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The Impact of Different Unbundling Scenarios on Concentration and Wholesale Prices in Energy Markets

Working Paper

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Abstract

A recent highly disputed subject of regulating energy markets in Europe is the unbundling of vertically integrated down– and upstream firms. While legal unbundling is already implemented in most countries and indisputable in its necessity for approaching regulatory aims, continuative models as ownership unbundling or the alternative of an independent system operator are still ambiguous. Hence, this article contributes to the economic analyses of identifying the differences of separate types of unbundling. Via simulation, we find that legal unbundling brings about the lowest prices in a market under Cournot competition. Moreover, under Bertrand competition, no differences between legal unbundling and ownership unbundling can be identified.

1 Introduction

The energy supply industry is one of the most important sectors in a modern industrial economy. As the price of electricity and gas increased continuously during the last few years, energy prices have been brought back on the agenda of recent economic and political discussions. From a socially optimal point of view, and due to the fact that energy is a basic need for humans in contemporary societies, regulatory policy intends prices to be low enough to satisfy everyone's basic needs, but, on the other hand, high enough in order to compensate generators appropriately (for production).

One of the fundamentals of stable and fair energy prices is given by a proper regulatory framework in order to stipulate the competition between companies, that depend on networks and are embedded in a natural monopoly. An additional central argument for the privatisation of the energy industry was the fact that private ownership leads to higher efficiency and lower production costs than public ownership. Nevertheless, these lower costs do not necessarily imply that profit maximising companies pass the benefits onto customers, especially when the market allows price rigging. This emphasises the necessity for further reorganisation within the electricity sector towards more advanced regulatory methods.

In this context, a recent highly disputed subject concerns the unbundling of electricity companies. While legal unbundling is already implemented in most countries and indisputable in its necessity for approaching regulatory aims, continuative models as the separation of ownership and control (ownership unbundling) are ambiguous. Bolle and Breitmoser (2006) for example showed that ownership unbundling may contribute to higher efficiency, but also leads to additional intransparencies and inefficient pricing, which contradicts the regulatory scopes. Furthermore, Höffler and Kranz (2007) criticised the concept of ownership unbundling as they see no additional benefit to the already implemented legal unbundling, for social welfare and competitive pricing. In contrast to this, Pollitt (2008) mentioned the advantages of ownership unbundling through higher competition. Nevertheless the latest directive of the European Commission Directive 2009/72/EC requests the implementation of ownership unbundling or the alternative of an independent system (ISO) or transmission (ITO) operator, which raises the interest in the unbundling topic additionally.
While most of the articles up to now deal with the analysis of transmission or distribution firms, only a few studies analyse the impact of unbundling on energy production units and the resulting level of competition and prices at electricity spot markets. Hence, the following article analyses the impact of different types of unbundling including a third possibility with endogenous determination of the grid tariff. Herein, the resulting effects on concentration within the generating market and energy pricing are examined. This is done by means of a simulation model, based on solving mixed complementary problems (MCP).

Therefore, the remainder of this article is organised as follows. The next section will give an overview of the different types of unbundling and adjacent literature. Section 3 gives the model framework in which legal unbundling, ownership unbundling and a third way with endogenous grid tariff rule are differentiated. Then, the simulation models are calibrated with respect to German data in order to give some insights, how unbundling affects competition and consumer prices, in a country which has not yet implemented continuative models. Finally, we test the model's sensitivity by means of a comparative statics analysis. The last section summarises the findings and draws together the principal conclusions.

2 Literature and Regulatory Background

In the literature, the consequences of vertical integration in the electricity sector are frequently discussed and emphasise the impact of these on competition and market entry. Prior to liberalisation, the vertical character of firms in a natural monopoly position was seen as major advantage for cost of service charges due to strong synergies and possible cross-subsidisations. Now, the existence of integrated upstream[1] and downstream[2] firms is assumed to hinder the evolution of effective competition and social welfare. As a consequence, the European Commission implemented several stages of unbundling for overcoming the previously mentioned problems. In a first step, accounting systems of each company division have to be separated in order to assure proper and transparent cost application. A step further, leads to legal unbundling which induces a separation of company parts under company law. Accordingly, discretionary power is reduced while ownership of the certain parts remains at the parent company. The strongest form of unbundling is given by ownership unbundling. Herein, the part forming the natural monopoly has to be separated from the rest of the vertically integrated company, i.e. the network becomes an independent and commercial operator which is neither subject to directives, nor owned by the holding company.

In Europe (EU–15), most countries have already implemented ownership unbundling as recent step in liberalising the national electricity market. Nevertheless, some countries refuse realisation and focus on a different framework, which should contribute to regulatory scopes but leaves ownership within the vertically integrated company, as for example the independent system operator (ISO). This system allows the transmission firm to operate independently, while ownership remains at the former holding companies.

In the last years, several articles dealing with consequences and (dis)advantages of these certain legal structures came up. An influential article dealing with this is Joskow and Tirole (2000) who showed that under the existence of vertically integrated companies with certain market power, the retaining of transmission capacity allows them to increase profits. Based on this, also Joskow (2004) mentioned the strong incentive for integrated companies to reduce capacities and to shift market power to the adjacent generator. Additional studies, dealing with the possible discrimination of market entrants in upstream or downstream markets were given by Mandy (2000), Beard et al. (2001), Mulder et al. (2005), Haucap (2007), or Baarsma and de Nooij (2007). Moreover, Bolle and Breitmoser (2006) analysed the impact of unbundling on allocative efficiency under Cournot competition. They found that ownership unbundling increases a regulator's efficiency, but is dominated by the resulting double marginalisation which implies higher prices in the long run. Moreover, Höffler and Kranz (2007) have to be mentioned in this context who showed that demand and optimal output under legal unbundling are higher than under ownership unbundling or vertical integration. By incorporating additional features in their model, as for example price competition in downstream markets, they came to the conclusion that also consumer surplus and overall welfare are not necessarily increased when implementing ownership unbundling (in comparison to legal unbundling). Our model comes to a similar result indicating that legal unbundling may prevail certain advantages for adjacent markets and should therefore be preferred to ownership unbundling.

With respect to the latter two articles, we implement a GAMS[3] simulation model based on MCP[4] when analysing the impact of unbundling under Cournot[5] and Bertrand[6] competition at the upstream generation market. Similar simulation models are for example given by Andersson and Bergman (1995) or

[1]The term upstream firm refers to a grid operator.
[2]The term downstream firm refers to a producer of energy.
[3]GAMS is the abbreviation for General Algebraic Modelling System.
[4]MCP denotes the abbreviation for Mixed Complementary Problem.
[5]In a Cournot game, the firms face competition in quantities.
[6]In a Bertrand game, the firms face competition in prices.

Kopsakangas-Savolainen (2003). A more recent study using the systematics of MCP for simulating an energy market can be found in Tanaka (2009), who analysed the Japanese wholesale electricity market as a transmission–constrained Cournot market.

Based on the previously mentioned discussion and the existing simulation models covering the electricity market, we implement three different frameworks for generating markets in which the agents play a Cournot or Bertrand game. The frameworks are distinguished by the different regulatory setups. Herein, legal unbundling, ownership unbundling and a third way with endogenous grid tariffs are analysed. Our findings emphasise the existing degree of competition in the market, when implementing a new regulatory framework. In a market with Bertrand competition the third way model leads to the most favourable results for competition and prices, whereas legal unbundling seems only advantageous in a market with Cournot competition. Ownership unbundling lies in between these cases, thus indicating no extraordinary benefits or disadvantages with its introduction in this framework.

3 The Model

The underlying model is based on the numerical and static short–term model of conjectural variation developed by Andersson and Bergman (1995) for Sweden which was afterwards applied by Kopsakangas-Savolainen (2003) for the Finnish electricity market. Herein, conjectural variation refers to the possibility of switching directly between Cournot– and Bertrand competition. Building on this, we start with the description of the basic model which is extended afterwards in order to analyse the impact of different types of unbundling on the generation market and the adjacent degree of concentration.

