ELASTIC ELECTRICITY AND HEAT DEMAND IN THE BALMOREL MODEL

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ABSTRACT

The paper is focused on the modelling of electricity and heat demand as a part of developing a model and supporting analyses of the energy sector in the Baltic Sea Region, with emphasis on the electricity and combined heat and power sectors. The ultimate goal is to produce a partial equilibrium model with endogenous demands and prices for electricity and heat as well as international electricity trade. The key parameters in this further model development are partial price elasticities for electricity and heat at sectoral or aggregate levels. The paper will discuss the possible numerical values of these parameters and their implementation into the Balmorel model (Baltic Model of Regional Energy Market Liberalisation). In conclusion, aggregate price elasticities may be specified for each national electricity market and each type of local heat market.

INTRODUCTION

The Balmorel project is carried out during 1999 and 2000 in co-operation between research institutes in the region. The project is supported by the Danish Energy Research Programme. It is co-ordinated by Elkraft System Ltd., which is the system operator for the electricity market in part of Denmark.

Optimisation model

The first version of the model under development is a techno-economic bottom-up model with exogenous demand for electricity and heat. It is a linear optimisation model written in the GAMS modelling language. The objective function used for the optimisation, so far, is cost minimisation for the whole region each year. It means that the model determines the minimal cost of production and new investments given some constraints for each year, which might concern the current production capacity, national or regional emission limits, etc. This optimisation rule is different from the EFOM or MARKAL models, in which the objective function is minimisation of the total discounted costs for the whole modelling period. However, the latter rule is more suited for traditional long-term planning with perfect foresight, rather than the emerging competitive electricity market.

Partial equilibrium model

Elasticities for the energy demand have been widely published from numerous studies using different estimation techniques or calibration within a modelling framework. An important task in the model development will be the selection of appropriate numerical values and the implementation of these parameters into a partial equilibrium model, focusing on the calculation methods, validity, and interpretation of the parameters.

Publication

All details concerning the model development and data used in the model are published continuously on the Internet: *(www.balmorel.dk)*. This website also contains conference papers etc. with presentations of the model development and applications of the model.

DEMAND ELASTICITIES

Elasticities are the most widely used concepts in economic modelling to describe the demand for goods as a function of income and prices. These parameters should be specified within a framework of functions that are useful for the development of an objective function and equilibrium condition for a partial equilibrium model.

Elasticity concepts and standard functions

Table 1 shows the elasticities concepts to be considered for the modelling of electricity and heat demand in the Balmorel model. It also shows two widely used standard functions to be used for optimisation or equilibrium condition.

Table 1. Elasticities and standard functions

e_i share of budget for good *i*.	Cobb-Douglas	CES function
Income elasticity: The change in demand for good *i* per percent change in income.	1	1
Own price elasticity: The change in demand for good *i* per percent change in the price for good *i*.	-1	$-E+(E-1)e_i$
Cross price elasticity: The change in demand for good per percent change in the price for good *j*.	0	$(E-1)e_j$
Own price elasticity compensated for the income effect	$\alpha_i - 1$	$-E(1-e_i)$
Cross price elasticity compensated for the income effect	α_j	Ee_j
Substitution elasticity. The change in the relative consumption of goods *i* and *j* per percent change in their relative prices.	1	E

The *Cobb-Douglas functions* are the most basic function type for this purpose. The only parameters are the shares of goods that are considered in the model. The values of the elasticities are restricted to their unit values. However, price elasticities with compensation for the income effect are dependent on the budget share of the goods.

The *CES functions* (constant elasticity of substitution) allow much more flexibility of parameters. The income elasticity must be unity, but price elasticities can be specified individually for each pair of goods. This restriction to pairs of goods may be overcome by a hierarchy of pairs of goods in *nested CES functions*.

The numerical values are estimated either by econometric methods from time-series or cross-section analyses, or they are calibrated within a model framework. Estimations by econometric methods require a large amount of good-quality statistical data, which is found in national account statistics. This statistics has been developed over several decades in all developed market economies, and concepts and methods have been harmonised by international organisations such as the OECD and the European Union. In most transitional economies this statistics is under development, but it is obviously not available for econometric estimations on long time-series. In these countries it is necessary to use parameter values from cross-section analyses or model calibrations.

