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# Simulating the restructuring the Flemish electricity distribution sector

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## *Abstract*

In Flanders (Belgium), distribution companies are to a large extent owned by the municipalities and as such these municipalities collect an important share of the profits from electricity distribution. This situation (by many it is seen as a hidden tax) cannot be maintained because, in the process of electricity market liberalisation, the ownership will be reshuffled and because the old regulation mechanism, allowing for such cash flows, will be revised.

This paper presents some simulations on the restructuring of the electricity distribution sector, using a partial equilibrium model. The focus of the simulations is on the impact of the choice of the regulation mechanism on prices and on the municipalities' budget. Three regulation schemes are simulated, 'rate-of-return' (ROR) regulation, 'constant profit per unit of output' (CPU) regulation and 'price-cap' (PC) regulation. The simulations show that, irrespective of the regulation scheme, it is not obvious that end-user electricity prices will decrease after the liberalisation. Moreover, the restructuring will have a large impact on the profits received by the municipalities. The sign of this impact depends on the regulation mechanism that is imposed, but it appears that, from the three regulation mechanisms that were analysed, the ROR-mechanism performs worst, both in terms of municipal cash flows and of economic welfare.

**Keywords:** **Electricity distribution, Electricity markets, Electricity modelling, Regulation, Strategic behaviour**

**JEL-classification:** **D42, L13, L43, L94**

# 1. INTRODUCTION

In Flanders, the Dutch-speaking part of Belgium, the electricity distribution sector is in the middle of a process of fundamental restructuring. Until recently, vertically integrated companies carried out electricity distribution as well as retail activities[1]. Each company had a monopoly in its own supply area for both these activities. The objective of the Flemish government is to restructure the sector, such that distribution and retail activities are separated. Distribution remains a monopoly activity, but the retail market will be open for competition. This process should be finished within the next one to two years. The restructuring requires a fundamental rethinking of the way in which the sector is operated and regulated. The basic idea is to introduce more competition in those market segments where competition is viable and to introduce (better) regulation in those branches – usually transmission and distribution transport – where competition is not viable.

This paper focuses on the impact of the choice of the regulation mechanism on the budget of the municipalities and on the end-user prices for electricity. In the pre-reform world, the ownership of the distribution sector was in the hands of the municipalities and as such they collected an important share of the profits. This situation could easily be maintained, as electricity distribution and retail were monopoly activities. Due to the restructuring, ownership is reshuffled. Depending on the initial type of the distribution company in which they participated, the municipalities take a majority share in the distribution companies (ranging from 70% to 100%), and a minority share in (some of) the retail companies. According to many, this will result in reduced cash flows for the municipalities because of two reasons. First, as electricity distribution activities will be subject to regulation, municipalities cannot expect large profit margins in this segment of the market. Second, competitive pressure will also reduce profit margins on retail activities. Furthermore, it is the explicit objective of the Federal as well as of the Flemish authorities to reduce end-user electricity prices through this liberalisation of the electricity markets as it is often claimed that end-user electricity prices are among the highest in Europe.

However, we claim that the impact on municipal cash flows and on end-user electricity prices will crucially depend on the extent of increased competition in generation and in retailing, and on the type of regulation that is chosen for the distribution and transmission activities. In practice, the Federal and the regional regulatory authorities opt for a rate-of-return regulation mechanism, both for transmission and distribution[2]. From the literature on regulation, we know that rate-of return regulation has some drawbacks and it is the objective of this paper to

[1] In this paper, whenever we use the term 'electricity distribution', we mean the transport of electricity at the distribution level. 'Retail' activities, are activities related to the selling of electricity.

[2] In Belgium, transmission is a Federal matter and distribution is a Regional matter.

illustrate these potential negative impacts, relative to other types of regulation such as price cap regulation or constant profit per unit of output regulation[3].

The paper follows a numerical approach and presents some simulations on the restructuring of the electricity distribution sector. We use a partial equilibrium model that captures the most fundamental features of the sector. The modelling approach is similar to the modelling approach followed by, for example, Hobbs (2001) and Wei and Smeers (1999)[4]. The model in this paper is different in the sense that it does not incorporate a network. It does, however, distinguish one transmission and three distribution grid operators, each behaving strategically.

In the (discussion of the) simulations, attention will be paid to changes in the relative size of the profit flows generated by the restructuring, and on the impact of liberalisation and (re-) regulation on end-user prices and welfare. It is not the intention of this paper to simulate the monetary impact of the restructuring on the municipal cash flows. Rather, the paper intends to illustrate how different regulation mechanisms can have different impacts on the resulting outcome.

Section 2 describes the model and the fist-order conditions for the solution. These first-order conditions are explicitly presented because the model is solved as a complementarity problem. The model that is described in this section is a general formulation of the model that will be used for the simulations. Section 3 then describes the data, the model calibration and the simulated scenarios. In this section some assumptions are made that further simplify the model. Section 4 presents and discusses the simulation results and, finally, section 5 summarises and concludes.

## 2. THE MODEL

Let $\mathcal{H}, \mathcal{I}$ and $\mathcal{T}$ be the sets of retail customers, of distribution companies and of non-overlapping time periods, respectively. Furthermore, define $\mathcal{M}$ as the Cartesian product of $\mathcal{H}$ and $\mathcal{I}$, i.e.

$$\mathcal{M} = \mathcal{H} \times \mathcal{I} = \left\{ (h,i) | h \in \mathcal{H} \text{ and } i \in \mathcal{I} \right\} \tag{1}$$

The set $\mathcal{M}$ contains all combinations of retail customers and distribution companies that are distinguished in the model. Retail customers cannot choose the distribution company that transports their electricity.

Consumer $h$'s inverse demand for electricity in period $t$ through distribution company $i$ is written as $p_{m,t}\left(\mathbf{q}_m^d\right)$, with $m \in \mathcal{M}$ and $\mathbf{q}_m^d = \left[q_{m,1}^d, \ldots, q_{m,\mathcal{T}}^d\right]$. This formulation allows for substitution between different time periods (e.g. from peak to off-peak periods.), but implicitly assumes that customers are not affected by the demand of other customers. Inverse demand is assumed downward sloping and concave.

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[3] See for example Train (1991) and Laffont and Tirole (1994).

[4] See for example Hobbs (2001), for a short survey of models based on a similar approach.

The focus of the model is on electricity demand via the distribution grid, although demand via the transmission grid is also taken into account. Therefore, apart from retail customers, we also have direct customers, i.e. large companies buying electricity directly from the generators. This electricity is delivered through the transmission grid and does not involve any distribution activity. The direct customer's inverse demand for electricity is written as $p_{dc,t}\left(\mathbf{q}_{dc}^{\mathrm{d}}\right)$, with $\mathbf{q}_{dc}^{d} = \left[q_{dc,1}^{d},...,q_{dc,\mathcal{T}}^{d}\right]$. Again, this inverse demand is downward sloping and concave. Finally, the set $\mathcal{M}^{+}$ is defined as $\mathcal{M} \cup \{dc\}$.

The per-unit price paid by customers is equal to the sum of the prices charged by the different firms operating in the electricity sector plus the value added tax $(t)$, i.e.

$$p_{m,t} = (1+t)\left(p_{m,t}^{w} + p_{m,t}^{tr} + p_{m,t}^{di} + p_{m,t}^{r}\right). \qquad \forall m \in \mathcal{M}^{+}, \forall t \in \mathcal{T} \tag{2}$$

The generation, transmission, distribution and retail firms charge the price $p_{m,t}^{w}, p_{m,t}^{tr}, p_{m,t}^{di}$ and $p_{m,r}^{r_j}$ respectively. By definition, direct customers are not supplied through the distribution grid, and therefore, we have $p_{dc,t}^{di} = p_{dc,t}^{r} = 0$.

The following paragraphs describe the basic structure of the model. It is assumed that all market players act in their own interest, i.e. all firms maximise profits and consumers maximise utility. Generators set quantities, taking transmission, distribution and retail (if applicable) prices as given. The transmission, the distribution and the retail firms all set the prices of their service, taking the prices set by the other players as given. The first-order conditions for each player’s optimisation problem are explicitly written down as they serve as an input for the numerical computations. In many cases, some additional results can be obtained from a simplification and reshuffling of these conditions. However, this is not done as we focus on the numerical results.

**Electricity generation**

One incumbent $(in)$ and one entrant $(en)$ generate electricity. Both firms maximise profits. In the most general formulation of the model, both firms have market power. The entrant supplies electricity to the liberalised market, whereas the incumbent supplies both the liberalised and the regulated market. In the liberalised market a Cournot game is played, in the regulated market the regulator sets the price.

Let $\mathcal{R}$ and $\mathcal{U}$ be the sets of regulated and liberalised (or unregulated) market segments, respectively, with $\mathcal{R} \cup \mathcal{U} = \mathcal{M}^{+}$ and $\mathcal{R} \cap \mathcal{U} = \varnothing$. Then $\mathbf{q}_{\mathcal{U}}^{in}$ and $\mathbf{q}_{\mathcal{R}}^{in}$ are the incumbent's output vector in the liberalised and the regulated markets. His profit is written as

$$\Pi^{in}\left(\mathbf{q}_{\mathcal{R}}^{in}, \mathbf{q}_{\mathcal{U}}^{in}\right) = \sum_{t \in \mathcal{T}}\left[\sum_{r \in \mathcal{R}} p_{r,t}^{w} q_{r,t}^{in} + \sum_{u \in \mathcal{U}} p_{u,t}^{w} q_{u,t}^{in} - C_{t}^{in}\left(Q_{t}^{in}\right)\right], \tag{3}$$

with $Q_{t}^{in} = \sum_{m \in \mathcal{M}^{+}} q_{m,t}^{in}$. This formulation assumes that each market segment has its own wholesale price $p_{j,t}^{w}$, with $j \in \{\mathcal{R}, \mathcal{U}\}$. This assumption is maintained all through the paper and also holds for the other players in the market. The incumbent firm takes the output decision of the entrant as given, as well as the prices set by the transmission, the distribution and the retail companies. Its impact on end-user prices is described through equation (2), with a tilde added to the prices that are considered as given, i.e.

$$p_{m,t}\left(\mathbf{q}_m^d\right) = (1+t)\left(p_{m,t}^w + \tilde{p}_{m,t}^{tr} + \tilde{p}_{m,t}^{di} + \tilde{p}_{m,t}^r\right) \qquad \forall m \in \mathcal{M}^+, \forall t \in \mathcal{T} \tag{4}$$

In some simulations, the generator is faced with a price ceiling $\overline{p}_{r,t}$ set by the regulator, i.e.

$$p_{r,t}^w + \tilde{p}_{r,t}^{tr} \leq \overline{p}_{r,t}\,, \qquad \left(\lambda_{r,t}^w\right) \qquad \forall r \in \mathcal{R}, t \in \mathcal{T} \tag{5}$$

with $\lambda_{r,t}^w$ the Lagrange multiplier of this price constraint.

The transport of electricity induces some losses, both at the transmission and at the distribution level. These losses are denoted $l_{tr}$ and $l_{di}$, respectively. Therefore, in order to satisfy the demand $q_{m,t}^d$, the generators have to supply $q_{m,t}^j$ with $j \in \{in, en\}$, such that

$$q_{m,t}^{in} + q_{m,t}^{en} = (1 + l_{tr})(1 + l_{di})\, q_{m,t}^d\,, \qquad \forall m \in \mathcal{M}^+, \forall t \in \mathcal{T} \tag{6}$$

with

$$\begin{aligned} l_{di} &\geq 0 && \forall m \in \mathcal{M} \\ l_{di} &= 0 && m = dc \end{aligned}$$

Note that, depending on the market segment and the scenario, the supply of the entrant can be zero.

