | –0.2 | –0.1 | 0.1 | –0.1 | n/a | –0.1 | n/a |
| rub | –0.1 | –0.1 | 0.4 | 0.0 | n/a | 0.2 | n/a | –0.2 | –0.2 | 0.4 | 0.0 | n/a | 0.2 | n/a |
| nmm | 1.4 | 1.8 | –2.4 | –0.7 | 0.6 | –2.6 | n/a | 1.2 | 1.7 | –2.3 | –0.8 | 0.6 | –2.6 | n/a |
| mtl | 7.8 | 5.2 | 0.7 | 2.1 | n/a | 0.5 | n/a | 6.2 | 4.7 | 0.3 | 1.7 | n/a | 0.5 | n/a |
| fmt | 0.0 | 0.8 | –0.2 | 0.0 | n/a | –0.4 | n/a | 0.1 | 0.7 | –0.2 | 0.0 | n/a | –0.4 | n/a |
| cmp | 0.4 | 0.4 | 0.2 | 0.0 | 0.3 | 0.0 | 0.0 | 0.3 | 0.3 | 0.2 | 0.0 | 0.3 | 0.0 | 0.0 |

| | GEMPOL 31a | | | | | | | GEMPOL 31b | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes | Output | Exports | Imports | VAT | Excise tax | Import tariffs | Other product taxes |
| mvh | 0.4 | 0.3 | 0.1 | 0.0 | 0.3 | –0.1 | 0.0 | 0.3 | 0.2 | 0.1 | 0.0 | 0.2 | –0.1 | 0.0 |
| oth | –0.1 | –0.1 | 0.2 | –0.1 | n/a | 0.0 | n/a | –0.1 | –0.2 | 0.2 | –0.1 | n/a | 0.0 | n/a |
| ele | –0.5 | 1.3 | 0.4 | 0.9 | 0.5 | n/a | n/a | –0.5 | 1.2 | –2.2 | 0.8 | 0.5 | n/a | n/a |
| wat | 0.3 | n/a | n/a | 0.1 | n/a | n/a | n/a | 0.3 | n/a | n/a | 0.1 | n/a | n/a | n/a |
| was | 1.5 | 1.4 | 1.2 | 1.0 | n/a | 1.0 | n/a | 1.2 | 1.1 | 1.0 | 0.8 | n/a | 1.0 | n/a |
| sew | 0.1 | –0.1 | 0.5 | 0.2 | n/a | n/a | n/a | 0.1 | –0.2 | 0.5 | 0.2 | n/a | n/a | n/a |
| con | 0.1 | 0.4 | –0.5 | –0.5 | n/a | n/a | n/a | 0.1 | 0.4 | –0.5 | –0.5 | n/a | n/a | n/a |
| trd | 0.1 | 0.0 | 0.4 | 0.0 | n/a | n/a | n/a | 0.1 | –0.1 | 0.4 | 0.0 | n/a | n/a | n/a |
| trn | –0.1 | –0.6 | 0.5 | 0.5 | n/a | n/a | n/a | –0.1 | –0.7 | 0.5 | 0.4 | n/a | n/a | n/a |
| prv | 0.1 | 0.0 | 0.3 | 0.0 | n/a | 0.1 | 0.0 | 0.1 | 0.0 | 0.3 | 0.0 | n/a | 0.1 | 0.0 |
| pub | –0.1 | –0.3 | 0.5 | 0.0 | n/a | n/a | 0.0 | –0.1 | –0.3 | 0.5 | 0.0 | n/a | n/a | 0.0 |

Source: Own elaboration.

## Annex 2. Detailed description of the in-house disaggregation of energy-related sectors

**1) Split of the product *Electricity, gas, steam and air conditioning***

At the beginning, auxiliary tables were used from the CSO containing data on the supply and use of particular subcomponents of the product CPA 35 (*Electricity, gas, steam and air conditioning*). This made it possible to divide the product into four goods: *Electricity*; *Transmission, distribution and trade of electricity*; *Distribution and trade of gas fuels*; and *Heat*. The basic supply and use tables were constructed based on the ESA 2010 methodology, while the auxiliary tables for the product CPA 35 were compiled on the basis of the ESA'95 methodology. In order to eliminate the resulting data imbalances, additional operations were performed using the RAS algorithm.

