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Evaluation of Renewable Energy Policies

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ABSTRACT

This paper presents first results of an empirical ex-ante analysis which evaluates the effects of possible renewable energy policies in the Polish bioenergy sector applying an Applied General Equilibrium model. In the model, producers respond to changes in market prices of different energy goods adjusting their output level and mix, and inputs demand. Consumers respond to the changes in energy products prices with a reduced demand of some goods and services and an increased demand of others.

Our empirical findings advocate that the Polish bioenergy sector benefits more from an indirect tax reduction than from a removal of fossil energy sectors' subsidies.

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INTRODUCTION

Renewable Energy Sector in the European Union

Bioenergy is seen as one of the key options to mitigate greenhouse gas emissions and as a substitute for fossil fuels. This is certainly evident in Europe, where a wealth of policies and programs are being executed for developing and stimulating bioenergy. Over the past 10-15 years in the European Union, heat and electricity production from biomass increased with from 2% to 9% per year between 1990 and 2000 and biofuel production, e.g. for transportation purposes increased about 8-fold in the same period. EU-15 accounted for 90% of the OECD countries' increase in electricity generated in this way between 1990 and 2002 (International Energy Agency 2004). Biomass now supplies about 4% of the EU's energy, mainly as fuel for heating and for CHP (Combined Heating Power) plants. It is the only renewable energy source that can be used to produce competitively-priced liquid fuels for transport (European Commission 2004, Renewable Energy Council 2004).

The renewable energy sector in general and bioenergy sector in particular are still in an early stage of development. After increasing its turnover tenfold from 1.5 billion EUR in 1990 to 15 billion EUR in 2004, the European renewable energy sector has only just begun to reveal its enormous potential for growth. As its contribution to Europe's economy grows, so will its workforce, with 1 million expected to work in the sector by 2010. Technology focused (small and medium sized) companies with ability to assimilate and commercialize new scientific knowledge are the driving force behind the renewable energy industry's expansion (Renewable Energy Council 2004).

Despite its relatively small size, the renewable energy sector can make a substantial contribution towards a number of major EU policies:

- the 'Lisbon' and 'Barcelona' objectives, which describe a dynamic 'knowledge' economy based around research, development and innovation with a specific focus on the competitive key sector of environmental technology; a weaker reliance on energy imports (Grubb 2001);
- the development and use of renewable energy resources as laid down in the EC's renewable energy directives and 1997 White Paper (European Commission 1997);
- fulfilling of international obligations such as the Kyoto Protocol.

Currently, Europe imports 50% of its energy needs making its social and economic well-being very vulnerable to events elsewhere in the world. Worse, with coal in decline and nuclear energy facing public resistance, this dependence on imported energy is growing so future generations will be even more at risk of supply disruption. The Green Paper on the security of energy supply forecasts state that EU dependence on imported energy will reach 70% by 2030 if nothing is done (Renewable Energy Council 2004). Furthermore, Europe produces around 14% of the world's greenhouse gases that contribute to global warming. Therefore, the EU is strongly committed to confronting the causes of climate change and is a leading supporter of the 1997 Kyoto Protocol. The EU is committed to an 8% reduction in annual greenhouse gas emissions by 2010.

For these reasons, indigenous, diversified renewable energy sources should be key components of Europe's energy strategy. Recognizing this, the 1997 White Paper on renewable energy sources gave a clear political signal and an impetus by setting an indicative target – doubling the renewable energy sources contribution to reach 12% of European gross energy consumption by 2010 (European Commission 1997).

Renewable Energy Sector in Poland

The European Union's overall renewable energies profile completely changed last May with the entry of ten new countries. Eight of the ten new European Union member States, representing nearly 99% of the population of this new group, come from the old Soviet block and are heirs to centralized economic planning characterized by energy production devoted almost exclusively to the industrial sector. Abundant coal and lignite resources (notably very polluting varieties) and hydrocarbon resources (especially in the ex-USSR) have supplied energy that is inexpensive but offering low energy efficiency (Oniszk-Poplawska, Rogulska & Wisniewski 2003).

The dominance of energy intensive, heavily polluting raw material industries was ingrained in the official ideology. The extensive industrial development had led to a lavish use of energy. Even stable imports of gas and oil from (then) the Soviet Union and abundance of domestic coal were not sufficient to meet the demand; power shortages were commonplace (Pietruszko et al 1996, Oniszk-Poplawska, Rogulska & Wisniewski 2003).

The fossil-based energy was heavily subsidized, and no motivation existed for increasing energy efficiency or looking for alternatives offered by renewable energy sources. During the first years of transition to a market economy and with a withdrawal of most of the subsidies, energy prices increased by nearly one order of magnitude. In the early 1990's, most of the energy intensive industries drastically reduced their output or collapsed. The few surviving plants and factories improved their energy efficiency. Consequently, the energy shortages soon turned into oversupply. This situation has remained until present in regards to electricity and gas supplies, which is an important factor when considering the use of biomass for power generation in particular (Oniszk-Poplawska, Rogulska & Wisniewski 2003).

Table 1. Share of renewable energy in selected EU countries

Country	Share of renewable energy, (%), 2002
Netherlands	2.7
Germany	2.8
Poland	2.6
France	9.4
Denmark	9.6
Austria	27.1[1]
Sweden	26.3
European Union	6.2

Source: IAE (2004)

In 1989, the first non-communist government in Poland cancelled plans made before 1980 to build nuclear power plants. The program has not been resumed and Poland remains nuclear free, which is another important factor for the development of Renewable Energy Sources (RES) in the long-term perspective (Pietruszko et al 1996, Oniszk-Poplawska, Rogulska & Wisniewski 2003).

In 2001, coal-fired power and CHP plants dominated electricity generation in Poland. The share of coal in electricity generation was 96.26%. The share of renewable electricity in 2002 was 2.61%. In 2004, the Polish economy still relies heavily on domestic coal, which provides 64.6% (c.a. 3 times more than in OECD countries) of primary energy, despite dramatic reduction of its output (from 76,2% in 1990). Oil and gas contribute 32.5%, and other sources, including RES, contribute the remaining c.a. 2.9%. At the moment large hydro power plants makes the biggest contribution in green electricity production, accounting for 53.5%, next is small hydro power plants at 24%, biomass at 17%, biogas at 5% and wind at 0.5%. If one excludes big hydro power plants from the share, small hydro power plants would account for 51.5%, biomass for 36.5%, wind for 1% and, biogas for 11% (IAE 2004, Renewable Energy Council 2004).

The technical potential of renewables is considerable and represents 41.8 Mtoe per year, or nearly 50% of Poland's needs. In the field of biomass,

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[1] Large differences in the utilization of renewable energy in the European countries are among other factors due to the possibility of utilizing hydropower in mountainous countries.

which will remain Poland's principal strong point and asset, forestry products as well as vegetal waste are abundant in this big agricultural country and it has a 1.5 million hectare potential for energy crops. For the production of heat as well as of electricity, the replacement or bringing up to standard a good half of its coal-burning power plant capacity is an important national issue (Renewable Energy Council 2004). Moreover, due to its local character, biomass is an important factor for social, economical and spatial development of individual regions. It may play a very important role, particularly in areas where access to the central gas grid does not exist or is limited. Biomass for energy production is of a particular importance for rural areas, where unemployment rates are usually high. The bioenergy business may create jobs and provide income to the local population in these areas.

Policy Framework for Renewable Energies in Poland

Improvements in energy efficiency in Poland have been driven primarily by price signals, which provided sufficient economic motivation without the need to refer to additional financial support (state or foreign). However, in the case of Renewable Energies this has turned out to be not sufficient or even possible. Thus, unlike energy efficiency, the driving factors of the development of RES have been Poland's international obligations related to Climate Change[2].