In equation (3), the first two terms in the square brackets are revenues from electricity sales to the regulated and the unregulated market segments, respectively. The last term represents production costs. By assumption, production costs are convex.

Generator $j$'s generation capacity (in MW) is labelled $\overline{Q}^j$. In each period, aggregate output cannot exceed available generation capacity, denoted by $h_t\overline{Q}^j$, with $h_t$ the length of period $t$ (in hours). Therefore, we have

$$Q_t^j = \sum_{m\in\mathcal{M}^+} q_{m,t}^j \leq h_t \overline{Q}^j \qquad \left(\gamma_t^j\right) \qquad t \in \mathcal{T}, j \in \{in, en\} \tag{7}$$

Summarising, we have the following maximisation problem for the incumbent:

$$\begin{aligned} \underset{q_{m,t}^{in}}{\text{Max}} \quad & \Pi^{in}\left(\mathbf{q}_{\mathcal{R}}^{in}, \mathbf{q}_{\mathcal{U}}^{in}\right) = \sum_{t\in\mathcal{T}}\left[\sum_{r\in\mathcal{R}} p_{r,t}^w q_{r,t}^{in} + \sum_{u\in\mathcal{U}} p_{u,t}^w q_{u,t}^{in} - C_t^{in}\left(Q_t^{in}\right)\right] \\ s.t. \quad & p_{r,t}^w + \tilde{p}_{r,t}^{tr} \leq \overline{p}_{r,t} && \left(\lambda_{r,t}^w\right) \quad \forall r \in \mathcal{R}, \forall t \in \mathcal{T} \\ & Q_t^{in} \leq h_t \overline{Q}^{in} && \left(\gamma_t^{in}\right) \quad \forall t \in \mathcal{T} \\ & Q_t^{in} = \sum_{m\in\mathcal{M}^+} q_{m,t}^{in} && \forall t \in \mathcal{T} \\ & q_{m,t}^{in} + \tilde{q}_{m,t}^{en} = (1 + l_{tr})(1 + l_{di})\, q_{m,t}^d && \forall m \in \mathcal{M}^+, \forall t \in \mathcal{T} \\ & p_{m,t}\left(\mathbf{q}_m^d\right) = (1+t)\left(p_{m,t}^w + \tilde{p}_{m,t}^{tr} + \tilde{p}_{m,t}^{di} + \tilde{p}_{m,t}^r\right) && \forall m \in \mathcal{M}^+, \forall t \in \mathcal{T} \end{aligned} \tag{8}$$

Once again, note that a tilde indicates variables that are considered as given by the player. The constraints without a multiplier are substituted into the objective function and the other constraints before derivatives are taken. With $\mathcal{L}^{in}$ the incumbent's Lagrange function, this results in the following first order conditions

$\forall \rho \in \mathcal{R}, \forall \tau \in \mathcal{T}$ :

$$\frac{\partial \mathcal{L}^{in}}{\partial q_{\rho,\tau}^{in}} = p_{\rho,\tau}^{w} + \sum_{t\in\mathcal{T}} \left( q_{\rho,t}^{in} - \lambda_{\rho,\tau}^{w} \right) \frac{\partial p_{\rho,t}^{w}}{\partial q_{\rho,\tau}^{in}} - \frac{\partial C_{t}^{in}}{\partial q_{\rho,\tau}^{in}} - \gamma_{\tau}^{in} \leq 0 \qquad q_{\rho,\tau}^{in} \frac{\partial \mathcal{L}^{in}}{\partial q_{\rho,\tau}^{in}} = 0 \tag{9}$$

$$\frac{\partial \mathcal{L}^{in}}{\partial \lambda_{\rho,\tau}^{w}} = \overline{p}_{\rho,t}^{w} - \left( p_{\rho,\tau}^{w} + \tilde{p}_{\rho,\tau}^{tr} \right) \geq 0 \qquad \lambda_{\rho,\tau}^{w} \frac{\partial \mathcal{L}^{in}}{\partial \lambda_{\rho,\tau}^{w}} = 0 \tag{10}$$

$\forall \upsilon \in \mathcal{U}, \forall \tau \in \mathcal{T}$ :

$$\frac{\partial \mathcal{L}^{in}}{\partial q_{\upsilon,\tau}^{in}} = p_{\upsilon,\tau}^{w} + \sum_{t\in\mathcal{T}} q_{\upsilon,t}^{in} \frac{\partial p_{\upsilon,t}^{w}}{\partial q_{\upsilon,\tau}^{in}} - \frac{\partial C_{\tau}^{in}}{\partial q_{\upsilon,\tau}^{in}} - \gamma_{\tau}^{in} \leq 0 \qquad q_{\upsilon,\tau}^{in} \frac{\partial \mathcal{L}^{in}}{\partial q_{\upsilon,\tau}^{in}} = 0 \tag{11}$$

$\forall \tau \in \mathcal{T}$ :

$$\frac{\partial \mathcal{L}^{in}}{\partial \gamma_{\tau}^{in}} = h_{\tau} \bar{Q}^{in} - Q_{\tau}^{in} \geq 0 \qquad \gamma_{\tau}^{in} \frac{\partial \mathcal{L}^{in}}{\partial \gamma_{\tau}^{in}} = 0 \tag{12}$$

Now, consider the unregulated part of the electricity market, where the incumbent is faced with a competitor whose maximisation problem is

$$\begin{array}{llll}
\underset{q_{u,t}^{en}}{\text{Max}} & \Pi^{en}\left(\mathbf{q}_{\mathcal{U}}^{en}\right) = \sum_{t\in\mathcal{T}} \left[ \sum_{u\in\mathcal{U}} p_{u,t}^{w} q_{u,t}^{en} - C_{t}^{en}\left(Q_{t}^{en}\right) \right] & & \\
s.t. & Q_{t}^{en} \leq h_{t} \bar{Q}^{en} & \left(\gamma_{t}^{en}\right) & \forall t \in \mathcal{T} \\
& Q_{t}^{en} = \sum_{u\in\mathcal{U}} q_{u,t}^{en} & & \forall t \in \mathcal{T} \\
& \tilde{q}_{u,t}^{in} + q_{u,t}^{en} = \left(1 + l_{tr}\right)\left(1 + l_{di}\right) q_{u,t}^{d} & & \forall u \in \mathcal{U}, \forall t \in \mathcal{T} \\
& p_{u,t}\left(\mathbf{q}_{u}^{d}\right) = (1 + t)\left( p_{u,t}^{w} + \tilde{p}_{u,t}^{tr} + \tilde{p}_{u,t}^{di} + \tilde{p}_{u,t}^{r} \right) & &
\end{array} \tag{13}$$

This results in the following first-order conditions for the entrant:

$\forall \upsilon \in \mathcal{U}, \forall \tau \in \mathcal{T}$ :

$$\frac{\partial \mathcal{L}^{en}}{\partial q_{\upsilon,\tau}^{en}} = p_{\upsilon,\tau}^{w} + \sum_{t\in\mathcal{T}} q_{\upsilon,t}^{en} \frac{\partial p_{\upsilon,t}^{w}}{\partial q_{\upsilon,\tau}^{en}} - \frac{\partial C_{\tau}^{en}}{\partial q_{\upsilon,\tau}^{en}} - \gamma_{\tau}^{en} \leq 0 \qquad q_{\upsilon,\tau}^{en} \frac{\partial \mathcal{L}^{en}}{\partial q_{\upsilon,\tau}^{en}} = 0 \tag{14}$$

$\forall \tau \in \mathcal{T}$ :

$$\frac{\partial \mathcal{L}^{en}}{\partial \gamma_{\tau}^{en}} = h_{\tau} \bar{Q}^{en} - Q_{\tau}^{en} \geq 0 \qquad \gamma_{\tau}^{en} \frac{\partial \mathcal{L}^{en}}{\partial \gamma_{\tau}^{en}} = 0 \tag{15}$$

These are the traditional first-order conditions for profit maximisation, i.e. marginal revenue equals marginal cost in all market segments. In fact, equations (11) and (14) are the reaction functions of the incumbent and the entrant, respectively. Given the assumptions on the demand and the cost functions, a pure strategy Cournot equilibrium exists in the liberalised market.

**Electricity transmission**

The simulations focus on the effects of structural and regulatory changes in the electricity sector. Therefore, the technical features of transmission and distribution are modelled in a very simple and straightforward way. The transmission grid contains one transmission line with capacity $\bar{Q}^{tr}$, and the grid operator is assumed to be a profit-maximising firm, subject to regulation. The transmission firm takes the generation, distribution and retail prices as fixed and optimises its profit by setting transmission prices $p^{tr}_{m,t}$ and transmission capacity $\bar{Q}^{tr}$. It is assumed that the cost of providing transmission services is separable into operating costs and capacity costs. In general, one transmission price can be set in each market segment, but it can also be imposed that the grid operator has to charge a postage stamp tariff. In the latter case, this uniform price should be such that the firm's profit equals zero. The firm is subject to a regulation constraint $R^{tr}$. Different regulation schemes can be simulated. They will be discussed later. This results in the following optimisation problem

$$\begin{aligned}
\underset{p^{tr}_{m,t},\bar{Q}^{tr}}{\text{Max}} \quad & \Pi^{tr} = \sum_{t\in\mathcal{T}}\left\{\sum_{m\in\mathcal{M}^+} p^{tr}_{m,t} q^{tr}_{m,t} - C^{tr}_t\left(Q^{tr}_t\right)\right\} - Hk^{tr}\bar{Q}^{tr} && && \\
s.t. \quad & \frac{Q^{tr}_t}{h_t} \le \bar{Q}^{tr} && \left(\gamma^{tr}_t\right) && \forall t\in\mathcal{T} \\
& Q^{tr}_t = \left(1+l_{tr}\right)\sum_{m\in\mathcal{M}^+} q^{tr}_{m,t} && && \forall t\in\mathcal{T} \\
& 0 \le R^{tr} && \left(\mu^{tr}\right) && \\
& q^{tr}_{m,t} = \left(1+l_{di}\right) q^{d}_{m,t} && && \forall m\in\mathcal{M}^+, \forall t\in\mathcal{T} \\
p_{m,t}\left(\mathbf{q}^d_m\right) & = (1+t)\left(\tilde{p}^{w}_{m,t} + p^{tr}_{m,t} + \tilde{p}^{di}_{m,t} + \tilde{p}^{r}_{m,t}\right) && && \forall m\in\mathcal{M}^+, \forall t\in\mathcal{T} \\
& p^{tr} = p^{tr}_{m,t} && \left(\xi^{tr}_{m,t}\right) && \forall m\in\mathcal{M}^+, \forall t\in\mathcal{T}
\end{aligned} \tag{16}$$

with $H = \sum_{t\in\mathcal{T}} h_t$. Furthermore, $Q^{tr}_t$ is the total amount of electricity transported through the transmission grid in period $t$. Three regulation constraints are considered

$$R^{tr}_{ROR}: \quad R^{tr} = \left(s^{tr} - k^{tr}\right) H\bar{Q}^{tr} - f^{tr}\left(H\bar{Q}^{tr} - \sum_{t\in\mathcal{T}} Q^{tr}_t\right) - \frac{g^{tr} H}{\left(\hat{Q}^{tr}\right)^{\xi-1}}\left(\bar{Q}^{tr} - \hat{Q}^{tr}\right)^{\xi} - \Pi^{tr} \tag{17}$$

$$R^{tr}_{CPU}: \quad R^{tr} = \left(s^{tr} - k^{tr}\right)\sum_{t\in\mathcal{T}} Q^{tr}_t - \Pi^{tr} \tag{18}$$

$$R^{tr}_{PC}: \quad R^{tr} = \left(1+l_{tr}\right)\left\{\sum_{t\in\mathcal{T}}\sum_{m\in\mathcal{M}^+} \overline{p}^{tr}_{m,t}\overline{q}^{tr}_{m,t} - \sum_{t\in\mathcal{T}}\sum_{m\in\mathcal{M}^+} p^{tr}_{m,t}\overline{q}^{tr}_{m,t}\right\} \tag{19}$$

Constraint $R^{tr}_{ROR}$ is rate-of-return regulation, where the cap on profits is a function of the regulated asset base. It is assumed that the asset base is proportional to transmission capacity, with $s^{tr}$ the allowed, fair rate-of-return, $k^{tr}$ the cost of capital, and $s^{tr} > k^{tr}$. $f^{tr}$ is a penalty for unused transmission capacity. The regulator has some exogenous idea on what is an acceptable level of transmission capacity, labelled $\hat{Q}^{tr}$. Investment in capacity beyond $\hat{Q}^{tr}$ is penalised at an increasing rate[5]. The ROR-regulation mechanism (17) gives incentives to increase capacity and to reduce large periodical differences in electricity demand. The underlying idea is that this latter incentive should induce lower transmission prices in periods

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[5] Note that, capacity levels below $\hat{Q}^{tr}$ are also penalised according to our formula.

where transmission capacity is not binding, because this smoothens demand and thus reduces the penalty.

