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The Anatomy of Electricity Demand: A CGE Decomposition for Norway

Abstract:
The paper derives a general equilibrium demand function for electricity by imposing a specific closure rule on a large CGE-model of the Norwegian economy. By a decomposition technique it quantifies the contribution from various mechanisms to the price sensitivity of aggregate electricity demand. Specifically, it identifies the contributions from substitution at the micro level, as well as changes in the industry structure to the substitution at the aggregate level. It also separates the substitution effects of equilibrium adjustments of other prices than the electricity price, and macroeconomic income effects on total demand. The direct price elasticity of aggregate electricity demand is estimated to -0.31. Within industry factor substitution contributes most to this response.

Keywords: Electricity demand, Computable general equilibrium model

JEL classification: Q41, Q43

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1 Introduction

Due to rich endowments of waterfalls, the price of hydro power has historically been low compared to the prices of alternative energy and electricity prices in other countries. The Norwegian economy has been adjusted to this situation. Nearly 100 percent of the electricity production in Norway is based on hydro power, and the electricity share in total Norwegian energy demand was 50 percent in 2003, see Statistics Norway (2004). Except from offshore production of oil and gas, the most export oriented industries are highly electricity intensive. However, increasing marginal costs in Norwegian hydro power production and environmental concerns imply that further growth in electricity demand must be met by supplies from other sources than domestic hydro power. Domestic production of gas power is a much discussed alternative. Investments in transmission capacity and deregulation of the Norwegian electricity market have already resulted in extensive electricity trade between the Nordic countries. Since most of the electricity supply in the Northern European countries is based on thermal power, increased or new indirect taxes on fossil fuels will raise the electricity price also in Norway. In effect, the electricity price facing Norwegian firms and households will to a larger extent be determined in a common Nordic market, and is likely to be significantly higher than it traditionally has been. This paper provides a quantitative assessment of the long run demand responses in the Norwegian economy to a permanent increase in the electricity price.

However, the need for yet another such assessment may be questioned. There is already a large literature on estimation of aggregate energy price elasticities, most of them studying residential energy demand. Madlener (1996) provides a comprehensive survey, including an assessment of the strengths and the weaknesses of the various approaches found in the literature. Other relevant literature surveys include Bye, Langmoen and Aasness (2004), Liu (2004), Dahl (1994), Pindyck (1979) and Taylor (1977). What does this paper add to the existing literature?

The credo motivating this paper is that aggregate price elasticities provide limited information about the adjustments taking place in the wake of an increase of the electricity price. Their informative value is confined to a highly reduced form of the underlying economic mechanisms. An aggregate price elasticity sheds no light on the empirical importance of the different kinds of substitution effects and other adjustments within firms and households generating the aggregate response. It is therefore of little help when one wants to explain what goes on in a particular economy when the electricity price changes. An aggregate response will be consistent with several plausible stories. The credibility of the aggregate elasticity would increase if it can be presented as the weighted sum of different quantified effects that have a clear economic interpretation. So would the possibilities for cross-checking the results.

The *substantive purpose* of this paper is to support an estimate the aggregate price sensitivity of the Norwegian electricity demand with a story of the empirical importance of the various adjustments made by firms and households that contribute to the aggregate response. Specifically, the ambition is to identify the importance of general equilibrium effects. From a theoretical point of view two general equilibirum effects deserve special interest in a small open economy like the Norwegian. First, assuming competitive equilibrium, constant returns to scale production functions and given world prices, an increase in the electricity price must be met by a reduction in the price of at least one other factor of production. More generally, the equilibrium change in the relative price structure, which drives the substitution effects within firms and households, includes endogenous price effects as well as the initial increase in the electricity price. Second, the industry structure may change. In a stylized small open economy producing traded goods only, the relatively most electricity intensive industries will contract, whereas other sectors will expand. Such a change in the aggregate factor intensities caused by reallocations of resources between industries with different factor intensities is well known from the international trade theory as the Rybczynski effect. It represents a substitution effect which is conceptually different from factor substitution within firms. The relevance of general equilibrium effects on both the industry structure and the relative price structure increases if the intention is to estimate long run rather than short run price sensitivity. This paper provides a decomposition of the aggregate price elasticity which makes it possible to identify the relative importance of these general equilibrium effects. Specifically, the analysis estimates the empirical importance of the following effects:

1. Factor substitution within 25 production sectors and substitution effects in household demand due to a *partial* increase in the electricity price.
2. The corresponding substitution effects caused by general equilibrium adjustments in other prices than the electricity price. Other prices are affected through two channels. First, the cost effect of a higher electricity price is shifted forward to the prices of non-traded goods both directly and indirectly through the input-output structure of the economy. Second, the cost effect of the rise in the electricity price will deteriorate the international competitiveness. In order to maintain the external balance, the wage rate must fall. Directly and indirectly, this general equilibrium adjustment of the wage rate affects the substitution effects involving electricity demand.
3. Rybczynski effects caused by changes in the industry structure

4. Adjustments to a higher electricity price take place at several stages in the production structure. The electricity share in the energy demand may be reduced, but the energy intensity in the composite of all inputs may also be reduced.

5. A rise in the electricity price will have macroeconomic income effects on total demand, which also affects the electricity demand.

6. The purchaser prices of electricity differ due to differences in transmission costs and indirect taxes between different consumers. The uniform electricity price net of these cost components will subsequently be referred to as the reference price of electricity. Most of the difference between the purchaser price and the reference price is additive. Consequently, the relative change in the purchaser prices will differ between consumers, and they will be smaller than the percentage rise in the reference price. The sensitivity of electricity demand in a given sector with respect to the reference price will be less the weaker is the dependency between the purchaser price in the sector and the reference price.

The *methodological purpose* of the paper is to present the method used for quantitative identification of each one of these effects. To this end we define a *general equilibrium demand function* for electricity by imposing a specific closure rule on a large CGE-model of the Norwegian economy. This model, MSG6, has been developed with the particular purpose of analysing long run trends in the supply and demand for energy in Norway. For the simulations discussed in this paper the electricity price is exogenous, whereas electricity demand can be separated from electricity supply. By using appropriate decomposition techniques it is possible to quantify the contribution from the various mechanisms in the aggregate electricity demand corresponding to the list above. The decomposition scheme developed in this paper also serves as a useful tool to shed light into a large and complex model that might be regarded as a black box. The relevance of both the concept general equilibrium demand function, as well as the decomposition method is obviously not limited to the Norwegian economy.

The substantive and the methodological purposes of this paper are related to Longva, Olsen and Strøm (1988). They use a CGE model to estimate so-called total elasticities of energy demand in the Norwegian economy. Their CGE model is a predecessor of the model used in this paper. The models share some similarities with respect to sectoral detail and factor demand. However, the models also differ substantially. In particular, the model used by Longva et al. described essentially the price sensitivity of a closed economy, since exports and import shares were exogenous, and world prices of exports and import were assumed to be endogenously determined in Norwegian markets. Thus, the scope for changes in the industry structure was more limited in Longva *et al.* (1988) than in this study. Methodologically, Longva *et al.* decomposes their total demand elasticities in a different way than the method applied in this paper. Longva *et al.* separates output-constrained elasticities from the total elasticities. The output-constrained elasticities are calculated by keeping the output levels for different groups of industries constant. However, this implies a different closure rule of the model, which affects the relative prices and thereby the substitution effects. This paper accounts for more effects, and they are all computed from the same model simulation.

The paper is organised as follows. Section 2 defines precisely what is meant by a general equilibrium demand function. Section 3 provides an overview of the CGE-model with focus on the most important determinants of the electricity demand. Section 4 develops a decomposition of the aggregate electricity demand from production sectors and households. Section 5 presents the main insights from the simulation experiment and the use of the decomposition scheme by estimating the identified components of the aggregate price sensitivity. The results are compared with estimates in related studies. Conclusions are drawn in Section 6.