The legal framework for the promotion of Renewable Energies has been established as a component of Sustainable Energy Development by the Energy Act of April 10th, 1997. The purpose of the Act is to create conditions to provide energy security, rational use of energy, and the development of competition. It also defines the conditions of conducting economic activities in the energy sector, imposes certain obligations on economic entities, and guarantees certain rights for them. The Act defines the principles of the national energy policy regarding the supply and use of energy, as well as concerning operation of energy enterprises, which agencies have jurisdiction over the issues of fuel and energy economy (Chwieduk 2000). Both basic components of energy sustainability: Energy Efficiency and Renewable Energy Sources (RES) are addressed in the Act as important factors in energy planning and policy-making. As far as energy planning is concerned, the Act stipulates that the main authority responsible for national energy planning is

[2] Poland signed the UNFCCC (United Nations Framework Convention on Climate Change) in 1992. The ratification procedure was completed in 1994 and Poland became party to the Convention. The Kyoto Protocol was signed in July 1998 and ratified in 2002. Poland's commitment was a 6% reduction of GHG emissions related to 1988, which - as trends indicate - is likely to be achieved or even exceeded.

the Minister of Economy, while energy utilities and municipalities are obliged to prepare plans for energy supplies in their respective service areas.

The Act entered into force in January 1998 and it still remains one of the main legal documents in the field of energy in Poland. Since 1998, the Energy Act was updated several times. The most recent and major amendment was done in July 2002 and the changes entered into force in January 2003 (Chwieduk 2000). The main legal framework for RES is the Development Strategy of Renewable Energy Sources, adopted by the Polish Parliament in 2001. The Strategy sets a goal to increase the RES share in Poland's primary energy balance from the present ca. 2.5% to 7.5% in 2010 and 14% in 2020. The goal is ambitious and achieving it will not be easy. The problem is the huge amount of investment needed in order to achieve these targets, which is the main barrier to a wider use RES.

The integration process with the European Union obliges Poland to undertake actions aimed to develop energy use from renewable sources[3]. At the same time, this provides a chance to take advantage of substantial Community assistance in this field (European Commission 2004). This emphasizes the significant role and impact of the EU legislation and accession requirements on Poland's policy making and as a consequence, on the progress achieved in the development of Renewable Energy Sources. Although, targets set in the Accession Treaty with the European Union for the development of Renewable Energy Sources (RES) are ambitious (7.5% in 2010 and 14% in 2020), Poland is not on the way to meet them, as the introduced support mechanism doesn't prove to be effective. There is a need for accompanying measures, without which Poland will not be in a position to reach the required 14 percent level by 2020. In order to increase the share of biomass for energy production and to develop the resources available within Poland, a more strongly coordinated policy approach is desired to guarantee the achievement of the obligations associated with the Accession Treaty with the European Union. Poland needs more comprehensive R&D trajectories for an international biomass market allowing for international trade and an integral policy approach for bioenergy incorporating energy, agricultural, forestry, waste and industrial policies. The Common Agricultural Policy (CAP) of the (extended) EU should fully incorporate bioenergy and perennial crops in particular.

Accompanying measures, which are to be prepared, implemented and verified during the financial frameworks 2000 – 2006 and 2007 – 2013, should allow for doubling the renewable energy share in Poland, and to achieve the required level of 7.5% in 2010 and 14% in 2020. To prepare,

[3] In its White Book, the European Union imposed on the accession countries the requirement to adjust their energy use level from renewables to that of the Member States on the level of 12 percent by 2010 (European Commission 2003).

implement and verify accompanying policy measures, socio-economic benefits, costs, and trade-offs associated with each measure must be identified and their impact on social welfare estimated. This is the main goal of this study.

1. THEORETICAL FRAMEWORK

There are many different approaches to evaluate impacts of renewable energy policies, ranging from those which focus simply on considering effects of individual policy instruments on employment, investment, and the movement of industry, to far more ambitious methods based upon cost-benefit analysis (Bovenberg & Mooij 1994, Bovenberg & Goulder 1997). One of the most important considerations in developing or selecting a model for the use in the renewable energy context is the ability of the model to reproduce the policy alternatives or problems in which the politicians are interested. Moreover, to be useful for planning purposes, renewable energy sector models must possess several additional characteristics. The required characteristics of a renewable energy policy impacts assessment model can be summarized as follows:

First, the model must be able to deal explicitly with the interactions between policy variables, and the feed-back characteristics of energy-environment relationships. It is unlikely that any attempt to model the behaviour of energy systems which does not incorporate the important feedback mechanisms can ever be more than partially successful, because the system as a whole will behave in ways that cannot be deducted from an examination of the parts separately (Bergman 1988). Second, it is essential that the model is internally consistent. This means that the economy must be treated as a set of interdependent elements (sectors, policies, households, firms etc). Whenever one part of the economic system is affected by an exogenous shock (e.g. an increase of the oil price on the world market), this will have reverberations throughout the entire economy. The model must be capable of predicting the "full system effects" of any such shocks (Wajsman 1995). Third, the model must be sufficiently detailed so that the major planning authorities (e.g. renewable energy development, employment, rural planning) can be provided with information about sector-specific policy implications. Thus, a detailed industrial breakdown of output and employment forecasts is required if local or national authorities are to construct effective renewable energy development plans (Bergman 1988). Finally, an obvious implication is that the model should have an elabourated treatment of the supply and demand for energy. In particular, it should have a possibility to substitute other forms of energy, and other factors of production, for fossil vs. renewable fuels (Bergman 1988).

A Computable General Equilibrium (CGE) model is one of the few approaches that meet these requirements. It provides a comprehensive account of all circular flow payments in an economy. CGE models are widely applied to policy analysis in developed as well as developing countries. The comparative advantage of the CGE models lies in the analysis of policies, when there is a need to consider links between different sectors of production, links between macro and micro levels, and the disaggregated impact of changes in policies and exogenous shocks on sectors' structure, household welfare, and income distribution. There are four key features of a Computable General Equilibrium model that makes it particularly appropriate for analyzing impacts of various renewable energy policies (Kancs 2002).

First, CGE models have a micro-economically founded theoretic structure that captures the entire interactions of an economy. A consistent global perspective offers advantages compared to partial equilibrium models, which often miss important inter-market relationships and ignore macroeconomic impacts. Second, general equilibrium models are able to analyze large, discrete, external shocks such as the world market price increase for energy products by 40% as in the recent years. Econometric models, for example, make questionable inferences when shocks are outside the range of historic variation. The third advantage that CGE models have in the context of policy planning is that they are calibrated to actual input-output data, ensuring that the relative size and importance of various sectors and markets are taken into account when tracing policy impacts throughout the economy. Last, but not least, the focus of a CGE model can be steered on those parts of the economy where the most important adjustments take place. The scaling of markets and sectors in a CGE model founded on data focuses on impacts, which are initiated by policy changes' effects.

The Poland CGE is a multisectoral CGE model developed by Kancs (2002). It provides a simulation labouratory for carrying out controlled experiments, changing policies and other exogenous conditions (such as external price shock), and measuring the impact of these changes. To make it appropriate for renewable energy policy analysis, more advanced features have been added to the existing CGE model. Most importantly, the existing model has been extended to imperfect markets, allowing in such a way a more realistic capture of bioenergy markets in Poland. This feature is particularly important for agricultural and forestry sectors, which can produce both agricultural and forestry products, and bioenergy goods. The Poland CGE consists of three major blocks: production, consumption, and equilibrium conditions, which are explained in the following subsections (see Annex for the model's equations).

The Demand Structure

The representative consumer's decision problem can be decomposed into "three-stage budgeting". This specification allows for more substitutability between two energy goods or two industrial goods than between the set of all energy goods and an industrial good.

In the first stage (or top level), the representative consumer maximizes a CES function of a composite energy good and of all final non-energy commodities (both imported and domestic) given income and composite prices. In the second stage, the representative consumer maximizes a CES sub-utility function of all composite energy commodities subject to the expenditure allocated to total energy consumption from the first stage maximization. In the last stage, the representative consumer maximizes each of the sub-utility functions subject to the expenditure allocated to consumption of the i^{th} energy (non-energy) commodity from the second-stage (first-stage) maximization. This Armington assumption gives rise to both import and export flows in each sector. We assume that domestic and imported energy goods are less substitutable than industrial goods.

Domestic income corresponds to the total value added evaluated at net prices plus aggregate taxes minus aggregate subsidies. Savings are a fixed share of domestic income. Total demand is made up of final consumption, intermediate consumption and capital goods. An Armington assumption is set for intermediate and capital goods.

