

Louvain School of Management

The social cost of decentralization in regulation

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Abstract

Key words: regulation, power distribution, DEA benchmarking, decentralization

Electricity is everywhere and we use it for our daily needs: lighting, cooking, and working. The power is transported and brought to the consumers by means of the distribution network. Due to obvious economies of scale, it is reserved to limited number of operators who are monopolists over their territory. The society empowers a regulator whose mission is to monitor the activities of the monopolists in order to protect against excessive tariffs. Sometimes, the regulator makes use of benchmarking techniques: i.e. observing the best practices among comparable distributors to set a fair limit on their revenue. The benchmarking tool DEA (Data Envelopment Analysis) is suitable for this task because it estimates the cost function by drawing the best-frontier within the set of comparable DSOs.

In 2014, the regulation of distribution tariffs in Belgium has been subject to major changes. The 6th State Reform has transferred this jurisdiction from a federal authority (CREG) to three regional institutions (CWaPE in Wallonia, VREG in Flanders and Brugel in Brussels-Capital). This transformation is called the decentralization of the regulation.

Inspired from the Belgian case, we address in this thesis the theoretical impact of the decentralization for the operators, the consumers and the regulator(s). Mostly, we identify the effect on the benchmarking when a territory is partitioned into smaller subsets. In order to illustrate our insights, we have developed a quantitative model which uses DEA benchmarking. Based on a dataset containing operating details of 164 distributors in Sweden, we have simulated the partitioning of the dataset according four criteria: random, geographic, scale and ownership. The results are provided in the thesis.

Obviously, the decentralization decreases the number of firms benchmarked together. From the benchmarking theory, we prove that removing an entity from the set tends to displace the cost norm which results in an increase in the operators' cost target. If their revenue depends on the cost target, distributors would be allowed to raise their tariffs, at the expenses of the consumers. Since it produces a cost for the society, we call it the social cost of the decentralization. However, the choice of the criterion to partition the territory may impact the social cost. The random partition illustrates the global trend: a concave curve. The geographic partition shows that the social cost is statistically lower than for the random case. In addition, the social cost is lower as well when using the scale or ownership criterion.

Preface

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List of abbreviations

AE: Allocative Efficiency

CE: Cost Efficiency

COLS: Corrected Ordinary Least Square

COS: Cost of Service

CPI: Consumer Price Index

CREG: Commission de la Régulation de l'Electricité et du Gaz/Comissie voor de Regulering van de Elektriciteit en het Gas

CRS: Constant Return to Scale

CWaPE: commission Wallone pour l'Energie

DEA: Data Envelopment Analysis

DMU: Decision-Making Unit

DRS: Decreasing Return to Scale

DSO: Distribution System Operator

EI: Swedish Energy Market Inspection

ENTSO-E: European Network of Transmission System Operators

EU: European Union

IPF: Intercommunales Pures de Financement

IRS: Increasing Return to Scale

km: kilo-meter

kV: kilo-Volt

kWh: kilo-Watt-hour

LP: Linear Programming mathematical program

MPSS: Most Productive Scale Size

MW: mega-Watt

Ofgem: Britain's Office of Gas and Electricity Markets

OLS: Ordinary Least Square

OPEX: Operating Expenditure

OSP : Obligation du Service Public

PBR : Performance-Based Regime

QED: Quod Erat Demonstrandum (“what was to be demonstrated”)

ROR : Rate of Return

SDEA: Stochastic Data Envelopment Analysis

SE: Scale Efficiency

SEK: Swedish Crowns

SFA: Stochastic Frontier Analysis

TE: Technical Efficiency

TSO: Transmission System Operator

VREG: Vlaamse Regulator van de Elektriciteits en Gasmarkt

VRS: Variable Return to Scale

WACC: Weighted Average Cost of Capital

Introduction

The electricity that we consume is generated by production entities scattered across the country. The power is then transported through the energy network which brings the electricity directly to the consumer. The network is partly managed by agents called Distribution System Operators (DSOs). Due to obvious economies of scale, DSOs are monopolists over their territory. Legal monopolies are not subject to competition laws; as a result, such activities are regulated in order to protect the consumers from tariff increases. The regulator is usually a governmental institution whose mission is to approve the distribution tariffs. Sometimes, the regulator makes use of benchmarking techniques: observing the best practices among comparable distributors to set a fair limit on the revenue or the price.

In 2014, the regulation of distribution tariffs in Belgium has been subject to major changes. The 6th State Reform has transferred this jurisdiction from a federal authority (CREG) to three regional institutions (CWaPE in Wallonia, VREG in Flanders and Brugel in Brussels-Capital). This transformation is called the decentralization of the regulation.

Inspired from the Belgian case, we will address in this thesis the theoretical impact of the decentralization for the operators, the consumers and the regulator(s). Mostly, we will identify the effect on the benchmarking when a territory is partitioned into smaller subsets. In order to illustrate our insights, we have developed beforehand a quantitative model which uses DEA benchmarking. Based on a dataset containing operating details of 164 DSOs in Sweden, we have simulated the partitioning of the dataset according four criteria: random, geographic, scale and ownership. The results will be provided in the thesis.

The first chapter aims at providing a general background for the issues addressed in this work: the energy sector, the regulation, and the situation in Belgium. Then, we will expose the research questions that will guide the study. In order to enable the reader to understand the theoretical concepts used in the analysis, we will propose in the second chapter a review of the literature: the regulation theory, the benchmarking tools with an emphasis on DEA benchmarking, and the empirical applications of benchmarking in regulation. The third chapter is the core section of our work. After presenting the dataset and the initial situation, we will develop the theoretical implications of the decentralization. Then, the results of the four simulations will be presented. Finally, we will illustrate our findings with a contextualization to the Belgian situation.

Chapter 1 : Context

Since the dawn of time, humans have been transforming their environment in order to improve their lifestyle. Particularly during the industrial period, humans needed energy under several forms to pursue their conversion activities. In 1879, Thomas Edison developed the first electric light bulb and designed some years later the first electric plant in Manhattan. Step by step, electricity replaced steam and coal in industrial production; power spread in cities and countryside. Nowadays, our basic needs are dependent on energy resources: cooking, lighting our houses, powering our computers, communication means, etc... Furthermore, humans diversified their source of energy: coal-fired power plant, nuclear plant, wind power, solar panel and hydropower plant.

In order to understand the complexity of the energy sector, we start by an overview of its actors. Then, we will introduce the role of the regulator. At last, we will present the context of the electricity distribution and the regulation in Belgium.

1.1. Energy sector

Usually, the energy sector concerns the activities relative to the electricity and gas. In the course of the thesis, we will focus on the electricity business. Each country of the world has developed its energy sector and is responsible for the coverage of its territory. The energy sector gathers an important number of actors, which are grouped into four segments: power generation, energy network (transmission and distribution) and supply (see **Figure 1-1**).

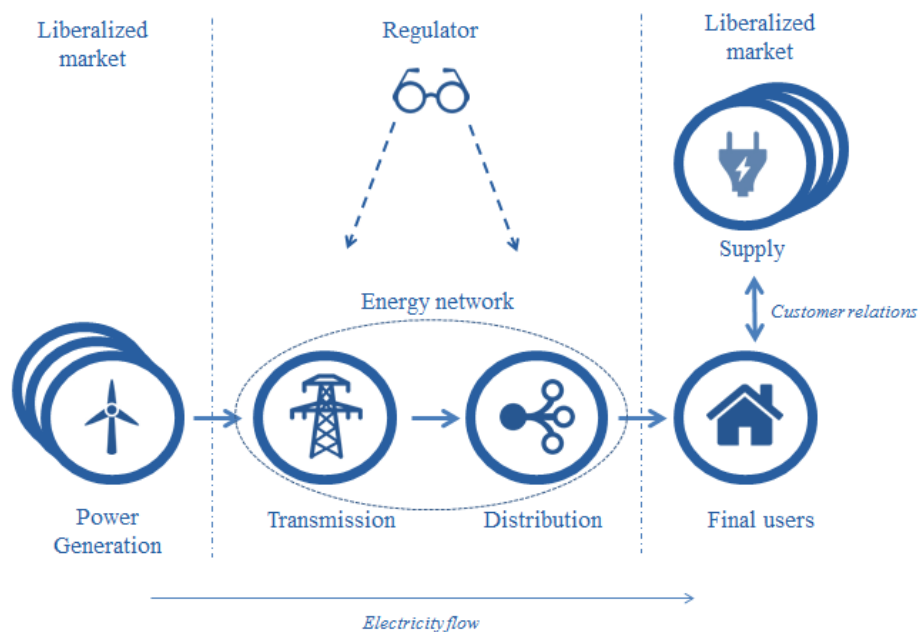


Figure 1-1 Actors in energy sector (Source: own illustration)

1.1.1. Power generation

The generation segment regroups all the companies involved in the electricity production. Electricity is called a secondary energy, meaning that it is produced by transforming primary energies such as coal, nuclear energy, natural gas, fuel, or renewables energies (wind, solar, biomass, hydropower, geothermal). For many reasons, electricity is more convenient than other primary energy source. For safety matters, people would rather use electricity to light streets and houses, instead of petroleum or kerosene lamps. Furthermore, due to its intrinsic nature, electricity is more practical for transportation than other sources of energy. At last, electricity resource enables people to use electronic devices as computers and televisions, which is not possible with primary resources.

1.1.2. Energy network

The nature of electricity requires a particular transportation network compared to other type of energy that are fluids such as fuel and gas. The network is composed by a grid built with physical electric lines, pylons and underground cables. The grid covers a specific territory, on which final users are plugged. The electricity network is usually split between *transmission* operators and *distribution* operators.

Transmission

The transmission segment is managing all the activities related to the high-voltage network: meaning the deployment and maintenance of high-voltage pylons and cables throughout a territory. The threshold between high and low-voltage may vary between countries. Transmission System Operators (TSOs) are responsible for the transportation of electricity in large quantities over long distances from the generation plant to the electrical grid. Due to the huge fixed cost of this activity, the TSO is usually acting as a legal monopoly over its territory.

Moreover, TSOs are also responsible for the connection and electricity transfer between countries. Europe is particularly advanced on that matter and is evolving towards an integrated market place for electricity trade. ENTSO-E¹ is a European organization that gathers 43 TSOs from 36 countries across Europe, whose mission is to coordinate the internal energy market, to support the integration of renewable energies and to maintain security of supply (ENTSOE, 2015).

¹ (European Network of Transmission System Operators)

Distribution

The Distribution Service Operators (DSOs) are focusing on the transportation of low-voltage electricity. It is all the activities related to the maintenance and connection of final consumers to the electricity network. Generally, DSOs are also responsible for lighting in public areas and the road lighting.

Similarly, distribution activities require huge fixed investments in terms of network deployment. Consequently, DSOs are usually in legal monopoly over their respective territory.

1.1.3. Supply

This segment includes the companies responsible for the sales of electricity to end-users (business and private customers). Energy suppliers manage marketing activities, customer relationships and invoicing. Electricity is a pure commodity good, meaning that all the electrons are the same and it is hard for companies to differentiate merely on the product's quality. Consequently, firms rather compete on prices and services.

As a conclusion, the final users are only in contact with the energy suppliers for invoicing and services, and with the distributor for maintenance and metering matter (see **Figure 1-1**)

In the course of the thesis, we will focus on the distribution segment.

1.1.4. Energy sector in Europe

The European Union has strongly worked on the liberalization of the energy market. In 2009, the European Union enacted the Third Energy Package¹, which is a set of rules in order to improve the functioning of the internal energy market. The EU forced the separation between the ones that generate and sell the electricity, and the ones that transport the electricity (TSOs and DSOs). Indeed, if a single company was selling energy and ruling the network at the same time, it could easily obstruct the competitor's access to the network. It would lead to unfair competition and higher prices for consumer (European Commission, 2017).

In addition, the generation and supply segments have been liberalized in order to attract new entrants in the market, while the transmission and distribution activities remain monopolies over a specific territory. As a result, the consumers have the possibility to choose their energy supplier while the DSO and TSO are assigned according to the consumer's localization.

¹ More details on Third Energy Package in Appendix 1.

1.2. The regulator

The liberalization of the energy market triggered by the European Union concerns only the generation and the energy supply segments. As a result of the huge network's investments, the governments authorize TSOs and DSOs to be monopolist on their respective territory. It is called a legal monopoly. In the economic literature, monopolists are able to generate higher rents since they are not subject to competition laws. To avoid excessive tariffs, the society empowers a regulator: its aim is to monitor the activity of the monopolists in order to maintain low prices and good quality.

In a nutshell, the role of the regulator is to ensure the respect of liberalized market's rules, to ensure the transparency and competition in the energy market and to protect consumers' interests. Concretely, the regulator develops a pricing methodology resuming all the rules and principles that need to be respected by the DSOs.¹ The regulator fixes the amount of budget allowance granted to each distributor. The budget allowance is the authorized revenue that the monopolist can generate from its activity. The regulator also approves the tariffs proposed by the monopolist. The tariffs must be established such as the revenue generated equals the authorized budget allowance.

Another mission of the regulator is the adjustment of *regulatory balance*. At the end of the year, the revenue generated may not attain the amount of budget allowance fixed ex-ante (due to a consumption decrease or too low tariff). Thus, the regulator owns a debt towards the monopolist. Inversely, if the revenue generated outperformed the authorized income, the monopolist owes money to the regulator. These divergences, called the regulatory balance ("solde régulateur"), need to be adjusted by the regulator over successive periods.

Diverse methods are used by regulators across the world to determine the fair budget allowance. The *cost-plus* approach permits the monopolist to be reimbursed for his operational cost plus a predefined margin on capital investments. Some other methods, called incentive regulation, give incentives to monopolists for cost-reduction. With a designed system of penalty/reward, the entities are motivated to increase their cost efficiency. The *revenue-cap* sets an upper limit on the revenue. The cap represents a fair portion of a base-revenue, including yearly imposed improvements for cost reduction. The *yardstick* regulation simulates the competition over monopolists by comparing each entity to other comparable

¹ Usually, these rules are adopted after public consultations.

firms in the sector. The most efficient firms are rewarded while non-efficient firms are penalized.

However, most of the time, the setting of a fair revenue is not trivial. Indeed, the DSOs detain private information on their actual costs. The regulator can then hardly observe the real cost utilization and real performance of the distributors. In order to catch up with its ignorance, the regulator compares the firms in the sector by using some tools known as the *benchmarking*.

Usually, regulatory methodologies are defined over regulatory periods: the tariff mechanisms are fixed over some period of time to ensure the continuity. The length of regulatory period may vary from one country to another. For instance, in Germany, after a transition period with cost-plus approach, the regulator has developed an incentive-based methodology with several benchmarks over regulatory periods of five years.¹ France is finishing its fourth regulatory periods of four years² where the budget allowance is adjusted to compensate the discrepancies between actual and forecasted revenues.

Our study covers the regulation of electricity distribution in Belgium. Thus, we will successively address those two topics in the following section.

1.3. Energy network in Belgium

In Belgium, the power threshold that defines high-voltage is 70 kV. The transportation of electricity above this limit is under the control of the sole transmission operator Elia who is working in a legal monopoly (ELIA, 2017). Besides, DSOs are running the medium and low-voltage distribution³. Besides, DSOs are also responsible for the lighting in public areas, metering yearly checks and ensuring private data confidentiality.

1.3.1. Distribution in Belgium

Historically, the municipalities took over the electricity distribution after the Second World War. Step by step, they pooled their strengths and gathered into municipal associations called “intercommunales”. The distinction is made between “*intercommunales pures*”, which are entirely owned by the municipalities, and “*intercommunales mixtes*”, which are partially owned by private entity. Belgium has seventeen DSOs serving end-users through the

¹ 2009-2013 and 2014-2018

² 2014-2017

³ DSOs are called « Gestionnaire des Réseaux de Distribution » (GRD) in Belgium

territory. The assets are owned by the DSOs but the day-to-day network operations are frequently transferred to separate service companies. (Agrell & Teusch, 2015)

Wallonia

The main DSO in Wallonia is **ORES Assets** who is present over 200 municipalities. The organization is the result of the merger in 2013 between Wallonian distributors. It is still structured in provincial sub-branches.¹ Originally, the private actor ENGIE-Electrabel held a financial contribution of 25% within ORES Assets, alongside the 75% majority shareholders owned by municipalities and IPF². At the end of the year 2016, ENGIE-Electrabel withdrew from ORES Assets' equity and sold its shares for 400 million euros. This movement is in line with the market liberalization which should increase the transparency and tasks' separation between actors (ENGIE, 2015). ORES is then entirely owned by public funds. The daily operations are entrusted to the service company ORES SCRL. Despite the merger, the tariffs over different areas under ORES' control continue to vary from one province to another (Agrell & Teusch, 2015).

The second biggest distributor is **RESA** who is responsible for a territory of 71 municipalities in the province of Liège. In the past, RESA was an “intercommunale pure” but in 2014 it integrates the group Publifin to constitute a public limited company.

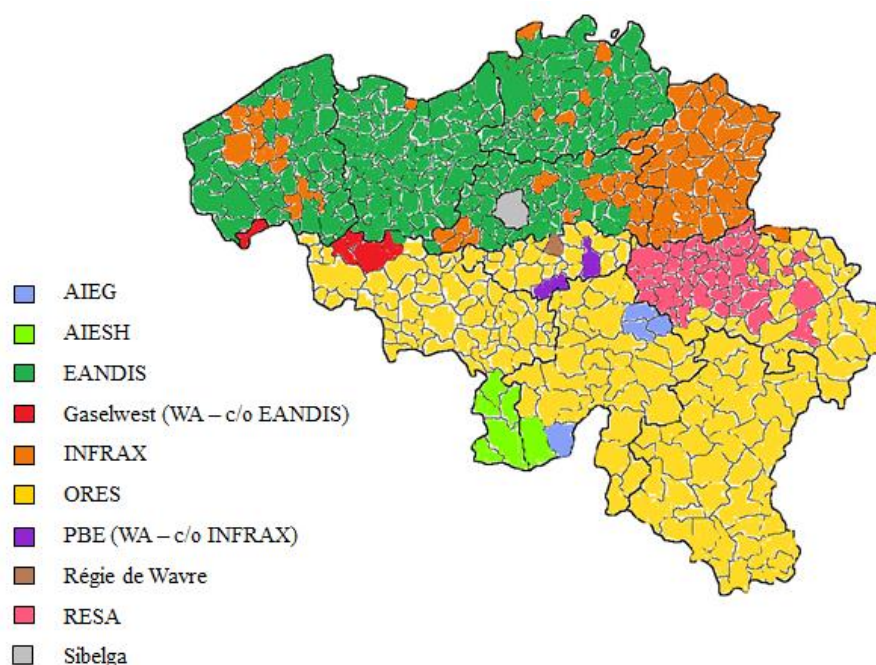


Figure 1-2 DSOs in Belgium (Source: own illustration based on CWaPE, VREG, Brugel)

¹ ORES Brabant Wallon (ex Sedilec), ORES Est (ex INTEREST), ORES Hainaut Electricité (IEH), ORES Luxembourg (ex Interlux), ORES Mouscron (ex Simogel), ORES Namur (ex IDEG), ORES Verviers (ex Intermosane).

² Intercommunales Pures de Financement

Besides the two biggest distributors, small local operators are managing the electricity distribution over the few remaining municipalities, namely **AIEG, AIESH and Régie de Wavre**. They are entirely owned by public authorities, i.e. “intercommunales pures”. Some border territories are ruled by Flemish operators, respectively Gaselwest, and PBE.

Flanders

In Flanders, the electricity distribution is owned by 11 pure municipal organizations¹. However, they delegate the daily operations to two independent service companies: **EANDIS** and **INFRAX**. These service companies are jointly owned by the DSOs of which they operate the network.

Brussels

Over the 19 municipalities² of Brussels, there is one distributor called **Sibelga**, who entrusted the management of its network to a subsidiary, **BNO**.

Figure 1-3 displays the regional repartition of DSOs by number of connections.³ In Flanders, EANDIS and INFRAX form an unbalanced duopoly, while Sibelga is in situation of monopoly in Brussels. In Wallonia, the situation is more diversified despite ORES being largely dominant. In conclusion, many distributors exist in Belgium, but there are only eight independent decision-makers: five in Wallonia, two in Flanders and one in Brussels. (Agrell & Teusch, 2015)

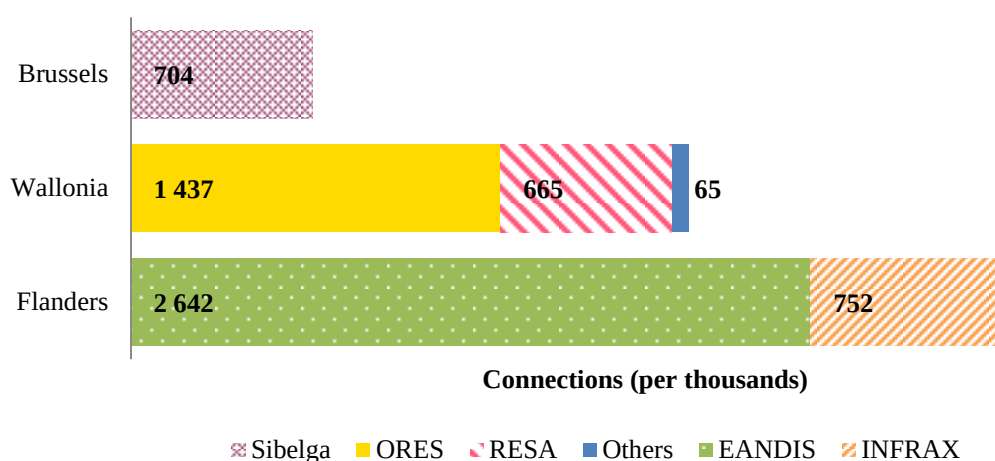


Figure 1-3 Regional repartition of DSOs
(Source: own illustration based on annual reports of DSOs)

¹ Gaselwest, IMEA, Imewo, Intergem, Iveka, Iverlek and Sibelgas for EANDIS
Infrax Limburg, Infrax West, Iveg and PBE for INFRAX

² Anderlecht, Auderghem, Berchem-Sainte-Agathe, Etterbeek, Evere, Forest, Ganshoren, Ixelles, Jette, Koekelberg, Molenbeek-Saint-Jean, Saint-Gilles, Saint-Josse-ten-Noode, Schaerbeek, Uccle, Bruxelles-Ville, Watermael-Boitsfort, Woluwe-Saint-Lambert, Woluwe-Saint-Pierre

³ More details on DSOs in Appendix 2.

1.3.2. Regulation in Belgium

Until 2014, there was one federal regulator in Belgium called the CREG¹ who was responsible for the regulation of both transmission (Elia) and distribution (DSOs). Since the ratification of the 6th State Reform in 2014, many federal competences have been transferred to regional entities, including the tariff regulation of electricity (and gas) distribution².

As of July 1st 2014, four institutions (one federal, three regionals) are responsible for the control of the electricity distribution and tariff approval.

CREG - federal

Until July 1st 2014, the CREG was regulating the Belgian DSOs with a hybrid model. A large part of the costs was under a *rate-of return* regulation: the DSOs were covered for the totality of these cost and they could expect a return-on-investment. On the other hand, a small part of the costs was under a *revenue* regulation. So, these costs were compensated with a fixed (and indexed) budget. Nevertheless, the regulated distributors had all incentives to reallocate costs from the revenue regulation to the other *rate-of return* regulation (Bouckaert, 2015). The outcome of such behavior was a costly monitoring from the regulator's side and it resulted in painful ex-post negotiation between both parts (operators and regulator) for the cost allocation.

Since the 6th State reform, the CREG is focusing on the regulation of the unique TSO, Elia. In the meantime, the CREG is publishing reports on the energy sector in Belgium.