2 A General Equilibrium Demand Function

While it is easy to argue that several general equilibrium effects are relevant for the aggregate electricity demand, it is not obvious how one should define a general equilibrium demand function for a specific good. Within a general equilibrium framework it is conceptually problematic to compute a demand function since all markets balance through endogenous adjustments of relative prices. How should one define and compute the change in electricity demand - not supply - caused by an *exogenous* change in the electricity price? The *general equilibrium demand function* used in this paper can be precisely defined by taking the following reduced form of a general equilibrium model of a Small Open Economy (SOE) as a point of departure:

$$X_i = S_i\left(P_T, P_N, W, P^E, Z\right),\ i \in S \tag{1}$$

$$S_i\left(P_T, P_N, W, P^E, Z\right) - D_i\left(P_T, P_N, W, P^E, Z\right) = T_i,\ i \in S \tag{2}$$

$$T_j = 0,\ j \in N \tag{3}$$

$$\sum_{i \in S} f_{ik}\left(P_T, P_N, W, P^E, Z\right) = F_k,\ k \in F \tag{4}$$

$$D_E\left(P_T, P_N, W, P^E, Z\right) = S_E\left(P_T, P_N, W, P^E, Z\right). \tag{5}$$

S is the set of all production sectors, and N is the set of non-traded goods/sectors except electricity, E. F is the set of production factors. There are n sectors in addition to the electricity sector. P_N is the vector of endogenous prices of non-traded goods, except electricity. W is the vector of endogenous factor prices, and P^E is the endogenous price of electricity. Z is a vector of the exogenous variables in the model, including constant parameters. $D_i(.)$ is the aggregate demand function associated to good i, and electricity, E. P_T is the vector of exogenous prices of traded goods. X_i is the production of good i, and $S_i(.)$ is the corresponding supply function. It is assumed that production technologies in all sectors exhibit decreasing returns to scale, and the supply functions and the factor demand functions are derived from the first order condition of profit maximization, i.e. $\frac{\partial \pi_i\left(P_T, P_N, W, P^E, X_i, Z\right)}{\partial X_i} = 0$, $j \in S$, where $\pi_i\left(P_T, P_N, W, P^E, X_i, Z\right)$ is the profit function of sector i. T_i is the excess supply (demand) of good i, which is equal to the net export (import) of this good determined in (2). $f_{ik}(.)$ is the demand for factor k from sector i. The budget constraint underlying the demand functions is assumed to imply balanced trade, i.e. $\sum_{i \in T} P_i T_i = 0$. (3) and (4) express that supply equals demand in all markets for factors and non-traded goods. (5) is the equilibrium condition for the electricity market, assuming that electricity is a non-traded good. . The equations determine a unique solution for the endogenous variables X, T, P_N, W, and P^E as functions of P_T, F_K and Z, where X is the vector comprising $X_1, ..., X_n$ etc.

Our general equilibrium demand function is defined by letting the electricity price be exogenous and replacing (5) by two separate identities, which define, respectively, aggregate demand and supply of electricity, i.e. $E \equiv D_E\left(P_1, P_2, ..., P_n, P^E, Z\right)$ and $T_E \equiv S_E\left(P_1, P_2, ..., P_n, P^E, Z\right)$. The relevant equation system now consists of the equations included in (1)-(4, and the equation defining aggregate electricity demand. This implies that E will depend on all the equilibrium mechanisms that are captured by the model when the solutions for T, P_N and W balances trade as well as supply and demand in all markets for factors and non-traded goods, except the electricity market.

3 Electricity Demand in a CGE-Model of the Norwegian Economy

3.1 The CGE-Model: An Overview

The applied CGE model, MSG6, is explicitly designed to analyse the Norwegian energy markets in a long run macroeconomic context. Heide, Holmøy, Lerskau and Solli (2004) explains the structure and the empirical properties of the model. MSG6 includes backward looking dynamics related to accumulation of fixed capital and financial assets, as well as forward looking dynamics derived from intertemporal behaviour of producers and consumers with perfect foresight. From the general equilibrium theory of a small open economy, see e.g. Woodland (1982), we know that changes in industry structure may contribute significantly to the price sensitivity of the total electricity demand. The model is sufficiently disaggregated to capture this effect; it specifies 60 commodities and 40 production sectors, and the classification is chosen to make the model well suited for studies of industrial policies as well as energy issues. Specifically, the model singles out the three extremely electricity-intensive and export oriented industries producing, respectively, Metals, Industrial Chemicals and Pulp and paper.

The Norwegian economy is small, and the exchange rate is normalised to unity. Thus, all agents face exogenous world prices. Financial capital is perfectly mobile across borders, and the interest rate is exogenously given in international capital markets. Fixed capital and labour are assumed internationally immobile. However, all goods, services and production factors are perfectly mobile between industries within the economy. Supply equals demand in all markets but the electricity market in all periods. Tax rates and real government consumption are exogenous. The public budget constraint is satisfied through endogenous lump-sum transfers. Parameters are estimated or calibrated on the basis of the Norwegian National Accounts and relevant micro-econometric studies.

The time paths of private consumption of 26 consumer goods and labour supply are determined by an infinitely lived representative consumer who maximizes an intertemporal utility function subject to an intertemporal budget constraint. The consumer has perfect foresight and considers prices as exogenous. The decision problem of the consumer can be solved by a stepwise budgeting procedure due to a nested system of origo-adjusted CES structure of the utility function (see Figure 1 in Appendix).

All firms in the private business sector are run by managers who maximise the net present value of the cash flow to owners. Commodities produced by primary industries are assumed to be homogenous and traded in perfectly competitive markets. Domestic markets for manufacturing goods and services, which constitute the main part of the economy, are described by monopolistic competition among firms. In the export markets Norwegian firms are price takers. Bowitz and Cappelen (2001) and Klette (1999) provide econometric support for monopolistic price setting in the domestic market. It is assumed costly to reallocate deliveries between the domestic and foreign markets.

The model captures that output and input in an industry may change both because of changes at the firm level and as a result of endogenous entry or exit of firms. The model includes a rough description of productivity differentials between firms within the same industry causing firms to differ in size and profitability, see Holmøy and Hægeland (1997). Based on the econometric work in Klette (1999) the production structure in all private industries exhibits decreasing returns to scale. This has two implications: First, the traded goods sector becomes more diversified than in the case of constant returns. Second, decreasing returns imply adjustment costs related to real capital formation. In all industries the composition of the input factors is derived from a nested structure of linearly homogeneous CES-functions (see Figure 2 in Appendix). The parameters in the factor demand functions are calibrated to the econometric estimates Alfsen, Bye and Holmøy (1996, Ch. 3).

3.2 Electricity demand

Equilibrium in the electricity market implies

$$E = \sum_{j \in P} E_j + E^O + E^H + E^Z, \tag{6}$$

where E is the total supply, net of power loss in the transmission and distribution system. E_j is the electricity demand in the private industry $j \in P$, where P denotes the set of private industries. E^O is government consumption, E^H is household consumption, and E^Z is net exports. In the following we confine the analysis to electricity demand from the domestic business sector and households.

3.2.1 Private Industries

In the separable production structure electricity is combined with fuels, F, to form energy input $U = U(E, F)$. At this and all other nests in the separable technology the functional form is the Constant Elasticity of Substitution (CES) function with constant returns to scale. The contingent electricity demand function is

$$E_j = e_j \left(\frac{P_j^E}{P_j^U} \right)^{-\sigma_{Uj}} U_j, \tag{7}$$

where $j \in P$. e_j is the share parameter of electricity in the CES function, and σ_{Uj} is the elasticity of substitution between electricity and fuels. P_j^U is the ideal energy price index defined as

$$P_j^U = \left[e_j \left(P_j^E \right)^{1-\sigma_{Uj}} + (1 - e_j) \left(P_j^F \right)^{1-\sigma_{Uj}} \right]^{\frac{1}{1-\sigma_{Uj}}} \tag{8}$$

where P_j^E and P_j^F are the industry specific prices of electricity and fuels, respectively. Alfsen, Bye and Holmøy (1996, Ch. 3.3) describes the econometric estimation of the contingent electricity demand function in (7).