The Production Structure

Production makes use of capital and labour (perfectly mobile across sectors) and, for some sectors, of a specific factor (land and/or natural resources) (see Annex for the sectoral classification). Following Bovenberg & Goulder (1997) and Diedrich & Petersik (2001) factor endowments are assumed to be fully employed.

Sectoral production is characterized by a two-level nesting. The nesting approach minimizes the requirements for elasticities that need to be estimated or calibrated. On the other hand it requires a hierarchical assumption on the substitutability and complementarily, which cannot be defined in all cases straightforwardly. At the first level, there is a Leontief input-output production function of which arguments are value added and total intermediate consumption. At the second level, each of the Leontief function arguments is defined.

For sectors, which only use generic factors, value added is a CES function of capital and labour. For bioenergy sectors using a specific factor, value added is a CES function of this specific factor and of a generic factor of production (which is a composite of labour and capital). This specification allows for different degrees of substitution between the three factors of production. We thus assume that the elasticity of substitution between labour and capital is higher in industrial and service sectors than in bioenergy industries.

Composite intermediate inputs are a fixed share of total intermediate consumption. Each sector uses intermediate inputs, which come from domestic and foreign sources. Intermediate inputs demand in a given sector is a composite of domestic and imported intermediate goods and is given by a CES function. Final energy goods are part of intermediate inputs.

A CET function of the output reflects, in each sector, the substitution possibilities in sales between the domestic and the export markets. As the elasticity of transformation increases, goods for sales on the domestic and export markets become more homogenous. On the domestic market, firms fix the price at the marginal cost whereas, on the export market, they sell at the world price increased eventually by an export subsidy.

There are two types of sectors in the model, perfectly competitive and imperfectly competitive industries (see Annex for the sectoral classification). In each imperfectly competitive sector i, firms offer their own and unique variety of the same good and horizontal differentiation of products exhibit a love for variety. We thus add a stage in the nesting of consumer demand. Following the Armington nesting between domestic and imported goods, consumption of domestic goods in these sectors is a CES function of domestic varieties.

The total cost function of imperfectly competitive firms breaks down into a fixed cost and a variable cost. Fixed costs are expressed as a fixed quantity of output whereas variable costs incorporate primary factors (labour and capital) and intermediate inputs and are proportional to the firms' output. The marginal cost is assumed to be constant and the average cost equals the sum of marginal cost and unitary fixed cost.

Given the focus of the study on energy sectors in Poland, imperfectly competitive firms are assumed to exert their market power only on the domestic market. On the foreign market, on which they naturally have less market power, they are price-takers whereas, on the domestic market, they apply to the price of a variety a mark-up that depends on the price elasticity of demand as perceived by the firms. The mark-up is a function of the elasticity of substitution between varieties which corresponds to the opposite of the price elasticity of demand addressed to a variety (there is always a high number of varieties in each sector) and thus to the opposite of price elasticity of demand as perceived by a firm. In the short-run, the number of firms is held constant and profits can vary but in the long run, free entry and exit is assumed so that the number of firms fits in order to get the zero profit condition.

Equilibrium Conditions

Equilibrium prevails on the market of goods and on the market of factors of production. The model includes an accounting balance constraint, which states that domestic income is allocated among consumption, investment and trade imbalance. Sectoral investment is a fixed share of aggregate investment. To carry out this investment, firms can buy domestic or imported capital goods according to a CES function.

Like most CGE models, the Poland CGE is written as a set of simultaneous linear and non-linear equations defining the behaviour of economic agents[4]. Each solution provides a full set of economic indicators, including household incomes, prices, supply and demand quantities for factors and commodities, and welfare indicators. There is no objective function. The Poland CGE is solved in a comparative static mode. The model is implemented by the General Algebraic Modeling System (GAMS) and solved using CONOPT and MINOS (Brooke et al 1988).

2. DATA AND PARAMETERIZATION

Data that characterize the interrelationships between sectors, commodities and economic agents within an economy are of primary importance in determining socio-economic impacts of any policies. Many of the impacts of increasing renewable energy's share indirectly increase the costs of production and consumption. Furthermore, higher energy prices raise production costs, especially in sectors that use energy-intensive processes.

Database

The data base used to calibrate the Poland CGE model draws on the most recent Input-Output tables and National Accounts available. Tomaszewicz (2000) has developed a Social Accounting Matrix (SAM) that fully tracks the intensities of commodity use in each of the 57 Poland's production and consumption sectors. The Tomaszewicz data was completed by two additional data sources. First, energy production and energy input data from the Polish Emission Centre was used to get a more accurate representation of Poland's energy profile. Second, data from the United Nations Statistics Division (2000) was used to estimate the foreign trade matrix. Additional macro-

[4] See Annex for the model's equations.

economic data like foreign direct investments, foreign trade balance, government deficit, total labour supply, saving rate of private households and sectoral investment shares come from the GTAP database. GTAP version 5.2, which provides 1997 data on input-output, value added, final demand, bilateral trade, tax and subsidy data for 76 regions and 57 sectors (Dimaranan & McDougall 2002). For the purpose of the present study, the database is aggregated into 2 regions (Poland and Rest of the World) and 8 sectors (see Annex for the sectoral classification).

Special attention was given in building a consistent data set for the CGE model that was devoted to the renewable energy sector. It turned out extremely difficult to evaluate the volume of renewable energy used in Poland because information is only available through special fact-finding research techniques. Although, various national institutions, such as the Main Statistical Office, Ministry of the Economy, EC Baltic Renewable Energy Centre, have estimated the share of renewable energy in the fuel and energy balance, the figures given by the institutions vary considerably. This makes a correct estimation of the actual utilization of renewable energy in Poland almost impossible. For example, in the statistical yearbook 'Fuel and Energy Economy in 1997-98' (published in Polish by the Main Statistical Office in 1999), the share of the remaining sources (firewood, peat, waste fuels, water energy and other renewable energy carriers) in the consumption of primary energy was around 4.16% in 1997. According to (Pietruszko et al 1996) renewable fuels had a 5.23% share in the consumption of primary energy in 1996. Furthermore, in the expert appraisal on 'Economic and Legal Aspects of Utilization of Renewable Sources in Poland' prepared by the EC Baltic Renewable Energy Centre (2005) it was estimated that the share of energy from renewable sources was 2.61% (being 104 PJ). The former two figures above 4% seem to be overestimated because combustion of non-renewable sources such as peat was included. Recognizing these rather high variations among sources, we assumed that the share of renewable energy in the consumption of primary energy was around 3% in 1997.

Calibration

In order to parameterize the CGE model, a technique known as calibration, has been used. Initial elasticities of substitution were set according to Dimaranan & McDougall (2002) and are subject to sensitivity analysis. For the elasticity of substitution between mobile factors of production and for Armington elasticities, energy sectors are differentiated from non-energy sectors. The values of elasticities are presented in Table 2 and Table 3.

Table 2. Supply side elasticity specification[5]

	sf_i	sv_i	st_i	fe_i	fm_i
Energy sectors	0.63	0.41	4.02	4.01	4.09
Non-energy sectors	0.97	-	4.01	3.08	4.04

Source: GTAP 5 (Dimaranan & McDougall 2002)

Table 3. Demand side elasticity specification[6]

	sk_i	sz_{ij}	sd_i	ss_i	sg	sc
Energy sectors	2.21	2.24	2.58	6.03	1.12	0.57
Non-energy sectors	3.11	3.16	2.82	6.05		

Source: GTAP 5 (Dimaranan & McDougall 2002)

For imperfectly competitive sectors, we set the elasticity of substitution between varieties and the number of firms in order to calibrate the mark-up. We thus assume that there are initially a high number of firms by sector in order to calibrate output per firm. The elasticity of substitution between domestic varieties then equals the opposite of the price elasticity of demand. The fixed cost is calibrated by assuming that initially the long-run equilibrium with zero-profits prevails.