CWaPE³ - regional

The CWaPE is the regional institution for Wallonia. It is regulating the DSOs active in Wallonia: AIEG, AIESH, ORES, RESA, Régie de Wavre, as well as the activities of Gaselwest and PBE that takes place in Wallonian territory. Its mission is to support the development of energy distributors and to offer incentives in order to improve network performances in the short and long-run.

The CWaPE became in charge of tariff regulation in 2014. It established a transition period in 2015-2016 in order to ensure the continuity. So, during this transition, the CWaPE kept the same methodology applied previously by the CREG. In 2016, the CWaPE decided to extent

¹ Commission de la Régulation de l'Electricité et du Gaz/Commissie voor de Regulering van de Elektriciteit en het Gas

² The second part of the 6th State Reform has been signed the 11th of April 2014 (Belgium.be, 2014)
More details on 6th State Reform in Appendix 3.

³ Commission Wallone pour l'Energie

the transition until 2018. The tariffs for the network utilization have already been approved (CWaPE, 2017).

After the transition, a five-year regulatory period will start for 2019-2023 (see timeline in **Figure 1-4**). The *cost-plus* approach has been chosen. To do so, the CWaPE has defined the set of cost drivers that could enter in the computation of the budget allowance. The total costs include the operating expenditure (OPEX), amortization of infrastructure investments and public obligations called OSP (Obligation du Service Public).¹ Among that, the regulator will grant a fair margin that constitutes the retribution of invested capital. The regulator will determine ex-ante the percentage return on all the regulated assets (Bougnouch, 2015).

VREG - regional

The VREG² is the regional institution responsible for the regulation of DSOs active in Flanders: EANDS and INFRAX.

The VREG wants to differentiate from the former model of regulation defined by the CREG. It aims to provide DSOs with incentives for cost-reduction. To do so, the VREG has defined a *revenue regulation* on a two-year period which started in 2015 (see timeline in **Figure 1-4**). The VREG distinguishes *exogenous costs*, not under the DSO's control – mainly green certificates, and *non-exogenous costs*, under the operator's control. For the first period in 2015-2016, the VREG estimated the linear trend using historical costs from 2010-2013.

Hence in 2015, each DSO received a similar share based on the trend resulting from the linear extrapolation (Bouckaert, 2015). Consequently, if the DSO's actual costs are evolving at lower speed than the estimated trend, the company will receive a reward. Inversely, the company will suffer from lower profit margins if its costs are not under control. For the second year of the regulatory period, the revenue is indexed using CPI (Consumer Price Index) and productivity requirements. Hence, the framework developed by the VREG offers incentives to operators for cost-reduction and efficient behavior.

¹ Public institutions impose the distributors to perform actions such as supportive social actions, environment protection and safety. These obligations are included in the cost analysis.

² Vlaamse Regulator van de Elektriciteits en Gasmarkt

Brugel – regional

Brugel is the regional institution that regulates the only electricity DSO in Brussels: Sibelga. Considering the simpler context, Brugel already approved the pricing methodology as well as the tariffs for the five-year regulatory period 2015-2019 (see timeline in **Figure 1-4**). The methodology follows the *cost-plus* approach, since there is a unique operator.

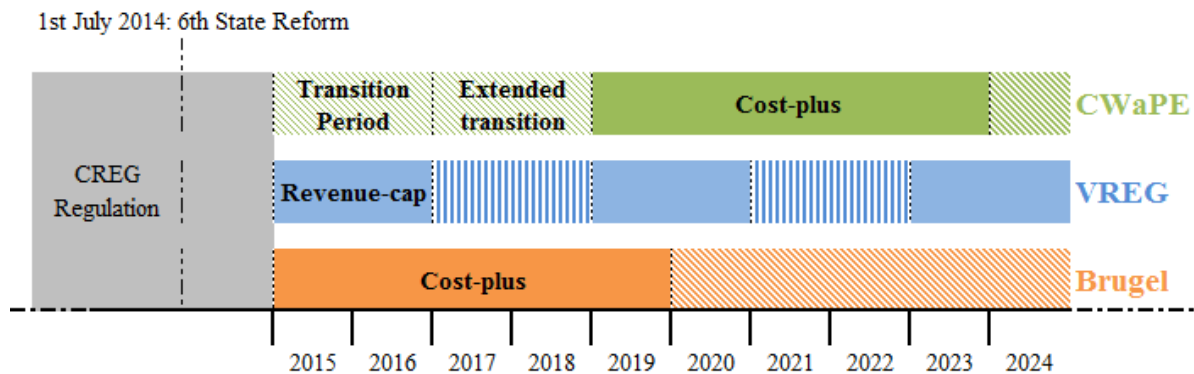


Figure 1-4 Timeline of regulatory methodologies in Belgium
(Source: Own illustration based on Bouckaert, 2015; Bougnouch, 2015; Lexgo, 2016)

Figure 1-4 displays the timeline for regulation in Belgium. Since 2015, the three regulators have imposed different regimes. VREG is already starting its second period, while the CWAPE has extended the transition period until 2019.

1.3.3. Summary

As a conclusion, the electricity network in Belgium is composed of various protagonists. There is one TSO regulated by one federal regulator. There are eight DSOs among three regions, with a regulator per region. Each regulator develops its own methodology to set the revenue of the operators over a non-synchronized calendar. In the following section, we will introduce the research questions that will be answered in the thesis.

1.4. Research questions

The regulation of distribution tariffs in Belgium has been subject to major changes since 2014. The former federal competence has been transferred to regional authorities. It leads to the unbundling of the regulatory actors: from one unique power to three regional controllers (in Wallonia, in Flanders and in Brussels). This transformation is called *decentralization of the regulation* in the course of the thesis. In Belgium, the decentralization was not the outcome of a careful study for improvements. It was rather a reaction to external factors, mostly political decisions under the willing of regionalists. As any transformation, it may impact both the operators and the consumers. Does it cause an increase or a decrease of the distribution tariffs? Does it force more or less the DSOs to adopt a cost-efficient behavior? In front of these issues, the regulators are facing new challenges.

The thesis focuses on the capacity of the regulator to govern the DSOs. As a reminder, the society empowers a regulator to protect itself against the excessive rents of monopolistic DSOs. The regulator sets the DSOs' revenue to ensure a fair remuneration of their investments while protecting the consumers. However, the regulator ignores the actual costs of DSOs so it bridges its ignorance by observing the sector: this practice is known as the benchmarking analysis. The regulator sets the DSO's revenue according to the performance of others.

The decentralization of the regulation implies the *partitioning* of the regulatory environment: a territory is divided into regions where each region has its own regulator. As a result, the scope of each regulator is reduced. Regarding the power balance, the decentralization weakens the position of the regulator against the DSOs. It may result into a cost for the society.

Inspired by the Belgian situation, the research thesis addresses the theoretical implication of a decentralized regulation. Starting from the base of the regulation theory and benchmarking, the thesis studies the cost of decentralization thanks to some research questions.

Q1: Is there a social cost of the decentralization in regulation?

Q2: Does a partitioning on geography increase equity in regulation?

Q3: How is the cost of decentralization affected by an ex ante partitioning on scale?

Q4: How is the cost of decentralization affected by an ex ante partitioning on ownership?

1.5. Outline and limitations

The thesis is a theoretical study that estimates the social cost of the decentralized regulation. It analyses the effect of the partitioning on the benchmarking exercise. Inspired by the practices, we make use of a particular benchmarking tool called DEA (Data Envelopment Analysis). The DEA benchmarking is developed in a quantitative model which is used to validate our research questions.

To introduce the theoretical concepts, a review of the literature is proposed in Chapter 2. The review is organized in three parts. First, we expose an overview of the regulation theory: the mechanism and the methodologies. Second, we tackle the performance evaluation: the notion of efficiency and a classification of the benchmarking tools. In the meantime, we focus on the DEA which is the benchmarking method used in the quantitative analysis. Third, we address the empirical applications of the regulatory benchmarking: how the efficiency analysis is used by national regulators to monitor their electricity distributors.

Thereafter, Chapter 3 studies the cost of the decentralization: from a quantitative model, we simulate the partitioning of the regulatory environment. First, we present the dataset and specify the model used. In addition, a complete overview of the initial situation is presented. Then, a theoretical proof demonstrates our insights.. Finally, we expose the results of our analysis. In order to tackle each of the four research questions, four partitioning have been performed according to four criteria: random, geographic, scale and ownership. We resume our findings by four propositions that answer the four research questions.

At last, we contextualize the theoretical implications to the Belgian context in Chapter 4.

Before getting to the heart of the matter, it is our duty to express few limitations:

- 1) A theoretical study implies that it is not based on empirical observations. The thesis took a step back from the reality in order to grasp the pure effect of the decentralization. Another work could be carried out from the empirical point of view: analyzing the effective impacts of the regionalization to the regulation in Belgium.
- 2) The dataset used in the quantitative analysis contains historical data of DSOs in Sweden. It may include some countries' specificities: Nordic country, low population-density, natural and wild environment. Thus, the results must be taken carefully when applied in a different context.

- 3) When talking about challenges for the regulator, it is important to distinguish the *challenges of the regulation* from the *challenges of the regionalization*. The former comprises the challenges of the regulators to incorporate the trends and transformations that the sector undergoes. Some interviews carried out with Climact¹ helped to identify the future challenges of the distribution activities: (1) the need for flexibility in terms of production and demand – Demand-Sized Management –, (2) the energy storage solutions in order to take advantage of the production variability within renewables energies. In addition, the distribution activity must encounter with (3) the development of local energy producers, e.g. photovoltaic panels, personal wind power. Generally, the regulator must help the energetic transition. Although this thematic is interesting, it will not be addressed in the course of this master thesis. Another work would need to be performed in order to expose a clear analysis of the challenges that the regulator(s) encounters in front of the upcoming energetic transition.

On the opposite, the current thesis tackles the challenges of the regionalization by identifying the impact of such transformation.

¹ Climact is a consultancy firm based at Louvain-La-Neuve who proposes prospective analysis and CO2-efficient solutions.

Chapter 2 : Literature review

2.1. Regulation theory

One of the precursors of the modern economy, Adam Smith, believed in the *market power* as the core of the economic transactions. He argued that the collective desires of the actors (sellers and buyers) present in a free economy naturally operate in such way that it tends to produce the most efficient goods in the most efficient manner, since the largest market share (and revenue) is earned by the most-efficient seller. Smith's theory of the invisible hand lies in the *market power*: free individuals, focused on their self-interest, take actions that result in benefiting the whole society even if it was not their primary goals (Investopedia, 2015). The core assumption on his theory is a liberalized economy which is completely open to competition. Contrary, infrastructure-intensive industries such as energy transport and telecommunications operate in a natural monopoly due to obvious reasons of efficiency. Thus, such activities need to be regulated in order to compensate the market power.

2.1.1. Why regulate?

In recent history, the public sector has played an important role in the functioning of our economy. Its involvement is mainly justified by ensuring the national security and addressing the market failures (Australian Treasury, 1999). "Network activities, such as distribution of electricity or water, are examples of natural monopolies" (Vanhanen, Vehiläinen, Virtanen, Agrell & Bogetoft, 2010, p.6).

Giannakis, Jamasb, and Pollitt (2004) detailed why regulating energy networks is more efficient than the free market by tackling the market failures. First, electricity networks possess the characteristics of natural monopolies due to obvious economies of scale¹. Second, electricity distribution is perceived as an "experienced good", i.e. the consumer is poorly informed of the service quality prior the consumption. Third, non-users of networks are likely to be affected by *external effects* (environmental, health or safety risks). Liberalized distribution network would lead to low-cost distributors which would affect the entire society (e.g. noisy electric lines, pylons fall, and electrocution).

Furthermore, the market limitations in electricity distribution are emphasized by (i) the presence of a single service's provider per customer, (ii) the low price elasticity due to the

¹ Underground cables, lines and pylons represent huge fixed costs for the network deployment.

absence of substitute, and (iii) substantial economic and legal barriers for new entrants (Vanhanen et al., 2010).

Consequently, in return for granting exclusive monopoly rights to operators, the society empowers a *regulator* to impose constraints on tariffs (prices) and monitoring the investments.

2.1.2. The regulator's problem

In economic literature, the interactions in regulatory context are expressed by a two-step game between a *principal* (the regulator) and few *agents* (regulated firms). The principal aims to maximize social welfare, formulated as the difference between customers/firms' surplus and the cost incurred. The agents seek the surplus maximization (Vanhanen and al., 2010).

Figure 2-1 below displays the mechanisms that occur in the regulatory two-phase game.

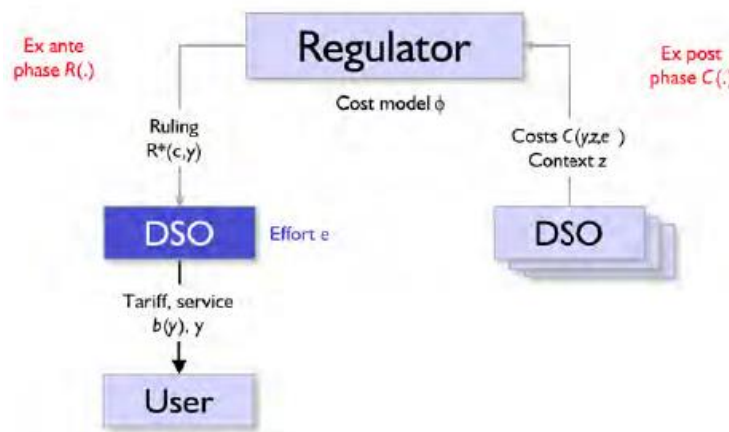


Figure 2-1 Regulatory interactions (Source: Agrell, 2015)

Phase 0

Prior to the game, the regulator determines the mechanism used to set the *regulated revenue* $R(c,y)$ of each agent which varies with the delivered services y and some cost estimation c . In addition, it sets the *estimated cost target*, using the cost model $\Phi(\cdot)$. The regulator can base its estimation on (costly) ex ante information x_0 and/or collect ex post information x_1 about the agents. “The main decision variables are for the agents, participation (market exit/entry), the effort e (moral hazard) and the tariff structure $b(y)$ (adverse selection).” (Agrell, 2015, p. 104) The regulated firm is setting a series of tariffs in order to generate the regulated revenue. After the regulator has approved the tariffs, the users react by consuming a level of services y , i.e. the amount of electricity demanded.

Phase 1

At the end of the period, the regulator compares the prior-estimated cost target and the effective cost C supported by the agent¹. Globally, the regulator experiences a “*double asymmetry of information*, where neither efficient costs, nor optimal efforts are verifiable” (Vanhanen and al., 2010, p.6). Indeed, the agents detain private information on their activity, hardly verifiable by the regulator.

In order to incite participation or effort, the regulator must define ex-ante some elements: the revenue function (see section 2.1.4) and the cost model (see section 2.2.2). A generic revenue function may be formulated as follow (Agrell, 2015).

$$R(.) = c_1 + a[\Phi(x_0, x_1) - c_1] \quad (\text{Eq. 1})$$

The allowed revenue is the actual cost plus a reward if the agent outperformed the cost target [$c_1 < \Phi(x_0, x_1)$] or minus a penalty if it did not reach the cost target [$c_1 > \Phi(x_0, x_1)$]. The lever of the reward/penalty is defined by $a \in (1,0)$, the incentive power.

Regulator's choices are included into the *degree of intervention* in the agent's actions: light-handed or heavy-handed. In *light-handed* regulation, “the regulator operates the minimal requirements, leaving the firms to decide upon both operations, tariffs and revenues as long as they do not violate other regulations, e.g. anti-trust, public safety, consumer protection laws.” (Agrell, 2015, p.105) It favors the self-regulation of the sector and reduces direct costs of regulation. In the other extreme, *heavy-handed* regulation² strongly intrudes in the internal/external agents' decisions. The regulator forces the regulated firm to adopt a certain behavior and curb the moral hazard. This approach tends to solve the adverse selection problem, provided that agents reveal good information. At the extreme point, the nationalization of the agents can be seen as a special case of a heavy-handed regulation: the agents are integrated to the state's duties and the regulator actually manages the firms.

2.1.3. Incentive regulation

A sub-section of the regulation literature focuses on the incentive regulation, i.e. the factor a in Eq. 1. As defined by Sappington and Weisman (1996), the incentive regulation is “the implementation of rules that encourages a regulated firm to achieve desired goal”.

¹The cost structure $C(y, z, e)$ is the level of cost for services provided y , for specific exogenous operating conditions z (environment) and for effort e .

² Heavy-handed regulation refers also to the Command and Control regulation where the regulator provided detailed instructions to be performed by the utility, it sets performance goals and it monitors personnel to ensure that procedures are respected.

Specifically, the incentive regulation includes the partial delegation of pricing decisions which allow the firm to retain profit from cost-reductions. (Vogelsang, 2002)

In other words, “government intervention establishes by definition a system of rewards and penalties for private decision-makers” (Berg, 1997), which fosters cost-efficient firms. Let’s pose some clarifications on the definition. First, the scope of the regulation is formulated symmetrically: there are risks and rewards (Agrell, 2015). Then, the regulated firm retains its decision rights: “allowing the company a role in choosing its goals is referred to as a *menu of options* whereby the regulator matches greater potential rewards with more ambitious goals” (Jamison, 2007, p.4). This menu of options (or menu of contracts) should address the principal-agent problem faced by the regulator, by forcing the firm to surrender its private information (Laffont and Tirole, 1993). Furthermore, the firms must have the autonomy to decide how to achieve the goals, unlike to control and command regulation (Berg, 1997), or gambling and insurance (Agrell, 2015).

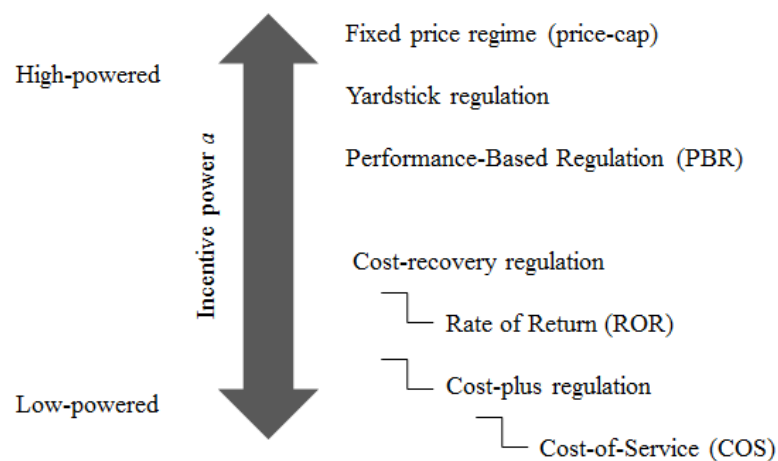


Figure 2-2 Regulatory classification
(Source: Own illustration based on Laffont & Tirole, 1993)

2.1.4. Regulatory toolbox

A classification of the existing regulatory schemes has been introduced by Laffont & Tirole (1993). It is based on the incentive power, parameter a in Eq. 1. It distinguishes *low-powered* and *high-powered regime*. In the former case, agents receive poor incentives for cost-reductions or performance improvements (very low a). On the other end, high-powered methods put pressure on agents to adopt efficient behavior by designing reward/penalties models (very high a). Fixed-price regime, price-cap, yardstick are examples of high-powered regulation. Through such models, the regulator transfer part (more

or less important) of the risk on the agents' shoulders. Hence they can have substantial profit or loss expectations. **Figure 2-2** displays different schemes of regulation which depend on the degree of incentives. Each of the regimes will be covered below.

Cost-recovery regulation

In the cost-recovery approach, the regulator authorizes the firms to be covered for the totality of their costs (Berg, 1997). Logically, this approach is based on the ex-post reporting of actual costs for each agent. It is possible to distinguish two categories of cost-recovery methods:

- The cost-plus approach is characterized by the conceptual revenue function:

$$R = (1 + g)c_{operating} \quad (\text{Eq. 2})$$

Let $c_{operating}$ denotes the direct operating expenditure (OPEX) and g represents a mark-up factor that grants a fair return on capital to maintain the activity. In the case $g = 0$, it is called cost-of-service (COS), mostly used in presence of public ownership. (Agrell, 2015)

- The rate of return regime (ROR), commonly applied in US system, covers all operating costs plus a fair margin on the regulated asset base x_{cap} . As simplified below:

$$R = (WACC + d)x_{cap} + c_{operating} \quad (\text{Eq. 3})$$

Let WACC be the Weighted Average Cost of Capital and d be the depreciation rate.

The literature identifies a series of problems in the cost-recovery approaches:

- **Allowable costs:** both methods are frequently organized in the shape of negotiation/consultation where principal and agents must find an agreement around the table on what enters in the operating cost as well as deciding a fair return rate. Combining negotiations with benchmarking would limit the bargaining space. (Agrell and al., 2010)
- The utilities receive **few incentives to reduce operating costs**, since these can be reimbursed by the tariffs. Then, production is not achieved in an efficient way. Furthermore, Agrell & Teusch (2015) stated that “it undermines the bargaining position of the firm towards suppliers and staff, creating a common interest to maintain favorable working conditions, social stability and high equipment standards”.
- From the regulator point of view, it provokes an important **administrative burden**, “because regulators need to closely monitor firms to avoid inflated operating expenditures or unnecessary investments (known as gold-plating or Averch-Johnson effect)” (Agrell & Teusch, 2015, p. 164).

In reality, these schemes tend to be abandoned by governments in order to be replaced by more incentive-based methodologies.

Price cap and revenue cap regulations

Proposed by Littlechild (1983), the price cap regulation has been developed originally in Britain, in response to the problems of cost-recovery approach, explained in the previous section. In his report, Littlechild defends that price cap would give desirable incentives to achieve efficient production, while limiting the administrative burden of the regulation (Australian Treasury, 1999). Conceptually, the regulator sets ex-ante the maximum inter-temporal evolution for the price (or the revenue in case of revenue cap regulation) during a predefined regulatory period (of length T) as displayed in **Figure 2-3**.

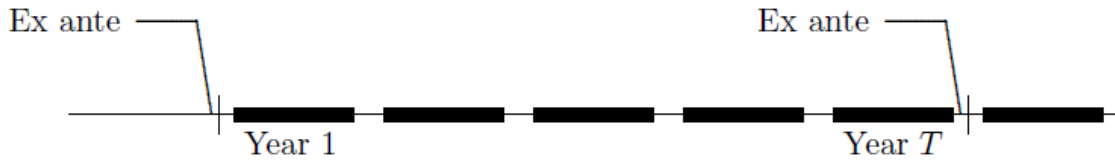


Figure 2-3 Ex ante regulation (Source: Agrell & Bogetoft, 2013)

Revenue cap regulation is sometimes called CPI-X model because the regulator ex-ante determines a fixed reduction (X) of some base-level price or revenue (Agrell & Bogetoft, 2010). It means that approved prices (revenues) are periodically actualized using the CPI index¹ and constrained by a certain factor x^k which represents the adjustments for productivity requirements of firm k (Agrell & Bogetoft, 2013).

Simple revenue function for firm k is then:

$$R^k(t) = C^k(0)(1 + CPI - x^k)^t \quad (\text{Eq. 4})$$

Let $R^k(t)$ be the allowed revenue in period t , $C^k(0)$ is the actual cost of firm k in period 0.

The revenue cap methodology contains a fixed-payment that is independent of the firm's actual performance. Hence, profit-maximizing utilities will find it optimal to minimize costs (Agrell & Teusch, 2015). At the equilibrium, the revenue cap scheme allows the utilities to retain the profits they would receive by improving efficiency, while avoiding price increase

¹ Consumer Price Index

for the consumer. The x -factor reflects the potential cost savings that the firm can generate due to technological progress or increased efficiency (Australian Treasury, 1999).