Price elasticities in CES functions

Two types of parameters are used in a CES function for the demand side: the share of total expenditure and a price or substitution elasticity. If one of these elasticities is known the others can be calculated. Among these elasticities concepts most references consider own price elasticities. Own and cross price elasticities have a good intuition, while substitution elasticities are more difficult. Table 2 describes the numerical values of the relations of the various concepts using budget shares and own price elasticities as entries.

Table 2. Elasticities in CES functions

Budget share for electricity	$e_i=0.10$			
Own price elasticity	E_p	*-0.10*	*-0.50*	*-1.00*
Cross price elasticity	$1-E_p$	-0.90	-0.50	0.00
Own price elast., compensat.	$E_{p+}e_i$	0.00	-0.40	-0.90
Cross price elas., compensat.	$-(E_{p+}e_i)$	0.00	0.40	0.90
Substitution elasticity	$-(E_{p+}e_i)/(1-e_i)$	0.00	0.44	1.00
Own price elast., compensat.	E_{pI}	*-0.10*	*-0.50*	*-1.00*
Cross price elast., compensat.	$-E_{pI}$	0.10	0.50	1.00
Own price elasticity	$-E_{pI}-e_i$	-0.20	-0.60	-1.10
Cross price elasticity	$1-(E_{pI}-e_i)$	-0.80	-0.40	0.10
Substitution elasticity	$-E_{pI}/(1-e_i)$	0.11	0.56	1.11

Compensation of price elasticities for income effects of price changes will depend on the scenario specification. Changes in import prices for energy do not provide any compensation for import effect, while revenue-neutral taxes or 'grandfathered' emission permits will provide some compensation, but these measures may have an impact on the income distribution.

For a given budget share of the demand for a good (electricity or heat) the series of elasticity concepts become linear functions of the own price elasticity. For very inelastic demand, e.g. own price elasticity at –0.1 for electricity, the substitution and cross price elasticities become negative. It means that higher electricity or heat prices without compensation for the income effect will therefore lead to lower demand for other goods. This was a common experience for the consumers in many transition economies during the 1990s.

Key assumptions for demand projection in Latvia

Income and price elasticities are key assumptions used in domestic electricity demand projection for transition countries. Table 3 and Table 4 show examples of values used for mid-term energy projections for Latvia from the World Bank mission to Riga 1996.

Table 3. GDP/electricity elasticity

	Industry	Agriculture	Households	Other
1996	0.76	1.09	1.04	0.98
1998	0.72	1.07	1.02	0.94
2000	0.68	1.05	1.00	0.90
2002	0.64	1.03	1.00	0.86
2004	0.60	1.01	1.00	0.82
2005	0.58	1.00	1.00	0.80

Source: World Bank 1996

In Table 3 the elasticity for households is equal to unity after a few years with higher elasticities. The elasticities above unity in agriculture indicate the assumption that mechanisation is lagging behind. The elasticities far below unity in industry illustrate expected structural changes towards less energy intensive industries.

The short-term electricity price elasticity shown in Table 4 is very low, but the lagged values for the following years add to the impact of price changes. The long-term price elasticity shows that the electricity demand is assumed very inelastic and mainly dependent on economic growth.

Table 4. Price elasticity for electricity (numerical values)

t(0) short-term	0.08
t(1) lagged 1 year	0.06
t(2) lagged 2 years	0.04
Long term	0.18

Source: World Bank 1996

Wholesale electricity prices, taxes and consumer prices in Denmark

Electricity demand elasticities are assumed for the national electricity market for different types of customers. Price elasticities refer to consumer prices, which are composed by the electricity wholesale price (e.g. on the Nord Pool spot or forward market for electricity in Oslo, Norway), a fixed cost per MWh for electricity transmission and distribution, and excise taxes (electricity, CO_2, and SO_2 taxes). Table 5 shows some widely different assumptions for electricity price elasticities, which could be assumed on the basis of a database of published elasticities for electricity demand. Prices are in ECU 1990, which is used for fixed prices in several economic models within the EU, e.g. PRIMES. (ECU was the predecessor of the Euro, 1.27 US$= 1 ECU in 1990).

Table 5. Price elasticities, system cost and taxes

	Moderately elastic prices	Very elastic prices	System costs, Ecu90/-MWh	Excise taxes, Ecu90/-MWh
Heavy industry	-0.5	-0.8	4.80	2.40
Light industry	-0.2	-0.4	15.19	11.19
Transport	0.0	0.0	4.80	2.40
Residential, Service	-0.3	-0.8	15.19	62.36

Source: Grohnheit and Olsen, 2000.