**2) Split of the product and the industry *Coal and lignite***

In order to disaggregate the product *Coal and lignite* (CPA 05), the following assumptions were made:

- The value of *Lignite* supply in 2010 was PLN 3.5686 bn [ARE, 2011]; by subtracting this value from the total supply of the product *Coal and lignite* (CPA 05) in the industry *Coal and lignite* (NACE 05), the supply of *Hard coal* was residually calculated;
- The product CPA 05 supplied by other industries constitutes *Hard coal*;
- *Lignite* is not imported – all the imports of the product CPA 05 are treated as *Hard coal*;

- There are no trade or transport margins on *Lignite*;
- The taxes levied on the product CPA 05 were distributed between *Hard coal* and *Lignite* in proportion to the supply of these products provided by the industry *Coal and lignite* (NACE 05);
- The entire supply[16] of *Lignite* is consumed, as intermediate demand, by the industry *Electricity, gas, steam and air conditioning* (NACE 35).

In order to disaggregate the industry *Coal and lignite* (NACE 05), the following assumptions were made:

- Labour and capital costs as well as producer taxes were distributed between *Hard coal* and *Lignite* based on data from Eurostat's Structural Business Statistics (SBS);
- In the first step, material costs (intermediate use) were split between *Coal* and *Lignite* mining based on the SBS database, implicitly assuming identical product cost structures. In the second step, the value and structure of intermediate demand for particular products from *Hard coal* and *Lignite* mining was modified using the RAS-type algorithm in order to meet the balancing conditions within the use table.

**3) Split of the product and the industry *Crude petroleum and natural gas, metal ores, other mining and quarrying***

In order to disaggregate the product and the industry *Crude petroleum and natural gas, metal ores, other mining and quarrying* (NACE/CPA 06–09) into *Crude petroleum*; *Natural gas* and *Metal ores, other mining and quarrying*, a number of non-economic databases were used. This stems from the fact that no detailed data is available for this industry in Eurostat's SBS database – most probably due to "statistical secrecy" resulting from a small number of entities in those branches of Poland's economy. This prevents the statistical office from disclosing data for such sub-industries. Hence, it was assumed that:

- Domestic supply of the product *Natural gas* is provided by the industry *Natural Gas* and was derived from the industries *Electricity, gas, steam and air conditioning* (NACE 35, about 79% of the total supply of the product CPA 06–09 in this industry) and from the industry *Hard coal* (100% of the total supply of the product CPA 06–09 in this industry);
- Domestic supply of the product *Crude petroleum* is delivered solely by the industry *Crude petroleum* and was entirely derived from the industry *Electricity, gas, steam and air conditioning* (NACE 35, around 21% of the supply of the product CPA 06–09 in this industry) [IGSMiE PAN, 2013; IEA, 2015].
- The remaining supply of the product CPA 06–09 is treated as product *Metal Ores, other mining and quarrying*;
- For each of the three separated products, the same rates of product tax and trade and transport margin were applied through a distribution of the

[16] According to IGSMiE PAN (2013), the precise figure is 98%. A separation of the remaining supply between the other branches of the economy and the final demand could cause numerical problems in the model solution.

product tax and margins levied on the CPA 06–09 product proportionally to the total (i.e. domestic and imported) supply of the derived products;

- The difference between the domestic use and supply of the products *Natural gas* and *Crude petroleum* is covered by imports;
- *Natural gas* is entirely used in the form of intermediate demand by two industries: *Electricity, gas, steam and air conditioning* (NACE 35) and *Chemicals and chemical products* (NACE 20);
- *Crude petroleum* is entirely used in the form of intermediate demand by one industry – *Coke and refined petroleum products* (NACE 19);
- *Crude petroleum* and *Natural gas* cannot used in the form of final demand (including exports);
- The remaining use of the product CPA 06–09 is treated as product *Metal ores, other mining and quarrying*;
- The cost structure (labour, capital, materials) in the industries *Crude petroleum* and *Natural gas* was directly taken from the industry *Electricity, gas, steam and air conditioning* (NACE 35);
- Producer tax paid by the derived sub-industries was calculated residually.

**4) Split of the industry *Electricity, gas, steam and air conditioning***

As previously explained, a split of the sector *Electricity, gas, steam and air conditioning* (CPA/NACE 35) using auxiliary supply and use tables was only possible in terms of products, and not in terms of industries. In order to perform a similar disaggregation of the NACE 35 industries, it was therefore necessary to take advantage of some additional data sources.