Despite the positive attributes, the fixed-price regimes face some challenges:

- The regulator faces a tradeoff when **determining the initial cap $C^k(0)$** . If the cap is set too tight (low), firms may go bankrupt or may not participate (Agrell, Bogetoft & Tind, 2005). On the opposite, if the cap is set too high, informational rents¹ will be excessive and firms will generate immoderate profits (Agrell & Teusch, 2015).
- An appropriate **x -factor is difficult to choose** in practice. It faces a similar tradeoff. “If x is set too high, the firm will not be able to cover its costs, but if x is set too low, then prices will remain excessive and the firm will earn supernormal profits” (Australian Treasury, 1999, p.8). Ideally, the x -factor should rely on expected future productivity improvements. Benchmarking and DEA analysis may solve this difficulty.
- The CPI index is not necessarily linked to the input prices thus it can conduct to some positive (negative) discrepancies with the reality when input prices increase less (more) than the CPI. Moreover, CPI-X scheme does not include the evolution in outputs (as quality, innovation, flexibility), which provides hereby disincentives to invest in such improvements.
- Highlighted by Weitzman (1980), the **ratchet effect** is a side-effect of dynamic-incentive regime as CPI-X, which “arises from the tendency of planners to use current performance as a criterion in determining future goals” (Weitzman, 1980, p.302). In other words, agents may tend to willingly operate below efficiency because “they face a dynamic tradeoff between present rewards from better current performance and future losses from the assignment of higher targets”.²

To conclude, the fixed price regulation demands non-trivial exercise for the regulator, but it eases the work during the regulatory periods because negotiation with operators no longer exists.

Yardstick regulation

First introduced by Shleifer (1985), the “yardstick” regulation is an interesting alternative to previous regimes. The concept is “to set individual cost target for each operator that equals

¹ The informational rents are the gain that firms are able to retain due to their private cost structure

² More details on ratchet effect’s computation in Weitzman (1980)

the realized cost by other (comparable) agents” (Agrell & al., 2005). In other words, the yardstick scheme tries to mimic the market competition by estimating the real cost function with an exogenous cost-target (competitive benchmark), obtained through real observations - average or best-practice performance (Agrell, 2015).

Revenue of firm k can be formalized by:

$$R^k = c^k + a[f(x_{-k}) - c^k] \quad (\text{Eq. 5})$$

In the equation, x_{-k} corresponds to all the firms in the sector, excluding the firm k . The revenue of each agent is not determined by its own cost but by the performance of the other agents. Consequently, it solves the ratchet effect since agent's previous performance has not impact on the future cost target.

The second advantage is that the productivity development is predicted rather than observed (Agrell & Bogetoft, 2013). As displayed on **Figure 2-4**, it means that the revenue is set *ex post* after each year. As a result, it decreases the informational rents generate by the operators, by bridging the information gap¹. Moreover, it avoids the arbitrariness encountered in CPI-X models.

Despite the theoretical merits, the implementation of yardstick regime comprises several challenges:

- The success of yardstick regulation relies on **sufficient number of firms**.
Otherwise, the benchmarking exercise would have major inconsistencies, e.g. agent would strategically allocate its costs to virtually improve its performance (Ofwat, 2012).
Furthermore, the *risk of collusion*, e.g. cartel, is real if the comparators are few (Agrell & Bogetoft, 2013)
- Besides, the analysis requires **comparable firms**. But the comparability is subject to be harmed under “special circumstances”, e.g. environment, ownership, size (Australian Treasury, 1999).
- At last, the regulator must ensure that all the dimensions are taken into account in the comparison analysis, in order to avoid perverse incentive to focus on one side of the efficiency.²

¹ By utilizing the maximum amount of information, yardstick is tailoring the revenue cap to individual agents such that informational rent is minimized (Agrell et al., 2005)

² As an example, if the regulator emphasizes on the reparation time, while forgetting the number of reparation, agents will allocate the staff for correcting the faults but not for preventing them (Australian Treasury, 1999).

To conclude, yardstick scheme is information-intensive and requires large implication from the regulator in the agents' monitoring, i.e. heavy-handed regime. Nowadays, the trend is to develop a harmonized system which allows comparing firms internationally. It would give more consistencies to the comparison analysis and would solve the major challenges addressed above.¹

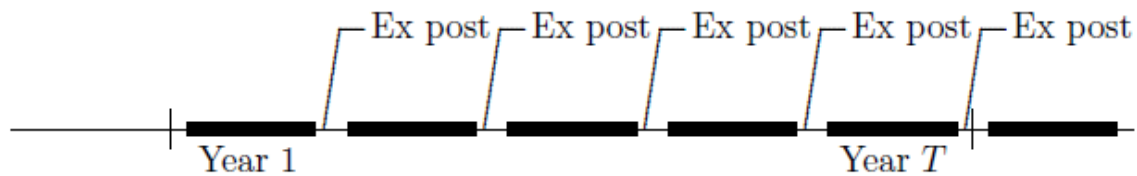


Figure 2-4 Ex-post-regulation (Source: Agrell & Bogetoft, 2013)

Performance-based regulation (PBR)

Close to the traditional regulatory regimes, the Performance-Based Regulation (PBR) has been proposed by Comnes, Stoft, Green & Hill (1995) before its application in US. This incentive regulation “links the firm’s profits (or employee remuneration) to performance measures in such way that profits increase if certain performance standards are achieved” (Australian Treasury, 1999, p. 9). PBR regulation includes in fact different models.

First, the ‘sliding scale’ regime allows “firms with higher cost to share more of this cost with consumers through a higher regulated price” (Hawdon and al., 2007). Furthermore, it has been applied to gas utilities that “were permitted to pay dividends that were *inversely proportional* to the price of gas” (Australian Treasury, 1999, p.9), which give incentives to owners for reducing the consumer’s price. The second PBR model defends that profits are split between shareholders and employees which motivates these parties to perform at higher efficiency.² The third PBR model is called the output floor scheme. Conceptually, the regulator sets a minimum level of output production and the regulated firm has substantial freedom on prices, inputs mix, and generated profit. If well-implemented, “the firm will likely reduce its overall price level in order to stimulate sufficient demand to meet the output floor” (Australian Treasury, 1999).

The main difficulties of such schemes is to define the objectives of performance that should be not too high (realistic) and not too loose (incentive).

¹ More details on Agrell and Bogetoft, 2010

² The scheme can be adapted to return part of the profits to consumers

Franchise auction

Franchise auction introduces a form of competition in natural monopolies for the attribution of given area.¹ Based on tender auctions, the government can “award to one firm an exclusive right to sell a particular good in a particular market” (Australian Treasury, 1999, p. 12).

Formally, K bidders for a project ask simultaneously an offer $B^h, h = 1, \dots, K$. Agent k is the winner if $B^k = \min\{B^1, \dots, B^K\}$ and would be compensated for $R^k = \min\{B^{h \neq k}\}$.

(Agrell & Bogetoft, 2013)

This procedure is called *second-price principle* where the winning bidders can compensate for the second minimum offer. Indeed, it creates a dominant strategy for all agents to reveal their true cost and it provides incentives by giving a reward to best-in-class firms.² In this form, the second-price principle is similar to yardstick regime.

Despite the capacity for franchise auctions scheme to bridge the informational gap between principal (regulator) and agents (regulated firms), it presents a risk of collusion. Indeed, the problem with highly concentrated markets is that “bidding may be collusive” (Agrell & Bogetoft, 2013, p. 10). However, tendering off specific investments - e.g. smart-metering installation, off-shore generation connections – may be an interesting option (Agrell & Teusch, 2015).

2.1.5. Summary

To conclude with the theory of regulation, it is an important and complete economic topic: there exist many methodologies with each its advantages and drawbacks. Thus, the choices of the regulator may differ from one country to another. Because, the regulator is here to protect the consumers, the current trend is to provide the agents with some incentives to reduce their costs and tariffs. However, it may be not trivial for the regulator to set fair revenue with realistic improvement requirements. The comparative analysis of firms’ performance, called benchmarking, may solve the issue.

The next section will address the performance evaluation. It will introduce the measures of efficiency from a theoretical point of view; it will classify the benchmarking tools; and the DEA benchmarking will be detailed.

¹ The French water utility is a good example: while the municipality owns the network, a lease company is responsible for operations and its attribution is performed with franchise auctions (Australian Treasury, 1999).

² Otherwise, if payment depends on actual bid of the winner, each agent will submit the bids with a mark-up, which would pull prices up.

2.2. Performance evaluation

In a profit-based society, the main driver for companies is to create value. Thus, an important indicator for firms' performance is the concept of productivity and efficiency. One of the most used tools to assess companies is the *benchmarking* – or relative performance evaluation. It consists in the systematic performance's comparison of one firm against other comparable firms in the sector. The comparators are some entities which transform the same type of resources into the same types of products/services (Bogetoft & Otto, 2010). In order to present a clear review of the benchmarking, it is essential to define the main criterion for performance evaluation: the *efficiency* as it is used in the literature. Secondly, it exists many ways to build the reference (DEA, COLS or SFA) which will be introduced afterwards. At last, the DEA method will be detailed since it is the one used in the quantitative analysis.

2.2.1. Efficiency measures

A firm can be conceptualized as a decision-making unit (DMU) which goal is to transform resources into products, based on a specific production plan, i.e. a combination of *inputs* x and *outputs* y (see **Figure 2-5**). To do so, the DMU makes choices (*effort*), under some *exogenous factors*: dimensions which are out of DMU's scope (Bogetoft & Otto, 2010).

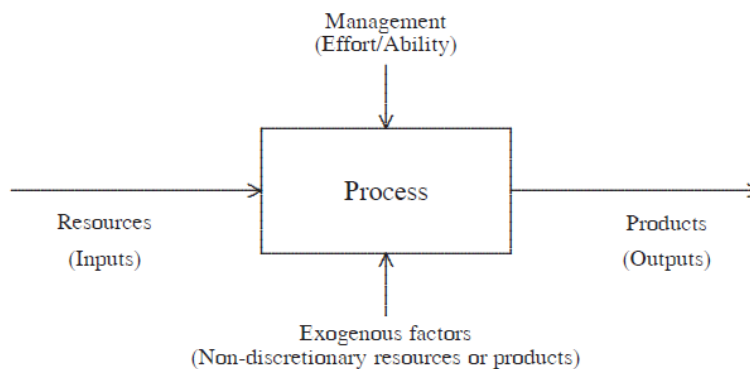


Figure 2-5 System View (Source: Bogetoft & Otto, 2010)

In a logical thinking, “efficiency is generally a question of using few inputs (resources) to produce many outputs (products/services)” (Bogetoft & Otto, 2010, p. 24). On the **Figure 2-6**, Firm 2 is able to create more products with proportionally less resources. Consequently, Firm 2 (dominant firm) is more efficient than Firm 1 (dominated firm) since its productivity ratio output per input is bigger.¹

¹ Productivity is the actual ratio *output/input* while the efficiency is a comparison (ratio between firm's productivity).

This introductory approach, called KPI approach, is simple on purpose and contains many implicit assumptions (return-to-scale, single input/output model, partial evaluations) that will be relaxed in the following sub-sections.

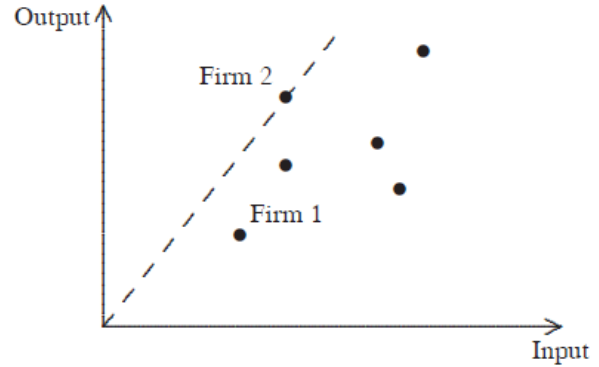


Figure 2-6 Input-output combinations
(Source: Bogetoft & Otto, 2010)

Technology Set

“The technology set T is the set of combinations of input and output such as the input can actually produce the output” (Bogetoft & Otto, 2010, p.11).

$$T = \{(x, y) | x \text{ can produce } y\} \quad (\text{Eq. 6})$$

Four assumptions must be made to complete this definition (Bogetoft & Otto, 2010):

a) Free disposability: if (x, y) is included in the technology set, any combination where the input is larger and/or the output is smaller, is also feasible. In other words, “we can always produce fewer outputs with more inputs” (Bogetoft & Otto, 2010).

b) Convexity: the weighted average of two feasible combinations input-output is also part of the technology set. Geometrically, the line between two feasible points is also in T , which serves to enlarge the technology when only a limited number of observations are available (see **Figure 2-7**). It must be highlighted that convexity does not take into account the economies of scale and specialization that are present in some industries.

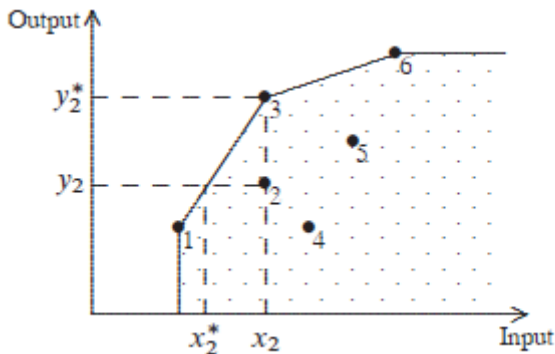


Figure 2-7 Free disposability and convexity
(Source: Bogetoft & Otto, 2010)

c) Additivity: the sum of two feasible points is feasible as well.

d) Scaling: the technology set is defined also by the scaling possibilities (up or down) of any feasible points. Conceptually, a factor λ must be discussed in order to permit that $\lambda(x, y) \in T$ for any $(x, y) \in T$.

- *Constant returns to scale (crs):* $\lambda \geq 0$

Any feasible combination can be scaled up and down. On a graph, it means that any line passing from (0,0) and (x,y) is part of technology set.

- *Decreasing returns to scale (drs):* $0 \leq \lambda \leq 1$

Scaling down is feasible, meaning that the output tends to increase less than the input. It is valid whether it is possible to reduce speed or capacity of the firm's process.

- *Increasing returns to scale (irs):* $\lambda \geq 1$

Scaling up is feasible, meaning that the output tend to grow faster than the input, when “larger scale implies more experience and more efficient processes” (Bogetoft & Otto, 2010).

A technology set that displays crs, drs and irs in various regions is called *variable return to scale (vrs)*.

Figure 2-8 displays illustration of the detailed scaling assumptions.

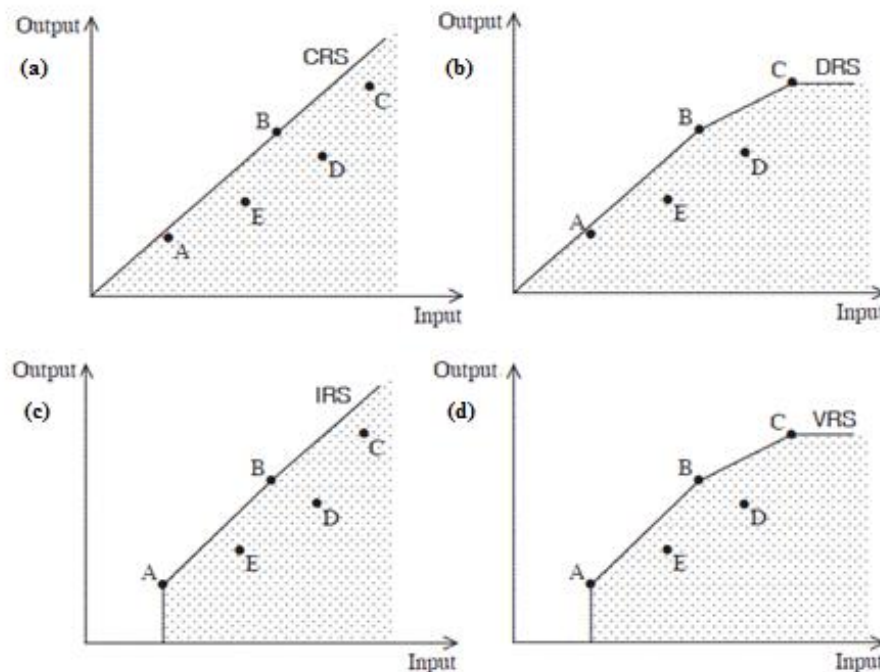


Figure 2-8 Scaling assumptions: (a) constant return to scale, (b) decreasing return to scale, (c) increasing return to scale, and (d) variable return to scale

(Source: Bogetoft & Otto, 2010)

Farrell Efficiency

The previous analysis dealt with single-input/single-output model which rarely appears in reality. The efficiency analysis in multi-input and multi-output is referred as Farrell efficiency (1957). “The idea of the Farrell measures is to focus on proportional changes” (Bogetoft & Otto, 2010) - i.e. the possibility to reduce the input without changing the output.

Farrell distinguished:

- *input efficiency* E , the maximal proportional contraction¹ of inputs x that allows to produce same level of outputs y : $E = \min\{E > 0 \mid (Ex, y) \in T\}$.
- and *output efficiency* F – i.e. the maximal proportional expansion of outputs y that can be produced with given inputs x : $F = \max\{F > 0 \mid (x, Fy) \in T\}$.

Graphically, the input (output) efficiency is the ratio between the optimal combination x^* , found as the intersection of the line $(0, x)$ with the isoquant², and the observed combination of inputs x (see **Figure 2-9**). A similar reasoning is available for output efficiency.³

In practice, Farrell efficiency is mostly useful to quantify the amount of dominance of one firm in its sector. Moreover, it can be used to rank firms according to their performance.

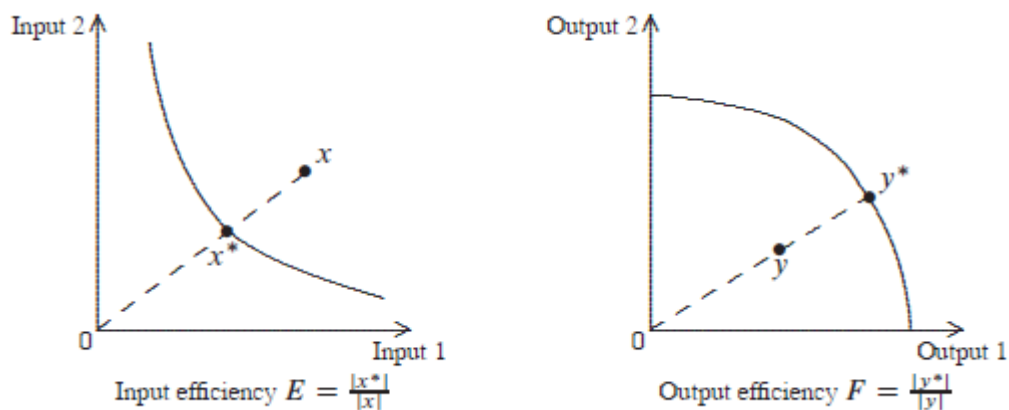


Figure 2-9 Farrell efficiency (Source: Bogetoft & Otto, 2010)

Cost efficiency

For now, the model shows a preference for *more outputs and fewer inputs*, without consideration of costs and prices. Nevertheless, it exists in reality relative weights or prices that allow building priorities among the efficient combinations. The introduction of prices

¹ Maximal contraction implies a minimum

² The isoquant is the curve that contains all input combinations for a given output level.

³ This graphical analysis is only valid in case of 2 inputs or 2 outputs.

allows us to decompose the efficiency into “*technical efficiency*, associated with the use of optimal procedures, and *allocative efficiency*, associated with the optimal combinations of inputs or the production of optimal combinations of outputs” (Bogetoft & Otto, 2010, p. 36).

In order to address the cost-efficiency, let w be the vector of input prices. **Figure 2-10** illustrates this decomposition, where x is the level of inputs effectively used and x^* the optimal level. This optimal level is found at the tangent between the isoquant (input combinations that produces given output level) and the isocost (input combinations with the same cost). The *cost-efficiency* CE is the ratio between optimal cost and actual cost $CE = wx^*/wx$.

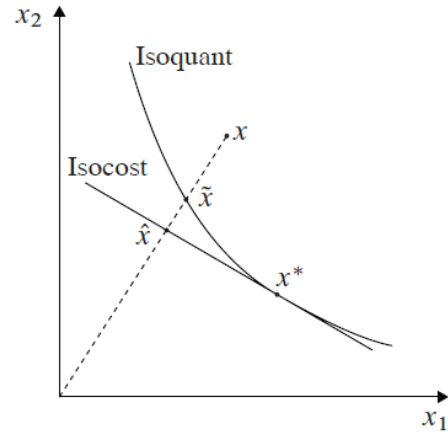


Figure 2-10 Cost efficiency
(Source: Bogetoft & Otto, 2010)

The CE is decomposable as detailed in Bogetoft & Otto (2010):

- First, the *technical efficiency* is similar to Farrell efficiency explained above – i.e. the ratio between actual cost and projection on isoquant: $TE = wx\tilde{x}/wx$.
- However, it is graphically clear that $\tilde{x}$ is not costly optimal since there exists combinations with a better isocost (**Figure 2-10**). Thus, the loss of having picked the technical-efficient combination $\tilde{x}$ rather than a less expensive input mix x^* is an allocation problem, defined in the *allocative efficiency*: $AE = wx^*/w\tilde{x}$.
- At last, the scale of the firm is also a lever for the cost-efficiency. Indeed, under crs assumption, re-scaling a firm may have an impact on its efficiency; whereas, vrs leads to efficient firms at different scale. In reality, there is an input level, called Most Productive Scale Size (MPSS), where the average cost is minimal. Hypothetically, every firm would like to operate at this scale. Hence, the *scale-efficiency* measures the loss from not operating at optimal scale size: $SE = TE_{crs}/TE_{vrs}$.

$SE = 1$ when the firm operates at optimal scale. It is thus a good indicator of the likely gain from adjusting the firm scale, e.g. deciding a contraction or expansion strategy for the firm, or evaluating the structural efficiency of the industry¹ (Bogetoft & Otto, 2010).

¹ Does the industry integrate the right number of firms with the right size?

There exist some limitations on the scale-efficiency concept such as the inability of firms to change their scale of operations. More details in Bogetoft & Otto, 2010.

Mathematically, it is possible to find the relationship between the efficiency measures.

$$CE = AE * TE_{vrs} * SE \quad (\text{Eq. 7})$$

In other words, to be cost-efficient, “the firm must be able to choose the right mix of inputs and use them in a technical efficient manner” (Bogetoft & Otto, 2010, p. 37) and we can add “at the right scale”.

In this section, we addressed in details the input efficiency with input prices. A similar reasoning is possible on the output side (while using the revenue p). Furthermore, if the price and revenue information (w and p) are known, both for inputs and outputs, it is logically possible to evaluate firms on their ability to generate profit, by computing the *profit-efficiency*.¹

Super-efficiency

In reality, it may be interesting to operate a ranking between firms with cost-efficiency of 1. Moreover, fully-efficient firms have few incentives to improve since it is theoretically impossible to be better (Bogetoft & Otto, 2010). The super-efficiency may solve this issue.

The concept is to build the technology frontier – best-frontier – by avoiding the evaluated firm. Consequently, the efficient firms will outperform the virtual best-frontier and be granted an efficiency score superior to 1. Hence, it gives incentives to firms on the frontier to continuously be better. Please note that super-efficiency only impacts firms on the frontier and it has no influence on other entities included in the technology set.

2.2.2. Benchmarking theory

From a conceptual point a view, modern benchmarking tools solve two fundamental problems in practical efficiency evaluations: “The lack of clear preference is handled by moving from effectiveness to efficiency (...). The lack of priori technological information is handled by estimating the technological frontier and by evaluating relative efficiency (instead of absolute efficiency).” (Bogetoft & Otto, 2010, p. 15)

An illustration is provided in **Appendix 12**. The approximation of the technology is called the benchmark.

¹ The profit-efficiency is provided by $PE = \frac{py - wx}{py^* - wx^*}$, where (x, y) is the observed production and (x^*, y^*) the profit-maximizing situation (Bogetoft & Otto, 2010)

Benchmarking standards

Jamasb and Pollitt (2001) and Lowry and Getachew (2009) classified benchmarking tools between those derived from the *best frontier* performance, and those based on *average measure* of performance.