Energy is combined with Machinery, K^M, to produce "Services from Machinery" $N = N\left(U, K^M\right)$. N is combined with labour, L, to produce the input $R = R(N, L)$. R is then combined with transport services, T, to produce a "Modified Value Added" $R^T = R^T(R, T)$. R^T is combined with "Other Materials", V, to the composite input $S = S\left(R^T, V\right)$. Finally, S is combined with Buildings and Constructions, K^B, to produce the composite of all inputs $V^F = V^F\left(S, K^B\right)$. The energy demand function then becomes contingent on V^F:

$$U_j = Z_j^U \left(\frac{P_j^U}{P_j^N}\right)^{-\sigma_{Uj}} \left(\frac{P_j^N}{P_j^R}\right)^{-\sigma_{Rj}} \left(\frac{P_j^R}{P_j^{RT}}\right)^{-\sigma_{RTj}} \left(\frac{P_j^{RT}}{P_j^S}\right)^{-\sigma_{Sj}} \left(\frac{P_j^S}{P_j^{VF}}\right)^{-\sigma_{VFj}} V_j^F, \quad (9)$$

where the coefficient Z_j^U summarizes the intensity parameters in the nested CES-demand functions, and the relevant CES-price indexes are defined successively analogous to P_j^U.

The aggregate input V_j^F is used to produce export deliveries , X_j^W, and domestic deliveries, X_j^H. In MSG6 it is assumed that the cost function is additively separable in the costs associated with these two deliveries. The same decreasing returns to scale technology applies to both kinds of deliveries:

$$V_j^F = v_j^H \left(X_j^H\right)^{\frac{1}{s_j}} + v_j^W \left(X_j^W\right)^{\frac{1}{s_j}}, \qquad (10)$$

where $0 < s_j < 1$ is the scale elasticity. Typically, a description of the optimal factor demand stops at this point. The optimal industry demand for electricity and other input factors would then be contingent on, respectively, export deliveries and domestic deliveries. However, changes in the industry structure is *a priori* important for the aggregate electricity demand, and both export supplies and import shares are quite elastic with respect to the factor price index. Therefore, we include the determination of exports and domestic deliveries in this formal description.

Firms are price takers in the export markets. The export supply function becomes

$$X_j^W = a_j^W \left(\frac{P_j^W}{P_j^{VF}}\right)^{\frac{s_j}{1-s_j}},$$

where P_j^W is the world price in the export market for good j, and a_j^W is a constant. In MSG-6 s_j is set close to 0,85, which implies that the price elasticity of exports is as large as $\frac{s_j}{1-s_j} \simeq 6$.

In the domestic markets products from Norwegian firms are close but imperfect substitutes for corresponding imported products. Firms engage in monopolistic competition. The optimal price setting rule takes the form:

$$P_j^H = \beta_j^H \frac{P_j^{VF}}{s_j} \left(X_j^H\right)^{\frac{1}{s_j}-1}, \tag{11}$$

where P_j^H is the price of product j in the domestic market, and β_j^H is the mark-up factor, which is multiplied with the marginal cost of domestic deliveries. The domestic demand for product j produced by the corresponding domestic firm, X_j^H, is given by

$$X_j^H = \delta_j^H \left(\frac{P_j^H}{P_j^{HI}}\right)^{-\sigma_{HIj}} D_j, \tag{12}$$

where δ_j^H is the share parameter of domestic varieties in the CES sub-utility function of domestic and imported varieties of good j, and σ_{HIj} is the elasticity of substitution between domestic and imported varieties of good j. D_j is total domestic demand for the composite good j, being the sum consumption, gross investments and the total use of good j as intermediate input in all production sectors. P_j^H is the price of domestic varieties, and P_j^{HI} is the ideal price index of the composite of domestic and imported varieties defined by

$$P_j^{HI} = \left[\delta_j^H \left(P_j^H\right)^{1-\sigma_{HIj}} + \left(1-\delta_j^H\right)\left(P_j^I\right)^{1-\sigma_{HIj}}\right], \tag{13}$$

where P_j^I is the import price of product j. Inserting the expressions for P_j^H and P_j^{HI} in (11)and (13) into (12) yields X_j^H as a function of P_j^I and D_j. Changes in industry electricity demand result from factor substitution effects caused by changes in relative factor prices, a change in export caused by changes in the exogenous world price, a change in the import share caused by changes in the price of domestic deliveries relative to the exogenous import price, as well as changes in the domestic demand from households, private industries and the government production sectors. Tracing the electricity demand further would require accounting for all the mutual interactions between sectors and markets. A formal description of this would be too complex to be enlightening.

3.2.2 Households

Household demand is described by one representative consumer. His utility function is separable, see Figure 2. The parameters in the corresponding demand system are estimated in Aasness and Holstmark (1995).

Electricity is consumed for two purposes: i) Heating (U^H) and ii) Use of electric equipment (D). Household consumption of electricity, E^H, is

$$E^H = E_O^H + E_M^H, \tag{14}$$

where E_O^H denotes electricity used for Heating, and E_M^H denotes electricity used on electric equipment. Heating is obtained by combining E_O^H with Fuels, F^H, according to an Origo-adjusted CES (OCES) production function. The OCES functional form allows non-homothetic preferences so that the model captures the econometric findings of non-unitary contingent expenditure elasticities. The contingent demand function for E_O^H takes the form

$$E_O^H = \bar{E}_O^H + e_O \left(\frac{P_H^E}{P_H^U} \right)^{-\gamma_U} U^H, \tag{15}$$

where $\bar{E}_O^H$ is the exogenous "minimum consumption level", and γ_U is the elasticity of substitution between $E_O^H - \bar{E}_O^H$ and $F^H - \bar{F}^H$. We have $P_H^U = \left[e_O \left(P_H^E \right)^{1-\gamma_U} + (1-e_o) \left(P_H^F \right)^{1-\gamma_U} \right]^{\frac{1}{1-\gamma_U}}$. The contingent demand function for E_M^H is analogous to (15):

$$E_M^H = \bar{E}_M^H + e_M \left(\frac{P_H^E}{P^D} \right)^{-\gamma_D} D, \tag{16}$$

where $P^D = \left[e_M \left(P_H^E \right)^{1-\gamma_D} + (1-e_M) \left(P_H^M \right)^{1-\gamma_D} \right]^{\frac{1}{1-\gamma_D}}$.

Heating and Dwellings, R, enter the OCES subutility function $H = H\left(U^H, R \right)$, where H denotes "Housing related consumption". The contingent demand function for U^H becomes

$$U^H = \bar{U}^H + u \left(\frac{P_H^U}{P^H} \right)^{-\gamma_H} H. \tag{17}$$

H, D, Transport, and "Other Consumption" are combined into the CES composite "Goods and Services", C^H. C^H is then combined with Leisure into the CES composite "Full consumption", N^H. The demand functions for H and D, contingent on N^H, become

$$H = \bar{H} + h \left(\frac{P^H}{P_H^C} \right)^{-\gamma^C} c \left(\frac{P_H^C}{P_H^N} \right)^{-\gamma_N} N^H, \tag{18}$$

$$D = \bar{D} + d \left(\frac{P^H}{P_H^C} \right)^{-\gamma^C} c \left(\frac{P_H^C}{P_H^N} \right)^{-\gamma_N} N^H, \tag{19}$$

where P_H^C is the price index of C^H, γ^C is the elasticity of substitution between H, D, Transport, and "Other Consumption". γ_N is the elasticity of substitution between C^H and Leisure, and P_H^N is the ideal price index of Full Consumption.

Full Consumption enters an intertemporal CES utility function. The time horizon is infinite. When net-of-tax interest rate is assumed equal to the rate of time preferences, the Frisch-demand function for Full Consumption in period t takes the form (see Bye and Holmøy, 1992):

$$N^{H}(t) = \left[\lambda P_{H}^{N}(t)\right]^{-\gamma_I}, \tag{20}$$

where γ_I is the intertemporal elasticity of substitution, and λ is the marginal utility of wealth, which is endogenous in the model, but constant over time.

3.3 Equilibrium mechanisms in the Electricity demand response

Although the demand responses to an increase in the electricity price are the result of a large number of complex simultaneous interaction effects, it is instructive to explain them as a three-step iteration process.