Table 6 shows the results of a scenario study using the EFOM-CHP model for Denmark. The model and scenario specifications are described in details in Varming et al. 2000, while the introduction of elastic demand was made for this study.

Emission taxes or tradable permits at 11 Ecu90 per ton CO_2 may be transferred to the international wholesale price for electricity. However, the impact on consumer prices will be much lower, because both the payment for electricity system services (transmission and distribution, etc.) and excise taxes are cost elements that are independent of CO_2 emissions.

Table 6. Impact of price elasticities, fixed cost elements and taxes on electricity demand.

	2000	2010	2020
Wholesale price, Ecu90/MWh	15.19	15.37	15.62
- CO_2 ¨payment 11 Ecu90	*19.56*	*22.41*	*23.73*
Consumer price. Changes in %			
Industry	10.5%	16.9%	19.3%
Transport	19.5%	31.2%	35.5%
Tertiary/domestic	4.7%	7.6%	8.7%
Wholesale price. Changes in %	28.7%	45.8%	51.9%
Electricity demand. Changes in %			
Industry	-2.1%	-3.4%	-3.9%
Transport	0.0%	0.0%	0.0%
Tertiary/domestic	-1.4%	-2.3%	-2.6%
Total electricity demand	-1.7%	-2.7%	-3.1%
Aggregate wholesale price elast.	-0.058	-0.059	-0.059

Source: EFOM-CHP model, Varming et al. 2000.

The impact of CO_2 taxes or tradable permits will be most significant for large energy consuming industries, not only because energy is a significant part of the production values, but also because they have traditionally been exempted from national excise taxes. In contrast, the electricity wholesale price is only a small fraction of the electricity price paid by residential end users in Denmark, because most of the electricity price is taxes.

Considering price elasticities on the electricity wholesale market, which could be useful for the implementation of the Balmorel model, own price elasticities must be must lower. This is shown in the last row of Table 6.

For this initial model exercises the aggregate wholesale price elasticity for electricity at –0.1 was used. For Denmark this value is between the assumptions "moderately elastic prices" and "very elastic prices", cf. Table 5.

THE GEOGRAPHICAL STRUCTURE OF THE BALMOREL MODEL

Fig. 1 shows the structure of a set of co-ordinated model results from techno-economic optimisation model for standardised CHP generators and partial equilibrium models that are used to describe the price formation and trade volume on an international electricity market.

The figure describes the structure used for the EFOM-CHP model, which has been used for bottom-up model analyses of technology choice (Grohnheit 1999). In the optimisation model CHP generators are treated as standardised agents that are serving a given demand for electricity and heat at minimum cost either by own-generation or by purchase from outside.

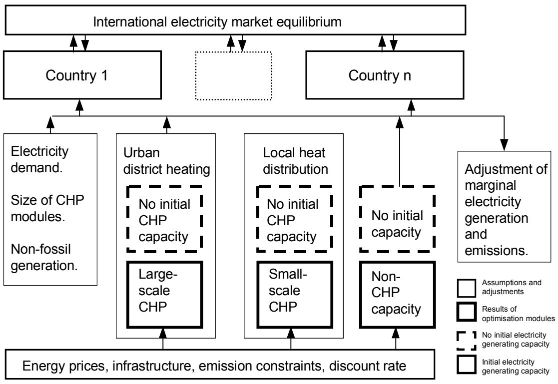

Fig. 1. Electricity market model based on optimisation modules for CHP generators

The price elasticities for the electricity demand apply to the national markets "Country 1" through "Country n" in the upper part of Fig. 1, while price elasticities for heat apply to the local heat markets.

The model results for the different types of CHP regions have been be used as 'building blocks' or modules to represent the existing and future infrastructure of the electricity and heat markets in actual geographical regions facing competition from electricity generators in neighbouring regions (Grohnheit 2000, Varming et al. 2000).

The geographical representation in Balmorel will follows the structure shown in Fig. 1. In contrast to EFOM-CHP, a simultaneous optimisation for all countries will be used in Balmorel focusing on international electricity trade.