- a) The frontier-based benchmarking estimates the efficient performance frontier from *best practice* in an industry. The efficient frontier becomes the reference against which the relative performance of firms is computed. Consequently it has a stronger focus on performance variations between firms (Jamasb & Pollitt, 2001). For instance, on the cost-efficiency assessment, the frontier standard is the minimum cost supported by a set of comparable firms (Lowry & Getachew, 2009). Obviously, it is more interesting to learn from the best than to imitate mediocre performance (Bogetoft & Otto, 2010). The methods based on frontier standards are Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), and Corrected Ordinary Least Square (COLS). They will be developed in the next section.

As explained in Lowry and Getachew (2009), frontier standards face some critics. First, best practice methods focus on short-run efficiency and might **obstruct long-run sustainability**. For instance, in the power distribution activities, firms may decide to postpone maintenance expenses, e.g. trees trimming and pylons replacement, in order to reach the efficient frontier. Consequently, distributors that operate at less than sustainable cost will experience deterioration in service quality in the long run.

Second, the **fairness** - i.e. protecting interests of both customers and owners - of frontier benchmarking is questioned. Indeed, frontier requirements could compromise the ability to reward investors for the risk they support. Hence, the fairness might be unbalanced in the direction of customers' protection.

- b) In contrast, average benchmarking produces the average performance of the firms in the sector. It may be used to *mimic competition* among firms with relatively similar costs or when there aren't sufficient comparators for frontier methods (Jamasb & Pollitt, 2001). The most common method, the Ordinary Least Square (OLS), estimates average cost function of a sample of firms, on which actual entities' performance is compared. Also, the performance-based regulation (PBR)¹ applied in the US may use sliding scale method which is a form of average benchmarking (Jamasb & Pollitt, 2001). Lastly, another

¹ See section 2.1.3

method based on average performance is the Total Factor Productivity (TFP) which is a measure of historical productivity growth of the sector, known as the Tornqvist index (Jamasb & Pollitt, 2001).

Frontier methods taxonomy

Among the frontier benchmarking, the literature distinguishes *parametric* and *non-parametric* models. Parametric models are defined a priori except for a finite set of unknown parameters that are estimated from data¹. Nonparametric models are less restricted a priori because the production set and cost function are estimated from the data.

Another distinction is made between *stochastic* and *deterministic* models. In the former case, it is assumed that individual observations may contain random noise. The objective is to identify the mean structure stripped from the impact of the random elements. In deterministic models, it is assumed that random noise is suppressed. Any variation in the data is significant information on the firms' efficiency (Bogetoft & Otto, 2010)

Table 2-1 proposes a summary of the taxonomy.

Corrected Ordinary Least Square (COLS) is analogous to ordinary regression model with a parallel shift to make all firms be above minimal cost. *Stochastic Frontier Analysis (SFA)* accepts that some of the variations are due to random noise and partially shifts the line (Bogetoft & Otto, 2010). In these techniques, the efficiency scores are estimated rather than computed. Moreover, both models require specifications of the production and/or cost function (Jamasb & Pollitt, 2001).

Table 2-1

Frontier methods taxonomy

	Deterministic	Stochastic
Parametric	<i>Corrected Ordinary Least Squares (COLS)</i>	<i>Stochastic Frontier Analysis (SFA)</i>
Non-parametric	<i>Data Envelopment Analysis (DEA)</i>	<i>Stochastic Data Envelopment Analysis (SDEA)</i>

Source: own illustration based on Bogetoft & Otto, 2010

Data Envelopment Analysis (DEA) computes the smallest production set that contains data, following the minimal extrapolation principle. In contrast to previous models, the efficiency scores in DEA are computed rather than estimated. Also, it allows computation of allocative

¹ For example, the parameters could refer to the relative importance of different cost drivers.

and technical efficiency and it can deal with multiple inputs and multiple outputs (Giannakis et al., 2005). Moreover, DEA can examine the effect of environmental variables – i.e. beyond the utility's control – and it can be conducted with a Malmquist index in order to measure productivity changes through successive periods.¹ Lastly, DEA does not require prior specification of the cost function. (Jamasb & Pollitt, 2001)

Despite many advantages, DEA owns a series of weaknesses. First, the results obtained with DEA analysis are sensible to the inputs' and outputs' choice. Particular care must be taken in the variable decision process. In addition, the model is focused on a limited amount of information, namely frontier firms. Therefore, the obtained results are highly sensitive to measurement errors in the frontier. (Jamasb & Pollitt, 2001)

Figure 2-11 displays the difference in the computation of efficient frontier for the frontier benchmarking. It shows the estimated cost function based on a sample of data.

The choice between DEA and SFA methods is a tradeoff between the flexibility in the mean structure and the precision in the noise separation (Bogetoft & Otto, 2010). As an important property of the benchmarking approach is to reflect the characteristics of the industry, it requires a model able to adapt to the sector specificities. *The nonparametric approaches - including DEA models - are by nature flexible models.* (Agrell, 2015) On the other hand, a good benchmarking approach must be able to cope with noisy data and should be robust to random variations in the data. *The stochastic models are particularly useful in this matter.* (Bogetoft & Otto, 2010)

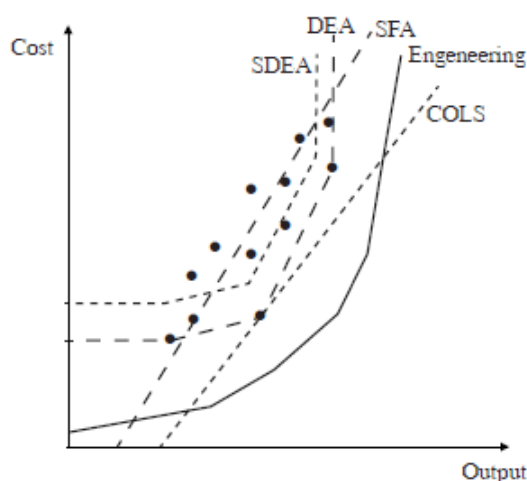


Figure 2-11 Frontier methods comparison
(Source: Bogetoft & Otto, 2010)

Finally, *Stochastic Data Envelopment Analysis (SDEA)* combines the flexible structure of DEA and the variability integration. Despite the perfect tradeoff at first sight, SDEA is highly demanding in data and time which explains why it is unlikely used in practice (Agrell, 2015).

¹ See (Coelli and al., 1998) and (Maniakias & Thanassoulis, 2004) for more details on Malmquist index

2.2.3. DEA model

In the current sub-section, we will detail the model that will be used on the course of this thesis: Data Envelopment Analysis model (DEA). As explained above, DEA is a frontier-based benchmarking method which is nonparametric and deterministic. Thus, it requires few prior assumptions but data volatility is not included in the model. DEA combines the two basic problems of benchmarking analysis: (a) defining frontier standard (best-practice) and (b) evaluating performances against the estimated frontier.

The DEA theory has been originally developed by Charnes, Cooper and Rhodes (1978) where they described the DEA as a “mathematical programming model applied to observational data, used to evaluate the activities of non-profit entities participating in public programs.”

Model definition

DEA model combines the idea of minimal extrapolation and Farrell efficiency (Bogetoft & Otto, 2010). Let K be the number of DMUs that consume m inputs to produce n outputs. Let $x^k = (x_1^k, \dots, x_m^k) \in \mathbb{R}_+^m$ be the input vector and $y^k = (y_1^k, \dots, y_n^k) \in \mathbb{R}_+^n$ be the output vector for $k = 1, \dots, K$. If input prices are available, let define $w^k = (w_1^k, \dots, w_m^k) \in \mathbb{R}_+^m$. Finally, let introduce the technology set T as defined in p.28:

$$T = \{(x, y) \in \mathbb{R}_+^m \times \mathbb{R}_+^n \mid x \text{ can produce } y\} \quad (\text{Eq. 8})$$

Because the exact technology set is rarely known, the DEA program will construct an empirical reference technology T^* according to the *minimal extrapolation principle*.

This principle states that T^* is the smallest subset of $\mathbb{R}_+^m \times \mathbb{R}_+^n$ that contains all the data (x^k, y^k) for $k = 1, \dots, K$ and satisfies certain technological assumptions. In other words, the model extrapolates the least by doing an *inner approximation* (Bogetoft & Otto, 2010). The predefined technologies assumptions are similar to those defined in section 2.2.1. In a vectorial writing, the return-to-scale is denoted by $\Lambda^K(\gamma)$ with $\gamma = crs, vrs, drs, irs$ ¹.

The input efficiency of firm i is found as follow:

$$\begin{aligned} E^i &= \min_{\lambda^1, \dots, \lambda^K} E \\ \text{s.t. } &Ex^i \geq \sum_{k=1}^K \lambda^k x^k, \\ &y^i \leq \sum_{k=1}^K \lambda^k y^k, \\ &\lambda \in \Lambda^K(\gamma). \end{aligned} \quad (\text{Eq. 9})$$

¹ $\Lambda^K(\gamma)$ is the set of possible scaling factor given by $\Lambda^K(crs) = \mathbb{R}_0$, $\Lambda^K(vrs) = \{1\}$, $\Lambda^K(drs) = [0, 1]$, $\Lambda^K(irs) = [1, \infty]$ (Bogetoft & Otto, 2010).

Thus, the DEA benchmarking is a mathematical optimization problem where (x^k, y^k) are the observed data and λ^k are the variables included in the scaling set $\Lambda^K(y)$. In other words, the program computes the minimum contraction of input vector for firm i such that it lays on the best-frontier computed with the observations of others firms $k = 1, \dots, K$. In the classic return-to-scale assumptions (VRS, CRS), the program is a simple *linear programming* (LP). Obviously, DEA computes the relative efficiency because each firm is compared to the best-practice. Firms located on the frontier receive a score of 1 (Cooper, Seiford & Zhu, 2004).

A similar mathematical program is valid to compute the *output efficiency* F^o .

Peer units

Hence, DEA projects the DMUs on the frontier. As denoted by the right-hand side of Eq. 9, the projection is a weighted average of others DMUs, where the decision variables λ^k are the weights¹. The *peer units* are the DMUs for which $\lambda^k \geq 0$, i.e. the extremities of the portion of the frontier on which the evaluated unit is projected onto (Numerical example in Appendix 5).

However, as a consequence of the LP solving, “the number of efficient firms on the frontier tends to increase with the number of inputs and output variables” (Jamasb & Pollitt, 2001, p. 109). Therefore, it is essential to include only relevant inputs and outputs in the computation. Otherwise, the model would lose its discriminatory power to distinguish high performers from the rest (Bogetoft & Otto, 2010). DEA researchers suggested the following *rule of thumb* $K > 3(m + n)$ and $K > m * n$, where K is the number of firms, m and n are respectively the number of inputs and outputs included in the analysis (Bogetoft & Otto, 2010).

Optimal cost

As a reminder, the firms’ preferences are included in the cost-efficiency analysis with the input price vector $w \in \mathbb{R}_+^m$. In such exercise, DEA is used to estimate the *optimal cost*. For $i, k \in \Omega$, the optimal cost for firm i is denoted by:

$$C_i^*(y^i|\Omega) = w * \sum_k \lambda^k x^k \quad (\text{Eq. 10})$$

The optimal cost is the horizontal projection (respectively vertical for output-oriented model) onto the best-frontier computed with the k firms included in the set Ω . The optimal cost corresponds to the minimal input utilization according a level of output.

¹ The projection is defined by $(\sum_{k=1}^K \lambda^k x^k, \sum_{k=1}^K \lambda^k y^k)$

For now, all the firms are included in a single set Ω . In Chapter 3, we will study the impact on the optimal cost of the division of Ω into smaller subsets.

Extensions to DEA model

Cooper et al. (2004) proposed an overview of some extensions to the classic DEA model such as coping with nondiscretionary variables, i.e. exogenous inputs/outputs that are beyond the control of the DMUs management or integrating categorical variables.¹

2.2.4. Summary

The benchmarking exercise is the relative comparison of the firms with other comparable entities in the sector. There exist different benchmarking standards. The one used in the thesis is a frontier-based method called DEA (Data Envelopment Analysis). It starts by estimating the best-frontier based on the input utilization and output production of the firms in the sector. Then, each entity is projected onto the frontier. The point of projection is the optimal input level and the displacement is a measure of the efficiency. The multiplication with the price vector gives us the optimal cost, which is the minimal cost that should be used by a firm to produce its actual output level.

We will see now how the benchmarking techniques can be used in the regulation to help the regulator in setting fair cost target.

¹ More details on Cooper et al. (2004)

2.3. Regulatory benchmarking: the efficiency analysis in regulation

After deepening both on the regulatory theory and the benchmarking tools, it is time now to merge the two subjects by exposing how the efficiency analysis can be applied in a regulatory context. Several authors identified the benefits of benchmarking tools and proposed few practical applications¹. First, let's expose the pros and cons of the utilization of benchmarking by the regulator. Then, we will present some applications of benchmarking in the regulation. Finally, we will draw an overview of the regulatory regimes and benchmarking tools put in practice in several European countries.

2.3.1. *Why benchmark in regulation?*

In many countries, regulators and governments make use of benchmarking techniques when monitoring the activity of public utility such as electricity distribution.

On the positive side, the benchmarking aims to **reduce the regulatory cost**, particularly when regulators are freshmen in the control of utilities' activities (Lowry & Getachew, 2009). Indeed, benchmarking is a good tool to construct reference standards which become the baseline for setting prices or revenues of legal monopolists.

The second advantage is its ability to **externalize the terms of service**. Concretely, benchmarking enables to set prices/revenues based on external targets, rather than the utility's own cost of service (Lowry & Getachew, 2009). Moreover, it helps the regulator to bridge its informational disadvantage (Joskow, 2013).

At last, it gives the utilities some **incentives to reduce expenses**. Indeed, it uses data from the industry to set a target level of performance. With the incentive schemes developed by the regulator (penalty and reward)², the utility has the motivation to control its costs, in order to reach target (Lowry & Getachew, 2009).³

On the negative side, there exists a potential risk that a benchmarking **model of poor quality** would expose the entities to excessive risk. "While regulation must protect consumers from monopoly abuses, it must also not compromise the financial viability of regulated entities" (Lowry & Getachew, 2009, p.1325). Poor quality must come from incomparable data, missing data, lack of experience while choosing the performance variables – input/output variables –

¹ Lowry and Getachew (2009), Joskow (2013), Giannakis et al. (2005), Agrell et al. (2005)

² See section 2.1.3

³ In addition, benchmarking is particularly useful to monitor the expenses on affiliated companies such as customer service in order to ensure that earnings from regulated activity are not used to subsidize such competitive activities. (Lowry & Getachew, 2009)

or inappropriate benchmarking methods. Consequently, a particular care must be taken while choosing the benchmarking standards and methods as well as defining the assumptions.

Choice of benchmarking model

Since a wrong-fitted model could lead to unsuccessful outcome for the regulator as well as the evaluated firms, it is important to understand that choices depend on the regulator's objectives, which can be structured into several concerns.

- Benchmarking standard

“*Average-based approaches* are best suited to introduce yardstick competition between relatively efficient firms” (Giannakis et al., 2005). On the other hand, frontier methods are used to close performance gaps between heterogeneously efficient firms.

- Scalability assumptions

The decision of scalability assumptions may have strong incidence on regulated revenue imposed by the regulator. For example, *vrs* allows entities with different scale to be efficient. The choice between *drs* and *irs* depends on the willing to favor large firms or small firms respectively. Contrary, *crs* is the worst alternative for most entities since only one region – scale – of the frontier is obviously efficient and it doesn't include scale economies. (Bogetoft & Otto, 2010) Visual illustrations are displayed in **Figure 2-8**.

- Size of the model

Regulator would prefer large models¹ because it would increase the competition among companies. However, too harsh models would discourage firms to invest in maintenance and new investments, which would conduct firms into bankruptcy and/or lead to poor quality service in the long run.

- Structural development

Benchmarking might be used by the regulator in the perspective of reorganization. For example, the choice of CRS model will provide the firms with incentives for “merging ones that are too small and splitting ones that are too large, to adjust them to the optimal scale²” (Bogetoft & Otto, 2010, p. 90).

2.3.2. Applications of benchmarking in regulation

The first application of benchmarking is to set the x-factor in **fixed-price regimes** (see section 2.1.4 above). Concretely, the catch-up factor might be fixed in order to gap the distance to the

¹ Large models in the sense of the number of companies

² More details on scale efficiency on Bogetoft & Otto (2010)

best-frontier during the regulatory period (Pollitt, 2005)¹. Then, by basing the analysis on observed production cost instead of estimation, the arbitrariness of the CPI-X model is removed (Agrell et al., 2005). This configuration is applied in UK for power distribution regulation² for example.

The second application of benchmarking tool is present in the **yardstick regime** proposed by Shleifer (1985). It states that controllable costs are determined, based on a target designed with the cost of comparable firms. The DEA model is used to find the efficient projection on best-frontier which corresponds to the optimal cost target. Moreover, the yardstick regulation implies that the firm's optimal cost is not impacted by its own performance. The solution is proposed by the *super-efficiency* specification, i.e. removing the evaluated unit from the reference set (Agrell et al., 2005 and Agrell, 2015).

It exists also other applications of benchmarking to regulatory context enforced by public rulers such as stretch factors (Lowry et al., 2005) or average total cost benchmarking (Filippini & Wild, 2001) which are summarized in Lowry and Getachew (2009).

Nowadays, most of regulators employ national data to compare public utilities. It can reach some limitations, especially when the number of comparable firms is limited. The solution might be to perform *international benchmarking*, i.e. comparing utilities beyond borders. It is formally presented in Agrell and Bogetoft (2010) where they submitted a harmonized model which can be applied across national regulations.

2.3.3. European situation overview

In order to better grasp the reality, let's expose the regulatory practices in ten selected European countries in **Table 2-2**. For each country, the regulatory regime has been denoted as well as the benchmarking method – when used. The table cross-consolidates information found on Filippini (2011), Ernst & Young (2013) and Agrell and Teusch (2015).

Norway³ and Netherlands are the only European countries where a yardstick regulation scheme is in place. The trend in Europe is the revenue cap or price cap with DEA benchmarking method. Only limited number of countries maintains a cost-recovery, including France, Luxembourg and Wallonia (Belgium). Besides, Portugal supports its revenue cap

¹ For instance, if firm A is granted a DEA efficiency of 0.8 at the beginning of the 5-years regulatory period, the regulator may impose firm A to respect the catch-up factor of 4% per year.

² Ofgem (Britain's Office of Gas and Electricity Markets)

³ More details on established regulatory schemes in Germany and Norway in Agrell and Bogetoft (2013)

regime with SFA benchmarking model, while Germany sets efficiency requirements as the maximum between DEA and SFA comparison.³

In contrast, Spain developed engineering frontier to force utilities adopting efficiency behavior¹. At last, Sweden makes use of DEA benchmarking to impose revenue cap to regulated utilities.

Table 2-2

European overview in terms of regulatory practices

(Source: Agrell & Teusch, 2015; Filippini, 2011; Ernst & Young, 2011)

Country	Regime	Benchmarking method
Belgium*	Brussels and Wallonia: Cost plus	/
	Flanders: Revenue cap	Linear trend
France	Cost plus	/
Germany	Revenue cap	best of DEA – SFA
Great Britain	Revenue cap	COLS
Luxembourg	Cost plus	/
Netherlands	Yardstick	COLS
Norway	Yardstick	DEA
Portugal	Revenue cap	SFA
Spain	Revenue Cap	Engineering frontier
Sweden	Revenue cap	DEA

* After state reform (2014), DSO regulation has been regionalized

2.3.4. Summary

In Europe, most of the countries are regulated by a single regulator, responsible of the entire territory. The regulation is said *centralized*. Formally, all the firms are included in a single comparison set Ω (see section 2.2.3). However, the regulatory environment may sometimes be subject to external constraints which lead to the unbundling of the regulation: instead of a single regulator controlling the whole territory, each region has its own regulator. In that case, the regulation is said *decentralized*. As a consequence, each regulator is building the benchmarking on fewer companies; the quantity of information at its disposal is thus less complete. The benchmarking might be relaxed which could have an impact on the optimal cost and consequently, it might harm the capacity of the regulator to constraint the monopolists firms.

Chapter 3 will study the theoretical impact of the decentralization on the regulator, the operators and the customers. We will measure the cost of a decentralized regulation by means of a quantitative analysis performed on a dataset with DEA benchmarking.

¹ More details on existing regime in Spain in Ernst & Young (2013)

Chapter 3 : The cost of the decentralization

In Belgium, since the 6th State reform in 2014, the tariff regulation of electricity distribution has been transferred to regional institutions. In the facts, the territory has been partitioned into three regions (Wallonia in the south, Flanders in the north and Brussels in the middle), where a new regulator has been created for each region. Such transformation is seen as the *decentralization of the regulation*¹. In general terms, it is the delegation of the regulatory activity to smaller entities that will regulate smaller territory and so fewer firms.

The objective of the thesis is to study the impact of the decentralization on the regulatory environment. We will strive to estimate the theoretical cost of the decentralization for the society, called the social cost, as well as the consequences on the operators, the consumers and the regulator(s). To do so, we developed a quantitative model that makes use of DEA benchmarking to estimate the cost norm and the cost target of the operators.

In first instance, we will expose the dataset used in the study, define the model. Second, to understand the context, we will expose the initial situation. Finally, we will study how the social cost varies under several partitions based on four criteria: random, geographic, scale and ownership.

3.1. Data definition & model specification

3.1.1. Data

In our work, we analyzed the annual data of DSOs operating in Sweden during the year 2012.² The data has been provided by Professor Agrell. Besides a series of data on firms' activity – e.g. number of customers, amount of energy delivered, operating cost - , the dataset contains information on the ownership status (collectivity, public, private owner). In case of missing information, the ownership status has been personally collected through further researches on internet³. Furthermore, the GPS coordinates – latitude and longitude – have been added to the data using Google map localization which seems to be a good proxy for representing the area of activity. After the removal of the outlier⁴, i.e. operator with less than 100 connections, the dataset contains 164 observations. Since the data comes from Sweden, all the following monetary values will be expressed in kSEK = 1000 Swedish Crowns (SEK).

¹ From one to three regulators

² Full dataset in Appendix 9

³ Helped by the website <http://www.allabolag.se> and discussion with Ulf, member of the support team at Österlens Kraft

⁴ One observation has been excluded

3.1.2. Benchmarking model

The efficiency analysis is based on an input-oriented DEA model with two inputs x and three outputs y . It is inspired by the actual model used by the Swedish regulator – Swedish Energy Markets Inspection (EI) - to monitor Swedish electricity distributors, as described by NordReg (2011) and SUMICSID AB and Nordenergi (2005). **Figure 3-1** displays the inputs and outputs variables used. The outputs are consistent with the activity of power distribution:

- **Number of connections** represents the total amount of entities plugged to the network grid without distinction between low voltage and high voltage.
- The **network length** is the total length (in km) of the network composed by electric lines and underground cables.
- The **capacity installed** consists in the maximum transportation power installed by the distributor (in MW) – in contrast with the peak load which represents the maximum capacity used.

The inputs are the main sources of expenses: operational expenditure (OPEX) and capital. The associated input price vector is $w = (1, WACC)$ where the $WACC^1$ is set at 5.2%, based on the real index imposed by the Swedish regulator (NordReg, 2011).