Constraint $R_{CPU}^{tr}$ captures the idea that the transmission firm should be rewarded for low electricity prices (and thus higher demand). This constraint is equivalent to permitting the firm to earn a fixed profit per unit of output and gives the firm an incentive for cost minimisation. Thus, with $k^{tr} > 0$ the firm will not invest in capacity in excess of what is needed to transport the traded electricity flows. Note that this incentive for cost minimisation is not given with the first regulation mechanism, where capacity costs and other costs are treated asymmetrically in the sense that firms have an incentive to increase capacity in order to increase the profit ceiling.

The last constraint $R_{PC}^{tr}$ represents price-cap regulation. The (weighted) average transmission price should not exceed a predefined level, but it is left to the transmission firm to decide on the tariff *structure*.

With $\mathcal{L}^{tr}$ the Lagrange function, the first-order conditions are

$\forall m \in \mathcal{M}^+, \forall \tau \in \mathcal{T}$ :

$$\frac{\partial \mathcal{L}^{tr}}{\partial p_{m,\tau}^{tr}} = (1+l_{di}) \begin{Bmatrix} q_{m,\tau}^{d} + \sum_{t\in\mathcal{T}} p_{m,t}^{tr} \frac{\partial q_{m,t}^{d}}{\partial p_{m,\tau}^{tr}} \\ -(1+l_{tr}) \sum_{t\in\mathcal{T}} \frac{\partial C_t^{tr}}{\partial Q_t^{tr}} \frac{\partial q_{m,t}^{d}}{\partial p_{m,\tau}^{tr}} \end{Bmatrix} + \mu^{tr} \frac{\partial R^{tr}}{\partial p_{m,t}^{tr}} - (1+l_{tr})(1+l_{di}) \sum_{t\in\mathcal{T}} \frac{\gamma_t^{tr}}{h_t} \frac{\partial q_{m,t}^{d}}{\partial p_{m,\tau}^{tr}} - \xi_{m,\tau}^{tr} \leq 0 \qquad p_{m,\tau}^{tr} \frac{\partial \mathcal{L}^{tr}}{\partial p_{m,\tau}^{tr}} = 0 \tag{20}$$

$$\frac{\partial \mathcal{L}^{tr}}{\partial \xi_{m,\tau}^{tr}} = p^{tr} - p_{m,\tau}^{tr} = 0 \qquad \xi_{m,\tau}^{tr} \frac{\partial \mathcal{L}^{tr}}{\partial \xi_{m,\tau}^{tr}} = 0 \tag{21}$$

$\forall \tau \in \mathcal{T}$ :

$$\frac{\partial \mathcal{L}^{tr}}{\partial \gamma_\tau^{tr}} = \bar{Q}^{tr} - \frac{Q_\tau^{tr}}{h_\tau} \geq 0 \qquad \gamma_\tau^{tr} \frac{\partial \mathcal{L}^{tr}}{\partial \gamma_\tau^{tr}} = 0 \tag{22}$$

Furthermore, we have:

$$\frac{\partial \mathcal{L}^{tr}}{\partial \bar{Q}^{tr}} = -Hk^{tr} + \sum_{t\in\mathcal{T}} \gamma_t^{tr} + \mu^{tr} \frac{\partial R^{tr}}{\partial \bar{Q}^{tr}} \leq 0 \qquad \bar{Q}^{tr} \frac{\partial \mathcal{L}^{tr}}{\partial \bar{Q}^{tr}} = 0 \tag{23}$$

$$\frac{\partial \mathcal{L}^{tr}}{\partial \mu^{tr}} = R^{tr} \geq 0 \qquad \mu^{tr} \frac{\partial \mathcal{L}^{tr}}{\partial \mu^{tr}} = 0 \tag{24}$$

Depending on the regulation mechanism, the terms $\frac{\partial R^{tr}}{\partial p_{m,t}}$ and $\frac{\partial R^{tr}}{\partial \bar{Q}^{tr}}$ are replaced by

$R_{CPU}^{tr}$ :

$$\frac{\partial R^{tr}}{\partial p_{m,t}^{tr}} = (s^{tr} - k^{tr})(1+l_{di})(1+l_{tr}) \sum_{t\in\mathcal{T}} \frac{\partial q_{m,t}^{d}}{\partial p_{m,\tau}^{tr}} - (1+l_{di}) \left\{ q_{m,\tau}^{d} + \sum_{t\in\mathcal{T}} p_{m,t}^{tr} \frac{\partial q_{m,t}^{d}}{\partial p_{m,\tau}^{tr}} - (1+l_{tr}) \sum_{t\in\mathcal{T}} \frac{\partial C_t^{tr}}{\partial Q_t^{tr}} \frac{\partial q_{m,t}^{d}}{\partial p_{m,\tau}^{tr}} \right\} \tag{25}$$

$$\frac{\partial R^{tr}}{\partial \bar{Q}^{tr}} = Hk^{tr} \tag{26}$$

$R^{tr}_{ROR}$ :

$$\begin{aligned}\frac{\partial R^{tr}}{\partial p^{tr}_{m,\tau}} &= f^{tr}\left(1+l_{di}\right)\left(1+l_{tr}\right)\sum_{t\in\mathcal{T}}\frac{\partial q^{d}_{m,t}}{\partial p^{tr}_{m,\tau}} \\ &\quad -\left(1+l_{di}\right)\left\{q^{d}_{m,\tau}+\sum_{t\in\mathcal{T}}p^{tr}_{m,t}\frac{\partial q^{d}_{m,t}}{\partial p^{tr}_{m,\tau}}-\left(1+l_{tr}\right)\sum_{t\in\mathcal{T}}\frac{\partial C^{tr}_{t}}{\partial Q^{tr}_{t}}\frac{\partial q^{d}_{m,t}}{\partial p^{tr}_{m,\tau}}\right\}\end{aligned} \tag{27}$$

$$\frac{\partial R^{tr}}{\partial \bar{Q}^{tr}} = \left(s^{tr}-f^{tr}\right)H - \frac{g^{tr}H\xi}{\left(\hat{Q}^{tr}\right)^{\xi-1}}\left(\bar{Q}^{tr}-\hat{Q}^{tr}\right)^{\xi-1} \tag{28}$$

$R^{tr}_{PC}$ :

$$\frac{\partial R^{tr}}{\partial p^{tr}_{m,t}} = -\bar{q}^{d}_{m,t} \tag{29}$$

$$\frac{\partial R^{tr}}{\partial \bar{Q}^{tr}} = 0 \tag{30}$$

**Electricity distribution**

Distribution companies are local natural monopolies. In the pre-liberalisation period, it is assumed that electricity distribution and retail are integrated in one regulated company. These companies are then subject to a price cap. After the liberalisation, the structure of activities will be the subject of two simulation scenarios. In these latter scenarios a regulation mechanism is assumed along the same lines as the mechanisms that are analysed for the transmission firm.

The first post-liberalisation scenario assumes that electricity distribution and retail are vertically integrated in the distribution company. The second scenario assumes unbundling in electricity distribution and retail. This, however, does not change the formal structure of the distribution company's optimisation problem. By assumption, it will only affect the parameter values at the cost side.

The optimisation problem of distribution company $i$ is written as:

$$\begin{aligned}
\underset{p^{d}_{h,i,t},\bar{Q}^{di}_{i}}{\text{Max}} \quad & \Pi^{di}_{i} = \sum_{t\in\mathcal{T}}\left\{\sum_{h\times\mathcal{H}}p^{di}_{h,i,t}q^{di}_{h,i,t} - C^{di}_{i,t}\left(Q^{di}_{i,t}\right) - Hk^{di}\bar{Q}^{di}_{i}\right\} & & \\
s.t. \quad & \frac{Q^{di}_{i,t}}{h_{t}} \le \bar{Q}^{di}_{i} & \left(\gamma^{di}_{i,t}\right) \quad & \forall t\in\mathcal{T} \\
& Q^{di}_{i,t} = \left(1+l_{di}\right)\sum_{h\in\mathcal{H}}q^{d}_{h,i,t} & & \forall t\in\mathcal{T} \\
& 0 \le R^{di}_{i} & \left(\mu^{di}_{i}\right) \quad & \\
& q^{di}_{h,i,t} = q^{d}_{h,i,t} & & \forall h\in\mathcal{H},\forall t\in\mathcal{T} \\
& p_{h,i,t}\left(\mathbf{q}^{d}_{h,i}\right) = (1+t)\left(\tilde{p}^{w}_{h,i,t}+\tilde{p}^{tr}_{h,i,t}+p^{di}_{h,i,t}+\tilde{p}^{r}_{h,i,t}\right) & & \forall h\in\mathcal{H},\forall t\in\mathcal{T} \\
& p^{di}_{i} = p^{di}_{h,i,t} & \left(\xi^{di}_{h,i,t}\right) \quad & \forall h\in\mathcal{H},\forall t\in\mathcal{T} \\
& p^{di}_{h,i,t} \le \bar{p}^{di}_{h,i,t} & \left(\lambda^{di}_{h,i,t}\right) \quad & \forall h\in\mathcal{H},\forall t\in\mathcal{T}
\end{aligned} \tag{31}$$

$R_i^{di}$ describes the regulation mechanism for distribution company $i$. The same mechanisms as those described in the eqs. (17)-(19) are used. However, now we use the superscript $di$ to indicate distribution specific values. The first-order conditions for this optimisation problem are