3.1 Basic model

The output of a single supplier (f) is defined as the sum of energy produced by hydro power plants (X_{hy}), nuclear power plants (X_{nuc}) and thermal plants using fossil fuels (X_{fos}). Let F represent the total number of energy producing firms in the market:

$$X(f) = X_{hy}(f) + X_{nuc}(f) + X_{fos}(f); \quad \text{for } \ f = 1, 2, ..., F \tag{1}$$

Total supply of electricity (S_E) is thus defined as the sum of the individual firm's supplies.

$$S_E = \sum_{f=1}^{F} X(f); \quad \text{for } \ f = 1, 2, ..., F \tag{2}$$

In this model, we distinguish three different types of power plants, which implies a specification of three different types of marginal cost functions. The marginal cost function for nuclear power plants is given by:

$$\frac{\partial C_{nuc}}{\partial X_{nuc}}(f) = c_{nuc}; \quad \text{for } \ f = 1, 2, ..., F \tag{3}$$

Instead, hydro power production which comprises run–of–river as well as reservoir power plants yields a marginal cost function of the following form:

$$\frac{\partial C_{hy}}{\partial X_{hy}}(f) = c_{hy} + \lambda_{hy}(f); \quad \text{for } \ f = 1, 2, ..., F \tag{4}$$

Where c_{hy} stands for the operating costs in run–of–river power plants and λ represents the shadow price of stored water. Intuitively, λ implies a firm specific scarcity rent on the deployment of reservoir power plants. Only if the respective capacity of run–of–river power plants ($K_{hy}(f)$) is fully utilised, λ is allowed to deviate from zero. Given that production cannot exceed installed capacity[7]:

$$X_{hy}(f) - K_{hy}(f) \leq 0, \tag{5}$$

and following Andersson and Bergman (1995), the variable λ has to fulfil the following equations:

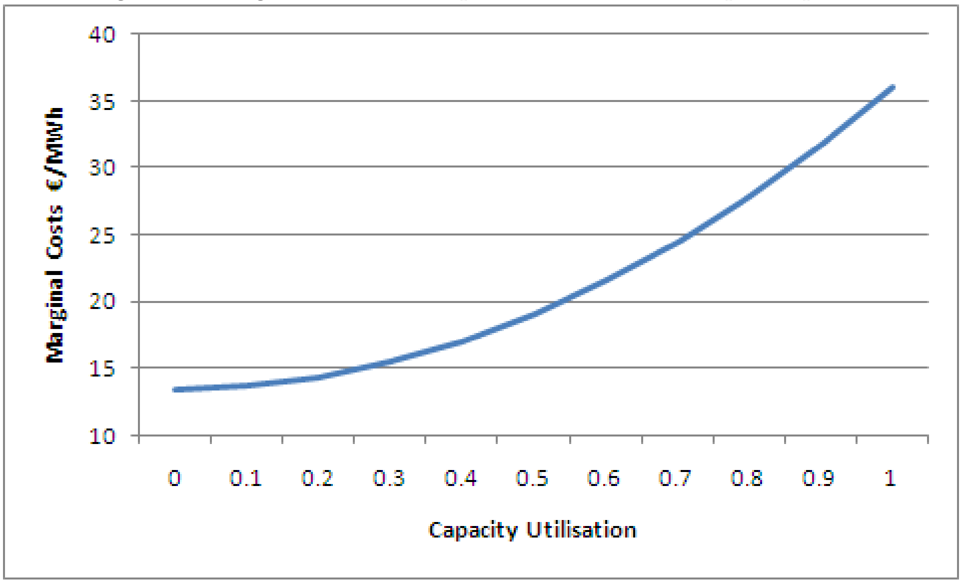
$$\lambda_{hy}(f) \cdot (X_{hy}(f) - K_{hy}(f)) = 0; \tag{6}$$
$$\lambda_{hy}(f) \geq 0; \tag{7}$$

Marginal costs in the category of energy production using fossil fuels are determined via a function, which is exponential increasing in the degree of capacity utilisation:

$$\frac{\partial C_{fos}}{\partial X_{fos}}(f) = a_o + a_1 \cdot \left(\frac{X_{fos}(f)}{K_{fos}(f)}\right)^{\sigma}; \quad \text{for } f = 1, 2, ..., F \tag{8}$$

The parameter a_0 stands for the marginal costs of the cheapest production type in this category. In our case this is determined by power plants using brown coal which determines the starting value of the cost function. The second part mentions a markup on these unit costs which applies as soon as more expensive fossil fuels (stone coal, gas, or oil) enter the production process. This markup depends on the degree of capacity utilisation, expressed as quotient of the produced amount ($X_{fos}(f)$) of each firm and its available capacity ($K_{fos}(f)$) in this category and ranges from 0 to 1. The parameter σ represents the speed of adjustment in marginal costs, when converging to full capacity deployment. It has to be greater than unity, which results in an exponential increase of marginal costs with respect to capacity utilisation. The possible evolution of this cost function is represented in Figure 1. Intuitively, a marginal cost function of the presented shape is needed for thermal power plants using fossil fuels in order to represent the distinct differences in marginal costs within this category (as also shown in section 4).

Figure 1: Marginal costs of the production in thermal power plants



Opposed to the producers in the market are the consumers, which are depicted by the following demand

[7]Installed capacity was entered as maximum production in MWh, given the installed capacity in MW.

for electricity (D_E):

$$D_E = D_0 \cdot \left(\frac{P_E}{P_0}\right)^{\epsilon} + NEX; \tag{9}$$

Where ϵ stands for the price elasticity of demand and P_E for the actual market price. D_0 and P_0 describe the previous demand and price for energy, respectively. The parameter NEX stands for net exports and is exogenously given.

Thus, the inverse demand function is given as:

$$P_E = P_0 \cdot \left(\frac{\sum_{f=1}^{F} X(f) - NEX}{D_0}\right)^{\frac{1}{\epsilon}}; \tag{10}$$

In order to accommodate demand, produced electricity has to be transported to final consumers. For this, the transmission and distribution network is used, which is an additional cost factor for generating firms. Let P_{net} represent the transportation costs for each unit supplied. Assuming further that each generator aims to maximise profits (implicitly also optimising the power plant mix), yields the following profit function[8]:

$$\Pi(f) = P_E \cdot X(f) - C(f) - P_{net} \cdot X(f); \quad \text{for } f = 1, 2, ..., F \tag{11}$$

Herein, revenues ($P_E \cdot X(f)$) are reduced by costs ($C(f)$) and transportation costs (P_{net}). Recall, $C(f)$ represents the respective cost function which has to be inserted according to the power plants used in the production process, while P_{net} and P_E represent unit prices.[9]
Within our setup, the parameter of conjectural variation (Θ) is included into the first order condition (FOC) which allows simulating of and switching between Bertrand and Cournot competition:[10]

$$P_E + \frac{1}{\epsilon} \cdot (1 + \Theta) \cdot \frac{X(f)}{S_E} \cdot P_E = \frac{\partial C(f)}{\partial X(f)} + P_{net}; \tag{12}$$

If $\Theta = 0$, the model simulates Cournot competition, whereas $\Theta = -1$ depicts the Bertrand framework.[11]

3.2 The introduction of unbundling

For introducing unbundling into the above mentioned framework, we refer to Höffler and Kranz (2007) who distinguished the different types of unbundling with respect to the resulting profit maximisation problems of up– and downstream firms.
For this, we incorporate three different types of firms in our model - vertically integrated enterprises (VIE) which operate in production as well as in transmission and distribution sector, pure generators and pure transmission and distribution operators. The downstream firms of the legal unbundled VIEs are subsumed under $g = 1, 2, ..., G$, with $G \subset F$.
For further analysis, it is assumed that transportation charges are regulated, i.e. under legal and ownership unbundling the grid operators are only allowed to set prices (P_{net}) at the permitted level. Nevertheless, regulation is assumed not to be perfect which implies that allowed prices do not necessarily equal real marginal costs. In order to account for this feature of concealment, an additional parameter (d) is included in the models of legal and ownership unbundling. In opposite to this, for modeling the third way, no exogenous price ceiling exists.