3. RENEWABLE ENERGY POLICY SCENARIOS

Based on the results of the expert appraisal on 'Economic and Legal Aspects of the Utilization of Renewable Energy Sources in Poland' (EC BREC 2005), (OECD 2005) and other expert assessments, three renewable energy sector's development scenarios have been designed, which assume implementation of certain policy measures, ATAXCUT (indirect activity tax reduction for bioenergy sector), ASUBCUT (removing of subsidies for fossil energy sectors) and PWMINCR (world market price increase for energy goods). The criteria used for the selection of policy measures were the minimization of required subsidies and tax relief with simultaneous provision of favorable conditions for the development of renewable energy sector. The principles of the three scenarios and a synthesis of the simulations' results are presented in the following sections.

[5] The elasticity of generic-specific factor substitution is only defined for energy industries with specific factor.

[6] The elasticity of import-home input substitution is the same for all users.

Reference Scenario – BR

Base run (BR) serves the reference point for measuring costs and benefits of alternative renewable energy policy scenarios. Since the base run is a benchmark for the entire quantitative analysis, its definition is one of the most critical issues in the reliability of the modeling results. Unreliable assumptions in the reference scenario could lead to errors in the results by changing renewable energy policies.

Several assumptions about exogenous policy and non-policy parameters of Poland CGE are made for projecting the 1997 base run situation to 2010. Non-price-induced growth in production is incorporated into the model according to the technical progress. For all scenarios, the energy sectors' output growth rates are set to 2% per year, which reflect the level of international long run averages. It expresses not only purely technical progress, but also the recovery of the Polish energy sector due to progress in privatization and restructuring. Energy input demand is also expected to increase with the expansion of production and the increase of GDP per capita. To account for technical progress or increased efficiency in energy use, growth rate of the technical progress for energy inputs are set at slightly lower levels than for outputs (1.5%). The technical progress growth rates are assumed to be scenario-uniform.

World market prices for energy products are kept stable until 2010 and are not accounted for explicitly in the model. Poland CGE aims at explicitly measuring the effects of world market price increase for energy goods on the energy sectors in the PWMINCR scenario.

Corresponding to the shift of supply curves, demand curves are shifted by the growth of population, individuals' income, and changes in consumer preferences. Population and labour supply growth are exogenous. Poland's population has decreased since independence, but this negative trend is slowing down and seems to be coming to a halt. Consequently, zero population growth until 2010 seems to be the most plausible assumption (Piazolo 2000). The second shift factor on the demand side is that of income or expenditure growth. Since long-term forecasts of economic growth for Poland are not available, the annual growth rate of income/expenditure has been set at 3% (Piazolo 2000). One could presume an accelerated income growth due to Poland's integration into the EU. However, since no reliable data is available, this will not be accounted for in the model. Land and (sector-specific) natural resources supply curves are price-sensitive within period, but land is only partially mobile across agricultural and forestry sectors.

ATAXCUT Scenario - Tax Reduction for Bioenergy Sector

Changes in the energy sectors' tax rates serve as the point of departure for policy experiments. Instead of increasing fossil energy sectors' taxes, ATAXCUT scenario assumes that the indirect activity tax has been reduced by 50% for bioenergy sector (ABEN), which also means that all fossil energy sectors ACOELPEA, AOIL and AELEC are taxed twice as high as the bioenergy sector compared to the reference scenario (BR). The tax rates for all other sectors in ATAXCUT scenario are kept at their base level.

Changes in the fossil energy tax touches on many issues, such as the tax base, the variation or uniformity among sectors, the association with trade, employment, revenue, or R&D policies, and the exact form of the mechanism (e.g., a fossil energy tax alone or in conjunction with other policy measures) (Bovenberg & Mooij 1994, Bovenberg & Goulder 1997). Since each of these factors can influence the effects of changes in the fossil energy taxes, they must be considered in the model. In the Poland CGE, the fossil energy tax requires the Polish energy sectors to pay an ad valorem rate for every output unit. It is treated as an indirect activity levy percent of output value and is collected from the domestic producers.

The main economic advantage of a fossil energy tax compared to other policy measures is that it limits the cost of the government interventions by allowing renewable energy to sink if production costs are unexpectedly high (Tietenberg 2000). However, fossil energy tax does not guarantee a particular level of renewable energy to be achieved. Therefore, it may be necessary to adjust the tax level after a first round of policy simulations to meet the internationally agreed renewable energy commitment in the Accession Treaty with the European Union, where the European Union imposed on the accession countries the requirement to adjust their energy use level from renewable sources 7.5% in 2010 and 14% in 2020 (European Commission 2004). The fossil energy tax might need to be adjusted due to changes in external circumstances, like inflation, technical progress, and increases in emissions (Tietenberg 2000). Especially in the transition economies of Eastern Europe, such as Poland, fixed tax rates in monetary terms can be significantly eroded by high inflation. Inflation increases abatement costs. Consequently, the tax rate needs to be adjusted for inflation in order to achieve a target renewable energy level (Haas, Wohlgemuth & Huber 2001).

In theoretical terms, fossil energy sectors could be taxed in order to achieve the renewable energy policy targets. Supposing that every fossil energy producer faces a uniform tax on every output unit (assuming that energy, factor, and product markets are perfectly competitive) would result in the least expensive increase of the share of renewable energy throughout the economy (Tietenberg 2000). In Poland, however, especially energy markets deviate from this ideal, so a fossil energy tax may not maximize economic efficiency. Rather, the efficiency of a fossil energy tax should be compared with alternative policy measures. Therefore, we develop an ASUBCUT scenario, which serves a renewable energy policy alternative to the ATAXCUT scenario.

ASUBCUT Scenario - Abolishment of Fossil Energy Subsidies

According to previous studies, even without adding new taxes, removing the subsidies and trade barriers to the fossil energy sectors could create a win-win situation, encouraging renewable energy's production and avoiding dead-weight losses to economy (Bovenberg & Mooij 1994, Bovenberg & Goulder 1997). The opposite effect has a renewable energy sector subsidy, which lowers the costs of energy from renewable resources by, for example, paying a subsidy per kWh produced, providing investment subsidies or fiscal benefits.

Criteria other than sustainability and efficiency, such as distributional impacts, are likely to influence the design of the energy sectors' subsidies in Poland currently, where some fossil energy taxes are coupled with tax exemptions or indirect activity subsidies. However, since the use of energy subsidies for competitive purposes may cause problems due to the WTO agreement on subsidies and countervailing measures (Haas, Wohlgemuth & Huber 2001), and because energy sectors' subsidies are currently under review in Poland (in some cases reforms have already taken place), changes in Producer Subsidy Equivalents (PSE) serve as a second pillar for policy experiments.

The objective of the ASUBCUT scenario is to decrease fossil energy sectors' subsidies compared to the bioenergy sector, which also means a relative increase in the bioenergy sector's PSE level compared to the fossil energy sectors in relative terms. ASUBCUT scenario assumes that all fossil energy sectors' subsidies have been removed, by keeping renewable energy sectors' subsidies at the initial level. The subsidy rates for all other sectors in ASUBCUT scenario are kept at their base scenario level.

According to the economic theory, the main difference to an activity tax is that in the short run, a subsidy may allow some firms to continue operating that would not continue in the case of a tax (those with average variable costs above prices). Besides, a subsidy requires that revenue be raised somewhere else in the economy, which can also produce dead-weight losses. Indeed, it is a policy challenge to bring energy prices in line with real energy production costs. This is particularly true in transition economies such as Poland, where private customers (households) pay a high cost for low-quality energy services (or a low cost that is heavily subsidized). The CGE modeling task is to find out which of the policy instruments, an activity tax or an activity subsidy, is a more appropriate measure for supporting the renewable energy sector.

PWMINCR Scenario - World Market Price Increase for Energy Goods

In order to assess existing or proposed renewable energy policies, analysts require credible measures for their impacts on social values. Often the direct costs and benefits of a policy measure can be estimated by applying market prices to the quantities of real resources required for its implementation and benefits gained from its impact. Where impacts occur in efficient markets, their social values can usually be readily and appropriately estimated from changes in market prices and quantities (as in ATAXCUT and ASUBCUT scenarios).