$\forall \iota \in \mathcal{I}, \forall \eta \in \mathcal{M}, \forall \tau \in \mathcal{T}$ :

$$\begin{aligned}\frac{\partial \mathcal{L}^{di}}{\partial p^{di}_{\eta,\iota,\tau}} = &\left\{ q^d_{\eta,\iota,\tau} + \sum_{t\in\mathcal{T}} p^{di}_{\eta,\iota,t} \frac{\partial q^d_{\eta,\iota,t}}{\partial p^{di}_{\eta,\iota,\tau}} - (1+l_{di}) \sum_{t\in\mathcal{T}} \frac{\partial C^d_{\iota,t}}{\partial q^d_{\eta,\iota,\tau}} \frac{\partial q^d_{\eta,\iota,t}}{\partial p^{di}_{\eta,\iota,\tau}} \right\} \\ &+\mu^{di}_\iota \frac{\partial R^{di}_\iota}{\partial p^{di}_{\eta,\iota,\tau}} - (1+l_{di}) \sum_{t\in\mathcal{T}} \frac{\gamma^{di}_{\iota,t}}{h_t} \frac{\partial q^d_{\eta,\iota,t}}{\partial p^d_{\eta,\iota,\tau}} - \xi^{di}_{\eta,\iota,\tau} - \lambda^{di}_{\eta,\iota,\tau} \le 0 \end{aligned} \qquad p^{di}_{\eta,\iota,\tau} \frac{\partial \mathcal{L}^{di}}{\partial p^{di}_{\eta,\iota,\tau}} = 0 \quad (32)$$

$$\frac{\partial \mathcal{L}^{di}}{\partial \xi^{di}_{\eta,\iota,\tau}} = p^{di}_\iota - p^{di}_{\eta,\iota,\tau} = 0 \qquad \xi^{di}_{\eta,\iota,\tau} \frac{\partial \mathcal{L}^{di}}{\partial \xi^{di}_{\eta,\iota,\tau}} = 0 \quad (33)$$

$$\frac{\partial \mathcal{L}^{di}}{\partial \lambda^{di}_{\eta,\iota,\tau}} = \bar{p}^{di}_{\eta,\iota,\tau} - p^{di}_{\eta,\iota,\tau} \ge 0 \qquad \lambda^{di}_{\eta,\iota,\tau} \frac{\partial \mathcal{L}^{di}}{\partial \lambda^{di}_{\eta,\iota,\tau}} = 0 \quad (34)$$

$\forall \iota \in \mathcal{I}, \forall \tau \in \mathcal{T}$ :

$$\frac{\partial \mathcal{L}^{di}}{\partial \gamma^{di}_{\iota,\tau}} = \bar{Q}^{di}_\iota - \frac{Q^{di}_{\iota,\tau}}{h_\tau} \ge 0 \qquad \gamma^{di}_{\iota,\tau} \frac{\partial \mathcal{L}^{di}}{\partial \gamma^{di}_{\iota,\tau}} = 0 \quad (35)$$

$\forall \iota \in \mathcal{I}$ :

$$\frac{\partial \mathcal{L}^{di}}{\partial \bar{Q}^{di}_\iota} = -Hk^{di}_\iota + \sum_{t\in\mathcal{T}} \gamma^{di}_{\iota,t} - \mu^{di}_\iota \frac{\partial R^{di}_\iota}{\partial \bar{Q}^{di}_\iota} \le 0 \qquad \bar{Q}^{di}_\iota \frac{\partial \mathcal{L}^{di}}{\partial \bar{Q}^{di}_\iota} = 0 \quad (36)$$

$$\frac{\partial \mathcal{L}^{di}}{\partial \mu^{di}_\iota} = R^{di}_\iota \ge 0 \qquad \mu^{di}_\iota \frac{\partial \mathcal{L}^{di}}{\partial \mu^{di}_\iota} = 0 \quad (37)$$

Again, the definition of $\frac{\partial R^{di}_\iota}{\partial p^{di}_{\eta,\iota,\tau}}$ and $\frac{\partial R^{di}_\iota}{\partial \bar{Q}^{di}_\iota}$ depends on the regulation mechanism:

$R^{di}_{CPU,\iota}$ :

$$\begin{aligned}\frac{\partial R^{di}_\iota}{\partial p^{di}_{\eta,\iota,\tau}} = &(s^{di} - k^{di})(1+l_{di}) \sum_{t\in\mathcal{T}} \frac{\partial q^d_{\eta,\iota,t}}{\partial p^d_{\eta,\iota,\tau}} \\ &- \left\{ q^d_{\eta,\iota,\tau} + \sum_{t\in\mathcal{T}} p^{di}_{\eta,\iota,t} \frac{\partial q^d_{\eta,\iota,t}}{\partial p^{di}_{\eta,\iota,\tau}} - (1+l_{di}) \sum_{t\in\mathcal{T}} \frac{\partial C^d_{\iota,t}}{\partial q^d_{\eta,\iota,\tau}} \frac{\partial q^d_{\eta,\iota,t}}{\partial p^{di}_{\eta,\iota,\tau}} \right\}\end{aligned} \quad (38)$$

$$\frac{\partial R^{di}_\iota}{\partial \bar{Q}^{di}_\iota} = Hk^{di} \quad (39)$$

$R^{di}_{ROR,\iota}$ :

$$\begin{aligned}\frac{\partial R^{di}_\iota}{\partial p^{di}_{\eta,\iota,\tau}} = &f^{di}(1+l_{di}) \sum_{t\in\mathcal{T}} \frac{\partial q^d_{\eta,\iota,t}}{\partial p^d_{\eta,\iota,\tau}} \\ &- \left\{ q^d_{\eta,\iota,\tau} + \sum_{t\in\mathcal{T}} p^{di}_{\eta,\iota,t} \frac{\partial q^d_{\eta,\iota,t}}{\partial p^{di}_{\eta,\iota,\tau}} - (1+l_{di}) \sum_{t\in\mathcal{T}} \frac{\partial C^d_{\iota,t}}{\partial q^d_{\eta,\iota,\tau}} \frac{\partial q^d_{\eta,\iota,t}}{\partial p^{di}_{\eta,\iota,\tau}} \right\}\end{aligned} \quad (40)$$

$$\frac{\partial R^{di}_\iota}{\partial \bar{Q}^{di}_\iota} = (s^{di} - f^{di})H - \frac{g^{di} H \xi}{\left(\hat{Q}^{di}_\iota\right)^{\xi-1}} \left(\bar{Q}^{di}_\iota - \hat{Q}^{di}_\iota\right)^{\xi-1} \quad (41)$$

$R^{di}_{PC,\iota}$ :

$$\frac{\partial R^{di}_{\iota}}{\partial p^{di}_{\eta,\iota,\tau}} = -\bar{q}^{d}_{\eta,\iota,\tau} \tag{42}$$

$$\frac{\partial R^{di}_{\iota}}{\partial \bar{Q}^{di}_{\iota}} = 0 \tag{43}$$

**The retail sector**

Two firms operate in retail when the distribution sector is unbundled. Retail companies are independent and profit maximising firms that sell in all market segments supplied via the distribution grid. Retailer $j$'s profit function is

$$\Pi^{r_j} = \sum_{t\in\mathcal{T}}\left\{\sum_{m\in\mathcal{M}} p_{m,t}q^{r_j}_{m,t} - C^{r_j}_t\left(Q^{r_j}_t\right)\right\} \tag{44}$$

with $Q^{r_j}_t = \sum_{m\in\mathcal{M}} q^{r_j}_{m,t}$ in all periods $t \in \mathcal{T}$. Retail companies merely act as sales companies and, therefore, they are not subject to any kind of physical capacity constraint, as it was the case for the generation, transmission and distribution firms. The sector is behaves competitively, and the first-order conditions that characterise the outcome for firm $j$ are

$$\frac{\partial \mathcal{L}^{r_j}}{\partial q^{r_j}_{\mu,\tau}} = p_{\mu,\tau} - \frac{\partial C^{r_j}_t}{\partial q^{r_j}_{\mu,\tau}} \leq 0 \qquad q^{r_j}_{\mu,\tau}\frac{\partial \mathcal{L}^{r_j}}{\partial q^{r_j}_{\mu,\tau}} = 0 \qquad \forall \mu \in \mathcal{M}, \tau \in \mathcal{T} \tag{45}$$

**Welfare evaluation**

Simultaneously solving the first-order conditions that emerge from the behaviour described above, results in the outcome for the electricity sector. On the basis of this, welfare is calculated as the sum of consumer surpluses, the producer surpluses of the generators, the transmission and the distribution firms, and the tax revenues (value added tax). In the welfare calculation we assume that $\left(1-\omega^{j}\right)$ percent of the incumbent's and the entrant's surplus flows abroad. This share is not taken into account in the welfare calculation. Welfare $W$ is then calculated as

$$W = \sum_{m\in\mathcal{M}^{+}} CS_m + \omega^{in}PS^{in} + \omega^{en}PS^{en} + PS^{tr} + PS^{di} + \sum_{j} PS^{r_j} + T\,. \tag{46}$$

# 3. SCENARIOS, DATA AND MODEL CALIBRATION

The model is calibrated on the basis of data for the Flemish electricity distribution sector in 1998[6]. The next subsections discus the scenarios, the functional forms and parameters and the simulation results.

6 This year was chosen because of data availability. The Statistical yearbook of the Beroepsfederatie van de Producenten en Verdelers van Elektriciteit in België (1999) was used as the major source of data. Some information was also collected from a selection of 1998 annual reports of the Flemish mixed and pure intermunicipalities and regies and through contacts with the distribution sector.

## 3.1. The scenarios

Two post-liberalisation scenarios are considered. In the first, the distribution sector is vertically integrated. Distribution companies can choose between two electricity generation companies when buying electricity on the wholesale market. Furthermore, a new regulation mechanism is imposed. The second scenario separates the old distribution firms into a regulated distribution companies for the transport activities and two competitive (non-regulated) retail companies for the sales activities. These latter companies merely buy electricity from the generators in order to sell to the final customers. Clearly, when retail firms would have market power, this would result in an additional double marginalisation problem[7]. However, as the retail sector is assumed to behave perfectly competitive, this double marginalisation problem can safely be omitted.

Furthermore, note that if the old integrated distribution firm would be unbundled in two separate firms, where the separation would not result in cost savings nor increases, then there would be no difference in the simulation results of scenario 1 and scenario 2. That is, $p^{di}_{m,t}$ in scenario 1 would be equal to $p^{di}_{m,t} + p^{r}_{m,t}$ in scenario 2. For the simulations in this paper, it is assumed that marginal retail costs are equal to a weighted average of the marginal cost reductions realised in the three types of distribution companies when they are unbundled. Therefore, some changes in the simulation results can be expected, although they are likely to be small.

Apart from the two post-liberalisation scenario's, one additional scenario is simulated that mimics the situation before the liberalisation. This scenario serves as a benchmark. The next subsections describe the scenarios in more detail.

### 3.1.1. The reference scenario

The reference scenario simulates an electricity market that has the typical characteristics of the Flemish electricity distribution sector in the late nineties. One incumbent generator supplies all markets[8]. These markets are regulated through the fixing of price ceilings at the wholesale as well as at the retail level. The regulator, through a cost-plus based procedure, sets these price ceilings. The electricity transmission company is owned and controlled by the incumbent and it is assumed that it operates under a zero profit condition. Revenues are collected through a postage stamp charge.

Three distribution companies carry out electricity distribution, i.e. a mixed intermunicipality (MIC), a pure intermunicipality (PIC) and a Regie. The incumbent generator and some Flemish municipalities jointly own the MIC, the PIC is owned by municipalities and the Regie is a small-scale distribution company owned and operated by one single municipality. Each firm

[7] A double marginalisation problem already exists between the generation, the transmission and the distribution firms.

[8] Note that in Belgium, there are two incumbent generators, the first one (Electrabel) covering about 90% of the market, the second one (SPE) covering about 8% of the market. As both generators cooperate intensively, we can safely assume that, in the reference scenario, the Flemish market is supplied through one single generator.

maximises profit, without taking into account cross-ownership structures. The difference in ownership structures is assumed to have no effect on the nature of the different optimisation problems[9]. The MIC distributes and supplies electricity to 80% of the household and SME market, the PIC has a market share of about 18% and the Regie supplies the remainder.