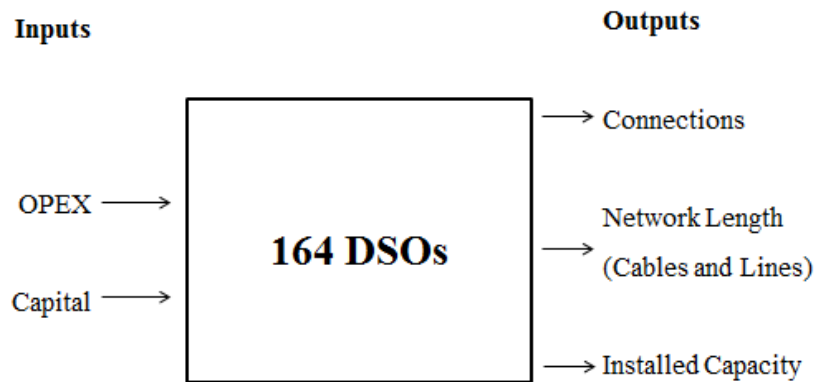


Figure 3-1 DEA model variables

The DEA model is programmed on the statistical tool R. It is based on the “Benchmarking” package developed by Bogetoft and Otto (2010). It is static (not dynamic) and based on the simple efficiency (and not super-efficiency) since our goal is not to give incentives to efficient firms neither to rank them.

¹ WACC denotes for Weighted Average Cost of Capital

Concretely, the DEA model draws the best-frontier reference. Based on the input price vector w , it performs a cost-efficiency analysis. The efficiency score is computed for each DSO as well as the projection on the frontier reference. As a reminder, the projection represents the cost target that DSO is supposed to attain.¹

3.1.3. Regulatory scheme

The work studies the impact of the decentralization on the benchmarking power. Hence, the model should be basic and it should include the incidence of one firm on the others. In addition, it does not need to include productivity requirements, neither indexation factor since the model is static and is not calculated through successive periods.

We chose a regime based on a pure *yardstick regulation*. As explained in section 2.1.4, yardstick regulation imposes that the allowed revenue is set as a function of the performance of other firms in the sector. In our model, the revenue of the evaluated firm k is equal to the cost target computed via the DEA model.

$$R^k = C^*(y_k | \Omega) \quad (\text{Eq. 11})$$

The optimal cost, or cost target, is found as the projection on the best-frontier. The frontier is estimated thanks to the firms included in set Ω . Actually, the best-frontier represents the *cost norm*, i.e. the minimal cost for a certain output level.

3.2. Initial situation

3.2.1. Descriptive statistics

Table 3-1 displays descriptive statistics for the model variables. For each variable, the mean is always higher than the median: the variables follow a *right-skewed distribution*. In other words, the dataset contains many small firms and few large firms. Furthermore, the standard deviation is relatively large compared to the mean which proves that the dataset is heterogeneous in terms of size.

Table 3-1

Descriptive statistics

Category	Unit	Variable	Mean	Median	SD
Input	kSEK ²	OPEX	46,460	17,140	119,101
	kSEK ²	Total capital	652,300	142,900	2,465,271
Output	/	Connections	32,550	10,620	97,305
	Km	Network length	3,086	939	10,727
	MW	Capacity installed	290	106	859

¹ Numerical example developed in Appendix

² kSEK = 1000 Swedish crowns (SEK), MW = Mega-Watt is a measure of the power quantity.

3.2.2. DEA analysis

The benchmarking analysis is performed with an input-oriented DEA model, using *vrs* (variable return-to-scale) assumption. The choice of an input-oriented model is obvious. Since the DSO is providing a public service through a fixed territory, it cannot choose to serve or not customers/areas, neither to boost the number of connections (the demand is not extensible). Hence, the operator has only the control on its costs, at least in the short-run. Consequently, the model's objective is to determine if the DSOs are using their resources in an efficient way for a given output level. Second, the descriptive statistics showed that the dataset is highly heterogeneous in terms of size: firms with different scales operate on the territory. Hence, the *vrs* assumption allows being efficient at different scales which is likely the case in reality. Finally, the model respects the rule of thumb¹ as denoted p.35.

The results of the cost-efficiency analysis provide a mean cost-efficiency of 0.7748, while 17 DSOs are cost-efficient, i.e. cost-efficiency of 1. Moreover, DEA computes the cost target for firm k as the product of the optimal input vector with the price vector w

$$C_k^* = OPEX_k^* + CAPITAL_k^* \times 5.2\% \quad (\text{Eq. 12})$$

$OPEX_k^*$ and $CAPITAL_k^*$ are the optimal inputs levels, respectively operational expenditure and capital investments, for firm k . As a reminder, 5.2 % is the pre-determined cost of capital (WACC). In our model, the firm's revenue equals its cost target. Thus, the total budget allowance for the whole territory is the sum of individual cost target: 11,684,184 kSEK.

3.2.3. Ownership status

The dataset contains the ownership status of each DSO. In total, there exist five categories of ownership (see **Table 3-2**).

- **Limited company, private ownership (type p):** the distribution activity is owned by private actors, organized under a limited company. The company can be traded on the stock market. Moreover, the private stakeholders expect annual dividends and returns on investment. In Sweden, the main private electricity operators are *E-ON Sverige* – German owners (E-ON, 2017) – and *Fortum Distribution* – owned by a private consortium (Fortum, 2015).
- **Limited company, municipal ownership (type k):** the distribution network belongs to a limited company, with a majority public owner: the municipalities.

¹ $164 > 3(m + n) = 15$
 $164 > m * n = 6$

The limited liability implies that the owners (i.e. municipalities) are protected in case of bankruptcy.

- **Limited company, state ownership (type s):** in some areas, the power is distributed by agencies owned by the state. The main state-owned utility is *Vattenfall Eldistribution*.
- **Client cooperative (type e):** the distribution network is owned by a consumers' association who get involved into the daily operations. Consequently, we can assume that the wages are not excessive and the cooperative does not support tremendous operating costs. However, in case of maintenance or reparation, the cooperative usually hire independent reparation service whose tariffs might be more important.
- **Public utility (type f):** the power distribution is integrated to the municipality's duties. As a result, the employees of the public utilities are civil servants. In addition, the debt and investments are covered by the municipality's budget.

Table 3-2
Ownership status

Ownership	DSO	Mean CE	Sum C* (kSEK)	Efficient DSO	Mean size
<i>p</i> Limited company: private-owner	26	79.5%	4,941,118	6	80,652
<i>k</i> Limited company: city-owner	92	75.1%	3,655,140	4	22,653
<i>s</i> Limited company: state-owner	5	91.3%	2,602,414	3	185,508
<i>e</i> Client cooperative	34	80.3%	369,548	2	4,605
<i>f</i> Public utility	7	77.5%	115,963	2	10,533
Total	164		11,684,184	17	

Notes: kSEK = 1000 Swedish crowns (SEK), CE : cost-efficiency, size = connections

From the DEA analysis per ownership (see **Table 3-2**), we can observe that state-owned utility are highly efficient. Despite few occurrences, the cost-efficiency for this category amounts for 91%, where the others are fewer than 80%. It can be explained by the fact that the government wants to show the example by ruling its property in an efficient manner.

Another observation concerns the scale: cooperatives (*e*) and public utilities (*f*) have significant lower cost target than the other categories. Their average size (expressed by the number of connections) is smaller as well. Hence, it seems that they operate at smaller scale. On the other hand, the private and state-owned categories contain mostly medium and large distributors.

3.2.4. Plot

In order to confirm our sayings, let's plot the firms according to *OPEX* (input) and *connections* (output). As denoted in **Figure 3-2**, there exists a significant correlation between both variables. The correlation is obvious since the more customers are served; the more operational budget is required. In a similar way, the high correlation value is also valid between the variables *capital* and *power* or *network length* because large infrastructures require huge investments.

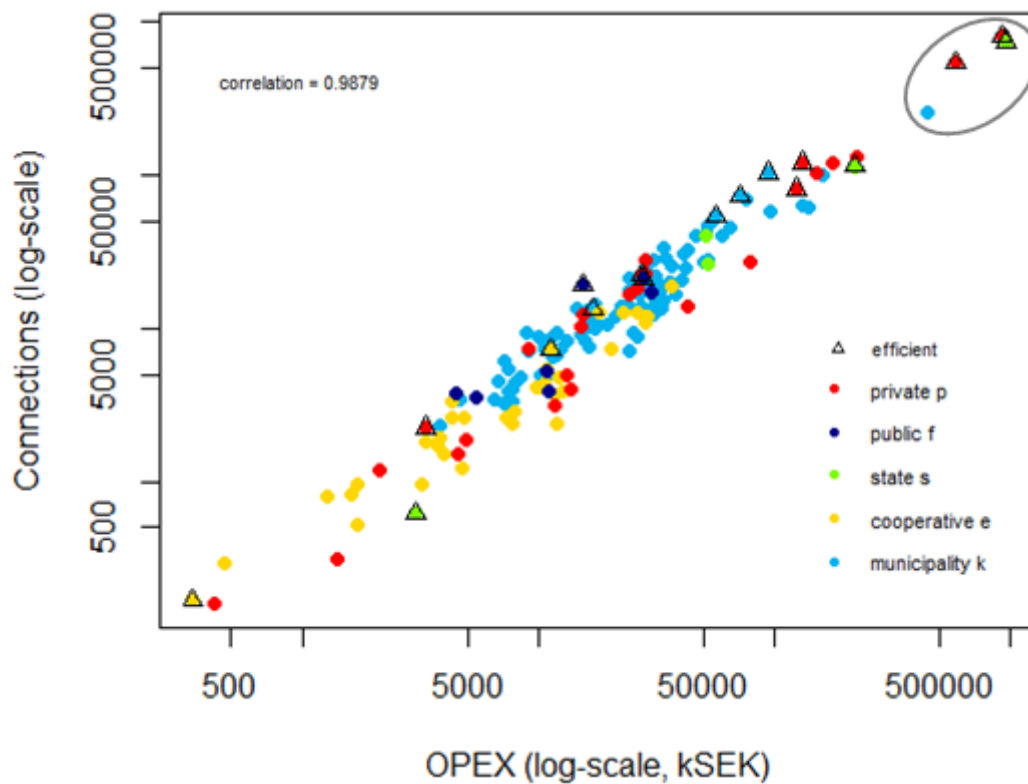


Figure 3-2 Plot OPEX and Connections (log-scale)

On the log-scale plot, it is possible to observe that there exists in Sweden a majority of small-medium DSOs. However, four huge distributors (grey circle) operate with more than 200,000 customers. Moreover, it confirms the insight that cooperative *e* and public utility *f* are mostly small entities since they appear in the bottom left extremity. Contrary, state-owned operators are huge companies, present on the top right extremity of **Figure 3-2**.

Another observation is that efficient DSOs (highlighted by a triangle) are present at different scale which is a consequence of the choice for VRS assumption.

3.2.5. Mapping

The coordinates (latitude/longitude) of each DSO have been collected; it is then possible to map the localization of the power distributors in Sweden (see **Figure 3-3** next page). We colored the points according to the ownership status and efficient firms have been highlighted with a triangle.

It is possible to observe that the large majority of DSOs are concentrated in the south of the country. This observation is consistent with the population density in Sweden. Furthermore, there is no clear pattern of the ownership categories' repartition. At last, the efficient DSOs (in a triangle) are equally distributed within the territory. The map of Belgium has been disposed besides with the same scale. It puts in perspective the size of both countries.

3.2.6. Summary

The analysis of the initial situation highlighted some observations. The dataset is heterogeneous in terms of size: there are many small-medium firms and four mega-distributors. Second, there are five ownership categories which are subject to different constraints. We observed that cooperatives (e) and public utilities (f) are smaller distributors. On the other hand, state-owned distributors (s) are bigger and more efficient. However, this observation is limited by the small number of observations and by the fact that since they operate at bigger scale they have few comparable firms: they are alone on their side of the best-frontier. Third, the map of Sweden shows that the efficient firms are well-distributed through the country. Moreover, we saw as well on the plot that firms with different size were efficient: an efficient DSO can be small or big, in the north or in the south. Intuitively, we can assume that there exists no relation between the ability to be efficient and the geographical localization or the operating scale.

For now, we studied the situation where a single regulator is monitoring the whole territory: all the DSOs are included in a single benchmarking set. The objective of the thesis is to analyze the decentralization of the regulation: when many regulators are policing different regions. This transformation may have an impact on the incentive power of regulators. This impact is expressed by the social cost of the decentralization which will be measured in the next section.

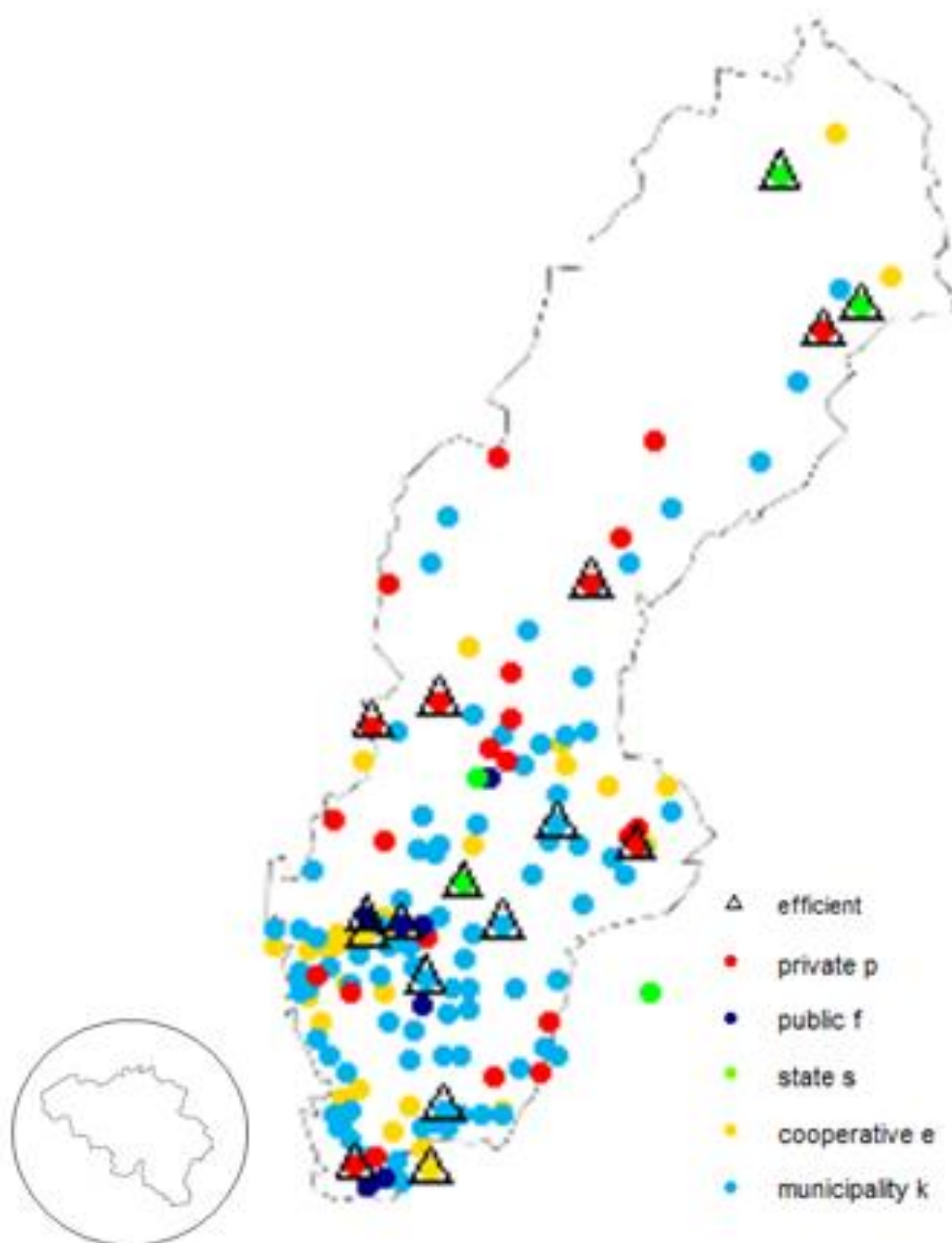


Figure 3-3 Map of DSOs in Sweden

3.3. Study of the social cost

The content of this section will study the social cost of the decentralization in regulation. First, we will analyze the theoretical implications of the decentralization on the DEA benchmarking. Then, we will successively partition the territory into subsets where a new regulator will be in charge of each subset. Hence, the DEA benchmarking will not be performed on the full bunch of companies anymore, but on smaller subsets containing fewer companies. After aggregating the total budget allowance for the whole territory, we will calculate the difference with the initial situation. The difference represents a cost for the society which will be called the *social cost*. In order to tackle the four research questions expressed in section 1.4, we will partition the territory according four criteria: random, geographic, size and ownership.

3.3.1. Methodology

The power distribution is entrusted to legal monopolists over specific territories. In economic-welfare literature, monopolists generate higher surplus since there are not subject to competition laws. The role of the regulator is to monitor monopolists' activities and to control the tariffs. The regulator aims at sharing the rents between operators (DSOs) and consumers.

As a reminder, the regulator faces asymmetric information: the DSOs detain private information on their cost structure which is not disclosed to the regulator. In order to bridge the information gap, the regulator makes use of benchmarking tools (e.g. DEA) to evaluate the performance of DSOs. The DEA benchmarking uses observable information from operators in the sector (e.g. number of customers or length of network) to estimate the best-frontier. The best-frontier represents the *cost norm*, i.e. it gives the minimal cost to produce a certain output level¹. The projection of a DSO on the cost norm represents its optimal cost or cost target (C^*).

Thereafter, the regulator chooses a regulatory methodology: it determines the strategy of reimbursement² for the operators. Either they are allowed to be reimbursed for the totality of actual costs (*low-powered*) or only their cost target (*high-powered*).

In the initial situation, the entire territory is regulated by one central institution. Each DSO is then benchmarked with the set Ω that includes all the other DSOs in the territory (solid line in

¹ The minimal cost is not absolute but based on the current performance of comparable firms.

² Operators are reimbursed for part of their cost via the distribution tariffs charged to the customers.

Figure 3-4). However, under external constraints (political, regional), the regulatory power is entrusted to regional institutions. As a result, each regulator benchmarks the DSOs of its region, without access or consideration of the performance of the others. Consequently, a DSO is compared to a smaller set Ω_2 (dotted line in **Figure 3-4**). This transformation is called the decentralization of the regulation.

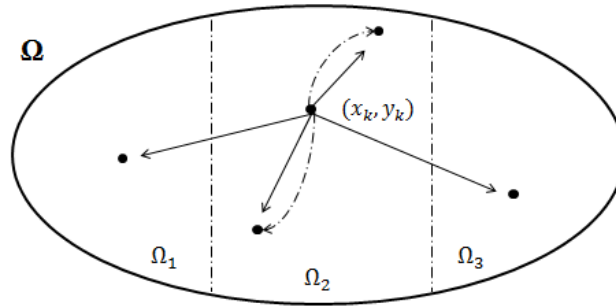


Figure 3-4 Decentralization methodology (Source: own illustration)

The goal of the thesis is to estimate the impact of the decentralization on both customers and operators. In order to structure the analysis, four research questions have been exposed in section 1.5.

Q1: Is there a social cost of the decentralization in regulation?

Q2: Does a partitioning on geography increase equity in regulation?

Q3: How is the cost of decentralization affected by an ex-ante partitioning on scale?

Q4: How is the cost of decentralization affected by an ex-ante partitioning on ownership?

To tackle these questions, different criteria will be used for the partitioning of the 164 DSOs: the random partition to grasp the general trend; the geographic partition to target the regionalization; the scale partition to prove that the size matters; and the ownership partition for ownership considerations

The results of these partitions will be detailed in section 3.3.3. to 3.3.6.

3.3.2. Theoretical implications

Let's start by expressing the following proposition:

Proposition 1: *Decentralization through partitioning in nonempty subsets increases the rents to operators through the regulation.*

Proof: Data Envelopment Analysis (DEA) is a benchmarking tool that works with a Linear Programming mathematical program (LP-program). Each evaluated firm is a DMU (Decision-Making Unit). DEA estimates the best-frontier using the DMUs included in a set Ω . Each DMU on the frontier is a *vertex*, i.e. a corner point of the frontier/plan. Considering the input vector x_k and the cost vector w , the DEA analysis is a cost-efficiency analysis where the best-frontier represents the *cost norm*: the optimal level of cost C^* according the output level y .

The optimal cost for firm k is:

$$C_k^*(y_k | k \in \Omega) \quad (\text{Eq. 13})$$

In respect to the Free Disposability and Convexity assumptions, the cost norm is a *minimal spanning hull*: the frontier is the minimal extrapolation of the DMUs and each DMU is either on the frontier (vertex) or spanned by one or two vertices.

In regards to the **Figure 3-5**, removing a vertex from the hull cannot lower the cost norm. In other words, excluding a DMU on the frontier cannot decrease the cost target of the others. For example, DMU_2 is initially located on the best-frontier (dotted line). By excluding it, the cost norm is translated to the right. For the same output level, the optimal cost is superior or equal.

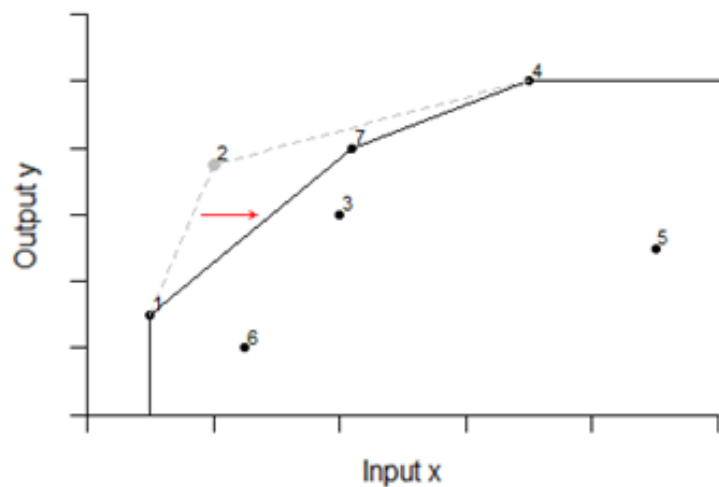


Figure 3-5 Illustration of cost norm translation

In case of decentralization, let N be the level of partitioning and Ω the initial subset. For each $\Omega_i \subset \Omega, \forall i \in [1, N]$:

$$C_k^*(y_k | k \in \Omega) \leq C_k^*(y_k | k \in \Omega_i) \quad (\text{Eq. 14})$$

The cost norm does not strictly increase. There exists one particular case where the cost norm stays constant: if all DMUs are efficient and identical with regards to allocative efficiency. In that case, DMUs are located on a hyperplane with proportional utilization of inputs and with constant return-to-scale (see **Figure 3-6**).

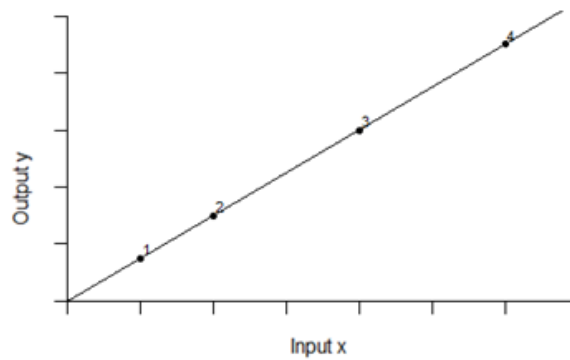


Figure 3-6 Illustration particular case (CRS and proportional input utilization)

Asymptotically, when pushing the decentralization at the extreme, each DMU is alone in its subset. Consequently, it spans itself and the cost norm becomes the DMUs' cost.

For $N \rightarrow |\Omega|, \Omega_i \subset \Omega, \forall i \in [1, N]$

$$C_k^*(y_k | k \in \Omega_i) = w \times x_k \quad (\text{Eq. 15})$$

Let w be the input price vector and (x_k, y_k) respectively the input and output utilization of firm k .

In a regulatory context, benchmarking DSOs in smaller subsets raises the cost norm. In our model, the operator's revenue is set as a function of C_k^* . Hence, the decentralization increases the rents to the operators.

Q.E.D. $\square$

The next sections will present the results for the four partitions introduced previously, namely random, geographic, scale and ownership.