[8]Note that this profit function and according FOC refer in the following to a stand alone generator.
[9]$\Pi(f) = \Pi(f)[P_E, P_{net}, X(f), C_{hy}, C_{nuc}, C_{fos}]; \quad \text{for } f = 1, 2, ..., F.$
[10]For a detailed derivation see Appendix A.
[11]For further insights into the setup of conjectural variation, see for example Andersson and Bergman (1995).

3.2.1 Legal Unbundling (LU)

In contrast to unregulated vertically integrated enterprises which aim to maximise the profit of the whole company, legal unbundling implies the legal separation of the up - and downstream firms. In this context, the grid operator is only allowed to optimise its own operative business, while the downstream firm incorporates the profit of the upstream firm, additionally.

$$\Pi_{up} = \Pi_{up} \qquad and \qquad \Pi_{down}^{LU} = \Pi_{down} + \Pi_{up} \tag{13}$$

Hence, the profit function of a network operating company is composed of revenues, given as product of the regulated grid tariff (P_{net}) and the aggregated amount of energy produced (S_E), subtracted by the adjacent marginal costs of operating the network (m) and the fixed costs (Fix).[12]

$$\Pi_{up} = P_{net} \cdot S_E - m \cdot S_E - Fix; \tag{14}$$

Under legal unbundling, the profit function of the downstream firm which belongs to the same corporation as a network company, is given by:

$$\Pi_{down}^{LU} = P_E \cdot X(g) - C(g) - P_{net} \cdot X(g) + P_{net} \cdot S_E - m \cdot S_E - Fix, \quad \text{for } \ g = 1, 2, ..., G; \ G \subset F. \tag{15}$$

After reshuffling terms, the FOC[13] states:

$$P_E + \frac{1}{\epsilon} \cdot (1 + \Theta) \cdot \frac{X(g)}{S_E} \cdot P_E + P_{net} \cdot (1 + \Theta) = \frac{\partial C(g)}{\partial X(g)} + P_{net} + m \cdot (1 + \Theta); \tag{16}$$

Compared to the optimality condition stated in Equation 12, Equation 16 is expanded by the terms $P_{net} \cdot (1 + \Theta)$ on the left hand side and $m \cdot (1 + \Theta)$ on the right hand side, visualising the differences between Cournot and Bertrand competition.

In case of a Cournot competition where $\Theta = 0$, the integrated company considers the upstream firmsḿarginal costs denoted by m which are lower than the allowed grid tariff and determined as follows:

$$m = P_{net} \cdot (1 - d), \tag{17}$$

where d represents the concealment parameter, expressing the percentage difference to the grid tariff.[14] In contrast to that, the effect of sharing a holding company with a net operator vanishes under Bertrand competition, as the two additional parts drop out by setting $\Theta = -1$, which results in prices equalling marginal costs.

3.2.2 Ownership Unbundling (OU)

The second case of unbundling refers to ownership unbundling in which the vertically integrated enterprises have to sell their transmission facilities to an independent company. Thus, both, the grid operator

[12]Note, for a country with N > 1 grid operators, S_E has to be multiplied with $\frac{K_{net}(n)}{NET}$, representing the grid operators share in the total network capacity.

[13]For a detailed derivation of the first order condition see Appendix B.

[14]Note that this specification is used in order to be able to enter exact data for the regulated grid tariff. It is included in all three scenarios.

as separated firm and the producer of energy maximise their own profits, which creates space for potential double marginalisation.

$$\Pi_{up} = \Pi_{up} \qquad and \qquad \Pi^{OU}_{down} = \Pi_{down} \tag{18}$$

Hence, the profit function of the upstream firm is again given by:

$$\Pi_{up} = P_{net} \cdot S_E - m \cdot S_E - Fix; \tag{19}$$

The energy producing firms face the same optimality condition, as derived in Section 3.1, which is given by:

$$P_E + \frac{1}{\epsilon} \cdot (1 + \Theta) \cdot \frac{X(f)}{S_E} \cdot P_E = \frac{\partial C(f)}{\partial X(f)} + P_{net} \tag{20}$$

3.2.3 Third way

Finally, we compare the two scenarios of legal and ownership unbundling with a framework in which the grid operator sets the grid tariff endogenously. More precisely, this operator sets the grid tariff always equal to the sum of marginal costs (m) plus a shadow price if grid capacity becomes scarce (λ_{net}). This considered third way goes in line with the highly disputed third alternative of an independent system operator, as the transmission facilities of all companies are subsumed in an independent firm which is owned by former system operators. Nevertheless, in recent discussions the ISO is presented as a profit maximising institution, thus exhibiting too less differences to the ownership unbundling scenario modeled within our framework. Therefore, in this third way we refer to a more social endogenous grid tariff setting. In this setup, the simulation of the energy producing firms equals the situation under ownership unbundling, with FOC stated in equation 20.
The profit function of the grid operator is again given by:

$$\Pi_{up} = P_{net} \cdot S_E - m \cdot S_E - Fix; \tag{21}$$

The main difference lies in the price setting of the transmission operator. Here, the independent firm is not subject to grid tariff regulation but sets prices endogenously such that:

$$m + \lambda_{net} = P_{net}; \tag{22}$$

The lower bound for the grid tariff is given by marginal costs of net operation (m). Similar to the case of hydro power plants, the grid operator is allowed to set grid tariffs containing a markup λ_{net} on marginal costs, which represents a scarcity rent if the transmission capacities are nearly exhausted. Given that electricity supply cannot exceed net capacity:

$$S_E - K_{net} \leq 0, \tag{23}$$

the variable λ_{net} can be defined by the following equations:

$$\lambda_{net} \cdot (S_E - K_{net}) = 0; \tag{24}$$

$$\lambda_{net} \geq 0; \tag{25}$$

In our setup, the optimality conditions of the single producers of energy, combined with their respective capacity constraints and the market clearing condition constitute a mixed complementary problem

(MCP). For analysing the advantages of the different types of unbundling, we concentrate on the resulting quantities, prices, profits and market concentration. With respect to these, we are able to give insights into the socially optimal type of regulation and the adjacent disadvantages and advantages.

4 Market data

In order to analyse the different unbundling scenarios, the simulation model is calibrated with respect to data from Germany, as it forms an important transmission market for Europe and gives a good example of country, which had not implemented the third legislative package until 2008. All data refer to the year 2008. The price of electricity on the spot market of the European Energy Exchange (EEX) reaches an average value of 65.76 $\frac{€}{MWh}$ in 2008, while the minimum and maximum price were given by 21.03 $\frac{€}{MWh}$ and 131.4 $\frac{€}{MWh}$, respectively. For the simulations, we refer to a price of 42.84 $\frac{€}{MWh}$, which establishes the ten percent quantile of the observed prices.[15] These values also constitute the borders for the sensitivity analysis in section 5.2. The domestic electricity demand in Germany is given by 616.6 TWh plus 22.5 TWh net exports, as reported by the Federal Statistical Office (2009). In the following, the considered data for the power plant mix, the marginal costs of production, the price elasticity of demand and CO2 certificate prices are described.

4.1 Power plant mix

The German power plant mix consists of hydro, nuclear and thermal power plants, as well as renewable energy, generated by windmill and photo voltaic plants. Table 1 gives an overview of the installed capacity of the different energy producers in Germany and their according market shares. The six biggest producers encompass 88.59% of installed capacities. All firms with market shares below one percent are subsumed in the so–called Fringe. Overall, the model's approximation of installed capacities aggregates to 98,723.6 MW which accounts for 99.39% of the real installed capacity in Germany of 99,332.9 MW. The remaining 0.61% of overall production capacities referring to windmill-powered and photo voltaic plants are not included in the simulation.[16] Using the presented market shares for the German energy generating sector in 2008, the Herfindahl–Hirschman Inedx (HHI)[17] reaches a level of 1,816 points which indicates a high level of concentration.[18]

[15]We use the 10% qunatile instead of the mean, in order to prevent unrealistic increases in domestic demand, which are only driven by relative price decreases.