The three types of distribution firms are distinguished because of observed cost differences and mainly because they have different rules for the distribution of profits.

### *3.1.2. Liberalising generation with integrated distribution and retail*

The post-liberalisation scenarios introduce an entrant in the generation market. This entrant increases the available generation capacity with 30% and he is assumed to behave as a price taker[10]. Furthermore, all market segments are liberalised, i.e. the prices are set by the interaction of demand and supply.

Generation and transmission are unbundled. The transmission company and the integrated distribution companies are subject to regulation. The type of regulation is the subject of simulation exercises. The municipalities own the transmission company for 30%, and therefore, it is assumed that they receive a proportional share of transmission profits.

Transmission and distribution firms each decide on the price of their services, taking the prices of the other players as given.

### *3.1.3. Liberalising generation with unbundled distribution and retail*

The second scenario considers a separation of distribution and retail activities. The intermunicipalities and the Regie will take care of electricity distribution; retail activities are moved into two new firms. Clearly, this will have implications on the ownership structure of the firms operating in electricity distribution. In this paper, we adopt the following assumptions. The profit of the PIC is fully captured by the municipalities, whereas the municipalities capture 70% of the MIC's profit from distribution activities. The incumbent generator captures the remaining 30%. The municipalities supplied through the MIC's distribution area also reap 40% of the profits of the incumbents retail company.

9 One could assume that the players take into account the ownership structures in their maximisation problem. For example, the generator could maximise the sum of its generation profit and of its profit share in the MIC's profit. See for example Amundsen and Bergman (2002) for a model that explicitly considers ownership structure.

10 In section 2 we presented a model that allowed for Cournot competition. However, for the sake of simplicity and because of the illustrative nature of the simulations, we decided to assume the competitor to be a competitive fringe.

| | Reference Scenario | Integrated Distribution Scenario | Unbundled Distribution Scenario |
|---|---|---|---|
| **Description** | • All markets are regulated and subject to wholesale and consumer price constraints.<br>• Distribution and retail are integrated in one firm. Three types of distribution companies are distinguished. | • All markets are liberalised. No price constraints.<br>• Distribution companies have free choice as to where to buy electricity. | • Distribution and retail are unbundled.<br>• Retail companies have free choice as to where to buy electricity. |
| **Generation** | • One incumbent generator supplying all markets.<br>• The generator sets the wholesale price in all market segments (subject to the price constraint) | • Both the incumbent and the entrant can supply all markets.<br>• The incumbent generator has market power. The entrant acts as a price taker. One wholesale price in each market segment. | |
| **Transmission** | • Transmission and generation are integrated.<br>• The transmission company is assumed to operate under a zero profit constraint and charges uniform prices. | • Transmission and generation are unbundled.<br>• The transmission company is subject to regulation. | |
| **Distribution** | • Distribution and retail integrated in one firm. | | • The electricity distribution firm is subject to regulation. |
| **Retail** | • NA | • NA | • Retail firm sells electricity in a competitive market. Acts as a price taker. |

**Table 1:** Description of the scenarios simulated with the model.

Two retail companies emerge in the unbundled and perfectly competitive retail market. These companies are vertically separated from the generation companies. Due to the assumptions of perfect competitiveness and about the cost structure of the retail sector, retail profits are zero.

**Table 1** summarises the scenarios. Only changes relative to the previous scenario are indicated.

## *3.2. Data and model calibration*

The simulations in this paper serve as an illustration of what can be done with the model. The price and quantity data closely match the values that are observed for the Flemish electricity market in 1998. However, this is *not* necessarily the case for the implied price elasticities of demand and for the parameters of the regulation mechanisms. Therefore, not too much attention should be paid to the size of the simulated changes. At best, the simulations indicate and illustrate sensitivities and the effects of different incentive schemes. For the moment, our main intention is to illustrate the sign of the impact of different regulation mechanisms. The size of the simulated cash flows towards municipalities can drastically change when the model is solved with other parameter values than those that are assumed in this section.

**Electricity demand**

Six periods are distinguished: winter peak (w-p), winter off-peak (w-op), mid-season peak (m-p), mid-season off-peak (m-op), summer peak (s-p) and summer off-peak (s-op) demand. These periods have different length $h_t$, measured in hours (see Table 3). Furthermore, three different types of electricity customers are identified, i.e. direct customers (dc), households (hh) and Small and Medium Enterprises (SME). Households and SMEs are supplied through the distribution grid; direct customers are supplied via the transmission grid. The distinction between these three categories is based on the voltage level at which electricity is supplied to the customers. At the distribution level, three (types of) distribution firms are assumed, i.e. mixed intermunicipalities (MIC), pure intermunicipalities (PIC) and regies. This results in the following set definitions:

$$\mathcal{I} = \{\text{pic, mic, regie}\}$$

$$\mathcal{H} = \{\text{hh, SME}\}$$

$$\mathcal{T} = \{\text{w-p, w-op, m-p, m-op, s-p, s-op}\}$$

Linear inverse electricity demand in all periods is assumed. In each market segment, substitution between time-periods is allowed, i.e.

$$p_{m,t} = a_{m,t} + \sum_{\tau \in \mathcal{T}} b_{m,t}^{\tau} q_{m,\tau} \qquad \forall m \in \mathcal{M}^{+}, t \in \mathcal{T} \tag{47}$$

However, in the simulation exercises no inter-period substitution is assumed, i.e. cross-price elasticities are set to zero. In the base case, direct customers, households and SMEs buy electricity in the regulated market. As described in subsection 3.1, these assumptions will change through the simulation exercises.

| | Own | Cross |
|---|---|---|
| **Households** | -1,500 | 0,000 |
| **SMEs** | -2,200 | 0,000 |
| **Direct customers** | -2,500 | 0,000 |

**Table 2:** Own and cross-price elasticities for peak and off-peak periods.

Table 3 shows observed demand and prices in 1998. Using this information, the parameters of the inverse demand functions are constructed such that own-price elasticities of demand are close to the values in Table 2. The final result is demand parameters that – in the reference scenario – closely reproduce the observed data in Table 3.

| **Variable** | $h_t$ | **MIC** | | **PIC** | | **Regies** | | **Direct Customers** |
|---|---|---|---|---|---|---|---|---|
| | | **hh** | **SME** | **hh** | **SME** | **hh** | **SME** | **dc** |
| **Quantities (GWh)** | | | | | | | | |
| Winter Peak | 1.460 | 2.186,9 | 2.567,2 | 621,6 | 488,4 | 63,7 | 42,6 | 4.443,6 |
| Winter Off-peak | 1.460 | 1.711,5 | 1.457,9 | 466,2 | 273,8 | 47,4 | 23,4 | 2.665,5 |
| Mid-season Peak | 2.190 | 3.089,5 | 3.684,3 | 876,0 | 688,3 | 91,4 | 60,9 | 6.188,5 |
| Mid-season Off-peak | 2.190 | 2.690,4 | 2.291,8 | 758,6 | 408,5 | 73,0 | 35,9 | 3.685,6 |
| Summer Peak | 730 | 892,2 | 1.047,3 | 252,2 | 198,2 | 26,9 | 17,9 | 1.688,7 |
| Summer Off-peak | 730 | 863,1 | 735,2 | 244,0 | 131,4 | 23,0 | 11,3 | 1.198,7 |
| **Prices (€ per kWh, excl. VAT)** | | | | | | | | |
| End-user price (excl.VAT) | | 0,118 | 0,078 | 0,121 | 0,077 | 0,119 | 0,079 | 0,054* |

* average annual price

**Table 3:** Data for model calibration.

The consumer surplus is calculated by using the underlying utility function. Given the linear inverse demand functions, utility is quadratic, i.e.

$$CS_m\left(\mathbf{q}_m^d\right) = \sum_{t\in\mathcal{T}}\sum_{\tau\in\mathcal{T}}\frac{b_{m,t}^{\tau}}{2}q_{m,t}^{\tau}q_{m,\tau}^{t} + \sum_{t\in\mathcal{T}}a_{m,t}q_{m,t}^{t} , \qquad (48)$$

with $b_{m,t}^{\tau} = b_{m,\tau}^{t}$ .

**Electricity generation**

One incumbent ($in$) and (depending on the simulation run) one entrant ($en$) firm generate electricity. Both firms maximise profits. The incumbent firm has market power and sells electricity to all consumer types; the entrant is price taker and operates in the liberalised market segments. In liberalised markets, demand and supply determine the electricity price, in the regulated markets a price ceiling is set by the regulation office. The incumbent's profit function is described by (3), the entrant's profit function by (13). Both firms are subject to some technical and regulation constraints. The number and type of constraints that is imposed depends on the simulation run.

For both firms, the generation cost is written as

$$C_t^j\left(Q_t^j\right) = \left[c_{1t}^j + \frac{c_{2t}^j}{\left(1+\phi^j\right)}\times\left(\frac{Q_t^j}{\overline{Q}^j}\right)^{\phi^j}\right]\times Q_t^j + F^j , \qquad j\in\{in,en\} \qquad (49)$$

with $F^j$ the fixed generation cost of firm $j$ and $\overline{Q}^j$ the generation capacity in firm $j$. From (49), it can be derived that the marginal cost equals

$$\frac{\partial C_t^j}{\partial Q_t^j} = c_{1t}^j + c_{2t}^j\times\left(\frac{Q_t^j}{\overline{Q}^j}\right)^{\phi^j} . \qquad j\in\{in,en\} \qquad (50)$$

The marginal cost of producing with the cheapest available generation technology is $c_{1t}^j$. The marginal generation cost at maximum generation capacity is $c_{1t}^j + c_{2t}^j$.

In regulated markets, the incumbent firm acts as a monopolist. In liberalised markets, the incumbent is faced with a competitive fringe. From the assumptions on the demand and cost functions, it can be derived that an equilibrium exists in each market segment.

Table 4 summarises the parameter values for the generation cost:

| Parameter | | Value incumbent | Value entrant |
|---|---|---|---|
| $c_{1t}^j$ | (€/kWh) | 0,0100 | 0,0124 |
| $c_{2t}^j$ | (€/kWh) | 0,0397 | 0,0347 |
| $F^j$ | (Mln €) | 0,0000 | 0,0000 |
| $\phi^j$ | | 3,0000 | 2,0000 |
| $\omega^j$ | | 0,5000 | 0,0000 |
| $\overline{Q}^j$ | (MW) | 8.900 | 2.500 |

**Table 4:** Parameters for the generation firms.

In the welfare calculation, it is assumed that the entrant is a foreign firm. Ownership of the incumbent firm is for 50% in the hands of foreign owners, i.e. $\omega^{in} = 0.5$ and $\omega^{en} = 0$ .