Step 1: Firms and households reduce the electricity intensity in their use of inputs and consumption. Despite factor substitution the price of energy and energy intensive machinery increases. Thus, the substitution effects on several other margins than the energy composition affect the decrease in electricity demand.

The increase in the electricity price implies a positive shift in the cost functions of firms, depending on the direct and indirect electricity intensity of their production structure. This implies a contraction of exports so that the equality between the given world prices and the marginal costs of export supplies is restored in all industries. Recall that export supplies are quite elastic with respect to a shift in the price index of aggregate inputs relative to the world price. At this stage in the iteration process domestic deliveries will also decrease because the prices of domestic products relative to the import prices increase.

Step 2: At this stage we take into account that the adjustments in exports, domestic deliveries and domestic demand balance all product markets, except the electricity market. However, the labour market will not be in equilibrium, and the intertemporal constraint on foreign debt will not be met. More precisely, there will be unemployment since the scale effect of reduced output will dominate the factor substitution effect caused by the rise in the electricity price. The economy will accumulate exploding foreign debt since exports are reduced whereas import shares have increased. In order to restore labour market equilibrium and the foreign debt constraint the wage rate and the utility level of the consumer must adjust. As explained in greater detail in Holmøy, Olsen and Strøm (1998) the new general equilibrium is characterised by a lower wage rate and a lower utility level. Basically, the wage rate reduction is necessary to neutralize the negative effect on international competitiveness caused by the higher electricity price. The wage reduction turns the excess labour supply derived in Step 1 into excess labour demand. Labour market equilibrium is restored by the decrease in private consumption and leisure that follows a reduction of the utility level.

Step 3: At this stage we take into account that the decrease in the wage rate and the utility level affect the electricity demand. First, the wage rate reduction reinforces the substitution effects on electricity intensities in factor demand and private consumption. Second, the wage rate reduction implies, *cet. par,* improved international competitiveness, which raises exports and reduces the import shares in domestic demand. The resulting output effect will increase electricity demand. Third, the reduction in private consumption has a negative effect on electricity demand.

4 Decomposing the Price Sensitivity of Aggregate Electricity Demand

At a trivial first stage we decompose the change rate in the total electricity demand from domestic firms and households:

$$\hat{E} = \frac{E^P}{E}\hat{E}^P + \frac{E^H}{E}\hat{E}^H, \tag{21}$$

where we in the following writes marginal relative change rates as $\hat{E} = \frac{dE}{E}$.

4.1 Private Industries

The total input of electricity in private industries can be written

$$E^P = \sum_{j \in P} Z_j^E V_j^F, \tag{22}$$

where $Z_j^E = \frac{E_j}{V_j^F}$. The change rate of E^P can be written

$$\hat{E}^P = \sum_j \lambda_j^E \hat{Z}_j^E + \sum_j \lambda_j^E \hat{V}_j^F = \hat{Z}^E + \hat{V}^F + cov\left(\frac{Z_j^E}{Z^E}, \hat{V}_j^F; \lambda_j^{VF}\right), \tag{23}$$

where $Z^E = \frac{E^P}{V^F}$ is the aggregate or average electricity intensity, $V^F = \sum_j V_j^F$, $\lambda_j^E = \frac{E_j}{E^P}$, $\lambda_j^{VF} = \frac{V_j^F}{V^F}$. V_j^F is measured in fixed prices. $\hat{Z}^E = \sum_j \lambda_j^E \hat{Z}_j^E$ is defined as the weighted average of the change rates of the industry specific electricity intensities. $cov\left(\frac{Z_j^E}{Z^E}, \hat{V}_j^F; \lambda_j^V\right)$ $= \sum_j \lambda_j^{VF}\left(\frac{Z_j^E}{Z^E} - \sum_j \lambda_j^{VF}\frac{Z_j^E}{Z^E}\right)\left(\hat{V}_j^F - \sum_j \lambda_j^{VF}\hat{V}_j^F\right)$ is the weighted covariance between the industrial electricity intensities and the change rate of aggregate input by industry, where the weights are λ_j^{VF}.

(23) decomposes the relative change in E^P into 1) substitution effects, i.e. the relative change in the average electricity intensity (of the private business sector) attributable to changes in the industrial electricity intensities $\hat{Z}^E$; 2) reallocation effects, i.e. the relative change in the average electricity intensity attributable to changes in in the allocation of aggregate input between industries with different electricity intensities, $cov\left(\frac{Z_j^E}{Z^E}, \hat{V}_j^F; \lambda_j^{VF}\right)$; 3) scale effects, i.e. the relative change in the total aggregate input, $\hat{V}^F$. We will now decompose further the substitution and scale effects.

4.1.1 Substitution Effects

According to the nested CES structure of factor demand, the relative changes in Z_j^E can be written

$$\begin{aligned} \hat{Z}_j^E \;=\; & -\sigma_{Uj}\theta_{Fj}^U\left(\hat{P}_j^E-\hat{P}_j^F\right)-\sigma_{Nj}\theta_{KMj}^N\left(\hat{P}_j^U-\hat{P}_j^{KM}\right) \\ & -\sigma_{Rj}\theta_{Lj}^R\left(\hat{P}_j^N-\hat{P}_j^L\right)-\sigma_{RTj}\theta_{Tj}^{RT}\left(\hat{P}_j^R-\hat{P}_j^T\right) \\ & -\sigma_{Sj}\theta_{Vj}^S\left(\hat{P}_j^{RT}-\hat{P}_j^V\right)-\sigma_{VFj}\theta_{KBj}^{VF}\left(\hat{P}_j^S-\hat{P}_j^{KB}\right), \end{aligned} \tag{24}$$

where $\theta_{Fj}^U = P_j^F F_j / \left(P_j^E E_j + P_j^F F_j\right)$ is the cost share of F in energy costs in industry j, θ_{KMj}^N is the corresponding cost share of K^M in the the composite input N, and so forth for the other cost shares.

(24) distinguishes the substitution effects at different levels in the separable input structure. MSG-6 computes all factor prices entering (24), and the model contains empirical counterparts to all other variables in this expression. Specifically, the model computes the relative changes in the prices of other factors than electricity. Except for labour, all these factors are in general composites of imports and domestically produced goods. In MSG-6 four main mechanisms determine the changes in these factor prices:

1. The factor composites contain a share of electricity, which declines as one "moves upwards" in the nested input structure from energy to the aggregate input V_j^F.

2. The increase in the electricity price implies a positive shift in the cost functions in all industries using electricity directly or indirectly. By mark-up pricing this shift is transmitted to the prices of domestic deliveries. Through the input-output structure of the economy the prices of capital goods and intermediate goods will also increase.

3. As pointed out in the previous section, the wage rate must fall in order to restore general equilibrium. The wage rate reduction is also transmitted to the prices of other produced inputs.

4. The changes in the industry outputs will affect the relative prices since the production functions exhibit decreasing returns to scale.

Formally, the effects of a rise in the electricity price on the prices of composite inputs in the nested production are determined recursively: $\hat{P}_j^U = \theta_{Ej}^U \hat{P}_j^E + \theta_{Fj}^U \hat{P}_j^F$, $\hat{P}_j^N = \theta_{Uj}^N \hat{P}_j^U + \theta_{KMj}^N \hat{P}_j^{KM}$, $\hat{P}_j^R = \theta_{Nj}^R \hat{P}_j^N + \theta_{Lj}^R \hat{P}_j^L$, $\hat{P}_j^{RT} = \theta_{Rj}^{RT} \hat{P}_j^R + \theta_{Tj}^{RT} \hat{P}_j^T$, $\hat{P}_j^S = \theta_{RTj}^S \hat{P}_j^{RT} + \theta_{Vj}^S \hat{P}_j^V$, $\hat{P}_j^{VF} = \theta_{Sj}^{VF} \hat{P}_j^S + \theta_{KBj}^{VF} \hat{P}_j^{KB}$.