3.3.3. Random partition

In order to illustrate the increasing of the rents, we will perform a *random partitioning*. The original set is successively partitioned into N subsets in a random way. Let N be the number of reference sets, $N \in [1,164]$. For instance, if $N = 4$, it means that the 164 DSOs have been split into four groups of 41 firms. The subsets are roughly equally sized. In each subset, the cost norm is computed with DEA benchmarking model. Each DSO is compared to the cost norm of its subset: the individual cost target is calculated as the projection. In order to grasp the impact over the whole territory, the sum of individual cost target is computed. When $N = 1$, it is logically the initial situation. We set the reference:

$$C^{**} = \sum_{k=1}^{164} C_k^*(y_k|\Omega) = 11,684,184 \text{ kSEK}$$

Here, it is appealing to see the evolution of the total allowed revenue for the whole territory when partitioning the territory into smaller subsets. Because, the partitioning induces an augmentation of the operators' rent with no improvement of the service performance, it is seen as a loss for the society, called the social cost. The social cost represents the additional revenue that operators would be allowed to generate as a result of the decentralization of the regulation.

The (absolute) social cost corresponds to the difference with the initial situation.

$$\text{Absolute social cost (kSEK)} = \sum_i^N \sum_{k \in \Omega_i} C_k^*(y_k|\Omega_i) - C^{**} \quad (\text{Eq. 16})$$

Since the absolute social cost is expressed in local currency and/or depends on the country size, let's normalize to obtain the relative social cost.

$$\text{Relative social cost (\%)} = \frac{\text{Absolute social cost}}{C^{**}} \quad (\text{Eq. 17})$$

Obviously, the simulation contains high level of randomness. In order to limit the variability, the random simulation has been run 50 times for each N value. A confidence interval has been built around the sample mean of the social cost. The curve of the relative social cost is displayed in **Figure 3-7**. Some values of the absolute and relative social cost have been added. The full results are displayed in **Appendix 10**.

Discussion

The relative social cost follows a concave curve. On one hand, it grows sharply for low level of decentralization. For instance, in Sweden, the total budget allowance would rise of 500.000

kSEK in case of the fragmentation into three regions. On the other hand, it stagnates quickly at the level of the extreme situation where $N = 164$.

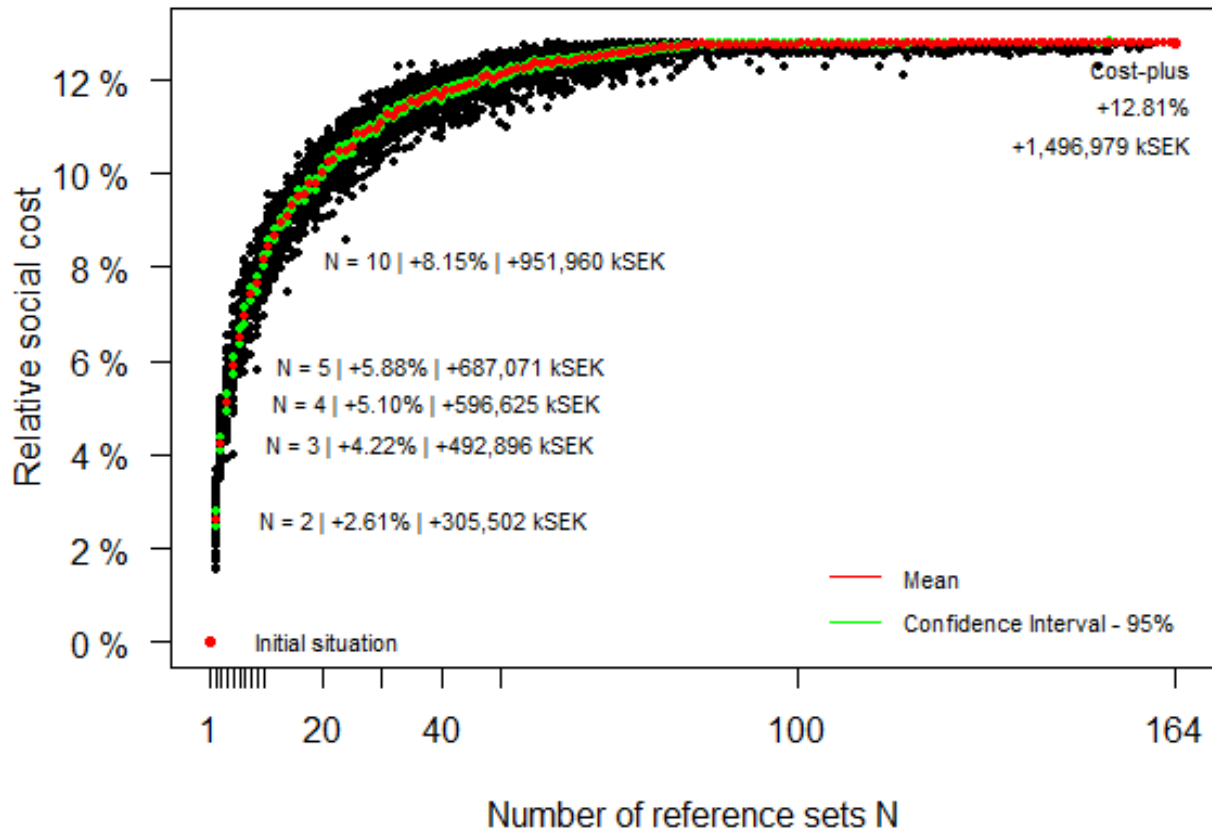


Figure 3-7 Curve of relative social cost in random partition

When N large, each DSO is alone in its subset; it is consequently compared to itself. Hence, the cost target equals the operator's cost. In regulatory scheme, it corresponds to the cost-plus approach where the DSOs compensate for the totality of their cost. In case of cost-plus methodology, the revenue of the DSOs would increase for 12.81%.

In view of the results in **Figure 3-7**, we can undoubtedly formulate the following proposition:

Proposition 1: *Decentralization through partitioning in nonempty subsets increases the rents to operators through the regulation.*

Corollary

For the regulator(s): the decentralization provokes the diminution of the number of firms regulated by each regulator. Hence, it decreases the amount of information available to estimate the best-frontier. Consequently, the smaller are the subsets, the more the benchmarking is relaxed. The cost target is less binding and thus easily attainable. In

conclusion, the incentive power of the regulation is limited by the decentralization: it is more complicated for the regulator(s) to provide DSOs with incentives for cost-reduction.

For the consumers: by fixing a limit on the revenue, the regulator controls the tariff charged to the consumer. If we assume that the operator does not make the distinction between private and business customers, the distribution tariff would be the allowed revenue divided by the number of connections. Proposition 1 states that a decentralized regulation would increase the revenue generated by the DSOs. The augmentation does not come from a cost-reduction behavior but it is obtained through an increase of the distribution fees charged to the final-users. For the consumers, the theoretical tariff increase is significant: 4.22% when the territory is simply decomposed in three and it reaches 10% if it is partitioned in 20 regions. This level of decentralization is not outrageous for large countries: for example Sweden is divided into 21 counties so a decentralized regulation could follow this historical breakdown. Let's assume that the distribution fees represent 30% of the total electrical bill. The delegation of the tariff regulation to the 21 counties in Sweden would increase the distribution fees of roughly 10% which is an increase of 3% of the total bill. For the typical household, 3% increase is marginal. However, for business consumers and huge energy-consuming industries (as metallurgy, car manufacturing, data centers), 3% increase represents an important loss.

For the operators: The impact of the decentralization for the operators has already been underlined. Since the cost target imposed by the regulator is higher, the DSOs will unlikely reduce their operating cost which results in better working conditions (e.g. frequent replacement of the furniture, latest computers, better company cars). It is a gain for the DSOs. In welfare analysis, it means that the consumer surplus decreases while the producer surplus rises: as the total surplus does not change, it is simply a *rent sharing gain* for the operators. Power distributors are paid more for the same performance.

Summary

Without changing their behavior, DSOs would observe an increase in their allowed revenue. It is a result of the displacement of the cost-norm further from the optimal situation (when all companies are benchmarked together). Furthermore, the decentralization decrease the incentive power of the regulator(s) and it causes an increase in the distribution tariffs charged to the consumers. Consequently, the decentralization induces a social cost (see **Q1**).

3.3.4. Geographic partition

In the last analysis, the territory has been partitioned in a random way. A more logical way to fragment a country is to use its natural geographic breakdown (e.g. “länders” in Germany, “states” in US). Administrative borders exist inside a country and the regulation of the power distribution may follow these geographic constraints. It is the case in Belgium where the tariff regulation has been given to regional authorities: three distinct entities are monitoring the activity, the CWaPE in the south, the VREG in the North and Brugel in the middle.

The objective of the geographic partitioning is to simulate the regionalization of the regulation. The territory will be divided into regions based on the geographic coordinates (latitude/longitude). The splitting has been performed based on the *Ward's Algorithm*. This method is an agglomerative clustering method whose objective is to cluster K observations. It



starts with K clusters containing one observation and proceeds until all the observations are included in one cluster. It produces a *dendrogram* which is a tree that conceptualize the clustering between closest entities. At each step, the algorithm computes the Error Sum of Square (ESS) and R-Squared (r^2) which are measures of proximity (or distance). Then, the pairs of units that produce the smallest ESS are grouped in the same cluster.¹ If we decide to partition the dataset into N clusters, the method “cuts” the dendrogram in such manner to produce N groups. A visual illustration is proposed in **Figure 3-8** where the whole set of 164 DSOs has been clustered into five groups.

Figure 3-8 Visual illustration of Ward algorithm

¹ More details on Ward algorithm in **Appendix 6**

Results

For each level of decentralization N , the DEA benchmarking analysis has been performed within each subset. As before, it estimates the cost norm; each DSO is projected onto the cost norm of its subset to find the cost target. The sum of individual cost target has been recorded.

As for the random decentralization, the case when $N = 1$ corresponds to the initial situation where all DSOs are benchmarked in by single regulator. The sum of cost target at this level is set as reference ($C^{**} = 11,684,184 \text{ kSEK}$). In order to estimate the impact of this partitioning, we calculated the absolute and relative social cost as the deviation with the initial situation (see Eq. 16, 17). Partial results are displayed in **Table 3-3**. At first sight, the trend is approximatively similar to the random decentralization: the partition induces a social cost which sharply increases for low level of decentralization and then stagnates until the extreme case ($N = 164$). The latter consists in the case where each DSO is alone in its subset; the cost norm is the operator's cost which leads to a cost-plus regulatory scheme.

Table 3-3
Relative social cost for random and geographic partition

N	Random Partition			Geographic	Statistic Test	
	Sample Mean	Confidence Interval		Partition	p-value	Reject?
1	0.00%	0.00%	0.00%	0.00%	/	/
2	2.61%	2.45%	2.78%	3.00%	1.54E-05	TRUE
3	4.22%	4.09%	4.35%	3.47%	2.19E-15	TRUE
4	5.11%	4.94%	5.27%	4.80%	4.94E-04	TRUE
5	5.88%	5.70%	6.06%	5.48%	3.82E-05	TRUE
6	6.52%	6.38%	6.66%	6.26%	6.36E-04	TRUE
7	6.96%	6.79%	7.12%	6.61%	1.20E-04	TRUE
8	7.42%	7.28%	7.55%	7.44%	0.744	FALSE
9	7.64%	7.47%	7.81%	7.77%	0.148	FALSE
10	8.15%	8.03%	8.27%	8.44%	1.02E-05	TRUE
20	10.01%	9.90%	10.11%	9.83%	1.17E-03	TRUE
30	11.09%	10.99%	11.18%	10.87%	2.13E-05	TRUE
40	11.63%	11.54%	11.72%	11.54%	0.065	FALSE
50	12.09%	12.01%	12.16%	11.69%	2.60E-14	TRUE
100	12.76%	12.74%	12.78%	12.56%	1.96E-27	TRUE
150	12.80%	12.78%	12.81%	12.81%	0.0103	TRUE
164	12.81%	12.81%	12.81%	12.81%	/	/

However, even if the shape is similar, there are some discrepancies with random approach at certain level of decentralization. To prove it statistically, we performed a hypothesis test for each value of N :

$$H_0: \mu_{random} = \mu_{geo}$$

$$H_1: \mu_{random} \neq \mu_{geo}$$

The test statistic under H_0 follows a student distribution with $n - 1$ degrees of freedom.¹

$$t = \frac{\hat{\mu}_{random} - \mu_{geo}}{\hat{\sigma}/\sqrt{n}}$$

The p-value has been recorded for each test. If the p-value is lower (higher) than 0.05, it means that we can (cannot) reject H_0 at 95% significance. Rejecting H_0 implies that the social cost in a geographic partition is significantly different than in a random partition. Please note that we can reject H_0 when the geographic value is outside the confidence interval computed with the 50 samples of random partition.

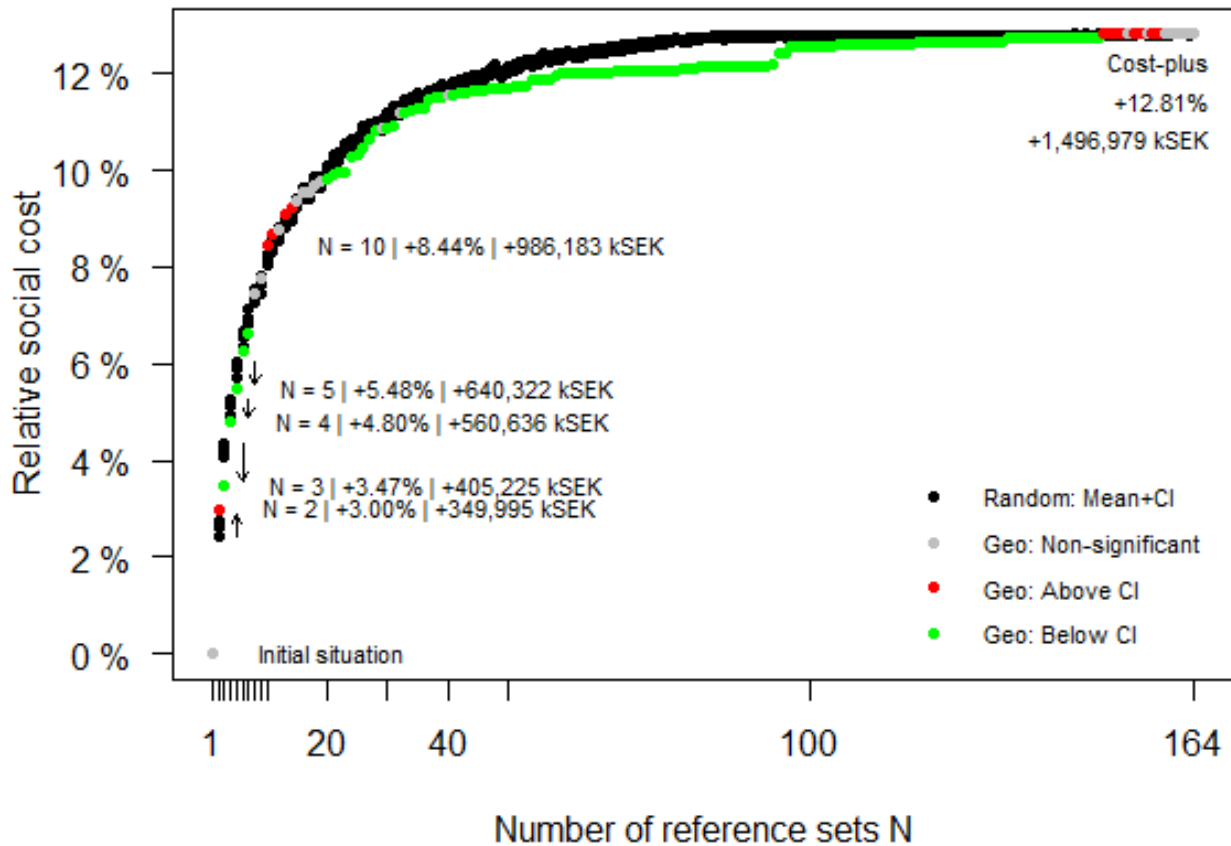


Figure 3-9 Curve of relative social cost in geographic partition

¹ In the test statistic formula, $\hat{\mu}_{random}$ denotes the sample mean, $\hat{\sigma}$ the sample standard error and n the sample size ($n = 50$ in our case).

Discussion

Figure 3-9 compared the evolution of relative social cost in random partition and geographic partition. The black dots are the random sample mean and its confidence interval with 50 samples. The grey dots are the levels where there are no significant differences between random and geographic. The red dots indicate that the geographic social cost is above the confidence interval while green dots correspond to the points below. For many values of N , the hypothesis test is rejected at 95% meaning that geographic partition causes a different effect on the optimal cost than random partition. However, the divergences are not important: the social cost (relative or absolute) in both partitions produce a concave curve between initial ($N = 1$) and cost-plus ($N = 164$) situations.

For instance, when $N = 2$, the geographic social cost (+3.00%) is higher than random but when $N = 3$, it is lower (+3.47%). In general, through all the levels of decentralization, the social cost is lower in case of a geographical partition than in a random partition. As above, our regulation model uses the cost target to determine the allowed revenue of the operators. It leads us to the second proposition.

Proposition 2: *In most decentralization levels, the increase of operators' rent is weakly lower in a geographic partition than in a random partition.*

The question to know if the geographic partition impacts the “equity” will be addressed here (see **Q2**). The equity is the quality of being fair, unbiased while taking into account the needs and background of everyone. It differs from the equality which is the idea of granting everyone the same privileges no matter the initial circumstances. The starting position of runners in an oval track is a good example. The equality would be to ensure that all runners start at the same position on the track, even if the inside lane is shorter. The equity would be to stagger the starting positions of the runners in order to offset the disadvantages faced by those in the outer lanes (Bernier, Clow & Hanson, n.d.).

The question of equity in regionalized regulation is tricky. Let's start with the arguments in favor. One of the main activities of DSOs is to build the distribution network, composed by underground cables and pylons, through a territory. The complexity of the task depends on natural constraints within the surroundings. Obviously, it is more costly to draw cables/pylons over mountains than in the sea coast. Another factor to take into account is the number of customers that it is possible to plug in the network. This factor depends on the population density: one km of line in cities serves more customers than in the wild countryside. Thus, by

partitioning the territory into regulatory regions, it is likely that operators will be benchmarked to those evolving in a similar context. Then, it is fairer for DSOs that their cost target is determined on the basis of the performance of actors distributing electricity in the same conditions. By including a contextual dimension, the geographic partition would increase the equity.

On the other hand, if we assume that the increase of operators' revenue is supported by the consumers via tariffs increase, the regionalization of the tariff regulation may have important consequence. The regionalization would allow DSOs in the mountains to increase their tariffs (to cover their higher costs) while DSOs in cities would lower them, *ceteris paribus*. As a result, it would be more costly to live in wild areas than in cities. Consequently, this principle harms the solidarity among regions and causes the concentration of population in cities and the creation of "human deserts", i.e. area where nobody lives. Before concluding something on this question, more detailed analysis must be performed, e.g. a partition that includes exogenous variables z (type of soil, the population density, the height difference).

Secondly, the division of national territory is arbitrary: it is not based on an environmental logic (e.g. mountains areas together, forest areas together) but rather on historical reasons. An operator belonging to a certain region may be underprivileged compared to another operator just on the other side of the regional border. From that point of view, the geographic partition would not bring equity in the regulation.

Summary

The geographic partition simulates the regionalization of the regulation. The results showed an impact on the cost target set by the regulator(s) which induces the augmentation of the operators' revenue, seen as the social cost. Although the overall evolution of social cost is similar to the random case, it shows in reality that a geographic partition leads to lower social cost than a random one, for most of the N values. In addition, a partition into arbitrary regions seems to harm the equity because it reduces the solidarity between regions and it causes differences in treatment.

3.3.5. Scale partition

Our dataset contains DSOs that operate at different scale. A good proxy to embrace the size of an operator is to look at the amount of connections served by the operator. The range of this variable goes from 158 to 800,590 connections through the 164 observations. Moreover, the median is 10,622 meaning that there are many small and few huge distributors (confirmed by **Figure 3-2**).

Since there are operators at different scale, it might be appealing to split up the small from the large operators in the regulation. The notion of small and large is determined by the a priori definition of a *threshold* $\tilde{s}$.

The k firms are spread into two subsets Ω_1 and Ω_2 based on the variable y_k^1 (connections).

$$\begin{aligned}\Omega_1 &= \{k \mid y_k^1 \leq \tilde{s}\} \\ \Omega_2 &= \{k \mid y_k^1 > \tilde{s}\}\end{aligned}\tag{Eq. 18}$$

Depending on the value of the threshold, the two subsets may be more or less balanced (all in one subset or two subsets of equal size). A measurement indicator of the equilibrium is the *balance index* φ computed as the size of the smallest subset over the size of the biggest.

$$\varphi(\tilde{s}) = \frac{\min_i |\Omega_i(\tilde{s})|}{\max_i |\Omega_i(\tilde{s})|}, \quad i \in (1,2)\tag{Eq. 19}$$

The evolution of the balance index against the threshold is displayed in **Figure 3-10**. As expected, the balance index varies from zero (when all DSOs are in one subset) to one (when each subset contains half of the observations). The perfect equilibrium is obtained at the maximum where $\tilde{s} = 10,622$ (the median). Hence, for a certain partition with balance index φ^* , there exist at least two values $\tilde{s}_a, \tilde{s}_b$ such that the partition with those thresholds gives a balance index of φ^* : one on the ascending curve and the other on the descending one. The decision to choose between $\tilde{s}_a, \tilde{s}_b$ depends on the regulator strategy. Choosing the threshold on the ascending curve reflects the will to isolate the smallest distributors (blue curve - *scenario 1*) while choosing the threshold on the descending curve aims at isolating the biggest ones (orange curve - *scenario 2*).

The range of threshold values to obtain a balanced partitioning is particularly narrow. Let's characterize that a partitioning is *balanced* if $\varphi \geq 0.7$ (*scenario 3*). This value is arbitrary but it makes sense: on 164 observations, when $\varphi = 0.7$, one subset comprises 68 observations and the other 96 observations, which is relatively balanced. For our dataset, a *balanced* partitioning requires that the threshold is included between 8,191 and 13,477 connections.

Results

As for the other simulations, DEA benchmarking estimates the cost norm in both subsets and computes the cost target for each DSO as the projection on the respective cost norm. The sum of individual cost targets is recorded. In addition, the relative and absolute social cost is calculated as above with the same value for $C^{**} = 11,684,184$. As a reminder, the social cost is the additional rents that DSOs are allowed to generate as a result of the decentralization of the regulatory environment. The full results are in **Appendix 11**.

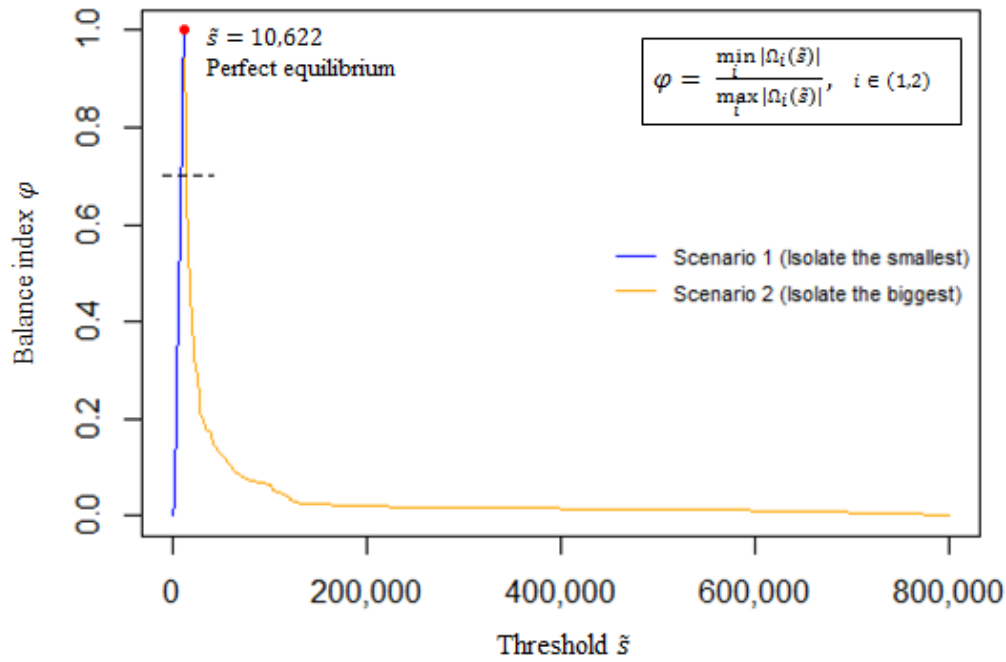


Figure 3-10 Evolution of the balance index against the threshold

Depicting the evolution of the social cost with the threshold $\tilde{s}$ would not have sense since the values of $\tilde{s}$ depends on the initial dataset. Rather, what we want to analyze here is the evolution of the social cost with the balance index φ : it is better to study the impact on the operators' revenue of either a balanced or an un-balanced partitioning on scale. The results are displayed in **Figure 3-11**. As expected, the social cost is null when $\varphi = 0$ since all the DSOs are included in the same set.