**Electricity transmission**[11]

In problem (16), it is assumed that the cost of providing transmission services is separable into operating costs and capacity costs. The operating costs contain a fixed cost component $\left(F^{tr}\right)$ and a volume dependent component $\left(c_t^{tr}\right)$. The transmission cost defined as:

$$C_t^{tr}\left(Q_t^{tr}\right) = \sum_{m \in \mathcal{M}} \left(c^{tr}\left(1 + l_{tr}\right) + \tilde{p}_{m,t}^{w} l_{tr}\right) q_{m,t}^{tr} + F^{tr} \tag{51}$$

Table 5 summarises the parameter choices for the transmission firm. In the simulation exercises, different assumptions are made with respect to the regulation mechanism that is imposed on the transmission company. The unit cost of transmission capacity $k^{tr}$ equals €0,0025 per kWh[12]. The allowed 'fair' return per unit of capital $s^{tr}$ is assumed equal to €0,00375 per kWh. Transmission losses equal 1% of the amount of electricity, which is put on the grid. We assume that the transmission firm pays for the cost of these transmission losses. The constant marginal cost of transmission is assumed equal to €0,0005, and the fixed transmission cost is equal to €99,157 Mln.

| Parameter | | Value |
|---|---|---|
| $k^{tr}$ | (€ per kWh) | 0,00250 |
| $s^{tr}$ | (€ per kWh) | 0,00375 |
| $f^{tr}$ | (€ per kWh) | 0,00000 |
| $g^{tr}$ | (€ per kWh) | 0,00000 |
| $\xi^{tr}$ | | 0,00000 |
| $l_t$ | (%) | 1,00000 |
| $c^{tr}$ | (€ per kWh) | 0,00050 |
| $F_t^{tr}$ | (Mln €) | 99,15741 |

**Table 5:** Parameters for electricity transmission.

**Electricity distribution**

Distribution firm $i$'s cost function is

$$C_{i,t}^{di}\left(Q_{i,t}^{di}\right) = \sum_{h \in \mathcal{H}} \left(\left(\tilde{p}_{h,i,t}^{w} + \tilde{p}_{i,t}^{tr}\right) l_{di} + \left(1 + l_{di}\right) c_{i,t}^{di}\right) q_{h,i,t}^{d} + F_i^{di}, \tag{52}$$

with $c_{i,t}^{di}$ the per-unit distribution cost of company $i$ in period $t$, and $F_i^{di}$ the distribution companies fixed cost. The distribution firms are regulated on the basis of the same principles as the regulation of the transmission companies. The unit cost of distribution capacity $k^{di}$ is set equal to €0,0025 per kWh. The allowed 'fair' return per unit of capital $s^{di}$ is equal to €0,00375 per kWh. Table 6 summarises the parameter choices for the distribution sector.

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11 See Bailey and White (1974).

12 The CREG, which is the Belgian Federal regulator, estimates the replacement value of the transmission grid at about €3.500 Mln. We assume that the Belgian grid has a capacity to absorb 17GW. On an annual basis, this implies a per kWh cost of €0,0235. Assuming a lifetime of 50 years and a 10% discount rate, this approximately results in a cost of 0,250 eurocent.

The profit of the distribution firms is distributed among the shareholders. In the case of the mixed intermunicipality, profits are distributed among the municipalities, the private firm and the province. The profit of the pure intermunicipality is almost fully captured by the municipalities. The profit of the Regie goes entirely to the municipality. Note that the profit sharing rules change after the liberalisation. Profits are shared on the basis of participation in ownership. The profit shares ( $\sigma^{Mun}, \sigma^{Inc}, \sigma^{Pro}$ ) are summarised in Table 6.

| Parameter | | MIC | PIC | Regie |
|---|---|---|---|---|
| **General parameters** | | | | |
| $k^{di}$ | (€ per kWh) | 0,00250 | 0,00250 | 0,00250 |
| $l_d$ | (%) | 4,00000 | 4,00000 | 4,00000 |
| $F_t^{di}$ | (Mln €) | 253,45928 | 78,62374 | 6,61405 |
| **Reference scenario** | | | | |
| $s^{di}$ | (€ per kWh) | 0,00375 | 0,00375 | 0,00375 |
| $f^{di}$ | (€ per kWh) | 0,00000 | 0,00000 | 0,00000 |
| $g^{di}$ | (€ per kWh) | 0,00000 | 0,00000 | 0,00000 |
| $\xi^{di}$ | | 0,00000 | 0,00000 | 0,00000 |
| $c^{di}$ | (€ per kWh) | 0,00407* | 0,00426* | 0,00454* |
| $\sigma^{Mun}$ | (%) | 58 | 97,50 | 100 |
| $\sigma^{Inc}$ | (%) | 40 | – | – |
| $\sigma^{Pro}$ | (%) | 2 | 2,50 | – |
| **After liberalisation (vertically integrated distribution and retail)** | | | | |
| $c^{di}$ | (€ per kWh) | 0,00407* | 0,00426* | 0,00454* |
| $\hat{\sigma}^{Mun}$ | (%) | 70 | 100 | 100 |
| $\hat{\sigma}^{Inc}$ | (%) | 30 | – | – |
| $\hat{\sigma}^{Pro}$ | (%) | – | – | – |
| **After liberalisation (unbundled distribution and retail)** | | | | |
| $c^{di}$ | (€ per kWh) | 0,00082* | 0,00085* | 0,00091* |
| $\hat{\sigma}^{Mun}$ | (%) | 70 | 100 | 100 |
| $\hat{\sigma}^{Inc}$ | (%) | 30 | – | – |
| $\hat{\sigma}^{Pro}$ | (%) | – | – | – |
| Profit share received from transmission firm (liberalised markets) | | | | |
| | (%) | 23,70 | 6,00 | 0,30 |

* Average values

**Table 6:** Parameters for the distribution sector.

**The retail sector**

Retail companies are independent, profit maximising firms, operating in a competitive market. They sell to all customer types supplied through the distribution grid. A retailer's profit function is defined in (44), and for simulation purposes the cost function is defined as

$$C_t^{r_j}\left(Q_t^{r_j}\right) = F^{r_j} + \sum_{m\in\mathcal{M}}\left((1+t)\left(\tilde{p}_{m,t}^{w} + \tilde{p}_{m,t}^{tr} + \tilde{p}_{m,t}^{di}\right) + c_t^{r_j}\right)q_{m,t}^{r_j} + \sum_{m\in\mathcal{M}} t\tilde{p}_{m,t}^{r} q_{m,t}^{r_j} \qquad (53)$$

In this exercise, we assume that all retailers act as a price taker. Table 7 describes the parameter values. Note that these parameters are relevant only for the scenario with unbundled distribution and retail activities.

| Parameter | | Retailer $in$ | Retailer $en$ |
|---|---|---|---|
| $c^r$ | (€/kWh) | 0,00343 | 0,00343 |
| $t$ | (%) | 21,00 | 21,00 |
| $F_t^r$ | (Mln €) | 0,00000 | 0,00000 |

**Table 7:** Parameter values for the retail firms.

The next subsection describes the simulated scenarios.

# 4. THE SIMULATION RESULTS

This section describes the simulation results. We focus on the impact of the regulation mechanism on electricity prices and on the cash flow of the municipalities.

### *4.1.1. The reference scenario*

Table 8 summarises the simulation results for the reference scenario. As expected, the results are close to the real world values.

| Variable | MIC | | PIC | | Regies | | Direct Customers |
|---|---|---|---|---|---|---|---|
| | **HH** | **SME** | **HH** | **SME** | **HH** | **SME** | |
| Market share | *23,33%* | *24,04%* | *6,57%* | *4,47%* | *0,66%* | *0,39%* | *40,54%* |
| **Electricity demand (GWh)** | | | | | | | |
| Winter Peak | 2.186,9 | 2.567,2 | 621,6 | 488,4 | 63,7 | 42,6 | 4.443,7 |
| Winter Off-peak | 1.711,5 | 1.457,9 | 466,2 | 273,8 | 47,4 | 23,4 | 2.665,5 |
| Mid-season Peak | 3.089,5 | 3.684,3 | 876,0 | 688,3 | 91,4 | 60,9 | 6.188,5 |
| Mid-season Off-peak | 2.690,4 | 2.291,8 | 758,6 | 408,5 | 73,0 | 35,9 | 3.685,6 |
| Summer Peak | 892,2 | 1.047,3 | 252,2 | 198,2 | 26,9 | 17,9 | 1.688,7 |
| Summer Off-peak | 863,1 | 735,2 | 244,0 | 131,4 | 23,0 | 11,3 | 1.198,7 |
| *Total* | *11.433,6* | *11.783,7* | *3.218,6* | *2.188,6* | *325,4* | *192,0* | *19.870,7* |
| **Consumer Prices (€ per kWh, excl. VAT)** | | | | | | | |
| All periods | 0,118 | 0,078 | 0,121 | 0,077 | 0,119 | 0,079 | – |
| **Sum of wholesale electricity prices and transmission prices (€ per kWh, excl. VAT)** | | | | | | | |
| Winter Peak | 0,067 | 0,067 | 0,067 | 0,067 | 0,067 | 0,067 | 0,067 |
| Winter Off-peak | 0,050 | 0,050 | 0,050 | 0,050 | 0,050 | 0,050 | 0,050 |
| Mid-season Peak | 0,061 | 0,061 | 0,061 | 0,061 | 0,061 | 0,061 | 0,061 |
| Mid-season Off-peak | 0,047 | 0,047 | 0,047 | 0,047 | 0,047 | 0,047 | 0,047 |
| Summer Peak | 0,055 | 0,055 | 0,055 | 0,055 | 0,055 | 0,055 | 0,055 |
| Summer Off-peak | 0,042 | 0,042 | 0,042 | 0,042 | 0,042 | 0,042 | 0,042 |
| **Distribution Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Winter Peak | 0,052 | 0,011 | 0,054 | 0,010 | 0,052 | 0,012 | – |
| Winter Off-peak | 0,068 | 0,028 | 0,071 | 0,026 | 0,069 | 0,029 | – |
| Mid-season Peak | 0,057 | 0,016 | 0,060 | 0,015 | 0,057 | 0,018 | – |
| Mid-season Off-peak | 0,072 | 0,031 | 0,074 | 0,030 | 0,072 | 0,033 | – |
| Summer Peak | 0,063 | 0,023 | 0,066 | 0,021 | 0,064 | 0,024 | – |
| Summer Off-peak | 0,076 | 0,035 | 0,079 | 0,034 | 0,076 | 0,037 | – |

* Consumer prices and wholesale electricity prices are taken from BFE (1999). The distribution prices are derived from the annual reports of the distribution companies.

**Table 8:** Simulation results for the reference scenario.

The resulting cash flows for the municipalities are as described in Table 9. They closely match the cash flows reported in the annual reports of the distribution companies.

| Intermunicipality | Reference | Scenario 1 | | | Scenario 2 | | |
|---|---|---|---|---|---|---|---|
| | | *ROR-regulation* | *Profit-per unit-regulation* | *Price-cap regulation* | *ROR-regulation* | *Profit-per unit-regulation* | *Price-cap regulation* |
| **CF from distribution** | | | | | | | |
| MIC | 100,0 | 31,4 | 50,9 | 86,6 | 31,3 | 50,9 | 86,8 |
| PIC | 100,0 | 22,5 | 37,1 | 53,5 | 22,6 | 37,1 | 54,3 |
| Regie | 100,0 | 22,6 | 33,1 | 53,9 | 22,8 | 33,2 | 55,3 |
| *Total distribution* | *100,0* | *28,6* | *46,4* | *76,1* | *28,6* | *46,4* | *76,5* |
| ***Total (distribution and transmission)*** | ***100,0*** | ***58,3*** | ***72,4*** | ***157,6*** | ***58,3*** | ***72,4*** | ***157,8*** |

**Table 9:** Cash flows directed to the municipalities (Relative to Reference).

## *4.1.2. Liberalising generation with integrated distribution and retail*

In this scenario, three cases are simulated, the difference being the regulation mechanism chosen by the regulator. In order to make the results comparable, the following procedure has been followed. First, scenario 1 is simulated with $R_{ROR}$ as the regulation mechanism for both the transmission and the distribution firms. Then, for the $R_{CPU}$ regulation case, we take the (equilibrium) per-unit profit of the $R_{ROR}$-case and use this as the constant profit per unit of output ($s-k$) in the $R_{CPU}$ simulation. Finally, for the $R_{PC}$ mechanism, we take the weighted average transmission and distribution prices from the $R_{ROR}$-case and use these as the price caps. The parameters of the $R_{ROR}$ regulation rule itself have been chosen from a range of values that are assumed to be acceptable.