[16]The German Federal Environment Agency records power plants starting from 100MW, therefore the relative share of windmill and photo voltaic plants is that small.

[17]The HHI is a measure for market concentration. It is solely driven by market shares and caluclated by:

$$HHI = \sum_{f=0}^{F} s_f^2; \qquad f = 0, 1, 2, ..., F \tag{26}$$

Herein, s_f^2 gives the squared market share of active companies within a certain market.

[18]See for example Tupa and Ellersdorfer (2005), who also found high concentration on the German electricity generating sector.

Table 1: Market Shares of Producers of Electricity in 2008

Firm	**Capacity in MW**				**Market share in %**
	Hydro	Fossil	Nuclear	Sum	
Firm 1	179.7	18,397.4	5,766	24,343.1	24.51
Firm 2	1,471.2	14,293.5	8,571	24,335.7	24.50
Firm 3	2,550	12,621	2,496	17,667	17.79
Firm 4	334	4,871.5	4,624	9,829.5	9.90
Firm 5	0	5,447.1	0	5,447.1	5.48
Firm 6	0	6,378.5	0	6,378.5	6.42
Fringe	3,008.7	7,714	0	10,722.7	10.79
Sum	7,543.6	69,723	21,457	98,723.6	99.39

Source: German Federal Environment Agency (Umweltbundesamt)

4.2 CO2 certificate prices

Since 2005, CO2 certificates are traded at the EEX. The EEX carbon index (Carbix)[19] reached a minimum value of 0.01 and maximum value of 29.95 € per ton CO2. In order to analyse whether CO2 prices influence the efficiency of different types of regulation or its impact on market concentration and energy prices, we distinguish three different cases for emission certificate prices in the sensitivity analysis. Herein, the CO2 price can take the values 0, 8 and 38 € per ton CO2, which covers the whole range of historical prices at the Carbix and leaves space for future increases.

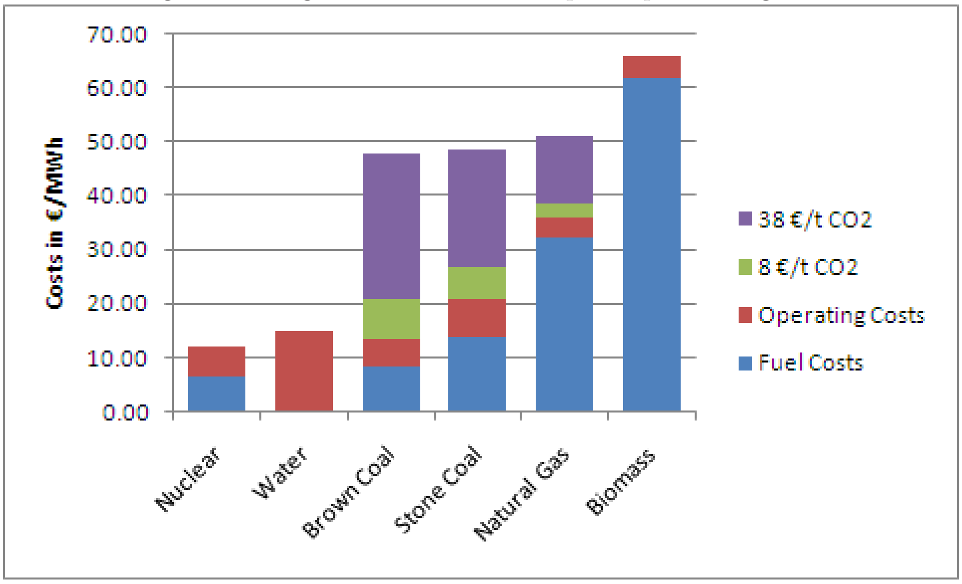
4.3 Marginal costs of production

The marginal costs of energy production, differentiated by the three different types of power plants, are set with respect to Wissel et al. (2008) and highlighted in Figure 2. The cost components encompass prices for the primary energy carriers, operating costs and costs for CO2 certificates with reference values of 8 or 38 € per ton CO2, respectively.[20]

[19] Carbix means Carbon Index and it is calculated and published by the European Energy Exchange (EEX). The EEX computes the Carbix as auction price, which is calculated according to the Principle of Most Executable Volume.

[20] Note that the shares referring to 38 € per ton CO2 only contain the respective markup from 8 to 38 € per ton CO2. Recall, the costs for CO2 certificates depend on the primary energy carrier, the effectiveness and the technology of the power plants and are therefore not added to all power plants at the same extent.

Figure 2: Marginal costs of different power plant categories



Source: Wissel et al. (2008)

As it is not possible to obtain a unique regulated grid tariff for Germany, we refer to the average variable costs, requested from the four network operators in Germany[21], which yields a reference value of d = $1.36 \frac{€}{MWh}$.[22] Recall, the marginal costs of network operation enter our simulation in dependency of the grid tariff, using a formulation via concealment.

4.4 Price elasticity of demand

The price elasticity of demand enters the simulation model as exogenous parameter. Historically, the demand was expected to be quite inelastic as electricity is hardly substitutable and not storable. Several empirical studies deal with the estimation of certain price elasticities in the electricity sector. Bohi (1981) for example mentioned that the short-run elasticity for aggregate electricity varies between -0.03 and 0.54. Concerning long–term elasticities, he found values ranging from -0.45 to -2.1. In recent years, the measures for elasticity include further analysis of time–of–use pricing. Herein, the demand elasticities are divided into peak, off–peak, as well as private and business customer elasticities, which range from -0.02 to -2.57. A sample of studies and their results are listed in Lafferty et al. (2001).

For the base case of the following simulation, we refer to different studies, e.g. Filippini (1999) who estimated a price elasticity of demand for wholesale customers of -0.30 for Switzerland. Additionally a study from NIEIR (2004), which estimated the price elasticities of a variety of Australian consumer groups, also arrives at a price elasticity of -0.35 for commercial consumers. In order to cope with the range of estimated price elasticities of demand and to monitor the sensitivity of the model, we allow the price elasticity of demand to vary between -0.15 and -1.

[21]EnBW Transportnetze AG, E.On Netz GmbH, RWE Transportnetz Strom GmbH and Vattenfall Europe Transmission GmbH.

[22]Although the grid tariff is usually a transitory item for the generators, it is explicitly modelled here. Recall, we only refer to marginal costs as we neglect the demand charge.

5 Simulation Results

The simulation results are divided into two parts. First, we analyse the effects of the different types of unbundling on energy prices, quantities produced, and gained market concentration. The second part gives insights into the sensitivity and interdependencies between results and parameters included. Therefore, we allow elasticities, initial prices, concealment power and CO2 prices to vary.

5.1 Effects of different types of unbundling — Reference scenario

The starting values for the analysis derived in Section 4 are summarised by the following table.

Table 2: Data for the reference scenario

Parameter	**Reference value**
Price elasticity of demand	-0.35
Concealment parameter	0.2
CO2 costs in € per ton CO2	0
base price in €	42.84
base demand in TWh	616.6
base net exports in TWh	22.5
σ	2

Notes: The concealment parameter states that marginal net operating costs lie 20% below the grid tariff. σ is the exponent of the marginal cost function in power plants using fossil fuels.

Table 3 presents the results for the different unbundling scenarios obtained under Cournot and Bertrand competition.

Cournot Results When referring to energy prices, legal unbundling achieves the most preferable results under Cournot competition. The worst performance according to social welfare is gained under the scenario of an independent system operator, while ownership unbundling can be found in between theses two extremes. In this case, production is highest under legal unbundling, because the integrated downstream firms take marginal costs of grid operation into account, which are lower than the grid tariff considered by the companies that operate in the generation sector solely. This results in lower energy prices under legal unbundling.