From (24) various decompositions $\hat{Z}_j^E$ can be made. The one chosen in this paper is the following:

$$\hat{Z}_j^E = \left(-\sigma_{Uj}\theta_{Fj}^U + \varepsilon_{UEj}\right)\hat{P}_j^E + \varepsilon_{Aj}, \tag{25}$$

where $-\sigma_{Uj}\theta_{Fj}^U$ is the relative change in the input of electricity in industry j attributable to the increase in the electricity price contingent on a given level of energy input, U_j. ε_{UEj} captures the total effect on U of a partial increase in the electricity price, contingent on V_j^F:

$$\begin{aligned}\varepsilon_{UEj} &= -\Big[\sigma_{Nj}\theta_{KMj}^N + \left(\sigma_{Rj}\theta_{Lj}^R + \sigma_{RTj}\theta_{Tj}^{R^T}\theta_{Nj}^R\right)\theta_{Uj}^N \\ &\quad + \left(\sigma_{Sj}\theta_{Vj}^S + \sigma_{VFj}\theta_{KBj}^{VF}\theta_{R^Tj}^S\right)\theta_{Rj}^{R^T}\theta_{Nj}^R\theta_{Uj}^N\Big]\theta_{Ej}^U < 0.\end{aligned}$$

ε_{Aj} captures the effect on Z_j^E of general equilibrium effects on other prices than the electricity price:

$$\varepsilon_{Aj} = \sum_{s=F,KM,L,T,V,KB} \varepsilon_{Esj}\hat{P}_j^s,$$

where the ε-coefficients are functions of the relevant substitution elasticities and cost shares. They are defined formally in the Appendix.

The relative change in the average electricity intensity can then be written

$$\begin{aligned}\hat{Z}^E &= \sum_j \lambda_j^E \hat{Z}_j^E \qquad (26)\\ &= \left(-\sigma_U\theta_F^U\right)\hat{P}^E + cov\left(-\sigma_{Uj}\theta_{Fj}^U, \hat{P}_j^E; \lambda_j^E\right) \\ &\quad + \varepsilon_{UE}\hat{P}^E + cov\left(\varepsilon_{UEj}, \hat{P}_j^E; \lambda_j^E\right) + \varepsilon_A, \qquad (27)\end{aligned}$$

where $\left(-\sigma_U\theta_F^U\right) \equiv \sum_j \lambda_j^E\left(-\sigma_{Uj}\theta_{Fj}^U\right)$, $\varepsilon_{UE} \equiv \sum_j \lambda_j^E \varepsilon_{UEj}$, $\varepsilon_A \equiv \sum_j \lambda_j^E \varepsilon_{Aj}$, $\hat{P}^E \equiv \sum_j \lambda_j^E \hat{P}_j^E$.

The motivation for introducing the covariances in (26) is that the relative change in the purchaser price of electricity will differ between industries when the common reference price increases. This reflects industry specific indirect tax rates and distribution costs, as well as price discrimination between industries.

We can obtain quantitative information about the importance for $\hat{Z}^E$ of the general equilibrium effects working through changes in other prices than the electricity price by decomposing ε_A, which was defined above as the weighted average of ε_{Aj}:

$$\varepsilon_A = \sum_{s=F,K^M,L,T,V,K^B} \left[\varepsilon_{Esj}\hat{P}^s + cov\left(\varepsilon_{Esj}, \hat{P}^s_j; \lambda^E_j\right)\right], \tag{28}$$

where ε_{EF}, ε_{EK^M} etc. are the weighted averages of the corresponding industry specific price elasticities, where the weights are the industrial electricity shares. $\hat{P}^F$, $\hat{P}^{KM}$ etc. are similarly defined averages of the corresponding industry specific factor prices.

4.1.2 Scale Effects

The scale effects are comprised by the relative change in total aggregate input $\hat{V}^F = \sum_j \lambda^{VF}_j \hat{V}^F_j$. Logarithmic differentiation of (10) yields

$$\hat{V}^F_j = \frac{\hat{X}_j}{s_j}, \tag{29}$$

where the relative change in output equals the weighted average of the relative change rates of domestic deliveries and exports, i.e. $\hat{X}_j \equiv v^{FH}_j \hat{X}^H_j + \left(1 - v^{FH}_j\right)\hat{X}^W_j$, where $v^{FH}_j \equiv \frac{V^{FH}_j}{V^{FH}}$, $V^{FH} = \sum_j V^{FH}_j$ and $V^{FH}_j = v^{FH}_j \left(X^H_j\right)^{\frac{1}{s_j}}$.

$\hat{V}^F$ can now be decomposed as follows:

$$\begin{aligned}
\hat{V}^F_j &= \left[\sum_j \lambda^{VF}_j \left(\frac{1}{s_j}\right)\right]\left[\sum_j \lambda^{VF}_j \hat{X}_j\right] + cov\left(\frac{1}{s_j}, \hat{X}_j; \lambda^{VF}_j\right) \\
&= \frac{1}{\bar{s}}\frac{X}{V^F_j}\sum_j \lambda^X_j Z^{VF}_j \hat{X}_j + cov\left(\frac{1}{s_j}, \hat{X}_j; \lambda^{VF}_j\right) \\
&= \frac{1}{\bar{s}}\left[\hat{X} + cov\left(\frac{Z^{VF}_j}{Z^{VF}}, \hat{X}_j; \lambda^X_j\right)\right] + cov\left(\frac{1}{s_j}, \hat{X}_j; \lambda^{VF}_j\right),
\end{aligned} \tag{30}$$

where $\frac{1}{\bar{s}} \equiv \sum_j \lambda^{VF}_j \left(\frac{1}{s_j}\right)$, $Z^{VF}_j = \frac{V^F_j}{X_j}$, $\lambda^X_j = \frac{X_j}{X}$, $X = \sum_j X_j$. X_j are volume indexes measured in fixed prices. The weighted covariance $cov\left(\frac{1}{s_j}, \hat{X}_j; \lambda^{VF}_j\right)$, based on the factor shares λ^{VF}_j as weights, is non-zero because the scale elasticities differ between industries. However, this variation is small. The weighted covariance $cov\left(\frac{Z^{VF}_j}{Z^{VF}}, \hat{X}_j; \lambda^X_j\right)$, is non-zero if the sectoral factor intensities, Z_j^{VF}, differ. Such heterogeneity has a positive impact on the total demand for inputs, and thereby electricity, if there is a positive correlation between the sectoral expansion and the sectoral factor intensities.

4.2 Households

Logarithmic differentiation of (14) - (20) yields

$$\hat{E}^H = \alpha_O^H \hat{E}_O^H + \alpha_M^H \hat{E}_M^H, \tag{31}$$

where $\alpha_O^H = \frac{E_O^H}{E^H}$, and $\alpha_M^H = \frac{E_M^H}{E^H}$. Moreover,

$$\hat{E}_O^H = \left(1 - \frac{\bar{E}_O}{E_O^H}\right) \left[\gamma_U \theta_F^U \left(\hat{P}_H^F - \hat{P}_H^E\right) + \hat{U}^H\right],$$

$$\hat{E}_M^H = \left(1 - \frac{\bar{E}_M}{E_M^H}\right) \left[\gamma_U \theta_M^D \left(\hat{P}_H^M - \hat{P}_H^E\right) + \hat{D}\right],$$

where θ_F^U and θ_M^D denote the cost shares of, respectively, fuels in the energy expenditure allocated to heating, and household equipment in the total expenditure allocated to the use of this equipment. We can then write

$$\begin{aligned} \hat{E}^H \;\; &= \;\; \alpha_O^H \left(1 - \frac{\bar{E}_O}{E_O^H}\right) \left[\gamma_U \theta_F^U \left(\hat{P}_H^F - \hat{P}_H^E\right) + \hat{U}^H\right] \\ &\quad + \alpha_M^H \left(1 - \frac{\bar{E}_M}{E_M^H}\right) \left[\gamma_U \theta_M^D \left(\hat{P}_H^M - \hat{P}_H^E\right) + \hat{D}\right]. \end{aligned} \tag{32}$$

As explained above, energy used for heating is combined with services from the stock of housing capital, R, in an OCES-function for housing related consumption $\dot{H}$. Logarithmic differentiation yields

$$\hat{U}^H = \left(1 - \frac{\bar{U}^H}{U^H}\right) \left[\gamma_H \theta_R^H \left(\hat{P}^R - \hat{P}_H^U\right) + \hat{H}\right], \tag{33}$$