ENERGY TARIFF CALCULATION SHEETS

In an earlier collaborative project concerning natural gas and energy tariffs in Latvia, completed in 1996, a system of Customer Calculation Sheets for the analysis of consumer expenditure and utility revenue was developed. The results of that study will be discussed as an appropriate source for demand elasticities for the Balmorel model.

The set of Customers Calculation Sheets is a multi-page spreadsheet, where the previous, current or proposed tariffs for electricity, natural gas and district heating and prices for oil and coal are listed and transferred via formulas to sheets for certain consumer groups.

On the sheet "Energy tariff sheet" energy prices and tariffs for different consumer groups (residential, service, industry) are specified. The tariffs for energy delivered through networks are divided into two groups:

- Tariffs based on consumption (per energy unit)
- Tariffs based on activities per year (i.e. per person, dwelling unit, etc.)

Other sheets describe the consumption and expenditure for different types of residential consumers (see Fig. 2) and non-residential customers.

Energy Tariffs Project - Latvia. Calculation Sheets

Customer calculation sheet - Multi family dwelling

District heating. Gas for cooking only. Energy tariffs, 01.01.96

Energy consumption	**Units**	**Useful energy**	**Delivered network energy** Elec.	Gas	Heat	**Purchased fuel** Coal	Fuel oil	LPG	Wood	**Local Efficiency**
Space Heating	GJ	75			85	0	0			0.88
Hot water	GJ	15			17					0.91
Cooking	GJ	5		5						1.00
Light and Appliances	GJ	10	12							0.83
Process energy	GJ	0								
Total	GJ	105	12	5	102	0	0	0	0	0.89
Tariffs and costs			**Energy tariffs, Ls/unit**			**Fuel prices, Ls/unit**				**Costs, Ls**
Tariffs based on consumption										
Electricity	kWh	3333	0.028							93
Natural gas	m3	132								0
District heating	GJ	102								0
Direct fuel	GJ	0				1.35	3.50	4.00	1.10	0
Tariffs based on activities per year										
Fixed fee	No	1		0.00						0
Persons	No	3		7.30	25.00					97
Floor space	m2	100			3.40					340
Total costs			93	22	415	0	0	0	0	530

Risoe (DK) - FEI (LV), 09.04.1996

Fig. 2. Example of Customer Calculation Sheets

Customer Calculation Sheets as a source for elasticity parameters

Fig. 2 shows an example of the Customer Calculation Sheets that was developed as a part of the "Energy Tariff Project – Latvia" in 1996. Six standardised customers were specified for residential energy use: Two types of customers in single family dwellings and four customer types in multi family dwellings. The prices are in Latvian Lat (Ls) 1 US$ = 0.55 Ls (1996).

The Customer Calculation Sheets were developed for a study of gas tariffs. Thus, the current version is not suited to study the impact of changes in electricity prices. It is better suited to analyse changes in prices for space heating, including district heating. Using the elasticity in Table 7 at -0.2 for 5 % decrease in the district heating price the demand for district heat will increase by 1 %. This increase may happen in different ways,

- Customer's reaction to price changes illustrated at the sheets for the various customer types.
- Shift in the distribution of customer types.

Table 7. Own and cross price elasticities for consumer groups. Latvia, 1997

	Natural gas		Distr. heat		Direct fuels		Electricity	
Increase(+)/Decrease(-)	+	-	+	-	+	-	+	-
Natural gas	-0.40	-0.20	0.10		1.00			
Direct fuels					-1.00			
District heat	0.20	-	-0.60	-0.20			0.06	0.10
Electricity	0.20	0.20	0.10		0.20		-0.06	-0.10

Source: PHARE 1998.

In Table 8 it is assumed that the demand for district heating increase because some new customers install district heating instead of boilers using direct fuels (oil, coal, peat or wood). This is implemented by moving 0.3 % of the customers using direct fuels to a customer type using district heating.