In order to compensate the negative effect of switching from legal to ownership unbundling, the grid tariff has to be reduced by 18.65%, which would result in equal prices for legal and ownership unbundling.[23] As the concealment parameter in the reference secnario was set to 0.2 this means that the regulatory authority would have to diminish the concealment possibilities of the grid operators. In other words, it needs distinct effort from the regulatory authority to achieve small changes in the market conditions for consumers, i.e. a decrease in grid tariffs of 18.65% would result in a decrease in the prevailing price for electricity of 0.41%. In opposite to energy prices, if market concentration is the major focus of regulatory authorities, the order reverses. In this case, the third way provides the lowest level of market concentration, while legal unbundling is characterised by higher concentration. Ownership unbundling lies again in between the two extremes. This reversed order is not surprising, as higher prices imply the option to produce in comparatively expensive power plants and thus provide the possibility for smaller producers to increase their market shares. In our static framework, the increasing concentration is caused by the asymmetric power plant capacities of the producers. Nevertheless, as the HHI only varies in a range of four points between the different unbundling scenarios under Cournot competition, the impact of unbundling on market concentration is rather small.

[23] This percentage change of the grid tariff was determined by calibration.

Bertrand Results In contrast to the results under Cournot competition, the stronger competition in the Bertrand scenario leads to a situation in which the most desirable result is reached by the framework with independent system operator, who is able to set the grid tariff according to the degree of net utilisation. As expected, the results under legal unbundling and ownership unbundling are identical[24] and provide a slightly higher price for electricity than the independent system operator. Consequently, production is highest under the third way framework. Nevertheless, as under Cournot competition, the relationship between prices for electricity and market concentration remains unchanged, such that according to market concentration, the framework of an independent system operator is less advantageous than legal or ownership unbundling. Furthermore, the lower prices for electricity under Bertrand competition also lead to an increase in market concentration, above the critical value of 1,800, indicating weak competition. This increase is caused by the asymmetry of the installed power plant capacities in the market.

Table 3: Impact of unbundling under Cournot and Bertrand competition

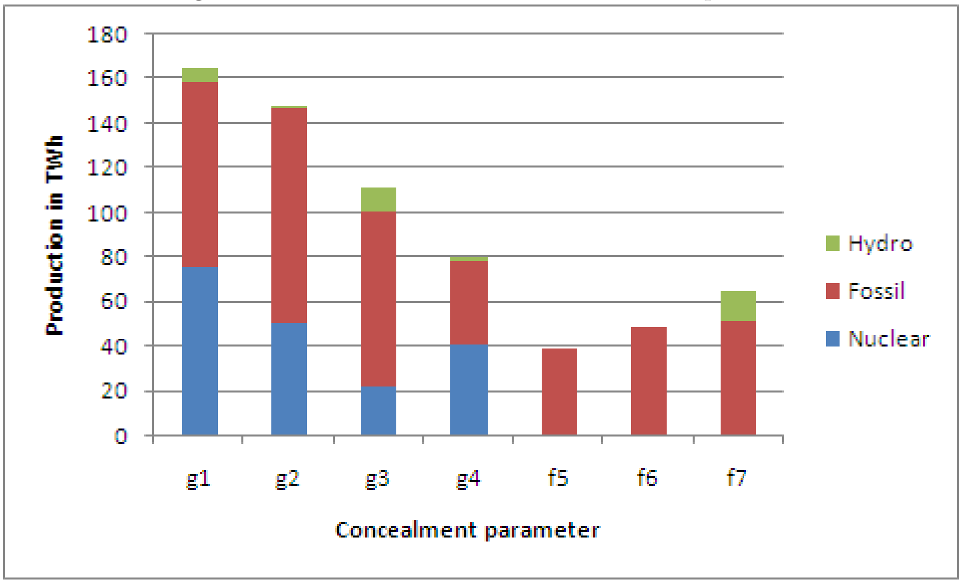
Case	Production in TWh	% of LU	Price in $\frac{€}{MWh}$	% of LU	HHI
Cournot					
Legal Unbundling (LU)	654	100	39.99	100	1679
Ownership Unbundling	653	99.85	40.18	100.45	1675
Third Way	652	99.69	40.34	100.88	1671
Bertrand					
Legal Unbundling (LU)	714	100	30.91	100	1808
Ownership Unbundling	714	100	30.91	100	1808
Third Way	715	100.14	30.73	99.42	1808

Notes: The legal unbundling scenario is used as reference case, as it is the prevailing regulatory framework in Germany. Hence, prices and production are given in absolute values and as percentage of LU. Last, the HHI is added to each scenario, in order to visualise the prevailing concentration in the market.

Moreover, our simulation results point out that the optimal production mix of each firm is independent from the prevailing regulatory framework. The changes in the used power plant mix only fluctuate within a one percent range. Exemplifying, Figure 3 and Figure 8 present the resulting production mix under legal unbundling for Cournot and Bertrand competition, respectively. Herein, all firms fully deploy their available capacities in hydro and nuclear power plants, whereas only firms $g4$, $f5$ and $f6$ run their thermal plants at full capacity in a Cournot framework.

[24]Recall, the parameter of conjectural variation is set to -1 for Bertrand competition, wherefore all additional parts drop out and the optimality condition reduces for all firms to marginal costs equalling the price for electricity.

Figure 3: Production Mix under Cournot competition



5.2 Structural analysis

In order to confirm the ranking of the different unbundling scenarios, a structural analysis is conducted. Herein, the concealment parameter, the price elasticity of demand, the base price anchor as well as the prices for CO2 certificates are varied.

In the following, we mainly concentrate on the results obtained under Cournot competition. Nevertheless, similar sensitivities can be obtained for the Bertrand framework.[25]

5.2.1 Concealment parameter

The concealment capability (d) is taken into consideration for the scenarios of legal and ownership unbundling, resulting in a possible difference between the grid tariff and marginal costs of grid operation. In opposite to this, the transmission company in the third way scenario has no incentive to conceal true costs, such that it is assumed to request a markup on marginal costs only if the net capacity converges to its limit. The potential consequences of concealment are examined by varying d between 0 and 1. While $d = 1$ implies full concealment capability, $d = 0$ indicates perfect regulation by circumventing any markups on marginal costs.[26] The resulting price levels for the different unbundling scenarios are visualized by Figure 4.

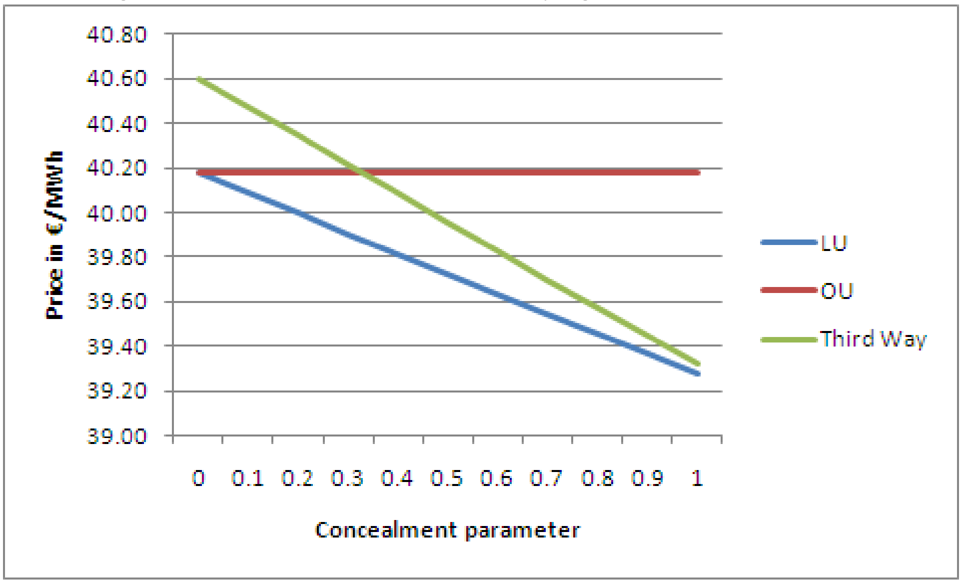
Under ownership unbundling all downstream firms pay a grid tariff of 1.36 $\frac{€}{MWh}$. Consequently, concealment power and resulting lower marginal costs of grid operation, only affect the profits of the grid operators, whereas the market price of electricity is independent to changes in d. In the remaining two scenarios, the price for electricity varies in a range of about 1 $\frac{€}{MWh}$. In case of legal unbundling, concealment power leads to lower marginal costs for the integrated downstream firms, who consequently increase their optimal electricity production. Thus, increasing concealment power is accompanied by lower prices for electricity under legal unbundling. Last, concealment power implicitly also affects an independent system operator, as marginal costs of grid operation are equal for all unbundling scenarios. Consequently, lower concealment power under legal and ownership unbundling enters the third way via higher marginal costs of grid operation, resulting in a higher price for electricity.