In the discussion of the results, we focus on the distribution sector. Therefore, only prices and results related to the distribution sector are presented in detail. The price results are summarised in Table 12. Capacity choices summarised in Table 11, and welfare effects are found in Table 10.

| Variable | Reference | Scenario 1 | | | Scenario 2 | | |
|---|---|---|---|---|---|---|---|
| | | *ROR-regulation* | *Profit-per unit-regulation* | *Price-cap regulation* | *ROR-regulation* | *Profit-per unit-regulation* | *Price-cap regulation* |
| **Consumer Surplus** | *100,0* | *59,3* | *122,5* | *67,6* | *59,3* | *122,5* | *67,4* |
| Households | 100,0 | 43,6 | 79,4 | 57,2 | 43,6 | 79,4 | 56,9 |
| SMEs | 100,0 | 57,5 | 178,8 | 63,5 | 57,5 | 178,8 | 63,2 |
| Direct Customers | 100,0 | 100,9 | 179,7 | 98,0 | 100,9 | 179,7 | 98,0 |
| **Producer Surplus** | *100,0* | *58,2* | *99,3* | *94,4* | *58,2* | *99,3* | *94,3* |
| Generation & Transmission | 100,0 | 61,7 | 118,3 | 102,2 | 61,7 | 118,3 | 101,9 |
| Distribution MIC | 100,0 | 51,1 | 61,8 | 81,4 | 51,1 | 61,8 | 81,5 |
| Distribution PIC | 100,0 | 52,4 | 61,1 | 70,8 | 52,4 | 61,1 | 71,3 |
| Distribution Regie | 100,0 | 49,0 | 55,6 | 69,4 | 49,0 | 55,6 | 70,4 |
| Retail | – | – | – | – | 0,0 | 0,0 | 0,0 |
| **Taxes** | *100,0* | *87,5* | *105,9* | *90,7* | *87,5* | *105,9* | *90,7* |
| **Social Welfare*(Mln €)** | ***100,0*** | ***66,7*** | ***102,2*** | ***94,3*** | ***66,7*** | ***102,2*** | ***94,2*** |

* Flemish Social Welfare is calculated by taking the unweighted sum of all surpluses, except the entrant's surplus, which is not taken into account and half of the incumbent's surplus.

**Table 10:** The welfare effects (Relative to Reference).

**Transmission and distribution capacity**

Liberalising the generation market and implementing rate-of-return regulation will give incentives to electricity transport companies to increase their installed capacity. The reason is obvious. Under ROR-regulation, allowed profits are positively related to the size of the so-called regulated asset base. For electricity transport companies, the grid is by far the most important asset, thus installing grid transport capacity increases the asset base and thus the allowed profit level.

In the CPU and the PC regulation mechanisms, this incentive is not present. With CPU regulation, allowed profits are related to total output. Since capacity has a cost ( $k^{tr}$ and $k^{di}$ ), a profit maximising firm will install no more capacity than effectively needed to satisfy transport demand in the peak period(s). The same argument holds under PC-regulation.

Thus, under ROR-regulation, the transport firms will invest in transport capacity, which is not used. This will not be the case under CPU or PC regulation. This point is illustrated in Table 11.

| Firm | Reference | Scenario 1 | | | Scenario 2 | | |
|---|---|---|---|---|---|---|---|
| | | $R_{ROR}$ | $R_{CPU}$ | $R_{PC}$ | $R_{ROR}$ | $R_{CPU}$ | $R_{PC}$ |
| Transmission | 7.369,4 | 38.150,4 | 8.412,8 | 5.952,6 | 38.149,0 | 8.412,5 | 5.945,8 |
| MIC | 3.386,5 | 11.783,5 | 3.604,0 | 2.333,4 | 11.770,5 | 3.602,4 | 2.327,5 |
| PIC | 790,7 | 2.486,3 | 739,4 | 548,0 | 2.495,0 | 740,3 | 546,8 |
| Regie | 75,6 | 270,8 | 72,6 | 53,9 | 273,2 | 72,9 | 53,8 |

**Table 11:** Capacity choices in the different scenarios (GW).

**Prices**

In order to understand the evolution of end-user prices, it is necessary to know how the different components of the end-user price evolve.

*Wholesale electricity prices*

From Table 12, it can be derived that the contribution of the wholesale electricity price is fairly constant, irrespective of the consumer type. The presence of a profit maximising and price-taking entrant with sufficiently large generation capacity forces all wholesale prices to be almost equal for all customer types. However, wholesale prices will differ significantly between periods. This cannot be seen in the tables, but prices range from €0,023 to €0,034 in 'summer off-peak' and 'winter-peak', respectively. Moreover, electricity generation is not a regulated activity. Therefore, the regulation mechanism should only play an indirect role via its impact on aggregate demand. This latter effect explains why the wholesale electricity price is larger under CPU-regulation. This regulation mechanism gives a large incentive for price reduction and output increase. Clearly, this results in increased wholesale prices for electricity, which partly compensate the decrease in transmission and distribution prices.

*Transmission and distribution prices*

The *structure* of transport prices does not differ significantly when different regulation mechanisms are applied. Under ROR-regulation as well as under CPU and PC-regulation, the transmission and distribution firms charge significantly lower prices to the SMEs and to direct customers. This result is a reflection of the well-known ‘inverse elasticity’ rule. For a profit maximising firm, the best way to proceed is to charge lower prices in those markets where price elasticities of demand are (relatively) high, which, in the setting of this model, is the case in for direct customers for SMEs.

Note that under the ROR-regulation mechanism, there is overinvestment in capacity. The capacity constraint is not binding, and all $\gamma_t$ are zero. Furthermore, for the simulations, we have assumed $f^{tr} = g^{tr} = 0$. One can then derive from the first-order conditions that the optimal pricing rule reduces the pricing rule of an unconstrained monopolist, i.e. pricing is such that marginal revenue is equal to marginal cost. Thus, a ROR-mechanism with these characteristics will not result in reduced prices for the customers compared to the pricing behaviour of an unconstrained monopolist. Introducing $f^{tr} > 0$ will induce the firm to stimulate output by reducing prices, but in general the incentive for overinvestment in capacity remains as long as $s^{tr} - k^{tr} - f^{tr} > 0$. Note that the ROR-mechanism converges to the CPU-regulation mechanism as $f^{tr}$ increases.

Under CPU-regulation, the pricing rule essentially follows the same principles as under ROR-regulation. However, now the overall price level is adjusted downward. This reflects the fact that CPU-regulation gives an incentive for firms to increase output, and the best way to achieve this is to induce increased demand through reduced prices.

With price cap regulation, the pricing rules essentially have the same features. Prices are adjusted downward compared to the prices under the ROR-regulation mechanism, but in our simulations, the downward shift is not as large as under CPU-regulation. The price adjustment under PC-regulation is function of its price elasticity, whereas under CPU-regulation this adjustment is time and customer independent.

Finally, note that for the transmission as well as for the distribution companies, the capacity is binding in the ‘mid-season peak’-period.

*End-user prices*

More variation in end-user prices is observed after the liberalisation, and in all cases the average price level increases for households. The increase is largest under the $R_{ROR}$- and the $R_{PC}$-mechanism. Under $R_{CPU}$, household prices also increase, but to a lesser extent. Average consumer prices for the SMEs also increase, except under the $R_{CPU}$ mechanism, where they decrease.

**Cash flows towards the municipalities**

Table 9 summarises the cash flows towards the municipalities. Due to the liberalisation, these cash flows will change drastically, but the sign and the size of the change depends on the regulation mechanism that is implemented.

First, consider the cash flows from distribution activities. Here, all simulations suggest that cash flows will reduce. The ROR-case produces the largest reduction. However, this reduction is compensated by an increased cash flow from transmission activities. In the case of PC-regulation, this compensation is even sufficient to turn the loss in cash flows from distribution activities into an overall increase in cash flows compared to the reference scenario.

| Variable | MIC | | PIC | | Regies | | Direct Customers |
|---|---|---|---|---|---|---|---|
| | HH | SME | HH | SME | HH | SME | |
| **ROR-Regulation** | | | | | | | |
| **Electricity demand (GWh)** | 7.568,0 | 9.075,5 | 2.113,6 | 1.578,8 | 213,5 | 140,7 | 19.798,2 |
| **Consumer Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,146 | 0,085 | 0,151 | 0,086 | 0,148 | 0,088 | 0,055 |
| **Wholesale electricity prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,028 | 0,029 | 0,028 | 0,029 | 0,028 | 0,029 | 0,029 |
| **Transmission Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,056 | 0,025 | 0,058 | 0,026 | 0,056 | 0,027 | 0,026 |
| **Distribution Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Winter Peak | 0,059 | 0,031 | 0,062 | 0,030 | 0,062 | 0,031 | |
| Winter Off-peak | 0,065 | 0,032 | 0,066 | 0,033 | 0,065 | 0,034 | |
| Mid-season Peak | 0,063 | 0,028 | 0,064 | 0,031 | 0,062 | 0,032 | |
| Mid-season Off-peak | 0,062 | 0,033 | 0,066 | 0,033 | 0,065 | 0,034 | |
| Summer Peak | 0,062 | 0,033 | 0,064 | 0,032 | 0,063 | 0,033 | |
| Summer Off-peak | 0,065 | 0,034 | 0,066 | 0,033 | 0,065 | 0,035 | |
| **CPU-Regulation** | | | | | | | |
| **Electricity demand (GWh)** | 10.220,8 | 15.950,6 | 2.830,7 | 2.774,4 | 292,5 | 249,6 | 26.565,3 |
| **Consumer Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,127 | 0,066 | 0,131 | 0,067 | 0,127 | 0,069 | 0,046 |
| **Wholesale electricity prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,043 | 0,044 | 0,044 | 0,044 | 0,044 | 0,044 | 0,045 |
| **Transmission Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,037 | 0,007 | 0,039 | 0,008 | 0,039 | 0,010 | 0,002 |
| **Distribution Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Winter Peak | 0,039 | 0,011 | 0,048 | 0,016 | 0,043 | 0,013 | |
| Winter Off-peak | 0,049 | 0,016 | 0,050 | 0,016 | 0,046 | 0,015 | |
| Mid-season Peak | 0,051 | 0,016 | 0,047 | 0,014 | 0,044 | 0,014 | |
| Mid-season Off-peak | 0,046 | 0,017 | 0,049 | 0,017 | 0,046 | 0,015 | |
| Summer Peak | 0,045 | 0,016 | 0,046 | 0,014 | 0,043 | 0,013 | |
| Summer Off-peak | 0,050 | 0,019 | 0,050 | 0,017 | 0,046 | 0,016 | |
| **PC-Regulation** | | | | | | | |
| **Electricity demand (GWh)** | 8.564,9 | 9.345,6 | 2.503,3 | 1.723,6 | 254,0 | 154,5 | 19.596,9 |
| **Consumer Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,139 | 0,084 | 0,140 | 0,083 | 0,137 | 0,086 | 0,055 |
| **Wholesale electricity prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,029 | 0,030 | 0,029 | 0,030 | 0,030 | 0,030 | 0,030 |
| **Transmission Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,051 | 0,024 | 0,056 | 0,026 | 0,055 | 0,027 | 0,025 |
| **Distribution Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Winter Peak | 0,053 | 0,027 | 0,053 | 0,027 | 0,051 | 0,027 | |
| Winter Off-peak | 0,059 | 0,030 | 0,054 | 0,028 | 0,052 | 0,029 | |
| Mid-season Peak | 0,064 | 0,032 | 0,057 | 0,030 | 0,055 | 0,032 | |
| Mid-season Off-peak | 0,056 | 0,030 | 0,054 | 0,028 | 0,052 | 0,029 | |
| Summer Peak | 0,057 | 0,030 | 0,052 | 0,026 | 0,051 | 0,027 | |
| Summer Off-peak | 0,060 | 0,032 | 0,054 | 0,028 | 0,053 | 0,029 | |

**Table 12:** Simulation results for scenario 1.

The following paragraphs clarify the driving forces for the cash flow changes. In order to understand these changes, one has to understand why transmission and distribution profits change. Clearly, the regulation mechanisms play an important role here.