However, other costs, environmental degradation, and many benefits such as the long-run access to energy supplies at relatively constant costs, cannot be reasonably estimated directly from market prices. When there are market failures or there is no market at all, then a shadow price is needed for example, the value of one percent of international fuel price fluctuations evaded. Often, these shadow prices are key factors in determining whether a policy measure has positive or negative net benefits.

The PWMINCR scenario offers a possibility for conducting an own valuation study of impacts associated with fluctuations of world market prices for energy goods. The objective of the PWMINCR scenario is to assess the benefits from an increased use of bioenergy, by securing long-run access to energy supplies at relatively constant costs for the foreseeable future in Poland. PWMINCR scenario simulates the world market price increase for energy goods by 40%[7].

In the PWMINCR scenario, the same technical progress growth rate is assumed as for the base scenario[8]. The motivation to associate an increase in the world market price with an increased productivity is given by the following two assumptions: (i) Higher output prices create incentives for private investment. Because of increasing returns to scale this leads to lower unit costs (ii) Higher output prices give rise to a higher revenue, which usually is associated with a higher investment in R&D. Technical progress

[7] In the past four years (2000 – 2004) world market price increase for oil has increased by more than 30% (IEA 2004).

[8] The need to endogenise the rate and direction of technical change in environmental policy models has been widely recognized in the literature. However, at present, the theory of induced technological change is still in development and computational models based on it hardly exist. Hence, technical change is exogenous in our model.

enters the model as changes in total factor productivity. The implication of this treatment is that technological progress in our model is assumed to be invariant to the renewable energy policies being considered. If in fact the policies lead to improvements in technology, then the costs may be lower then our model suggest.

4. SIMULATION RESULTS

The main virtue of computational general equilibrium models is the comprehensive and consistent quantification of direct and indirect policy impacts which also constitutes the major challenge for their use. As various partial effects, which may work in opposite directions, contribute to the overall effect, it can get very difficult to explain in depth the aggregate policy outcome. Numerical applications inherit some ambiguity in the interpretation of the results as long as it is not possible to make the sign and the magnitude of individual effects transparent. Therefore, we split the total policy effects into the price, quantity and generic welfare effects. This helps in the understanding and the interpretation of renewable energy policy simulations. Moreover, a deliberate decomposition not only facilitates the analysis of the various sources of the total effects, but also assures a more rigorous check for the correct numerical implementation of renewable energy policy questions. In this section, the main Poland CGE simulations' findings about the renewable energy policies effects are summarized and their implications to the renewable energy policy design in Poland are indicated.

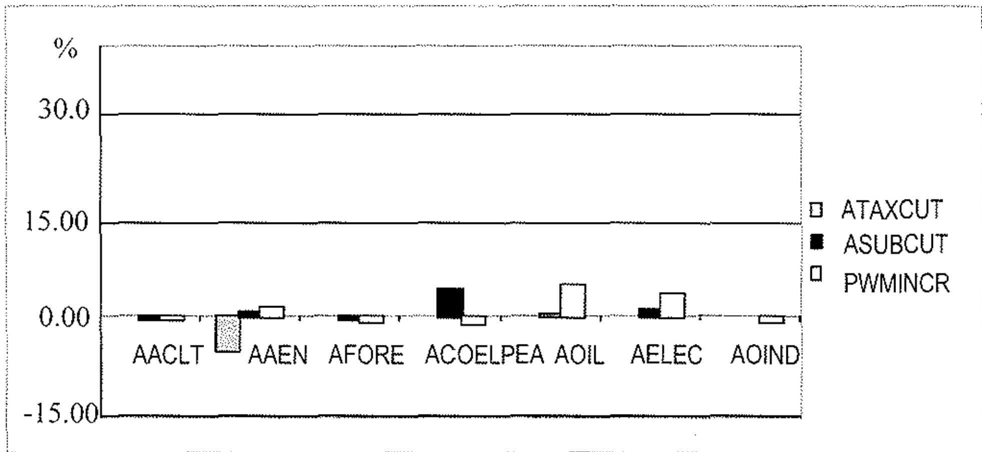
Changes in Relative Prices

It is convenient to start by examining the changes in relative prices because they can be considered as the initial effects of the change in the whole economy. According to the Poland CGE, the aggregate bioenergy sector's (AAEN) output price decreases by 5% compared to the reference scenario (BR), if the indirect activity taxes are reduced for the bioenergy sector by 50% (see left columns in Figure 1). All others' activities output prices have not been affected significantly by reducing indirect bioenergy sector's tax.

The extent of the impact of removing output subsidies depends on the specific characteristic of each sector, the type of subsidy involved, and the international co-ordination to implement similar measures. Different initial subsidies' rates in the base run lead to different changes in the output prices when implementing policy measures. According to the model's results, removal of fossil energy sectors' subsidies leads to a remarkable increase in the aggregate output price for the coal and peat sector (ACOELPEA) – 3.8%

compared to the reference scenario (BR) (see middle columns in Figure 1). Compared to the other two fossil energy sectors, AELEC and AOIL, the coal and peat sector has been subsidized much higher in the base run, 622.8 million PLN. The crude oil and natural gas sector has not been subsidized at all in the base run and electricity, gas, steam and hot water sector only marginally, 10.4 million PLN.

Figure 1. Changes in relative prices compared to the BR



Source: Own calculations

The third scenario, increase of energy commodities' prices on the world markets, has varying impacts on aggregate output prices (see right columns in Figure1). The largest aggregate price increases are calculated for the crude oil and natural gas sector (AOIL) as well as for the electricity, gas, steam and hot water sector (AELEC), 4.4% and 3.3% respectively. In contrast to expectations, the aggregate output price of the coal and peat sector (ACOELPEA) has decreased compared to the reference scenario (BR), which requires a more detailed explanation. An explanation of this phenomenon, when an increase in world market price leads to a decrease in domestic output price, starts by considering each commodity's output price, which has been produced by the coal and peat sector. The output price for agricultural and hunting products (CACLT), and forestry commodities (CFORE) produced by the coal and peat sector has decreased by –0.8%, that of coal and peat commodities (CCOELPEA) by –1.27%, and the output price of other industrial goods and services (COIND), which has been produced by the coal and peat sector has decreased by –0.9%. Though output prices of the two remaining activities have increased significantly, 18% of crude oil and peat commodities (COIL) and 9% of coke and refined petroleum products (CPET), their share in total coal and peat sector's output is tiny, 0.016% and 0.003% respectively. Since CACLT, CFORE, CCOELPEA and COIND have much greater weights in the ACOELPEA activity's price index, price increase effects have dominated over those of a price decrease.

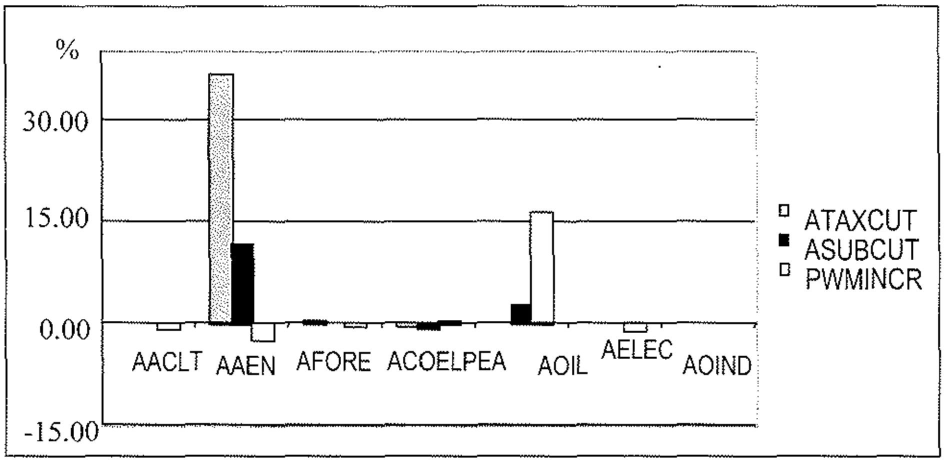
Aggregate Output Effects

It is fundamental to correctly perceive that in such an interrelated system as the whole economy, any change of the fiscal policy modifies all market equilibriums, i.e. prices, and due to substitution possibilities, quantities of producers and consumers in each sector/commodity. Therefore, in assessing the effects of various renewable energy policy measures, estimations of price-induced substitution possibilities between types of energy and between aggregate energy and other inputs are presented next.