[25]The results for the Bertrand framework are available from the authors upon request.

[26]Note, the marginal costs of grid operation are equal for all three scenarios, whereas the grid tariff is allowed to differ according to concealment power and the possible markup in the third way scenario for exhausted net capacity.

Without any concealment possibilities ($d = 0$), the price for electricity under legal unbundling and ownership unbundling coincides. But as long as concealment power exists, consumers are provided with lower prices for electricity under legal unbundling than under ownership unbundling. This difference is driven by the four big electricity producers in the simulated market, which constitute the integrated downstream firms under legal unbundling and, consequently, take lower marginal costs into account than the same firms under ownership unbundling. Referring to the third way, the transparency of setting the grid tariff influences the strategic behaviour of the downstream firms. Although the relation between legal unbundling and the third way alternative remains nearly unchanged, downstream firms decrease their production in comparison to the legal unbundling scenario in order to exploit the advantages of lower grid tariffs and higher electricity prices. Thus, the resulting price for electricity is higher under endogenous price setting (third way) than under legal unbundling. Nevertheless, for values of d between 0.3 and 1, the resulting lower grid tariff in the third way is sufficient to achieve an overall lower price for electricity than under ownership unbundling. For $d < 0.3$, this sufficiency vanishes and the price for electricity exceeds prices under ownership unbundling. To summarise, Figure 4 points out that the relation of the different unbundling scenarios strongly depends on the possibility for upstream firms to conceal their true marginal costs of grid operation. Whereas ownership unbundling is the least favourable alternative in a situation with full concealment ($d = 1$), it loses its comparative disadvantages with diminishing concealment.

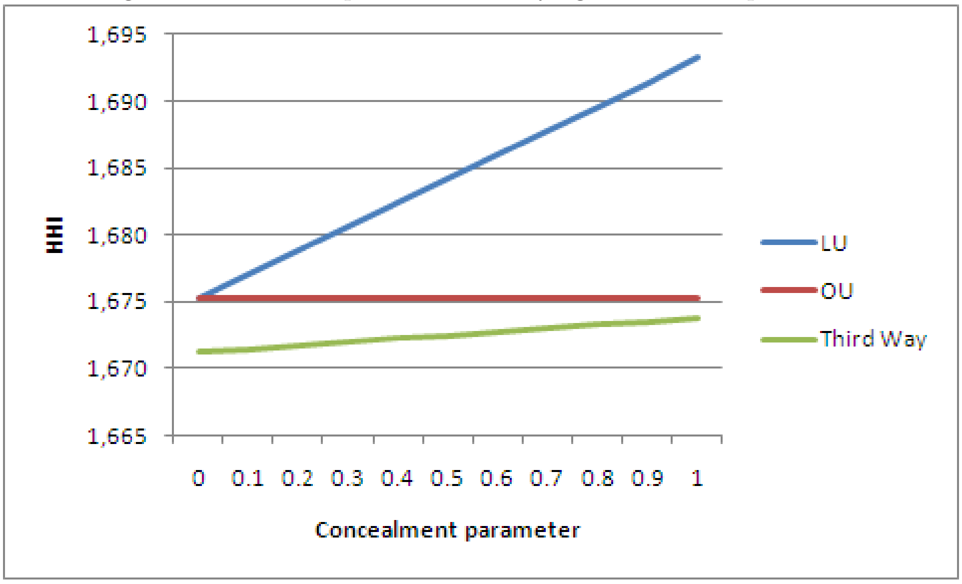
Figure 4: Price development under varying concealment parameter



Next, Figure 5 emphasises the trade–off between market concentration and the price for electricity. The concentration in the market, measured via the HHI, is decreasing with increasing prices. Intuitively, increasing prices are accompanied by decreasing production, and because bigger firms are able to conduct more significant reductions (in relatively expensive power plants), market concentration decreases. Thus, ownership unbundling leads to lower market concentration than legal unbundling for the whole range of concealment capabilities. Surprisingly, the third way yields lower concentration than ownership unbundling, although it additionally yields lower prices and is therefore able to break this trade–off. [27]

[27]The corresponding results for Bertrand competition can be found in the Appendix D.

Figure 5: HHI development under varying concealment parameter



5.2.2 Price elasticity of demand

Varying the price elasticity of demand, does not change the ranking of the different unbundling scenarios due to electricity prices and the HHI. Nevertheless, the price elasticity of demand is an important factor for market prices of electricity. Figure 6 shows the resulting price development for electricity under legal unbundling, when varying the price elasticity of demand between -0.15 and -1. Starting from a quite low level of -0.15, with increasing the elasticity of demand significant price decreases are observable.

In our simulations, the minimum price of 48.15 $\frac{€}{MWh}$ is reached at $\epsilon = -0.44$. From this point, the increase in marginal costs due to further production expansions outweighs the price reductions, resulting from an increase in the price elasticity. At $\epsilon = -0.71$, the capacity limit of the power plant mix of the economy is exhausted, such that further price increases are necessary for mitigating demand. Therefore, the observed price increases in our results, with $\epsilon > |-0.44|$, are driven by the static environment of the underlying model and would mark the necessity for further investments in production capacities in reality.

Figure 6: Price development under varying price elasticity of demand

5.2.3 Initial price (p0)

Additionally, the dependence of the simulation results on the entered initial price for electricity is examined. Therefore, the development of the price for electricity is analysed for base prices between 16.95 $\frac{€}{MWh}$ and 161.39 $\frac{€}{MWh}$, representing the minimal and maximal values for electricity traded at the EEX in 2008. Subject to these variations, the resulting price for electricity in our simulation varies between 29.31 and 82.34 $\frac{€}{MWh}$ which constitutes a rather big variation. Moreover, it emphasises the base price as being an important anchor for the simulation analysis which requires careful calibration. Nevertheless, these price changes do not affect the ranking of the different unbundling scenarios.

5.2.4 Varying CO2 prices

Finally, the consequences of increasing costs for CO2 certificates, that affect the marginal costs of energy production in thermal power plants, using fossil fuels, are examined. Therefore, three different situations concerning the costs of CO2 certificates are distinguished, namely 0, 8 and 38 € per ton CO2.

Subject to these variation, the ranking of the different unbundling scenarios remains unchanged, which confirms the previous results. Beside this, the nominal values of several variables are affected by an increase in the costs of CO2 certificates. Table 4 presents an overview of the resulting changes, when increasing the price for CO2 certificates from 0 to 8 and finally to 38 € per ton CO2. The increased costs for CO2 certificates trigger a rise in marginal costs which results in an increase in the prices for electricity. Due to the increased prices for electricity and the reduced amount produced in expensive power plants using fossil fuels, the profits of all producers of electricity are increased.