Discussion

As a reminder, the scale analysis partitions the dataset into two subsets. As a point of comparison, the social cost in random partition ($N = 2$) has been added on the plot with its confidence interval. The first observation is that for any values of φ (balanced or un-

balanced), the social cost is always inferior to the random case. It leads to the third proposition.

Proposition 3: *Compared to the random case, the social cost is less important after an ex-ante partitioning on scale.*

Above, we identified three scenarios, so let's observe how the social cost varies with them:

- Scenario 1: Isolation of the smallest DSOs (blue curve). This situation happens when φ is small (un-balanced partitioning) with the aim of isolating small distributors in one subset ($\tilde{s} < 8,191$). For this scenario, the social cost is small and increases slowly.
- Scenario 2: Isolation of the biggest DSOs (orange curve). This situation happens when φ is small (un-balanced partitioning) with the aim of isolating big distributors in one subset ($\tilde{s} > 13,477$). For this scenario, the social cost is important and more variable.
- Scenario 3: Balanced partitioning (grey zone). This situation happens when φ is above 0.7 with the aim of creating two subsets of roughly the same size $\tilde{s} \in [8,191 ; 13,477]$. For this scenario, the social cost is relatively constant around 1.24% (social cost when $\varphi = 1$).

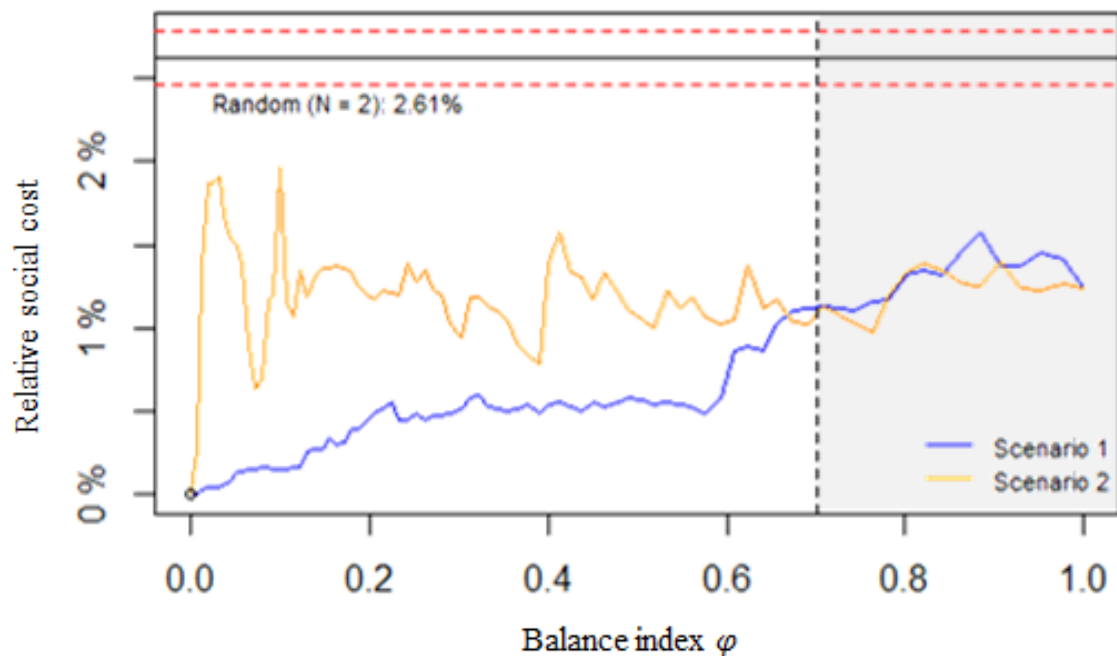


Figure 3-11 Curve of relative social cost on scale partitioning

As a reminder, from a DEA point of view, the partitioning implies a right-displacement of the cost norm as a result of the benchmarking relaxation. In addition, **Proposition 1** states that the cost target set by the regulator(s) is extended which increases the operator's revenue. Hence, isolating the smallest would extend their cost target. But since they operate at small scale, it only represents a tiny part of the general picture. On the contrary, isolating the largest has the same effect on the cost target but it represents a bigger part for the global situation.

Indeed, here, we only focus on a balanced partitioning in terms of the size of the subsets and not in terms of their share in the total distribution activity. For instance, setting the threshold at 100,000 connections would produce two subsets (154 observations in one and 10 observations in the other) which is unbalanced ($\varphi = 0.065$). But the 10 DSOs in the second subsets are serving 57% of the total territory.¹

So, it leads us to the conclusion: the threshold decision depends on the regulator will to maintain its incentive power on the smallest or the biggest. Undoubtedly, the regulator would prefer to keep the costs of biggest DSOs under control and by consequent it would rather keep them in a large subset, i.e. scenario 1: isolate the smallest.

Summary

In Sweden, the power distribution is given to operators with various sizes: from local DSOs to multinational distributors (e.g. E-ON or Fortum AB). Therefore, the benchmarking frontier in the initial situation spans DSOs from small to high scale. Why a DSO should be compared to a firm which has three times its size and benefit from scale economies? In this section, we distinguished the small from the big DSOs and looked at the social cost. First we observed that the social cost in scale partitioning is always lower than in a random one (see **Q3**).

Second, the split is based on a threshold. The choice of the threshold implies three scenarios: either isolate the small firms, or isolate the big ones, or create a balanced partitioning. The three scenarios produce diverse results. As a reminder, in DEA, the smallest is a subset; the highest is the extension of its cost target; and the lowest is the incentive power of the regulator. Thus, the regulator would rather maintain its incentive power on the biggest operators that impact a larger share of the consumers. Consequently, it would choose to isolate the smallest.

¹ The 10 DSOs serve 3,036,395 customers over the 5,338,919 customers of the total territory.

3.3.6. Ownership partition

Among the actors of the electricity distribution, there exist different types of ownership as explained in section 3.2.3. Sometimes, private companies are in charge of the distribution while in other cases, it is directly included in the municipality functions. In total, there exist five ownership categories: private (*p*), limited company owned by the municipalities (*k*), limited company owned by the state (*s*), cooperative ruled by the customers (*e*), public utility (*f*). Each category is subject to different rules, diverse funding policies, and various responsibilities in case of bankruptcy. The initial situation analysis showed that the mean of cost-efficiency is different among the categories (see **Table 3-2**). Let's observe how the revenue of the operators is affected when we partition the dataset according the ownership.

The ownership partitioning consists in dividing the dataset based on the ownership. Four cases have been simulated. Each time, DEA benchmarking has been performed to compute the cost norm and cost targets (as used in the previous analysis).

- Case 1: Private (*p*)/Public (*k, s, e, f*)
- Case 2: Private (*p*)/Public Limited Company (*k, s*)/Public (*e, f*)
- Case 3: Private (*p*)/Public Limited Company (*k, s*)/Cooperative (*e*)/Public utility (*f*)
- Case 4: Private (*p*)/City-Owner (*k*)/State-owner (*s*)/Cooperative (*e*)/Public utility (*f*)

Table 3-4
Ownership partitioning results

Ownership	DSO		Initial Situation (kSEK)	Absolute social cost (kSEK)				Cost target extension
				N = 2 p-ksef	N = 3 p-ks-ef	N = 4 p-ks-e-f	N = 5 p-k-s-e-f	
<i>Private</i>	<i>p</i>	26	4,941,118	+ 39,308	+ 39,308	+ 39,308	+ 39,308	+ 0.8%
<i>City-owner</i>	<i>k</i>	92	3,655,141		+ 208,430	+ 208,430	+ 235,562	+ 6.44%
<i>State-owner</i>	<i>s</i>	5	2,602,414	+ 138,055			+ 31,939	+ 1.23%
<i>Cooperative</i>	<i>e</i>	34	369,548		+ 20,598	+ 43,327	+ 43,327	+ 11.72%
<i>Public utility</i>	<i>f</i>	7	115,963			+ 10,004	+ 10,004	+ 8.63%
Total	164	11,684,184		+ 177,363	+ 268,336	+ 301,069	+ 360,140	
Relative			100%	+ 1.52%	+ 2.30%	+ 2.58%	+ 3.08%	

Note: kSEK = 1000 Swedish crowns (SEK)

The results are summarized in **Table 3-4**. The initial situation is the reference where all ownership categories are regulated in the same subset. The absolute social cost corresponds to difference with the initial situation for each case. For example, in N=2, the sum of cost target

for public companies (ksef) is 6,881,121 kSEK which corresponds to a difference of 138,055 kSEK.¹ The relative social cost is displayed in the last row.

Discussion

The first observation concerns the comparison with the random partition. **Figure 3-12** plots the social cost of ownership analysis in comparison with random case (and its confidence interval). Clearly, the social cost for an ownership partition is smaller than in a random partition (see **Q4**). Again, in our regulatory model, the augmentation of cost target is traduced by an augmentation of the revenue that DSOs are allowed to generate.

Proposition 4: *Compared to the random case, the social cost is less important after an ex-ante partitioning on ownership.*

The second observation concerns the simulation where each ownership category is insulated in a separate subset. The cost target extension when private (p) are alone is largely lower than for isolating city-owner DSOs (k). Proportionally, the ownership category that would be the most impacted to be regulated alone is the collectivity (e): the cost target would be extended for 11.72% in this category.

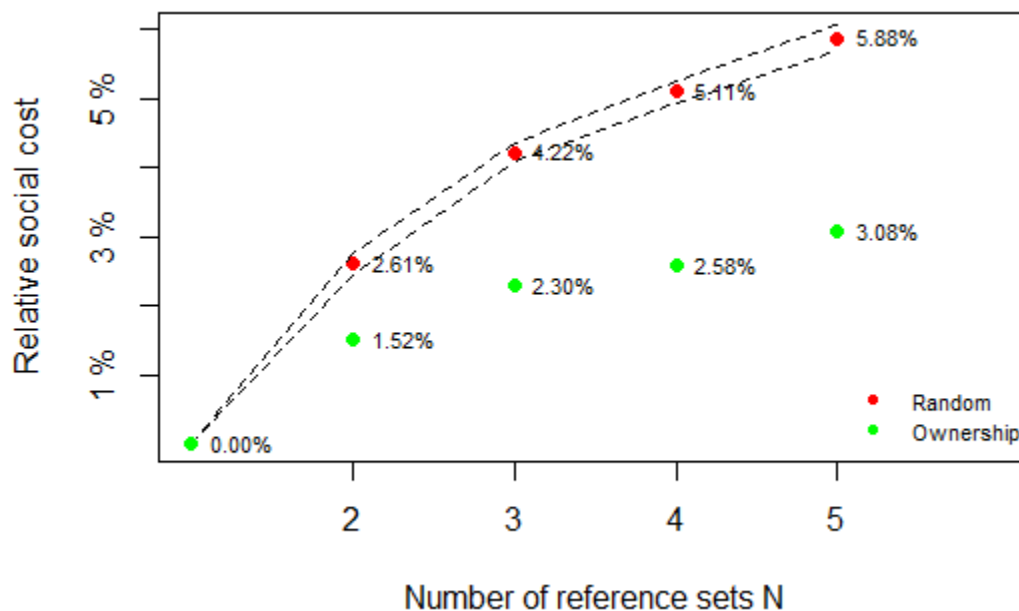


Figure 3-12 Comparison ownership and random partitioning

¹ $6,881,121 - (3,655,141 + 2,602,414 + 369,548 + 115,963)$

3.3.7. Summary

Chapter 3 studied the evolution of the social cost when the regulatory environment is partitioned into smaller subsets. The social cost is the augmentation of the revenue that DSOs are allowed to generate as a result of the relaxation of the benchmarking. By relaxation, we mean that the cost norm estimated with DEA cannot be lower when removing observations from the dataset. Hence, smaller subsets tend to shift the cost norm. As a result, the regulator(s) is losing its benchmarking power: there are fewer companies per subset which harms the regulator's ability to bridge the asymmetry of information. Hence, it results in poor incentives for cost-reductions. The decentralization of the regulation induces a social cost which is likely to be supported by the consumers through tariffs increase.

In order to study the evolution of the social cost under different cases, we simulated the decentralization using four criteria of partitioning:

- Random: the global trend of the social cost follows a concave curve between the initial case where all observations are in a single subset ($N=1$) and the other extreme where each observation is alone in its subset ($N=164$). In the latter case, each DSO spans itself and thus the cost norm equals the operator's cost. In regulation, it consists in the cost-plus approach where the DSO is covered for the totality of its costs.
- Geographic: it simulates the regionalization of the decentralization. In that case, the social cost follows approximately the same trend. However, a hypothesis test allows us to highlight that in most values of N , the social cost is lower than in the random case. In addition, the geographic partition seems to decrease the equity in the regulation: it harms the solidarity among regions and the arbitrariness of the borders leads to differences in treatment.
- Scale: it partitions the dataset into two subsets by distinguishing the smallest from the biggest DSOs. The question here is to determine which threshold to choose. We classified three scenarios (isolate the smallest, the biggest or balanced partition). First, in any case, the global social cost is lower than for the random case. Second, the regulator would prefer to preserve its benchmarking power on the biggest DSOs since they impact a bigger share of the consumers.
- Ownership: there exist five ownership categories. A distinction has been made according to the ownership: each entity is benchmarked with DSOs that have the same ownership status. First, the global social cost is lower than for the random case. Second, in case of isolation, the client cooperatives (e) are the one with the most important cost target extension.

For now, we mostly found theoretical implications. Many assumptions have been made regarding the benchmarking model, the regulatory scheme. In addition, we often assume that the transformation is immediate and that the regulator is only passive in front of the changes.

In Chapter 4, we will try to conceptualize some of the theoretical implications found in Chapter 3 to the situation in Belgium. Since we got inspired from the Belgian context to study the cost of decentralization in regulation, it is logical now to get back to the source.

Please note that it is a *contextualization* rather than an application which would have required to relax too many of the core assumptions

Chapter 4 : Situation in Belgium

After studying the hypothetic impact of the decentralization in the regulation, let's contextualize the theoretical implications to Belgian distribution sector.

4.1.1. Contextualization

The dataset used in the quantitative analysis includes the operating details for 164 DSOs in Sweden. Before applying the findings to Belgium, it is important to put both countries in perspective. **Table 4-1** compares Belgium and Sweden on geographic and demographic dimensions as well as on the structure of electricity distribution activity. The population in Belgium is bigger than in Sweden on a territory 14 times smaller. As a result, the Belgian population is extremely densified compared to Sweden. Even if some areas in Belgium seem uninhabited, it is nothing compared to wild areas in the North of Sweden. Given the demographical differences, the electricity distribution is not performed the same way: in Belgium, there are mostly pylons or underground cables in urban environment while in Sweden there are some areas where electricity is transported over longer distance, under extreme conditions (temperature, wind) and across mountains and valleys.

Table 4-1
Comparison Belgium vs. Sweden¹

	Belgium	Sweden
Population (hab) ²	11,447,664	9,923,783
Surface (km ²)	30,528	438,574
Population density (hab/km ²)	375	23
Number of DSOs	8	165
Average number of connections	786,143	32,357
Average network length (km)	45,608	3,067

The structure of the distribution sector is divergent as well. In Belgium, few large DSOs are in charge; in Sweden, many small DSOS cover the territory. For instance, the biggest distributor in Sweden is serving 800,000 customers which is roughly the average number of connections in Belgium.³

In summary, the Belgian regulation of distribution tariffs has been given to three regional institutions in 2014. It respects the geographic breakdown of Belgium in three regions:

¹ Distribution figures update: Belgium – 2016; Sweden - 2012

² Source: World Population Review, 2017

³ EANDIS is serving 2,650,000 customers in 2016

Flanders in the north, Wallonia in the south and Brussels-Capital which comprises the 19 municipalities of the Brussels' agglomeration. The map in **Figure 3-3** shows the size of Belgium compared to Sweden: it helps to realize that Belgium is already a small country for a single regulator.

In our simulation of geographic partitioning, we found that the decentralization of the Swedish regulation would increase the rents of operator by 3.47%. We can imagine that the unbundling of a country as small as Belgium would induce a higher cost for the society. Indeed, we saw that the fewer companies are used for the benchmarking, the more the cost norm is shifted which tends to relax the benchmarking. Yet, eight independent DSOs are not enough to perform an efficient benchmarking. So, a benchmarking with two (in Flanders) or five (in Wallonia) is not significant to provide DSOs with incentives for cost-reduction.

Nevertheless, the transposition is not easy since the regulatory methodology is not similar: cost-plus oriented in Wallonia and Brussels; revenue-cap without the use of DEA benchmarking in Flanders.

4.1.2. The decentralization in Belgium

The real outcome of the decentralization is mitigated. Let's start with the argument in favor. Bruno Vandezande (energy expert at Agoria¹) exposed during an interview the discrepancies that exist in Belgium. Such differences would justify the need for a local regulation.

- Demography: the population density in Flanders is higher than in Wallonia. The cost of distribution network per customer is then higher in the south.
- Sharing policy: previously, we assumed that the cost of network was equally distributed between households and companies. In reality, the regulator may choose to move the balance in order to favor one category. In right-wing political mind (in Flanders), business consumers would be favored and the individuals would support a bigger part of the cost. On the contrary, left-wing mind (in Wallonia) would protect the households at the expenses of the companies. These political divergences must impact the regulator.
- Social support: As a reminder, the DSOs are asked to provide a series of social services (OSP²) to needy customers, e.g. financial help. The legislation regarding the OSP may differ from one region to another.

¹ Agoria is a Belgian ASBL which represents and assists companies in technologic industries.

² Obligation de Service Public

- Green certificates: regional governments use different policies to refund the eco-certificates.

This argument goes with the question on equity in regulation. Some will say that the geographic decentralization brought a certain sense of equity in the regulation: distributors are compared to others that operate in the same conditions (political, environmental). In view of these discrepancies, it is appealing to study the distribution tariffs charged by operators across Belgium (see **Figure 4-1**). The heterogeneity of the tariffs appears clearly. The grey area displays the mean in each region. Wallonian DSOs are in average more expensive than Flemish; the cheapest is Sibelga in Brussels. Furthermore, operators in countryside, e.g. ORES Luxembourg or Verviers, charge higher fees than those in cities, e.g. Sibelga.

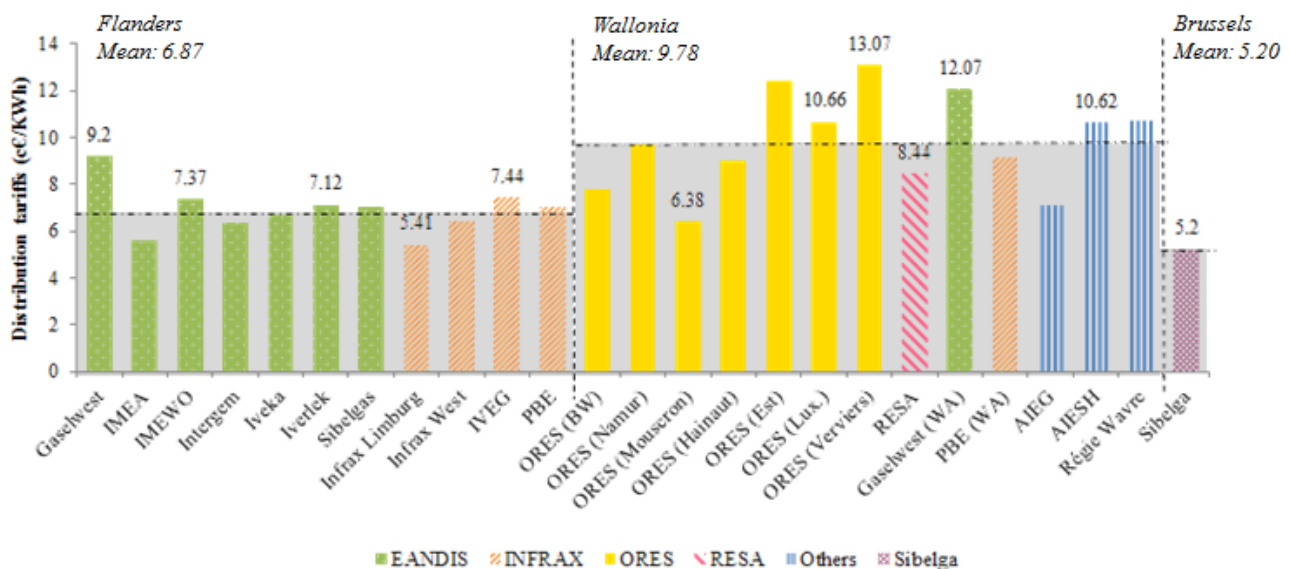


Figure 4-1 Distribution tariffs HTVA in Belgium – Without peak measurement, day tariff, 2017
(Source: Own illustration based on CWaPE, VREG, Brugel)

On the other hand, the contextual discrepancies are not extreme, compared to bigger countries. Three regulators on a so small country may induce more cost than real benefits in terms of regulation. In addition, the arbitrariness of the regional borders harms the fairness of regulation. A DSO located in one side or the other of the regional border may be subject to different legislation. For example, Gaselwest is a distributor serving customers in West-Vlaanderen and also in some localities just on the other side of the regional borders. In Flanders, the operations of Gaselwest is transferred to EANDIS and regulated under an incentive regulation. On the other side, Gaselwest in Wallonia is allowed to be compensated

for the totality of its cost (cost-plus). It results in a difference in tariffs¹ which is only explained by divergences in regulation policy. Why should it have so much difference for the DSOs or the customers?

4.1.3. Summary

The comparison of Belgium with Swedish demographic and power distribution characteristics highlights important differences: while Sweden is a large and expanded country with small population, Belgium is tiny with high population density. Consequently, the structure of the power distribution sector is different as well: in Sweden, many local DSOs are serving the consumers, while in Belgium mostly huge DSOs are operating.

By consequent, the social cost of the regionalization calculated on the basis of the Swedish dataset would be likely higher in Belgium. Indeed, the number of comparable firms is not sufficient in Belgium to perform an efficient benchmarking. Thus, the cost norm would be far from being incentive and the cost target would be close to the operator's cost. Nevertheless, the contextualization is questioned because most of our model's core assumptions are not respected in the Belgian case, i.e. use of DEA benchmarking, use of incentive regulation.

At last, we discussed the effect of the decentralization in Belgium. On one side, some will say that it produces a fair regulation because it would compare DSOs operating under the same conditions (political, social, environmental constraints). On the other side, we raised the same argument than in the question of equity in geographic partition: the arbitrariness of the border delimitation harms the fairness of the regulation.