According to the Poland CGE, the greatest increase in aggregate output - 36% is that of the bioenergy sector caused by an indirect activity's tax reduction by 50% (see left columns in the Figure 2). These output changes are considerably higher compared to the moderate price changes of 5% and, therefore, require a more detailed explanation. Since, there is no excess demand in the Poland CGE, and world market prices are determined exogenously, an increase in an activity's total output has to be led back either to an increase in commodities' total demand and/or to a decrease of commodities production by other activities. According to our results, there are no significant changes in agricultural and hunting products, and electricity, gas, steam and hot water goods and services output levels by other activities. On the demand site, the prices of composite goods CCOELPEA and CELEC did not significantly decrease either (see Figure 2). The large increase in the bioenergy sector's aggregate output might be associated with its rather low share in the total commodity's output, which is less than 1% in total commodities' supply, i.e. if the market's total demand for corresponding commodity increases by 1%, the bioenergy sector's output will grow by 100%, ceteris paribus.

The removal of subsidies for the fossil energy sector increases the aggregate output level of two energy sectors, bioenergy (AAEN) and crude oil and natural gas sector (AOIL) (see middle columns in the Figure 2). The bioenergy sector's output increase is caused by a decrease in relative output prices, 1.8% to 3-4% and minus 1.1% to plus 0.3-0.9%. The crude oil and natural gas sector extends production by 2.8%, because it has not been subsidized in the base run and, hence it has no direct income losses. In spite of these results, it is not possible to draw any general conclusion about the socio-economic effects of removing subsidies for the energy industry, because the effect of removing subsidies to coal producers depends heavily on the type of subsidy removed and the availability and economics of alternative energy sources, including renewable energy. There may also be cases where a removing of a subsidy to an energy-intensive industry in Poland could lead to a shift in production to other countries with lower costs or environmental standards, resulting in a net increase in global fossil energy production.

Figure 2. Changes in sectoral output compared to the BR



Source: Own calculations

Each of the four energy sectors reacts in a non-uniform manner, if the world market price for energy goods and services rises by 40% (PWMINCR scenario). The crude oil and natural gas sector extends its production by 16.2%, the bioenergy sector (AAEN), and the electricity, gas, steam and hot water sector (AELEC) reduce their output shares by 2.4 and 1.1% (see right columns in the

Figure 2). These diverse output-site effects are closely related to the commodities' import/export share. For example, domestic supply with crude oil and natural gas commodities has been dominated by imports, which count for more than 90% in the reference scenario (BR). As the price for imported commodities rise, domestic producers get a relative price advantage compared to foreign competitors and extend their shares in both, domestic and foreign markets. The import share has been considerably smaller for other three energy products – 1.1, 7.5 and 0.1 of CCOELPEA, CPET and CELEC respectively.

Interpreting the model's results it has to be kept in mind that price signals can only influence demand and supply if they actually reach economic agents and if those economic agents have the opportunity to respond to them. In

Poland, energy intensity increased by 24% between 1990 and 2000, while energy prices also increased tremendously (EC BREC 2005). This experience shows that it takes time for economic agents to adjust their behaviour to new price signals, not only because of the capital stock turnover, but also because consumers often do not have an accurate knowledge of their energy consumption, or the technical capacity to reduce it.

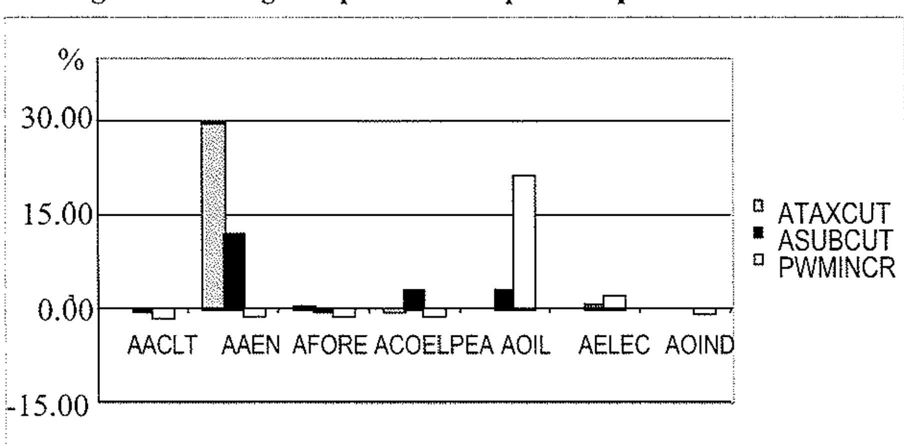
Welfare Impacts

Changes in producer welfare are measured as a difference between total revenue and total costs. Our simulations' results reveal that the renewable energy sector has the highest welfare gains in the case of producer tax reduction (ATAXCUT scenario) compared to the reference scenario (BR) and to the other two policy scenarios (see left columns in Figure 3).

There are no significant welfare losses on the producer side. According to these results, there are three sectors (AAEN, ACOELPEA and AOIL) whose total revenues increased in the case of the ASUBCUT scenario, 12%, 2.9 and 2.8% respectively. These revenue gains have to be led back either to the composite commodity's price increases and/or to the increases in sectors output level (see above).

A price shock on the world energy market (PWMINCR scenario) favors above all, the crude oil and natural gas sector, whose total revenue rises by 21% compared to the reference scenario (BR). All other sectors' welfare, except crude oil and natural gas, and electricity, gas, steam and hot water sectors, boost insignificantly, if the world market price for energy goods increases by 40 per cent.

Figure 3. Changes in producer surplus compared to the BR



Source: Own calculations

Simulation results and the following analysis report that an increase in the share of bioenergy in the total energy supply in 2010 would increase budgetary expenses from public sources. However, the state budget effects of reducing government revenues depend on how this additional or lacking money circulates in the economy. In the bioenergy CGE, it is assumed that increased/decreased state revenues are not distributed (flexible government saving balances state budget), which can lead to the fact that the models results over/underestimate aggregate welfare effects[9].

An alternative to this approach could be to assume that revenues collected from the fossil energy sectors' tax are used for correcting economic distortions in the economy, e.g. taxation of employment, which would benefit society not only by correcting the externality but also by reducing the costs of the distorting taxes (the so-called "double dividend"). Previous studies indicate that if the benefits from reducing existing taxes on labour are incorporated into the modeling, the projected economic impacts can be substantially more optimistic than if no compensation or lump-sum revenue compensation is assumed, although the size of the effect depends on model specification.

According to the model's results, the average reduction of the income to the state budget due to decreased excise duty on bioenergy with a mixture of liquid biofuels implies additional 12.4 million PLN/year. Simulations' results and the following analysis show that an increase of the share of bioenergy in the total energy supply in 2010 would increase the total required amount of funding from public sources and would require a much larger utilization of biomass (in cogeneration). The planned development of the renewable energy sector in Poland in the years 1997-2010 would allow a significant decrease of investment costs. An example is the United Kingdom, where within 9 years (1990-1999) the state support system allowed an average decrease of costs of energy generated from renewable energy sources at a level of 45%, which in some areas made renewable energy fully competitive to energy generation from fossil fuels. As such, a further development of the renewable energy sector in Poland according to the objectives and targets set by the Polish government would require only a selective support to the new technologies coming to the market and budgetary costs would decrease.

[9] To the extent that the role of the demand side of the model is not limited to determining prices and sectoral breakdowns - in other words, if changes in aggregate demand have real (level) effects, these differences in public-sector balances might influence the obtained results.

CONCLUSION

Our study of the impact of alternative renewable energy policy instruments has highlighted several areas, which might be useful for strategic decision making. Generally, an uniform subsidy can lead to the same increase of renewable energy supply as an equivalent uniform fossil energy tax. In an industry with homogeneous firms, both taxes and subsidies (set at the same levels) yield exactly the same outcome in the short run. According to the Poland CGE, however, a fossil energy tax is more efficient than a subsidy. While a subsidy lowers the average cost of production, a tax increases the average cost of production. Our empirical results suggest that bioenergy sector benefits more from an indirect tax reduction than from a removal of fossil energy sectors' subsidies.