Table 4: Effects of CO2 certificates

Variable	**0 $\frac{€}{t\ CO2}$**	**8 $\frac{€}{t\ CO2}$**	**38 $\frac{€}{t\ CO2}$**
a_0 in $\frac{€}{MWh}$	13.45	20.65	47.65
a_1 in $\frac{€}{MWh}$	22.51	17.79	3.49
Price in $\frac{€}{MWh}$	48.79	52.44	73.28
Production in TWh	726	709	633
Production hydro in TWh	33	33	33
Production fossil in TWh	505	488	412
Production nuclear in TWh	188	188	188
HHI	1,762	1,740	1,650
Profit $Int(g1)$ in € million	4,810	5,090	6,590
Profit $Int(g2)$ in € million	4,360	4,400	4,800
Profit $Int(g3)$ in € million	2,800	2,940	3,580
Profit $Int(g4)$ in € million	1,980	2,180	3,380
Profit $f1$ in € million	491	541	889E
Profit $f2$ in € million	637	701	1,150
Profit $f3$ in € million	1,120	1,240	2,000

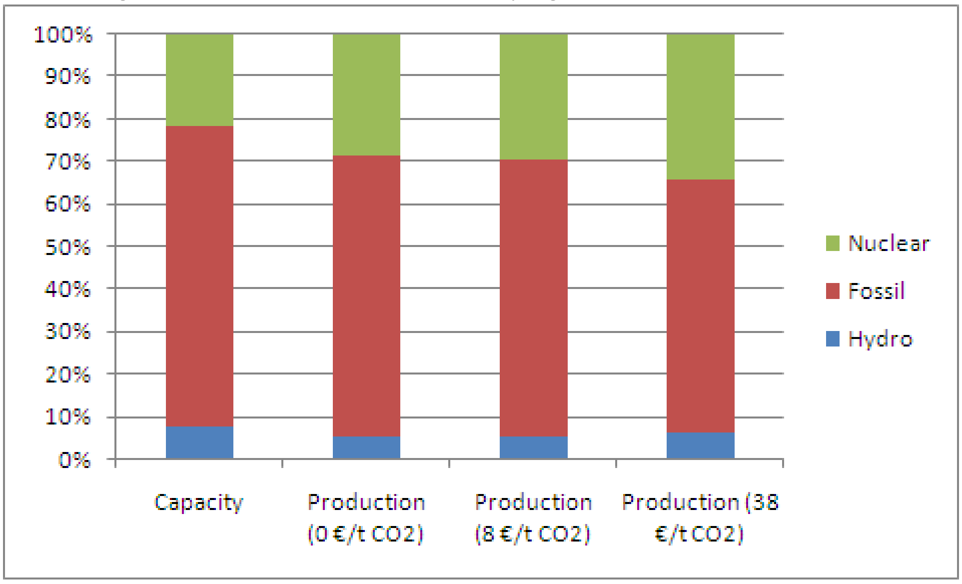
Notes: a_0 refers to the minimal marginal costs in thermal power plants. a_1 describes the difference between minimal and maximal marginal costs in thermal power plants. $Int(g)$ denotes the certain integrated company, whereas f refers to a downstream firm solely operating in the production market.

Figure 7 presents the development of the production mix with increasing prices for CO2 certificates in comparison to the composition of the installed capacities.[28] The installed capacities of hydro and nuclear power plants are fully deployed in all three scenarios. But, the production in thermal power plants, which is subject to increased marginal costs of production decreases recognisably, thus leading to an increase

[28]Note that the daily service life of hydro power plants only reaches twelve hours. Therefore hydro power plants lose in percentage proportion compared to the capacities, which refer to the maximum amount of energy which can be produced in one hour.

in the percentage of the other two categories. Consequently, the introduction of CO2 certificates will result in a shifting of production from thermal power plants to less pollutant power plants (although in the current state more expensive). Nevertheless, the resulting price increases for consumers must not be neglected.

Figure 7: Production mix under varying prices for CO2 certificates



6 Concluding remarks

Motivated by Directive 2009/72/EC of the European Commission, this paper examines the unbundling alternatives of legal and ownership unbundling as well as a third way implementing an endogenous price setting rule. The decision variables for ranking the different alternatives are the price for electricity with the adjacent produced quantity and the level of market concentration, measured via the Herfindahl–Hirschman Index. This analysis is done by means of a simulation model, formulated as MCP and solved in GAMS. The model is calibrated using data from the German electricity market.

We find that with respect to the electricity price, legal unbundling generates the most favourable conditions for consumers under Cournot competition, whereas the third way alternative yields the highest prices. Ownership unbundling, as the advised alternative of the European Commission, lies in between these two extremes, thus indicating no extraordinary benefits or disadvantages with its implementation. In order to compensate the negative effect of switching from the first best solution (legal unbundling) to ownership unbundling, the grid tariff has to be reduced by about 18.65%. This implies a rather high percentage for price inducements and the necessity to diminish the concealment possibilities of grid operators via regulation. With a view to market concentration, the order of the different scenarios reverses which highlights a trade–off relation between market concentration and the associated price for electricity.

In contrast to that, under prevailing Bertrand competition, legal unbundling and ownership unbundling yield identical results and the third way is most advisable, when referring to the price of electricity. Bertrand–competition is modelled via the optimality condition of prices equalling marginal costs. This implies that a transmission company with social endogenous price setting rule becomes more advantageous with increasing competition in the market. Thus, the prevailing degree of competition should be taken into account by regulatory authorities while deciding in favour of one of these unbundling alternatives. Nevertheless, the trade–off relation between market concentration and the price for electricity remains.

In an environment containing regulated grid tariffs, the only possibility for grid operators to maximise their profit is to manipulate their marginal costs of grid operating. One obvious possibility refers to reducing marginal costs by according investments in order to increase the difference between the grid tariff and costs and, therefore, maximise profits. Another option is to increase marginal costs in order to receive a higher grid tariff, allotted from the regulatory authority. This would for example be possible under legal unbundling by shifting costs from the producer to the grid operator. Both options would require a dynamic setup to be analysed, wherefore the dynamisation of the presented model would be an interesting extension.

APPENDIX

A Integration of the parameter of conjectural variation for separate downstream firms

The starting point for the simulation model with separated downstream firms builds the derivative of the profit function with respect to the produced amount of electricity.

$$\frac{\partial \pi_f}{\partial X(f)} = P_E + \frac{\partial P_E}{\partial X(f)} \cdot X(f) - \frac{\partial C(f)}{\partial X(f)} - P_{net} = 0; \tag{27}$$

As the price for electricity depends on the aggregated amount of electricity, S_E has to be included in the derivation of P_E with respect to $X(f)$.

$$P_E + \frac{\partial P_E}{\partial S_E} \cdot \frac{\partial S_E}{\partial X(f)} \cdot X(f) - \frac{\partial C(f)}{\partial X(f)} - P_{net} = 0; \tag{28}$$

The next steps refer to expanding the second summand by the two factors $\frac{S_E}{S_E}$ and $\frac{P_E}{P_E}$ and reshuffling terms:

$$P_E + \frac{\partial P_E}{\partial S_E} \cdot \frac{\partial S_E}{\partial X(f)} \cdot X(f) \cdot \frac{S_E}{S_E} \cdot \frac{P_E}{P_E} - \frac{\partial C(f)}{\partial X(f)} - P_{net} = 0; \tag{29}$$

$$P_E + \underbrace{\frac{\partial P_E}{\partial S_E} \frac{S_E}{P_E}} \cdot \underbrace{\frac{\partial S_E}{\partial X(f)}} \cdot \frac{X(f)}{S_E} \cdot P_E = \frac{\partial C(f)}{\partial X(f)} + P_{net}; \tag{30}$$

$$P_E + \frac{1}{\epsilon} \cdot (1 + \Theta) \cdot \frac{X(f)}{S_E} \cdot P_E = \frac{\partial C(f)}{\partial X(f)} + P_{net}; \tag{31}$$

Finally, we end up with the expression for the optimality condition stated in Section 3.1. Note, $\frac{\partial S_E}{\partial X(f)} = \frac{\partial (X(f)+X(-f))}{\partial X(f)} = (1 + \Theta)$. Herein, $X(-f)$ represents the supply of energy (S_E) without $X(f)$ and thus Θ stands for the derivation of $X(-f)$ with respect to $X(f)$.