The relative changes in H and D become

$$\hat{H} = \left(1 - \frac{\bar{H}}{H}\right) \left[\gamma_C \left(-\left(1 - \theta_H^{CH}\right) \hat{P}^H + \theta_D^{CH} \hat{P}^D + \theta_T^{CH} \hat{P}_H^T + \theta_A^{CH} \hat{P}^A\right) + \hat{C}^H\right]$$

$$\hat{D} = \left(1 - \frac{\bar{D}}{D}\right) \left[\gamma_C \left(-\left(1 - \theta_D^H\right) \hat{P}^D + \theta_H^{CH} \hat{P}^H + \theta_T^{CH} \hat{P}_H^T + \theta_A^{CH} \hat{P}^A\right) + \hat{C}^H\right]. \tag{34}$$

The optimal composition of material consumption and leisure, and of the time profile of full consumption, imply that the relative changes in C^H and N^H can be written

$$\hat{C}^{H} = \left[\gamma_{N}\theta_{L}^{NH}\left(\hat{P}_{H}^{L} - \hat{P}_{H}^{C}\right) + \hat{N}^{H}\right]$$

$$\hat{N}^{H} = -\gamma_{I}\left(\hat{\lambda} + \hat{P}_{H}^{N}\right),$$

where $\hat{P}_{H}^{C}$ and $\hat{P}_{H}^{N}$ denote the relative changes in the price indexes associated with marginal variations in, respectively, material consumption and the cost of living index.

5 A CGE Decomposition of Aggregate Price Sensitivity of Electricity Demand[1]

In this section we quantify the components in the price sensitivity of aggregate electricity demand by simulating the special version of the MSG6 model described in Section 2. First, we simulate a reference scenario where the reference price of electricity is kept constant over time. We then simulate an alternative scenario in which the reference price is 1 percent higher than in the reference scenario, whereas all other exogenous variables follow the same paths as in the reference scenario. We confine the discussion to the stationary effects, which are obtained after 10-15 years. The dynamics of the simulated price sensitivity is relatively modest.

5.1 Aggregate picture

The simulation shows that the 1 percent increase in the reference price reduces aggregate electricity demand from Norwegian firms and households by 0.31 percent, see Table 5.1. The demand reduction in the private business sector accounts for almost all of the reduction in total domestic electricity demand. The contribution to the total demand reduction from household demand is only 0.04 percent, reflecting a 0.13 percent reduction of electricity consumption and that the households consume about 1/3 of the total domestic electricity demand.

Table 5.1. Decomposing the change in aggregate electricity demand of a 1 percent increase in the reference price of electricity. Contributions from changes in main demand categories. Percentage change rates

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[1] More detailed decompositions are given in Holmøy (1998).

Change in total domestic demand ($\hat{E}$) = 1+2+3	-0.309
(1) Contribution from private industries = (1a)x(1b)	-0.266
(1a) Share of total demand ($\frac{E^P}{E}$)	0.510
(1b) Change in demand ($\hat{E}^P$)	-0.530
(2) Contribution from households = (2a)x(2b)	-0.043
(2a) Share of total demand ($\frac{E^H}{E}$)	0.320
(2b) Change in demand ($\hat{E}^H$)	-0.134
(3) Contributions from other sources	0.000

Interpreted as an aggregate own-price elasticity, the figure -0.31 is almost identical to the estimated long run own-price elasticity for final energy consumption in the UK by Hunt and Manning (1989). Their point estimate is -0.30. However, the study by Hunt and Manning, like most other related international studies, estimate the price elasticity of *energy*, not *electricity*, demand. When comparing the results in this paper with estimates of price elasticities of energy demand, one should keep in mind that energy demand is likely to be less price sensitive than electricity demand, since the latter can be substituted by other energy carriers. The estimate by Hunt and Manning is in line with the findings in Dahl (1994), Kouris (1983) and Prosser (1985), Bentzen and Engsted (1993). Dahl (1994) reports that the own-price elasticities of energy demand elasticities in about 50 studies for the developing world average -0.33. She also concludes that intermediate energy demand in individual industries is more price elastic than both aggregate industry demand and total demand. The latter pattern is also found in Table 5.1. Based on aggregate time-series data for the OECD countries, the estimates of the own-price elasticity in Kouris (1983) and Prosser (1985) vary between -0.15 and -0.43. Bentzen and Engsted (1993) estimates the corresponding long-run elasticity for Denmark to be -0.47. Older surveys by Pindyck (1979) and Taylor (1977) suggest that the long run own-price elasticity of total energy demand ranges from -0.3 to -0.5. Lower own-price elasticities, also for electricity, is estimated in Liu (2004) using panel data covering the period 1978-1999 for the OECD countries. On the other hand, Fiebig, Seale and Theil (1987) found that the aggregate energy own-price elasticity ranges from -0.66 to -0.88.

5.2 Private business sector

Table 5.2 decomposes the electricity demand reduction in the private business sector into contributions from 1) factor substitution within industries, 2) scale effect caused by changes in aggregate factor demand, and 3) factor substitution attributable to changes in the industry structure. About 3/4 of the demand reduction can be allocated to factor substitution within industries. Whereas the contribution from the scale effect is negligible, changes in the industry structure accounts for a significant share (about 1/4) of the demand reduction from the business sector. Most of this Rybczynski effect can be attributed to a contraction of the industries producing, respectively, Pulp and paper, Chemical raw materials, and Metals, which are the most electricity intensive industries. These industries are also export oriented, which implies that the elasticities of output with respect to the price index of the composite factor input in these industries are higher than in other industries.

Table 5.2. Decomposing the price sensitivity of electricity demand from private industries into substitution effects and scale effects. Percentage change rates

Change in electricity demand from private industries = 1+2+3+4	-0.525
(1) Substitution effect ($\hat{Z}^E$)	-0.387
(2) Scale effect, i.e. average growth in factor demand ($\hat{V}^F$)	-0.009
(3) Covariance el-intensities and changes in industry structure	-0.136
(4) Approximation error	0.007

Interestingly, Longva *et al.* (1988) found roughly the same price elasticity of electricity demand from private industries as in the present study. Their estimate also took general equilibrium effects into account. However, their model, MSG4, differed from the one used in this paper in several important respects. Specifically, their model did not include forward looking dynamics, and labour supply was exogenous. The most important difference is, however, that exports and import shares were exogenous in the model used by Longva *et al.*. Consequently, the scope for Rybczynski effects were much smaller in their model than in the study presented in this paper. This explains why reallocation of resources between industries plays a less significant role in their study than in the present one. On the other hand substitution effects within households and industries contribute less in the present study than in Longva *et al.* (1988).

Interpreted as an own-price elasticity of electricity demand in the aggregate Norwegian business sector, -053 is greater in absolute value than the estimates in Hesse and Tarka (1986). Based on panel data on electricity demand in the European manufacturing industry over the period 1973-1980, they find own-price elasticities between 0.14 and -0.49. Field and Grebenstein (1980) estimate a more price sensitive behaviour for US manufacturing in 1971. Based pooled cross-section data, their estimates range from -0.54 to -1.65.

Table 5.3 decomposes the within-industry substitution effects along two dimensions. First, we compute the substitution effects at different levels in the nested structure of factor demand. Second, we distinguish between substitution effects caused by the exogenous increase in the electricity price and the corresponding substitution effects caused by the endogenous equilibrium adjustments of other factor prices.

The decomposition shows that the latter set of substitution effects has a negligible impact on the electricity demand from private industries. This is, however, basically not a result of small technological substitution possibilities. Rather, it reflects very small endogenous equilibrium adjustments of prices of other inputs but electricity. Moreover, the reduction of electricity demand is foremost due to lower energy intensity in the composition of energy, machinery and labour. To a small extent the endogenous fall in the wage rate reinforces this substitution effect. The composition of energy is almost unaffected. In particular, this is the case for industries with a high electricity share in total energy use, since the rise in the electricity price then is transmitted to an almost proportional surge in the energy price.