Our empirical results also advocate that reductions in the output of fossil energy sectors below the reference case (base run) do not impact all fossil energy sectors equally. Various energy sectors have different costs and price sensitivities, so that they respond differently to policy measures. The aggregate rest-of-the industry and services sector augments their output as a result of the policy changes. Aggregate rest-of-the industry and services sector has a high share in national GDP, is much more diversified than small primary industries and energy sectors. Moreover, according to the multiple output production technology these sectors have a greater opportunity for substitution on the output side.

Like most CGE models, the Poland CGE is based on many assumptions concerning the economic development (market structure, elasticities of substitution and transformation, technical change, exogenous variables). It is a necessity and indeed the intention of all models, including the Poland CGE, to abstract from the much more complex reality. Focusing on those relations who are most important for modeling purposes, the Poland CGE contributes to a better understanding of the relevant issues and parameters. For the interpretation of the model results, the reader has to bear in mind the assumptions made in the model. It would be misleading to base policy decisions on the numerical analysis results without recognizing model's limitations and its assumptions. Major limitations of the Poland CGE are assumptions of fully employed factor markets, disregard of oligopolistic market structure in energy sectors, assumption of variable public-sector balance, and reliability of the data base and values of models parameters. Therefore, the quantitative results should not be overemphasized, but need to be seen in the context of the model's assumptions.

APPENDICES

A.1. Notation

Variable subscripts indicate sectors. If double subscripts are employed, the first one denotes the sector of origin and the second one, the sector of destination. Uppercase letters are reserved for endogenous variables, unless they have a bar, in which case they are exogenous. Parameters and are denoted by Greek or lowercase Latin letters.

There are i,j = 1,...,8 sectors: ien (inen) refers to the set of energy (non-energy) sectors; isf (insf) refers to the set of sectors with (without) specific factor; ipc (inpc) refers to the set perfectly (monopolistic) competitive; ied (ined) refers to the set of sectors with (without) export demand; ims (inms) refers to the set of sectors with (without) import supply.

A.2. Model Equations

Output

$$XD_i = XDF_i \cdot N_i \qquad i \in incp \tag{1}$$

$$XD_i = Min\left(\frac{VA_i}{v_i};\frac{CI_i}{io_i}\right) \tag{2}$$

Value added

$$VA_i = av_i \cdot \left[\beta_i \cdot \overline{FS}_i^{-\rho v_i} + (1-\beta_i)\cdot FM_i^{-\rho v_i}\right]^{-1/\rho v_i} \qquad i \in isf \tag{3}$$

$$\frac{FM_i}{\overline{FS}_i} = \left[\left(\frac{1-\beta_i}{\beta_i}\right)\cdot\left(\frac{WS_i}{WM_i}\right)\right]^{\sigma v_i} \qquad i \in isf \tag{4}$$

$$VA_i = FM_i \qquad i \in insf \tag{5}$$

Factors of production

$$FM_i = af_i \cdot \left[\alpha_i \cdot L_i^{-\rho f_i} + (1-\alpha_i)\cdot K_i^{-\rho f_i}\right]^{-1/\rho f_i} \tag{6}$$

$$\frac{K_i}{L_i} = \left[\left(\frac{1-\alpha_i}{\alpha_i}\right)\cdot\left(\frac{W}{R}\right)\right]^{\sigma f_i} \tag{7}$$

Output allocation

$$XD_i = at_i \cdot \left[\delta_i \cdot XXD_i^{\rho t_i} + (1-\delta_i) \cdot E_i^{\rho t_i}\right]^{1/\rho t_i} \tag{8}$$

$$\frac{E_i}{XXD_i} = \left[\left(\frac{1-\delta_i}{\delta_i}\right) \cdot \left(\frac{PD_i}{PE_i}\right)\right]^{-\sigma t_i} \tag{9}$$

Costs of monopolistic competitive firms

$$CTF_i = \left(\frac{PP_i}{PP0_i}\right) \cdot CTF0_i \qquad i \in inpc \tag{10}$$

$$CTV_i = v_i \cdot XDF_i \cdot WM_i + \sum_j \left(aij_{ji} \cdot io_i \cdot XDF_i \cdot PCI_{ji}\right) - sx_i \cdot XDF_i \qquad i \in inpc \tag{11}$$

$$CMA_i = \frac{CTV_i}{XDF_i} \qquad i \in inpc \tag{12}$$

$$CFU_i = \frac{CTF_i}{XDF_i} \qquad i \in inpc \tag{13}$$

$$CMO_i = CMA_i + CFU_i \qquad i \in inpc \tag{14}$$

Price setting

$$PP_i \cdot XD_i = PVA_i \cdot VA_i + \sum_j \left(PCI_{ji} \cdot CIJ_{ji}\right) - sx_i \cdot XD_i \qquad i \in ipc \tag{15}$$

$$PP_i = CMO_i \qquad i \in inpc \tag{16}$$

$$PDV_i = CMA_i \cdot \frac{\sigma s_i}{(\sigma s_i - 1)} \qquad i \in inpc \tag{17}$$

Output and value added prices

$$PVA_i = av_i^{-1} \cdot \left[\beta^{\sigma v_i} \cdot WS_i^{1-\sigma v_i} + (1-\beta_i)^{\sigma v_i} \cdot WM_i^{1-\sigma v_i}\right]^{1/(1-\sigma v_i)} \qquad i \in isf \qquad (18)$$

$$PVA_i = WM_i \qquad i \in insf \qquad (19)$$

$$WM_i = af_i^{-1} \cdot \left[\alpha^{\sigma f_i} \cdot W^{1-\sigma f_i} + (1-\alpha_i)^{\sigma f_i} \cdot R^{1-\sigma f_i}\right]^{1/(1-\sigma f_i)} \qquad (20)$$

$$PP_i = at_i^{-1} \cdot \left[\delta_i^{-\sigma t_i} \cdot PD_i^{1+\sigma t_i} + (1-\delta_i)^{-\sigma t_i} \cdot PE_i^{1+\sigma t_i}\right]^{1/(1+\sigma t_i)} \qquad i \in ipc \qquad (21)$$

$$PP_i \cdot XD_i = PD_i \cdot XXD_i + PE_i \cdot E_i + N_i \cdot CTF_i \qquad i \in inpc \qquad (22)$$

Prices of traded goods

$$PM_i = PWM_i \cdot (1 + tm_i) \cdot \overline{ER} \qquad (23)$$

$$PE_i = PWE_i \cdot (1 + se_i) \cdot \overline{ER} \qquad (24)$$

Import supply and export demand

$$PWM_i = \overline{PWM}_i \qquad i \in inms \qquad (25)$$

$$PWM_i = constm_i \cdot M_i^{1/\varphi m_i} \qquad i \in ims \qquad (26)$$

$$PWE_i = \overline{PWE}_i \qquad i \in ined \qquad (27)$$

$$PWE_i = conste_i \cdot E_i^{-1/\varphi e_i} \qquad i \in ied \qquad (28)$$

Taxes and subsidies

$$TARIFF = \sum_i \left(tm_i \cdot PWM_i \cdot M_i \right) \tag{29}$$

$$SUBE = \sum_i \left(se_i \cdot PWE_i \cdot E_i \right) \tag{30}$$

$$SUBO = \sum_i \left(sx_i \cdot XD_i \right) \tag{31}$$

Income

$$INCOME = \sum_i \left(PVA_i \cdot VA_i \right) + TARIFF - SUBE - SUBO \tag{32}$$

$$YFS_i = PVA_i \cdot VA_i - W \cdot L_i - R \cdot K_i \qquad i \in ifs \tag{33}$$

$$SAVINGS = mps \cdot INCOME \tag{34}$$

Capital goods demand

$$PCK_i \cdot K_i = kish_i \cdot INVEST \tag{35}$$

$$IT_i = ak_i \cdot \left[\kappa_i \cdot ID_i^{-\rho k_i} + \left(1 - \kappa_i\right) \cdot IM_i^{-\rho k_i} \right]^{-1/\rho k_i} \tag{36}$$

$$\frac{IM_i}{ID_i} = \left[\left(\frac{1 - \kappa_i}{\kappa_i} \right) \cdot \left(\frac{PD_i}{PM_i} \right) \right]^{\sigma k_i} \tag{37}$$

$$IDV_i = bv_i^{-1} \cdot ID_i \cdot N_i^{\sigma s_i / (\sigma s_i - 1)} \qquad i \in inpc \tag{38}$$