B Integration of the parameter of conjectural variation for integrated downstream firms

The starting point for the model with integrated downstream firm is the derivative of the profit function with respect to the produced amount of electricity.

$$\frac{\partial \Pi^{LU}_{down}}{\partial X(g)} = P_E + \frac{\partial P_E}{\partial X(g)} \cdot X(g) - \frac{\partial C(g)}{\partial X(g)} - P_{net} + P_{net} \cdot \frac{\partial S_E}{\partial X(g)} - m \cdot \frac{\partial S_E}{\partial X(g)} = 0; \tag{32}$$

As earlier mentioned, the price for electricity depends on the aggregated amount of electricity, such that S_E has to be included in the derivation of P_E with respect to $X(g)$.

$$P_E + \frac{\partial P_E}{\partial S_E} \cdot \frac{\partial S_E}{\partial X(g)} \cdot X(g) - \frac{\partial C(g)}{\partial X(g)} - P_{net} + P_{net} \cdot \frac{\partial S_E}{\partial X(g)} - m \cdot \frac{\partial S_E}{\partial X(g)} = 0; \tag{33}$$

Again, expanding and reshuffling terms, yields:

$$P_E + \frac{\partial P_E}{\partial S_E} \cdot \frac{\partial S_E}{\partial X(g)} \cdot X(g) \cdot \frac{S_E}{S_E} \cdot \frac{P_E}{P_E} - \frac{\partial C(g)}{\partial X(g)} - P_{net} + P_{net} \cdot \frac{\partial S_E}{\partial X(g)} - m \cdot \frac{\partial S_E}{\partial X(g)} = 0; \tag{34}$$

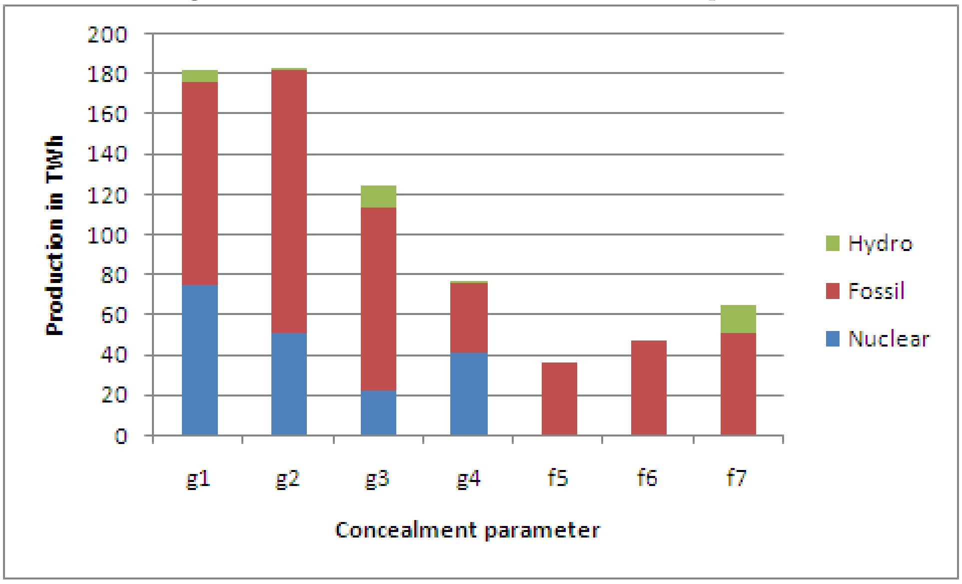
$$P_E + \underbrace{\frac{\partial P_E}{\partial S_E}\frac{S_E}{P_E}} \cdot \underbrace{\frac{\partial S_E}{\partial X(g)}} \cdot \frac{X(g)}{S_E} \cdot P_E + P_{net} \cdot \underbrace{\frac{\partial S_E}{\partial X(g)}} = \frac{\partial C(g)}{\partial X(g)} + P_{net} + m \cdot \underbrace{\frac{\partial S_E}{\partial X(g)}}; \tag{35}$$

$$P_E + \frac{1}{\epsilon} \cdot (1+\Theta) \cdot \frac{X(g)}{S_E} \cdot P_E + P_{net} \cdot (1+\Theta) = \frac{\partial C(g)}{\partial X(g)} + P_{net} + m \cdot (1+\Theta); \tag{36}$$

Finally, we end up with the expression for the optimality condition stated in Section 3.2.1. Note that $\frac{\partial S_E}{\partial X(g)} = \frac{\partial (X(g)+X(-g))}{\partial X(g)} = (1+\Theta)$. Herein, $X(-g)$ represents the supply of energy (S_E) without $X(g)$, and thus, Θ stands for the derivation of $X(-g)$ with respect to $X(g)$.

C Production mix under Bertrand competition

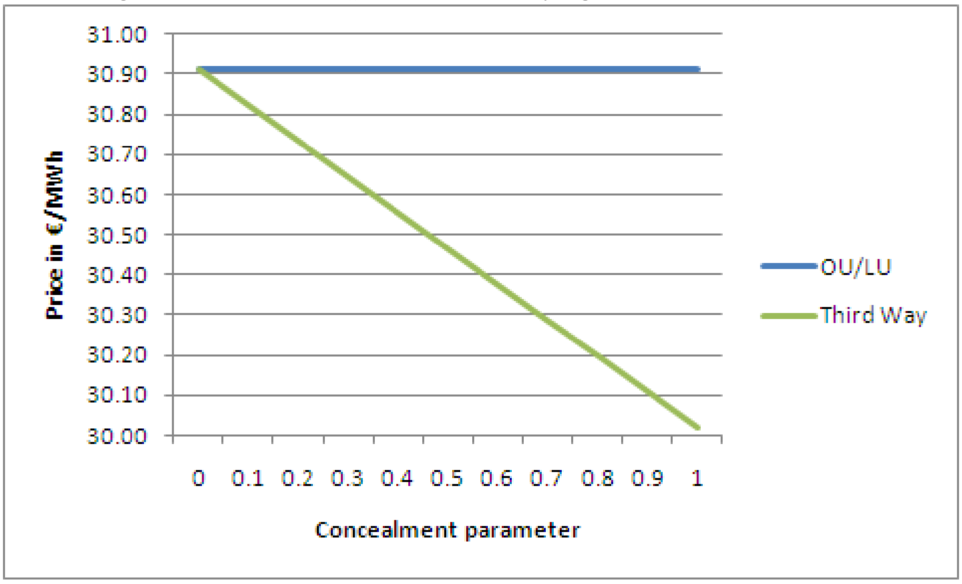
Figure 8: Production Mix under Bertrand competition



Notes: Figure 8 illustrates a rather similar production mix as under Cournot competition which appears to be very similar to the production mix under Cournot competition. The production mix under Bertrand competition is rather similar to the one presented in Figure 3 under Cournot competition. Nevertheless, due to lower prices for electricity, the optimal production level for each firm increases. Therefore, the available capacities in hydro and nuclear power plants are again fully deployed by each firm. Additionally, the aggregated production in thermal power plants using fossil fuels increases about 14.29%, including a slight reallocation of production between the single firms. Firm $g4$ slightly decreases its production in thermal plants, whereas all other firms increase production. In this scenario, although firms $f5$, $f6$ and $f7$ fully deploy their installed capacities in thermal power plants, the relative increase (of energy production with fossil fuels) is higher for the integrated producers $g1$, $g2$, $g3$, $g4$ which also trigger the increase in market concentration.

D Concealment power under Bertrand competition

Figure 9: Price development under varying concealment parameter



Notes: Under Bertrand competition all downstream firms optimise profits such that prices equal marginal costs. Consequently, concealment power only affects the profits of the grid operators. Legal and ownership unbundling provide an identical market concentration and price for electricity for all values of d. The most interesting result under Bertrand competition is given under the endogenous price setting approach (third way), as it is forced to provide a grid tariff equal to its marginal costs. Therefore, the firms lose their possibility to use their production decisions strategically. This results in a scenario, where the third way alternative provides a lower price for electricity than legal and ownership unbundling, for all values of d.[29]

[29] Due to the high production under Bertrand competition, which nearly reaches the capacity limits of the single firms, the slight price changes between the different unbundling scenarios do not trigger noticeable effects on market concentration. Therefore, we abstain from a graphical illustration of the development of the HHI.

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