In the first stage, the NACE 35 industry was divided into the "temporary" sector *Electricity* (including generation, transmission, distribution and trade of electricity), *Distribution and trade of gas fuels*, and *Heat*, under the following assumptions:

- The products *Electricity* and *Transmission, distribution and trade of electricity* are provided solely by the "temporary" industry *Electricity*;
- The product *Distribution and trade of gas fuels* is entirely produced by the industry *Distribution and trade of gas fuels*;
- The product *Heat* is entirely produced by the industry *Heat*;
- The supply of the remaining products (i.e. those from outside CPA 35) was allocated between the "temporary" industry *Electricity* and the industries *Distribution and trade of gas fuels* and *Heat*, proportionally to the supply values for *Electricity*, *Distribution and trade of gas fuels* and *Heat* in these industries;
- The use of the products *Hard coal*, *Distribution and trade of gas fuels* and *Coke and refined petroleum products* was split between the "temporary" industry *Electricity* and *Heat* proportionally to their quantities measured in physical units [CSO, 2012];
- The use of the product *Natural gas* was fully allocated to the industry *Distribution and trade of gas fuels*;

- The cost components (intermediate use, labour, capital, and producer tax) were split in the first step between the "temporary" industry *Electricity*, on the one hand, and *Distribution and trade of gas fuels* and *Heat*, on the other, based on the SBS data, implicitly assuming an identical product structure of material costs. In the second step, the value and structure of intermediate demand for particular products from the derived sub-industries was modified using the RAS-type algorithm in order to meet the balancing conditions within the use table.

In the second stage, the "temporary" industry *Electricity* was divided into *Electricity generation* and *Transmission, distribution and trade of electricity*, with the following assumptions:

- The industry *Electricity generation* supplies only one product – *Electricity*;
- The industry *Transmission, distribution and trade of electricity* supplies the product *Transmission, distribution and trade of electricity* and all other products previously assigned to the "temporary" industry *Electricity*;
- Labour and capital costs as well as producer tax were split between the industries *Electricity generation* and *Transmission, distribution and trade of electricity* based on the SBS data;
- The use of fossil fuels (*Hard coal*, *Lignite*, *Natural gas* and *Crude petroleum*) in the "temporary" industry *Electricity* was fully attributed to the industry *Electricity generation*;
- The use of the remaining products was separated in the first step between *Electricity generation* and *Transmission, distribution and trade of electricity* based on the SBS data, implicitly assuming an identical product structure of material costs. In the second step, the value and structure of intermediate demand for particular products from the derived sub-industries was modified using the RAS-type algorithm in order to meet the balancing conditions within the use table.

## Szoki technologiczne związane z wykorzystaniem energii w modelu CGE dla gospodarki Polski

**Streszczenie**: Pomimo rosnącej popularności obliczeniowych modeli równowagi ogólnej (CGE) w analizach z zakresu ekonomii energii i środowiska, dane statystyczne dla polskiej gospodarki wciąż charakteryzuje stosunkowo niewielki stopień dezagregacji sektorów paliwowo-energetycznych. Stąd ekonomiści wykorzystujący modele CGE stają przed koniecznością samodzielnego podziału poszczególnych produktów i gałęzi gospodarki – nie tylko dla uzyskania bardziej szczegółowych wyników, lecz również dla uniknięcia problemu „obciążenia agregacyjnego". Artykuł ma na celu weryfikację występowania tego zjawiska w przypadku Polski, przeprowadzoną przy wykorzystaniu modelu CGE dla małej gospodarki otwartej o nazwie GEMPOL, który uwzględnia samodzielny podział sektorów paliwowo-energetycznych. Kalibracji i rozwiązaniu podlegają trzy alternatywne wersje tego modelu. Wersja pierwsza obejmuje wyjściowy poziom dezagregacji sektorów paliwowo-energetycznych. Wersja druga uwzględnia ich samodzielny podział, w połączeniu z przypisaniem im wartości elastyczności Armingtona pochodzących bezpośrednio z sektorów „macierzystych". W wersji trzeciej elastyczności te ulegają zwiększeniu w celu odzwierciedlenia większej konkurencji międzynarodowej w odniesieniu do węziej zdefiniowanych subproduktów. Symulowany w układzie statyki porównawczej szok obejmuje egzogeniczną poprawę efektywności energetycznej. Następnie wyniki uzyskane ze wszystkich wariantów modelu podlegają porównaniu. Okazuje się, że wyniki symulacji pochodzące z obydwu agregacji i ze wszystkich trzech specyfikacji modelu są bardzo podobne na poziomie makroekonomicznym, lecz różnią się dość wyraźnie na poziomie sektorowym.

**Słowa kluczowe**: obliczeniowy model równowagi ogólnej, obciążenie agregacyjne, efektywność energetyczna

**Kody klasyfikacji JEL**: C68, D58, Q43

Artykuł nadesłany 26 lipca 2018 r., zaakceptowany 16 stycznia 2019 r.