Intermediate goods demand

$$CIJ_{ij} = aij_{ij} \cdot CI_i \tag{39}$$

$$CIJ_{ij} = az_{ij} \cdot \left[\gamma_{ij} \cdot ZD_{ij}^{-\rho z_{ij}} + \left(1 - \gamma_{ij}\right) \cdot ZM_{ij}^{-\rho z_{ij}} \right]^{-1/\rho z_{ij}} \tag{40}$$

$$\frac{ZM_{ij}}{ZD_{ij}} = \left[\left(\frac{1 - \gamma_{ij}}{\gamma_{ij}} \right) \cdot \left(\frac{PD_i}{PM_i} \right) \right]^{\sigma z_{ij}} \tag{41}$$

$$ZDV_i = bv_i^{-1} \cdot ZD_{ij} \cdot N_i^{\sigma s_i / (\sigma s_i - 1)} \qquad i \in inpc \tag{42}$$

Consumer goods demand

$$DT_i = ad_i \cdot \left[\lambda_i \cdot DD_i^{-\rho d_i} + (1-\lambda_i) \cdot DM_i^{-\rho d_i}\right]^{-1/\rho d_i} \tag{43}$$

$$\frac{DM_i}{DD_i} = \left[\left(\frac{1-\lambda_i}{\lambda_i}\right) \cdot \left(\frac{PD_i}{PM_i}\right)\right]^{\sigma d_i} \tag{44}$$

$$DDV_i = bv_i^{-1} \cdot DD_i \cdot N_i^{\sigma s_i/(\sigma s_i - 1)} \qquad i \in inpc \tag{45}$$

$$CPAG = ag\left[\sum_{i \in iag}\left(\theta_i \cdot DT_i^{-\rho g}\right)\right]^{-1/\rho g} \tag{46}$$

$$\frac{DT_j}{DT_i} = \left[\left(\frac{\theta_j}{\theta_i}\right) \cdot \left(\frac{PCF_i}{PCF_j}\right)\right]^{\sigma g} \qquad i, j \in iag \tag{47}$$

$$U = ac \cdot \left[\Omega \cdot CPAG^{-\rho c} + \sum_{i \in inag}\left(\omega_i \cdot DT_i^{-\rho c}\right)\right]^{-1/\rho c} \tag{48}$$

$$\frac{DT_i}{CPAG} = \left[\left(\frac{\omega_i}{\Omega}\right) \cdot \left(\frac{PINDEXAG}{PCF_i}\right)\right]^{\sigma c} \qquad i \in inag \tag{49}$$

Average purchase prices

$$PD_i = bv_i^{-1} \cdot PDV_i \cdot N_i^{1/(1-\sigma s_i)} \qquad i \in incp \tag{50}$$

$$PCK_i = ak_i^{-1} \cdot \left[\kappa^{\sigma k_i} \cdot PD_i^{1-\sigma k_i} + (1-\kappa_i)^{\sigma k_i} \cdot PM_i^{1-\sigma k_i}\right]^{1/(1-\sigma k_i)} \tag{51}$$

$$PCI_{ij} = az_i^{-1} \cdot \left[\gamma_{ij}^{\sigma z_{ij}} \cdot PD_i^{1-\sigma z_{ij}} + (1-\gamma_{ij})^{\sigma z_{ij}} \cdot PM_i^{1-\sigma z_{ij}}\right]^{1/(1-\sigma z_{ij})} \tag{52}$$

$$PCF_i = ad_i^{-1} \cdot \left[\lambda^{\sigma d_i} \cdot PD_i^{1-\sigma d_i} + (1-\lambda_i)^{\sigma d_i} \cdot PM_i^{1-\sigma d_i}\right]^{1/(1-\sigma d_i)} \tag{53}$$

$$PINDEXAG = ag^{-1} \cdot \left[\sum_{i \in iag} \theta_i^{\sigma g} \cdot PCF_i^{1-\sigma g}\right]^{1/(1-\sigma g)} \tag{54}$$

$$PINDEX = ac^{-1} \cdot \left[\Omega^{\sigma c} \cdot PINDEXAG^{1-\sigma c} + \sum_{i \in inag} \omega_i^{\sigma c} \cdot PCF_i^{1-\sigma c}\right]^{1/(1-\sigma c)} \tag{55}$$

Equilibrium

$$\sum_i L_i = \overline{L} \tag{56}$$

$$\sum_i K_i = \overline{K} \tag{57}$$

$$M_i = \sum_j ZM_{ij} + IM_i + DM_i \tag{58}$$

$$XXD_i = \sum_j ZD_{ij} + ID_i + DD_i \tag{59}$$

$$\sum_i PCF_i \cdot DT_i = (1 - mps) \cdot INCOME \tag{60}$$

$$SAVINGS - INVEST = \sum_i PWE_i \cdot E_i - \sum_i PWM_i \cdot M_i \tag{61}$$

A.3. Definition of Endogenous Variables

Variable	Definition
XD_i	Domestic output
XDF_i	Output of sector i firms
N_i	Number of sector i firms
CI_i	Aggregate intermediate consumption
VA_i	Value-added
FM_i	Aggregate capital and labour used in sector i
K_i, L_i	Capital and labour demands
CTF_i	Total fixed cost of sector i firms
CTV_i	Total variable cost of sector i firms
CMA_i	Marginal cost
CFU_i	Unit fixed cost
CMO_i	Average cost
XXD_i	Domestic sales
E_i	Exports
M_i	Imports
$TARIFF$	Tariff revenue

A.4. Definition of Exogenous Variables and Parameters

Parameter	Definition
$\overline{ER}$	Exchange rate
$\overline{LS}, \overline{KS}$	Labour and capital supply
$\overline{FS}_i$	Specific factor supply in sector i
$CTF0$	Initial fixed cost
$PP0$	Initial output price
$kish_i$	Shares of investment by sector of destination
mps	Marginal propensity to save
aij_{ij}	Coefficients of intermediate uses
$af_i, av_i, ak_i, az_{ij},$ ad_i, ag, ac, bv_i, a	Scale parameters of various CES and CET functions
$a_i, b_i, g_{ij}, k_i,$ l_i, q_i, w_i, W, d_i	Share parameters of various CES and CET functions. In particular å $_i q_i = 1$, å $_i w_i = 1 -$ W
$sf_i, sv_i, sk_i, sz_{ij}$ $sd_i, sg, sc, ss_i,$	Elasticities of substitution in value added, capital good demand, intermediate consumption and consumer good demand functions and elasticity of transformation
$rf_i, rv_i, rk_i, rz_{ij}$ rd_i, rg, rc, at_i	Parameters corresponding to the mentioned elasticities. In particular, $s = 1/(1+r)$, except $st = 1/(rt - 1)$
$conste_i, constm$	Constants in export demand and import supply functions
fe_i, fm_i	Foreign elasticities of export demand and import supply functions

A.5. Sectors of the model

Sector code	Sectors of the model	Nature of competition
Energy industries with specific factor		
AAEN	Agricultural bioenergy sector	Perfect competition
AFORE	Forestry bio energy sector	Perfect competition
ACOELPE	Coal and peat activity	Monopolistic competition
Energy industries without specific factor		
AOIL	Crude oil and natural gas	Monopolistic competition
AELEC	Electricity gas steam, hot water	Monopolistic competition
Non-energy industries (without specific factor)		
AACLT	Agricultural activity	Perfect competition
AFORE	Forestry activity	Perfect competition
AOIND	Other industry and services	Monopolistic competition

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