Table 8. Impact of 5% decrease in the district heating price

5% decrease in the district heating price. Own price elast. -0.2.	Dwell., DH	Other dwell.	Dwell., DH	Other dwell.	Diff. All dwell.
No. of customer units	220324	105676	222524	103476	
Expenditure, Mill. Ls					
Natural gas	4.8	3.8	4.9	3.7	-0.7%
District heating	91.4	0.0	87.7	0.0	-4.1%
Direct fuel	0.0	20.3	0.0	20.0	-1.6%
Total revenue	96.3	24.1	92.6	23.7	-3.4%
Energy cons., TJ					
Natural gas	1149	1406	1160	1392	-0.1%
District heating	22363	0	22586	0	1.0%
Direct fuel	0	14635	0	14379	-1.7%
Total consumption	23512	16041	23746	15771	-0.1%

It follows from the Customer Calculation Sheet for customers in multi family houses with district heating, shown in Fig. 2, that the district heating tariff was 3.40 Ls/m^2. Thus, individual consumers would have no incentive to respond to price changes by changing their heating behaviour. In contrast to district heating, the electricity tariff is based on consumption. Changes in the structure of energy tariffs may have significant impact on consumer behaviour and price elasticities.

THE OBJECTIVE FUNCTION AND EQUILIBRIUM CONDITION IN BALMOREL

The mathematical specification of the demand may conveniently be done in relation to a utility function that is additively separable with respect to electricity and heat and linear with respect to other goods. Any concave, non-decreasing function may be chosen for modelling of the utility function. Since data may be given in relation to standard forms, e.g. a CES function, such function should be approximated in the implementation. The model will be specified as is linear (i.e., piecewise linear and convex) and solved by linear programming.

For each time period, there are a reference demand and a reference price, which are specified outside the model. Thus income elasticities will not be considered in Balmorel. The response of consumers to changes in energy and heat prices or substitutable energy carriers is an important part of the model. The implementation is illustrated in Fig. 3 as deviations from a reference equilibrium path, which are specified by price elasticities.

These elasticities may be aggregated for all types of consumers and calculated outside the Balmorel model. For electricity they may be specified for each country. For district heating they may be specified for each type of local heat market.

Benchmark analyses using consistent assumptions for different types of models will be useful for model calibration and verification of results.

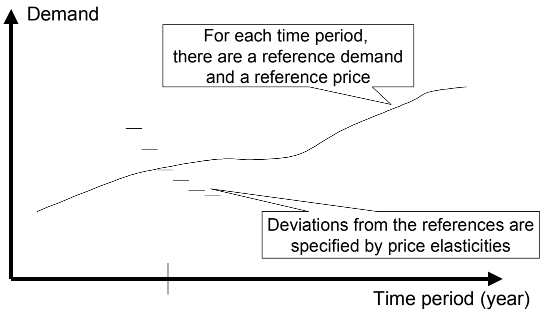

Fig. 3. Reference demand for electricity or heat.

REFERENCES

The Balmorel project: description and status. www.balmorel.dk

European Commission (1999), "The Shared Analysis Project: European Union Energy Outlook to 2020." *Energy in Europe*. Special Issue, European Commission, Directorate General for Energy. www.shared-analysis.fhg.de./.

Grohnheit, P.E., (1999), *Energy policy responses to the climate change challenge: The Consistency of European CHP, Renewable and Energy Efficiency Policies*. The Shared Analysis Project, Volume 14. www.shared-analysis.fhg.de./ (Printed as Risø.R-1147(EN). Risø National Laboratory, Roskilde, www.risoe.dk/rispubl/-SYS/ris-r-1147.htm)

Grohnheit, P.E., (2000), *Macroeconomic impact of micro-scale combined heat and power*. Paper presented at the meeting of the ENER Network, Brussels, 4-5 May 2000.

Grohnheit, P.E., Olsen, O. J. (2000) forthcoming in G. MacKerron and L. De Paoli (eds*), Organisation and regulation of the ESI in the EU*, Eathscan.

Harne, Niels J (Ed) (1996), *Energy Tariff Project - Latvia. Summary Report*. Danish Energy Research Programme, Nellemann, Nielsen & Rauschenberger,

Klavs, G.; Grohnheit, P.E., (1996), *Model development for energy tariffs in Latvia*. International conference on simulation, gaming, training and business process reengineering in operations, Riga, 19-21 Sep 1996.

PHARE (1998), *Multi-country Energy Programme "Natural Gas Pricing, Tariffs and Operational Twinning" Latvia - Country Report*.

Varming, S.; Eriksen, P. B.; Grohnheit, P. E.; Nielsen, L.; Svendsen, G. T.; Vesterdal, M. (2000), *CO_2 permits in Danish and European energy policy*. Risø.R-1184(EN). Risø National Laboratory, Roskilde, www.risoe.dk/-rispubl/SYS/ris-r-1184.htm). Forthcoming.

World Bank mission, Riga 1996.