Table 5.3. Decomposing the substitution effect in private industries into contributions from changes in different factor prices. Percentage change rates

Average substitution effect = 1+2+3+4 ($\hat{Z}^E$)	-0.387
(1) Contribution from increased electricity price (1.1+1.2+1.3+1.4):	-0.372
(1.1) Subst. between electricity (E) and fuels (F) ($= \sum_j \lambda_j^E \left(-\sigma_{Uj}\theta_{Fj}^U\right) \hat{P}_j^E$)	-0.025
(1.2) Subst. between energy (U) and machinery (K^M)	-0.203
($= \sum_j \lambda_j^E \left(\hat{U}_j - \hat{N}_j\right) \left(\frac{VE_j}{VU_j}\right) \hat{P}_j^E$)	
(1.3) Subst. between machinery/energy (N) and labour (L)	-0.142
($= \sum_j \lambda_j^E \left(\hat{N}_j - \hat{R}_j\right) \left(\frac{VE_j}{VN_j}\right) \hat{P}_j^E$)	
(1.4) Subst. between other factors ($= \sum_j \lambda_j^E \left(\hat{R}_j - \hat{R}_j^T\right) \left(\frac{VE_j}{VR_j}\right) \hat{P}_j^E$)	0.000
(2) Contribution from changes in other factor prices (2.1+2.2+2.3+2.4):	-0.018
(2.1) Subst. between electricity (E) and fuels (F),	0.000
(2.2) Subst. between energy (U) and machinery (K^M)	-0.003
(2.3) Subst. between machinery/energy (N) and labour (L)	-0.014
(2.4) Subst. between other factors	-0.001

5.3 Households

As pointed out above, the relatively weak price sensitivity of the households' electricity demand partly reflects that the consumer price of electricity increases by only 0.5 percent when the reference price increases by 1 percent. The reason is that the electricity consumption in *physical* units is the basis for transmission costs and indirect taxes. Table 5.4 shows that the demand response is somewhat stronger for electricity used for heating than for the electricity demand related to the use of electric equipment.

Table 5.5 shows that the composition of energy used for heating is relatively insensitive to the increase in the electricity price, because the initial electricity share in the energy demand is very high. More significant is the reduction of the total use of energy for heating. This effect contributes to 0.11 percent of the reduction in electricity demand for heating when the reference price of electricity is raised by 1 percent. The increase in the relative price of energy implies an incentive to substitute Housing capital for energy, which should be interpreted as more resources spent on isolation and other energy economizing measures.

Much more econometric work has been done on residential energy demand than on industry demand. Madlener (1996) provides a comprehensive survey, including an assessment of the strengths and the weaknesses of the various approaches found in the literature. Bye, Langmoen and Aasness (2004) survey econometric studies of residential electricity demand in the Nordic countries. They conclude that one can not reject the hypothesis that the price and income elasticities are equal in these countries. The average of the own-price elasticity estimates is -0.5, reflecting a substantially more price sensitive behaviour than the corresponding response in MSG6, which is based on Aasness and Holstmark (1995). Using data for 51 high, middle-, and low-income countries from 1970, 1975 and 1980 Seale, Walker and Kim (1991) estimate both income and own-price elasticities of residential energy demand to be larger than what they regard as the "consensus" values. They estimate the own-price elasticities of total energy demand to be near unitary for low-income countries and between -0.8 and -0.9 for all others. For Norway the own-price elasticity is estimated to be -0.87.

Table 5.4. Decomposing the price sensitivity of electricity demand from households. Percentage change rates

Change in electricity demand from households = 1+2+3 ($\hat{E}^H$)	-0.134
1. Contribution from Heating (= $\alpha_O^H \hat{E}_O^H$)	-0.076
1.1. Electricity share of Heating (α_O^H)	0.490
1.2. Change in electricity use for Heating ($\hat{E}_O^H$)	-0.157
2. Contribution from use of Electric Equipment ($\alpha_M^H \hat{E}_M^H$)	-0.056
2.1. Electricity share of use of Electric Equipment (α_M^H)	0.510
2.2. Change in electricity use for Electric Equipment ($\hat{E}_M^H$)	-0.111
3. Approximation error (= $\hat{E}^H - \left(\alpha_O^H \hat{E}_O^H + \alpha_M^H \hat{E}_M^H\right)$)	-0.004

Table 5.5. Decomposition of the change in electricity used for Heating by households. Percentage change rates

Change in electricity used for Heating ($\hat{E}_O^H$)	-0.157
1. Substitution between electricity and other energy ($\frac{E_O^H}{U^H}$) = -(1.3)×(1.1-1.2)	-0.050
1.1. Increase in the purchaser price of electricity ($\hat{P}_H^E$)	0.537
1.2. Increase in the purchaser price of energy ($\hat{P}_H^U$)	0.480
1.3. Effective elasticity of substitution between (E_O^H) and (F^H) = 1.3.1×1.3.2	0.878
1.3.1. Marginal elasticity of substitution between (E_O^H) and (F^H). i.e. σ_{U_H}	0.800
2. Scale effect from change in energy used for Heating (U^H) = 2.1×1.3.2	-0.107
2.1. Change in energy used for Heating ($\hat{U}^H$)	-0.097

6 Conclusions

This paper has used a special closure of a large scale CGE model of the Norwegian economy to estimate the aggregate sensitivity of domestic electricity demand to changes in the electricity price. A primary intention of the analysis has been to account for and quantify the contribution to the aggregate price sensitivity from a wide range of effects, including different substitution effects in the household demand structure and in heterogeneous production sectors, changes in the industry composition of the private business sector, as well as general equilibrium effects on the relative price structure and aggregate demand. The analysis supports the following conclusions:

1. The electricity demand from Norwegian Mainland firms and households falls by 0.31 percent when the reference price of electricity is raised by 1 percent.
2. The equilibrium adjustments of the private production sectors in the private Mainland economy account for 87 percent of the aggregate demand response. Whereas the demand response in the production sectors is in line with several international studies, household electricity demand is less price sensitive than in international studies.
3. The macroeconomic contraction resulting from the rise in the electricity price is too small to have but a negligible effect on the aggregate price sensitivity. The change in relative prices is the main determinant of the demand adjustments.
4. The change in the relative prices is basically due to the increase in the electricity price and the transmission of this change into other purchaser prices through the input-output structure of the economy. As a general equilibrium effect the wage rate must fall. However, the wage rate reduction is only 0.04 percent per percent increase in the reference price of electricity, which is too small to have a significant effect on relative prices.
5. Within industry factor substitution contributes most to the reduction of the electricity intensity of the aggregate production sector. This effect accounts for 0.39 percentage points of the 0.53 percent reduction in total electricity demand from private Mainland industries per percent increase in the reference price of electricity. The most important substitution effect is the reduction of the energy-labour ratio.
6. Reallocations of resources between industries with different electricity intensity in their factor composition contribute by 0.14 percentage points to the 0.53 percent

reduction in total electricity demand from private Mainland industries. This reallocation effect is basically a result of the high elasticity of output with respect to marginal costs in the export oriented electricity intensive industries.

A relevant criticism of the results presented in this paper is that the distinction between the contribution from within sector substitution effects and effects caused by reallocation between sectors includes an element of arbitrariness. The relative empirical importance of these effects will necessarily depend on the disaggregation and classification of industries and commodity flows. Our model must be regarded as rather disaggregated, specifying 40 production sectors and 60 commodity groups. However, the substitution within each sector will in reality be due to both genuine factor substitution within firms and reallocation between firms and subsets of firms within the specified sectors. Another classification of firms might have produced different estimates of the contribution from the specified effects to the price sensitivity of aggregate electricity demand. However, the results presented above are likely to be quite robust as long as the most electricity intensive industries are explicitly singled out in the model.