*Rate-of-return regulation*

The cash flow decrease under ROR-regulation occurs because we observe a sharp increase in transmission prices compared to the reference scenario. However, for a correct comparison, one should compare the sum of the wholesale price and the transmission price, because in the reference scenario, these activities were integrated in one firm. A compensating effect comes from a reduction in average wholesale prices (due to increased competition in the generation market), but this decrease is not sufficient to neutralise the transmission price increase. As a result, end-user prices increase, especially for households and to a lesser extent for SMEs. In the aggregate, these increased prices result in reduced demand and output. Clearly, this latter effect also contributes to reduced wholesale prices for electricity.

It was explained before that, with the parameterisation of $R_{ROR}$ in this paper, monopoly pricing would occur. Compared to the reference scenario, this will result in increased transmission prices. Note that in the reference scenario, transmission prices were uniform and based on a zero-profit condition[13].

Monopoly pricing will also occur at the distribution level, but here prices were already relatively high in the reference case. Thus, changes in distribution prices are rather modest under ROR-regulation, and the decrease in demand should necessarily result in reduced distribution profits and thus reduced cash flows towards the municipalities. Cash flows from transmission are not sufficient to compensate for this.

*Constant-profit-per-unit-of-output regulation*

CPU-regulation gives strong incentives to the transmission and the distribution firms to reduce their prices, because this would result in increased output and thus a softened regulation constraint. This increased demand will result in increased wholesale prices in the generation market. Relative to the reference case, prices for households will increase and prices for SMEs will decrease. Overall, transmission and distribution profits will decrease relative to the reference case. Compared to ROR-regulation, cash flows from distribution activities will increase, mainly because grid capacity investments are much lower.

*Price-cap regulation*

Note that the imposed price cap is based on the average prices that resulted from implementing the ROR-mechanism. In principle, the transmission and distribution firms could implement exactly the same price structure as under ROR-regulation. This would result in higher profits compared to ROR-regulation, because now the grid companies would not overinvest in grid capacity (cost would be much lower.). Thus, with PC-regulation, grid capacity will be binding, and the firms can even further increase profits by charging higher prices in periods with binding capacity. This would further reduce capacity and in order to keep the regulation constraint satisfied, prices in other periods should also be reduced.

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[13] The implicit assumption behind it is that, in the reference case, generation and transmission were integrated in one firm, charging one price covering both transmission and distribution. Here we separate the price by assuming that a zero profit condition applied to the transmission activities. This assumption has no impact on the simulation results, as, in the reference case, there is a price cap on the sum of generation and transmission prices, and there are no cash flows towards municipalities due to transmission activities.

The cost savings from reduced investment in grid capacity is the driving force behind the higher cash flows under PC-regulation compared to ROR-regulation.

**Welfare**

For consumers, welfare change is measured through the consumer surplus, and changes in the consumer surplus are closely related to changes in end-user prices. The simulations suggest that, relative to the reference scenario, households will be worse of after the liberalisation. This conclusion holds irrespective of the regulation mechanism that is applied. SMEs would also loose from the liberalisation if the ROR- or PC-regulation would be imposed. With CPU-regulation, the SMEs would benefit. Direct customers are most likely to benefit from the liberalisation, certainly if CPU would be applied.

Relative to the reference scenario, the incumbent generator will incur a reduction in profits. First, because he is faced with a competitive fringe, which puts a downward pressure on wholesale prices, and second, because aggregate output is decreased due to a reduction in market share and an average increase in end-user prices. This latter effect does not exist under CPU-regulation, because transmission and distribution firms then have an incentive to reduce their prices.

By definition, the change in welfare or producer surplus for the transmission and distribution firms is closely linked to the profit changes. These changes were discussed in the previous paragraphs.

In this model, tax revenues only reflect revenue from the value added tax.

### *4.1.3. Unbundling distribution and retail*

The assumptions of perfectly competitive retail markets and no (dis)economies of scale or scope in retail, explain why the results of the second scenario are very similar to the results of the first scenario. The results are shown in Table 11. We do not present a detailed discussion of the results, because the underlying reasoning is exactly the same as for the simulations with integrated distribution companies.

| Variable | MIC | | PIC | | Regies | | Direct Customers |
|---|---|---|---|---|---|---|---|
| | HH | SME | HH | SME | HH | SME | |
| **ROR-Regulation** | | | | | | | |
| **Electricity demand (GWh)** | 7.568,2 | 9.070,7 | 2.114,9 | 1.581,2 | 213,9 | 141,3 | 19.798,6 |
| **Consumer Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,146 | 0,085 | 0,151 | 0,086 | 0,148 | 0,088 | 0,055 |
| **Wholesale electricity prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,028 | 0,029 | 0,028 | 0,029 | 0,029 | 0,029 | 0,029 |
| **Transmission Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,056 | 0,025 | 0,058 | 0,026 | 0,056 | 0,027 | 0,026 |
| **Distribution Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Winter Peak | 0,053 | 0,028 | 0,059 | 0,027 | 0,058 | 0,028 | |
| Winter Off-peak | 0,061 | 0,029 | 0,063 | 0,029 | 0,061 | 0,031 | |
| Mid-season Peak | 0,060 | 0,025 | 0,061 | 0,027 | 0,029 | 0,028 | |
| Mid-season Off-peak | 0,058 | 0,029 | 0,063 | 0,030 | 0,061 | 0,031 | |
| Summer Peak | 0,059 | 0,030 | 0,061 | 0,028 | 0,060 | 0,029 | |
| Summer Off-peak | 0,062 | 0,031 | 0,062 | 0,030 | 0,061 | 0,031 | |
| **Retail Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,003 | 0,003 | 0,003 | 0,003 | 0,003 | 0,003 | |
| **CPU-Regulation** | | | | | | | |
| **Electricity demand (GWh)** | 10.218,0 | 15.943,2 | 2.833,0 | 2.778,3 | 293,2 | 250,5 | 26.566,1 |
| **Consumer Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,127 | 0,066 | 0,131 | 0,067 | 0,127 | 0,069 | 0,046 |
| **Wholesale electricity prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,043 | 0,044 | 0,044 | 0,044 | 0,044 | 0,044 | 0,045 |
| **Transmission Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,037 | 0,0007 | 0,040 | 0,008 | 0,039 | 0,010 | 0,002 |
| **Distribution Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Winter Peak | 0,036 | 0,007 | 0,044 | 0,012 | 0,040 | 0,009 | |
| Winter Off-peak | 0,045 | 0,013 | 0,046 | 0,012 | 0,042 | 0,012 | |
| Mid-season Peak | 0,047 | 0,012 | 0,044 | 0,010 | 0,040 | 0,010 | |
| Mid-season Off-peak | 0,042 | 0,013 | 0,046 | 0,013 | 0,042 | 0,011 | |
| Summer Peak | 0,042 | 0,012 | 0,043 | 0,010 | 0,039 | 0,009 | |
| Summer Off-peak | 0,046 | 0,015 | 0,046 | 0,013 | 0,042 | 0,012 | |
| **Retail Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,003 | 0,003 | 0,003 | 0,003 | 0,003 | 0,003 | |
| **PC-Regulation** | | | | | | | |
| **Electricity demand (GWh)** | 8.541,5 | 9.323,4 | 2.496,6 | 1.720,9 | 153,3 | 154,5 | 19.599,1 |
| **Consumer Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,139 | 0,084 | 0,140 | 0,083 | 0,137 | 0,086 | 0,055 |
| **Wholesale electricity prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,029 | 0,030 | 0,029 | 0,030 | 0,030 | 0,030 | 0,030 |
| **Transmission Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,051 | 0,024 | 0,056 | 0,026 | 0,055 | 0,027 | 0,025 |
| **Distribution Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Winter Peak | 0,050 | 0,024 | 0,050 | 0,024 | 0,048 | 0,024 | |
| Winter Off-peak | 0,053 | 0,026 | 0,051 | 0,024 | 0,049 | 0,025 | |
| Mid-season Peak | 0,060 | 0,029 | 0,054 | 0,027 | 0,052 | 0,028 | |
| Mid-season Off-peak | 0,053 | 0,027 | 0,051 | 0,025 | 0,049 | 0,025 | |
| Summer Peak | 0,054 | 0,027 | 0,049 | 0,023 | 0,048 | 0,024 | |
| Summer Off-peak | 0,056 | 0,028 | 0,051 | 0,025 | 0,050 | 0,026 | |
| **Retail Prices (€ per kWh, excl. VAT)** | | | | | | | |
| Weighted average | 0,003 | 0,003 | 0,003 | 0,003 | 0,003 | 0,003 | |

Table 13: **Simulation results for scenario 2.**

# 5. SUMMARY AND CONCLUSIONS

In Flanders (Belgium), distribution companies are to a (very) large extent owned by the municipalities and as such these municipalities collect an important share of the profits from electricity distribution. This situation cannot be maintained because, in the process of electricity market liberalisation, the ownership will be reshuffled and because the old regulation mechanism, allowing for such cash flows, will be revised.

This paper presents some simulations on the restructuring of the electricity distribution sector, using a partial equilibrium model. The simulations illustrate the potential impact of the regulation mechanism on prices and on the cash flows towards municipalities. Three regulation schemes are simulated, 'rate-of-return' regulation, 'constant profit per unit of output' regulation and 'price-cap' regulation.

With respect to the behaviour of the different players, it is assumed that they all act in their own interest, i.e. all firms maximise profits and consumers maximise utility. Generators set quantities, taking transmission, distribution and retail prices (if applicable) as given. The transmission, the distribution and the retail firms all set the prices of their service, taking the prices set by the other players as given.

The model is calibrated for the Flemish electricity distribution sector in 1998. The simulations show that, irrespective of the regulation scheme, it is not obvious that end-user electricity prices will decrease after the liberalisation. Moreover, the restructuring will have a large impact on the profits received by the municipalities, and the sign of this impact depends on the regulation mechanism that is imposed.

It appears that – for the parameter values that were used in this simulation exercise – the rate-of-return regulation mechanism performs badly, both in terms of generated municipal cash flows and in terms of welfare. We feel that this is likely to be the case for many parameterisations of rate-of-return regulation. Therefore, it should better not be adopted. For the presented simulations one should opt for price cap regulation if one cares about municipal cash flows. If one cares about welfare, then constant-profit-per-unit-of-output performs best.

It is important to keep in mind that the simulation results in this paper can only be interpreted as illustrations of what could happen when different regulation mechanisms are imposed on transmission and distribution companies. The numbers that come out of the simulations can and will change drastically (although not necessarily the conclusions) when other parameter values are used to calibrate the model. This points out a first direction of future research and the need for sensitivity analysis. Also, it would be worthwhile to look at the effect on the outcome of the model if market power in the retail sector would be assumed.

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