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Appendix

Analytical expressions for ε_{Aj}:

ε_{Aj} captures the effect on Z_j^E of general equilibrium effects on other prices than the electricity price. ε_{Aj} is given by

$$\begin{aligned} \varepsilon_{Aj} &= \varepsilon_{EFj}\hat{P}_j^F + \varepsilon_{EK^Mj}\hat{P}_j^{KM} + \varepsilon_{ELj}\hat{P}_j^L \\ &\quad + \varepsilon_{ETj}\hat{P}_j^T + \varepsilon_{EVj}\hat{P}_j^V + \varepsilon_{EK^Bj}\hat{P}_j^{KB}, \end{aligned} \tag{35}$$

where the terms on the r.h.s. are defined as

$$\begin{aligned} \varepsilon_{EFj} &= \left[\sigma_{Uj} - \sigma_{Nj}\theta_{KMj}^N - \left[\sigma_{Rj}\theta_{Lj}^R + \left(\sigma_{RTj}\theta_{Tj}^{RT}\right.\right.\right. \\ &\quad \left.\left.\left. + \left(\sigma_{Sj}\theta_{Vj}^S + \sigma_{VFj}\theta_{KBj}^{VF}\theta_{RTj}^S\right)\theta_{Rj}^{RT}\right)\theta_{Nj}^R\right]\theta_{Uj}^N\right]\theta_{Fj}^U, \end{aligned}$$

$$\begin{aligned} \varepsilon_{EK^Mj} &= \left[\sigma_{Nj} - \sigma_{Rj}\theta_{Lj}^R - \left[\sigma_{RTj}\theta_{Tj}^{RT}\right.\right. \\ &\quad \left.\left. + \left(\sigma_{Sj}\theta_{Vj}^S + \sigma_{VFj}\theta_{KBj}^{VF}\theta_{RTj}^S\right)\theta_{Rj}^{RT}\right]\theta_{Nj}^R\right]\theta_{KMj}^N, \end{aligned}$$

$$\varepsilon_{ELj} = \left(\sigma_{Rj} - \sigma_{RTj}\theta_{Tj}^{RT} - \left(\sigma_{Sj}\theta_{Vj}^S + \sigma_{VFj}\theta_{KBj}^{VF}\theta_{RTj}^S\right)\theta_{Rj}^{RT}\right)\theta_{Lj}^R,$$

$$\varepsilon_{ETj} = \left(\sigma_{RTj} - \sigma_{Sj}\theta_{Vj}^S\theta_{Tj}^{RR} - \sigma_{VFj}\theta_{KBj}^{VF}\theta_{RTj}^S\right)\theta_{Tj}^{RT},$$

$$\varepsilon_{EVj} = \left(\sigma_{Sj} - \sigma_{VFj}\theta_{KBj}^{VF}\right)\theta_{Vj}^S,$$

$$\varepsilon_{EK^Bj} = \sigma_{VFj}\theta_{KBj}^{VF}.$$

Figure 1: The preference structure of households in MSG6

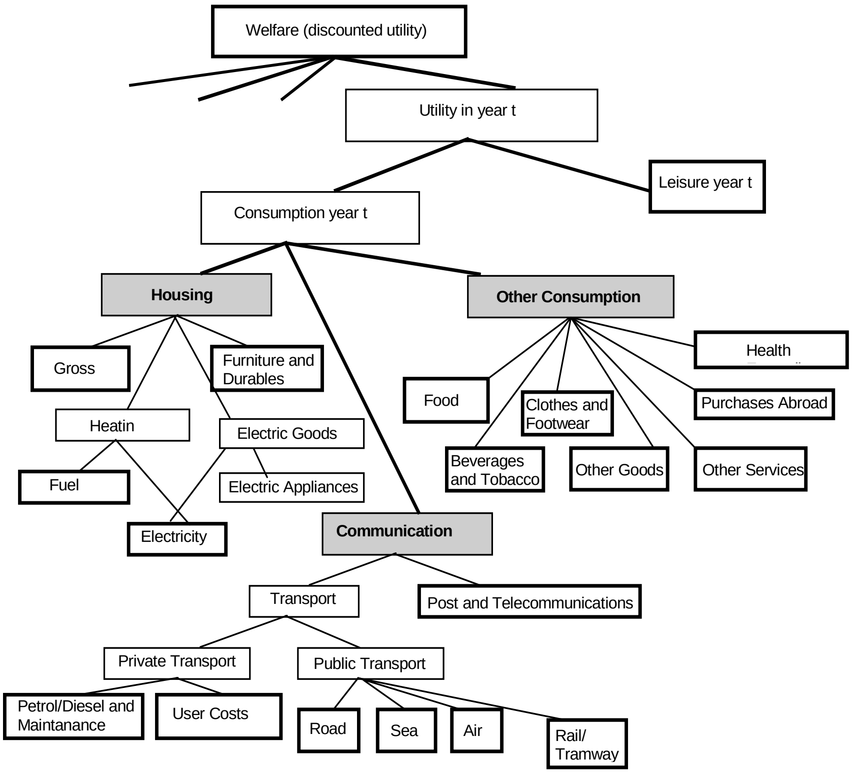
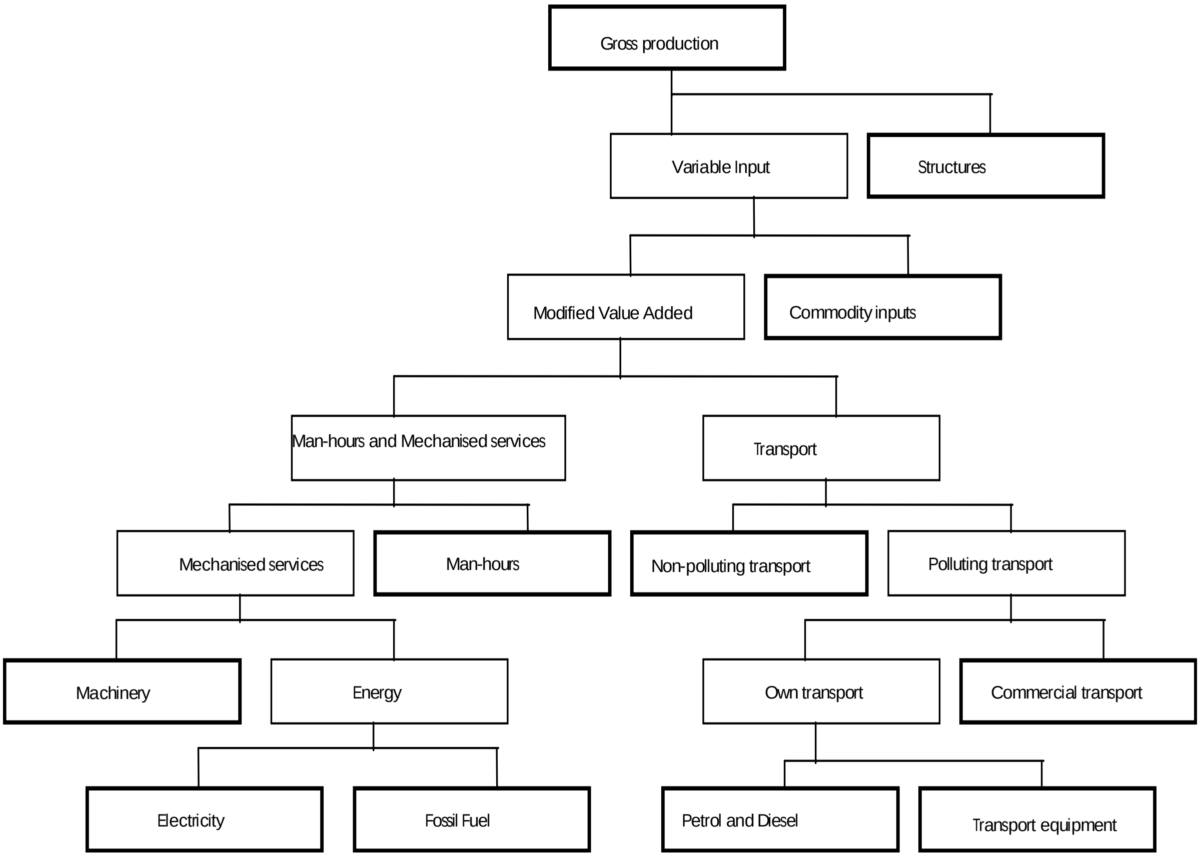


Figure 2: The production structure of firms in MSG6



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