¹ 9.2 c€/kWh in Flanders against 12.07 c€/kWh in Wallonia

Conclusions

The energy sector is a key element of our society. The power distribution is entrusted to monopolists over their territory, called DSOs. In order to limit the rent extraction of the legal monopolies, the society empowers a regulator to monitor their activity and protect the consumers' interest. There exist different approaches to control the costs of DSOs. Some of them make use of benchmarking techniques: observing the best practices among comparable distributors to set a fair limit on the revenue or the price. The benchmarking tool DEA (Data Envelopment Analysis) is suitable for this task because it estimates the cost function by drawing the best-frontier within the set of comparable DSOs. Then, it computes an appropriate cost target by projecting each firm onto the frontier.

In Belgium, the regulatory environment underwent major changes in 2014. Under the will of regionalists, the regulation of distribution tariffs has been transferred from a federal authority to regional responsibility. By consequent, instead of a single power regulating the territory, three institutions have been created to regulate each a region: the CWaPE in Wallonia, the VREG in Flanders and Brugel in Brussels-Capital. This transformation is called the decentralization of the regulation.

Inspired from the Belgian case, we addressed in this work the theoretical impact of the decentralization for the regulator(s), the operators and the consumers. Mostly, we identified the effect on the benchmarking when a territory is partitioned into smaller subsets. Based on a dataset containing operating details of 164 DSOs in Sweden, we developed a quantitative model which uses DEA benchmarking. The model simulated the partitioning of the dataset according four criteria: random, geographic, scale and ownership. At each step, it recorded the total budget allowance as the sum of individual cost targets. The difference with the initial situation is called the social cost.

Theoretical contribution

Before the quantitative analysis, we studied the hypothetic impact of the decentralization on the DEA benchmarking. We observed that the removal of a firm from the benchmarking set cannot lower the cost norm of the set. It leads to the first proposition.

Proposition 1: *Decentralization through partitioning in nonempty subsets increases the rents to operators through the regulation.*

The smaller are the subsets, the more the benchmarking is relaxed as a result of the displacement of the cost norm. In our model, the regulated revenue is function of the cost target determined by the cost norm. Without changing their behavior, the DSOs would observe an increase in their revenue. The increase would be supported by the consumers by means of an augmentation of the distribution tariffs. From another point of view, the decentralization would decrease the incentive power of the regulator(s). In this way, we can state that the decentralization would induce a cost for the society, seen as the social cost.

The random partition illustrates these implications: the relative social cost follows a concave curve from the initial situation (one benchmarking set) until the extreme case (each DSO alone in its subset). The latter corresponds to the regulatory methodology cost-plus where the cost target equals the operator's cost.

Second, the geographic partition simulates the regionalization of the regulation. Similarly, the use of geographic criterion to partition the territory would provoke the relaxation of the benchmarking. After a statistical hypothesis test, we concluded the following proposition.

Proposition 2: *In most decentralization levels, the increase of operators' rent is weakly lower in a geographic partition than in a random partition.*

Regarding the equity in regulation, the regionalization may lead to a divided opinion. Despite that the use of a contextual factor (i.e. the geographic localization) may benchmark entities operating in the same conditions; the arbitrariness of the border delimitation may harm the fairness of the regulation.

Third, the scale partition aims at distinguishing in regulation the small from the large DSOs, based on an a priori threshold. Thanks to this partition into two subsets, we observed the following proposition.

Proposition 3: *Compared to the random case, the social cost is less important after an ex-ante partitioning on scale.*

At last, since there exists five type of shareholding (from public to private); we successively isolated each ownership category in a subset. We concluded with the fourth proposition.

Proposition 4: *Compared to the random case, the social cost is less important after an ex-ante partitioning on ownership.*

Managerial implications

The theoretical findings induce some implications for managerial considerations. First, the decentralization in regulation tends to produce a social cost. From a welfare analysis, it corresponds to a rent sharing gain to the benefit of the operators. In case of incentive regulation using DEA benchmarking, the decentralization is not profitable for the society, *ceteris paribus*. Thus, if the regulatory scheme is similar in the nested regions than in the initial territory, the DSOs would be allowed to extract a bigger share.

However, despite these implications, the regulator may desire to favor a certain category of operators. For instance, the choice of the threshold in the scale partition may produce different scenarios according the number of firms in each subset: either it splits into two balanced sets, or it aims at isolating the smallest or the biggest. The theory showed that the fewer DSOs are in a subset, the more the cost target is extended. The analysis showed that the regulator may prefer to isolate the smallest DSOs and maintain the biggest ones in a large subset in order to keep their cost under control. Indeed, it is better to focus on the biggest actors since they are serving the most important market share.

Similarly, due to the discrepancies between shareholding statuses, the regulator may want to emphasize one of the categories. Doing so, the client cooperatives (*e*) would be highly favored by their isolation in benchmarking because their cost norm would be strongly displaced.

Critics, implications

In view of the analyses presented in this thesis, we need to express few critics.

First, the model always focuses on the global view: it compares by summing the individual cost targets over the whole territory. Indeed, we performed an aggregate analysis which allowed us to grasp the global trend. However, it prevents from identifying the impact on individual entities. For example, in the scale partition, we said that the regulator would prefer isolating the smallest DSOs because this scenario is the one that would induce the lowest social cost. Nonetheless, it would be appealing to see as well the impact at the individual level: how is cost target of a small DSO impacted by the three scenarios? How is cost target of a large DSO impacted by the three scenarios? These questions could be addressed in a further work.

Second, the partition on geographic criterion is based on the GPS coordinates (latitude/longitude). Consequently, close DSOs are benchmarked together. In the discussion, we assumed that close operators is likely working in the same environment. In reality, this

assumption is not true (e.g. there can be a large city surrounded by wild environment). Moreover, the Ward algorithm may sometimes create diversified subsets (e.g. the green subset in **Figure 3-8** touches the sea at one point and includes mountains on the other side). Hence, it is questionable to say that the geographic partition includes a contextual dimension. On the contrary, an analysis which would include some exogenous variables z could be considered. The variables z are contextual and could reflect the environment in which the DSO is working: for instance, the population density, the type of soil, the temperature, the height difference. Hence, a partitioning according these variables z should be appealing. The goal would be for example, to benchmark together the DSOs in cities or the DSOs in countryside. This study could be the content of a further work.

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APPENDICES

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Appendix 1: Third energy package

In 2009, the European Union enacted the Third Energy Package that contains, inter alia, the unbundling of energy suppliers from network operators. The generation and supply segments have been liberalized in order to attract new entrants in the market, while the transmission and distribution activities remain monopolies over a specific territory. In addition, the reform tends to unbundle large DSOs, i.e. the EU tends to decrease the administrative burden for small DSOs by allowing the member states to exempt small distributors.

Consequently, it can be interesting to see how the distribution market evolved in Europe.

Figure 0-1 compares the number of DSOs in European countries. It shows that the number of entities varies significantly between countries. For example, more than 800 operators are covering Germany, while only 21 distributors operate in UK. There are in Belgium, three times more DSOs than in Netherlands, even if the Belgian area represents 75% of Netherlands' area.

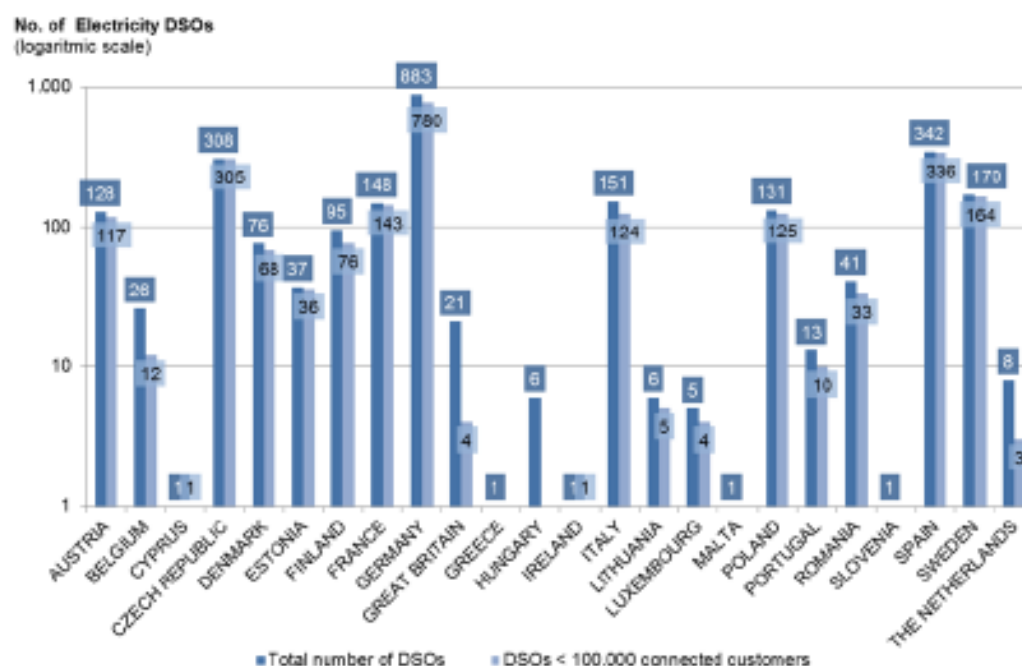


Figure 0-1 Number of electricity DSOs active in individual country (Source: CEER Report, 2013)

Appendix 2: Overview of DSOs in Belgium

Table 0-1 presents an overview of the DSOs in Belgium across the three regions. It includes the number of municipalities covered by each operator and the ownership status.

Table 0-1
Details of DSOs in Belgium

Region	DSO	Municipalities	Ownership Status	Website
<i>Flanders</i>				
	EANDIS	233		https://www.eandis.be/fr
	Gaselwest	56	Mixed Intermunicipality	
	IMEA	6	Pure Intermunicipality	
	Imewo	42	Pure Intermunicipality	
	Intergem	26	Pure Intermunicipality	
	Iveka	46	Pure Intermunicipality	
	Iverlek	52	Pure Intermunicipality	
	Sibelgas	5	Pure Intermunicipality	
	INFRAX	126		https://www.infrax.be/fr
	Infrax Limburg	44	Pure Intermunicipality	
	Infrax West	15	Pure Intermunicipality	
	IVEG	47	Pure Intermunicipality	
	PBE	20	Pure Intermunicipality	
<i>Wallonia</i>				
	AIEG	5	Pure Intermunicipality	http://www.aieg.be/
	AIESH	7	Pure Intermunicipality	http://www.aiesh.be/FR/
	GASELWEST (c/o EANDIS)	5	Mixed Intermunicipality	https://www.eandis.be/fr
	ORES	198		https://www.ores.be/
	ORES Brabant Wallon (ex Sedilec)	25	Pure Intermunicipality	
	ORES Est (ex INTEREST)	13	Pure Intermunicipality	
	ORES Hainaut Electricité (ex IEH)	56	Pure Intermunicipality	
	ORES Luxembourg (ex INTERLUX)	49	Pure Intermunicipality	
	ORES Mouscron (ex SIMOGEL)	3	Pure Intermunicipality	
	ORES Namur (ex IDEG)	36	Pure Intermunicipality	
	ORES Verviers (ex INTERMOSANE)	16	Pure Intermunicipality	
	PBE (c/o INFRAX)	4	Pure Intermunicipality	https://www.infrax.be/
	RESA-TECTEO	71	Limited Company	http://www.resa.be/
	REGIE DE WAVRE	1	Pure Intermunicipality	http://www.regiewavre.be/
<i>Brussels</i>				
	SIBELGA	19	SCRL *	http://www.sibelga.be/fr/

* Société Coopérative à Responsabilité Limitée

Appendix 3: The 6th state reform

The 6th State Reform is a set of rules and reforms that have been voted during the Di Rupo government. Divided in two parts (in 2012 and in 2014), the 6th State Reform required more than 450 days of negotiation. Also called “Accord Papillon”, the reform is structured into four chapters (Belgium.be, 2014; Joos, s.d.).

Political Reform

The first chapter is the piloting of government activities in order to improve the evaluation and the monitoring. The main objective is to reinforce the rules in terms of political ethic. A deontological code has been written by the Belgian commission in order to avoid conflict of interest. Ministers’ remuneration will be diminished and the donations to royal families will be re-discussed.

Moreover, the role of the Parliament will be reinforced and the reform plans to move to a bicameral system (“Sénat” and “Chambre des Représentants”).

BHV and Brussels

The second chapter of the Reform plans to rearrange the electoral circumscription of Brussels-Hal-Vilvoorde. The district has been split and thresholds have been determined for election results. The judicial district around Brussels has been reviewed.

Transfer of competences from federal authority to federated entities (regions)

The third chapter of the reform plans the transfer of competences from federal to regional authorities. The objective is to give more power and more responsibilities to regions.

Here is a non-exhaustive list of the transferred competences:

- Traffic laws
- Price control of electricity and gas distribution
- Labor market
- Waste recycling and transit
- Health care
- Family allowance

Funding reform

The fourth chapter aims to reinforce the fiscal autonomy of the regions. Furthermore, it aims to redesign the funding of the regions in order to support them in the achievements of the new competences.

Appendix 4: Weighted Average Cost of Capital (WACC)

The WACC (Weighted Average Cost of Capital) is a finance index used to determine the return of investments. Cash flows and Terminal Value (TV) must be discounted in order to reflect their present value. The discount rate, WACC, should reflect the after-tax return expected by the capital providers (equity and debt). Then, the WACC is the marginal cost of all sources of capital (equity and debt). Moreover, the WACC is computed after-tax since the cash flows are calculated after corporate taxes. Finally, the WACC must be adjusted for the risk supported by each capital provider because each provider expects a return that compensated the risk undertaken. At last, the market value of capital (equity, debt, preferred stock) must be used, because it reflects the true economic situation of each source of capital where the book value may not.

The WACC is computed as follow:

$$WACC = \frac{E}{(E + D + P)} * r_E + \frac{D}{(E + D + P)} * (1 - t) * r_D + \frac{P}{(E + D + P)} * r_P \quad (\text{Eq. 0-1})$$

where, E is the market value of equity; D is the market value of the debt; P is the market value of preferred stock. The WACC takes the form of a weighted average since the ratio of each source of capital is weighted by a factor that represents the cost of the capital: r_E is the cost of equity; r_D the cost of debt; r_P the cost of preferred stock and t the marginal tax rate.

Cost of equity r_E (CAPM method)

$$r_E = r_f + \beta * (r_m - r_f) \quad (\text{Eq. 0-2})$$

r_f is the risk free rate (10 years bond rate), $r_m - r_f$ is the market risk premium and β is predicted equity beta.

The beta is a measure of the volatility of a stock's return, compared to the equity returns of the overall stock market.

Cost of debt r_D

The cost of debt represents the marginal interest rate charged by the bank. Multiplying the debt part by $(1-t)$ captures the benefit of the tax shield arising from interest expenses.

Appendix 5: Numerical example of DEA model

Numerical example

In order to illustrate the theory, let's take a numerical example based on the database used in the quantitative analysis. For each of the ten selected DMUs, the amount of operational expenditure (OPEX in kSEK) – denoted as input – and the quantity of energy delivered (MWh) – denoted as output – have been collected. Afterwards, a DEA program has been run using the chosen input and output variables. **Table 0-** displays the data and the results obtained (efficiency score and peer units for each DMU).

Table 0-2
Data and results for numerical example

Firm	input x	output y	eff_score	peer 1	peer 2
1	15 821	118 136	0.516	3	4
2	25 242	540 484	1.000	2	/
3	9 264	169 757	1.000	3	/
4	7 164	70 894	1.000	4	/
5	9 608	98 808	0.807	3	4
6	34 559	344 358	0.486	2	3
7	17 323	139 267	0.497	3	4
8	25 962	400 620	0.740	2	3
9	14 952	170 520	0.622	2	3
10	21 121	221 009	0.543	2	3

Among the ten firms, three firms are fully efficient (firm 2, 3, 4). Indeed, they are located on the best-frontier calculated with VRS (see Figure 0-2). The frontier standard – the technology set T^* – is effectively calculated with minimal extrapolation principle since it is the smallest subset that contains all the data. Each firm is then compared to its projection on the frontier reference. Graphically, the firm 8 is projected horizontally¹ on the red cross between firm 2 and firm 3 which are the peer units. Precisely, the projected point corresponds to the minimal (optimal) input utilization for the same output level based on other firms' performance. The projection is the weighted sum of peer units' input, using λ^2, λ^3 as the weights.² Consequently, the efficiency score is simply the ration between optimal inputs over actual inputs.³

¹ Horizontally because the input-oriented Farrell efficiency is computed – vertically in case of output efficiency

² $0.623 * 25242 + 0.377 * 9264 = 19218$ (the optimal cost for firm 8).

³ Effectively, $Optimal/Actual = 19218/25962 = 0.740$

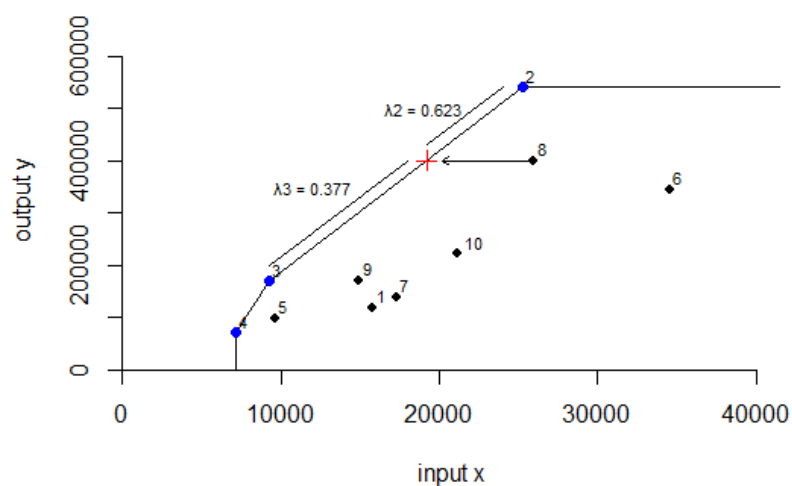


Figure 0-2 DEA plot with projection

A deeper approach concerns the super-efficiency. As explained in section 2.2.1, the super-efficiency consists in removing the evaluated unit when estimating the technology set. Consequently, fully-efficient firms are “outperforming” the best-frontier which grants them an efficiency score superior to 1. In **Figure 0-2** below, the firm 3 receives a super-efficiency score of 1.184. Super-efficiency is mostly used in regulatory context to provide incentives to efficient firms to continually perform better.

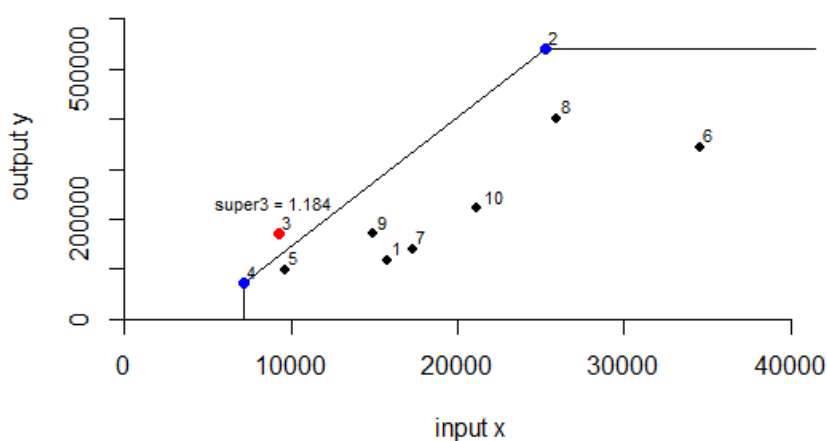


Figure 0-3 Super-efficiency

Appendix 6: Ward's Algorithm

The Ward's Algorithm is a method to perform a cluster analysis. It is characterized by a agglomerative clustering algorithm, i.e. it starts at the leaves and keep going until the trunk. To say it differently, Ward's algorithm starts with n clusters of size 1 and proceeds until all the observations are included in one cluster.

The objective of the Ward's method is to cluster a set of n observations into K clusters, based on their relative distance. The approach is based on the concept of Error Sum of Square (ESS) and R-Square (r^2). It starts with n clusters containing each one observation. The error sum of square and r^2 are computed for each combination. The pairs of units that produce the smallest ESS, or in a similarly way, the largest r^2 will be grouped in the same cluster. After the first step, it yields to $n-1$ clusters. The method is run until there is only one cluster.

Let denote X_{ij} the observation j in the cluster i .

$$ESS = \text{Error Sum of Square} = \sum_i \sum_j |X_{ij} - \bar{x}_i|^2 \quad (\text{Eq. 0-3})$$

$\bar{x}_i$ denotes the mean of the cluster i . So the ESS is the sum of the square distance of each observation to the mean of its cluster. In the first step, the ESS is null since each cluster contains only one observation. The next cluster is the one that minimize the ESS when adding a new observation.

$$TSS = \text{Total Sum of Square} = \sum_i \sum_j |X_{ij} - \bar{x}_{..}|^2 \quad (\text{Eq. 0-4})$$

The element $\bar{x}_{..}$ denotes the overall mean of the whole dataset. Hence, TSS computes the sum of square distance of each distance to the overall mean. Please remark that TSS doesn't change when adding or removing an observation to a cluster. It is then fixed and inherent to the original dataset.

$$r^2 = R - \text{Square} = \frac{TSS - ESS}{TSS} \quad (\text{Appendix 6.3})$$

r^2 measures the relative difference between TSS and ESS. In step 1, the r^2 equals 1 since ESS is null. In the last step, the r^2 equals zero because $ESS = TSS$. Between each step, the r^2 needs to me maximized.

Appendix 7: Interview with Climact

Date: 24th April 2017

Interlocutor: Quentin Jossen – Civil engineer

Dimitri Mertens – Legal expert

Présentation de l'entreprise

Dimitri : Climact est un bureau de conseil qui a 10 ans d'existence.

4 Piliers d'activité :

- Questions prospectives : réaliser des études technico-économiques sur les possibilités de dé-carbonner l'économie à l'horizon 2050. Les clients sont essentiellement les pouvoirs publics belges ou européen dans ce domaine la
- Réduire l'empreinte carbone des entreprises, essentiellement via des modèles classique de calcul de l'empreinte carbone et où il y a moyen d'améliorer
- Question juridique et réglementaire tant au carbone et à l'énergie
- Mis en place des recommandations.

Climact a mis en place une structure d'investissement qui permet d'investir en lieu et en place des clients dans les recommandations proposées. Les gains réalisés sont partagés. Ex : si installations photovoltaïques,

Quentin : On travaille aussi avec des régulateurs et des gestionnaires de réseaux mais on n'est pas spécialistes sur ces questions.

Transition énergétique

Corentin: Quels sont les manquements, décalage entre état actuelle et état idéal pour accompagner la transition?

Dimitri : Au niveau des réseaux de distribution, il y une grande frilosité et aversion au risque. Par exemple, tout ce qui est renouvelable et connecté au réseau de distribution génère une question que le réseau de distribution n'avait pas l'habitude de gérer.

Le cadre réglementaire wallon a donné un niveau d'assurance assez élevé au gestionnaire de réseau pour pouvoir déconnecter les entités qui produisent de l'énergie renouvelable intermittente (solaire, éolien) pour des question de stabilité du réseau.

Le législateur a permis au GRD de ne pas subir l'impact du renouvelable sur son réseau. L'avantage est que le réseau est sécurisé car il y a une marge de manœuvre qui leur est attribué. La capacité d'un réseau de distribution de déconnecter des producteurs quand ça lui chante, ça s'appelle de la flexibilité qui est une commodité qui a une valeur. Mais cette mesure n'est pas propice à la transition énergétique. En d'autre mots, le GRD a la possibilité de déconnecter un producteur d'énergie renouvelable pour des raisons objectives (ou

objectivables) ce qui veut dire qu'ils pourront décider de ne plus prendre l'électricité venant de cette personne-là.

La principale raison est que ça permet de sécuriser le réseau et ça donne la possibilité de couper le réseau si des travaux sont nécessaires. Cependant, peut-être que cela nécessite une compensation car dans le cas où des producteurs sont coupés du réseau, on les prive d'un bénéfice.

Quentin : On parle donc de 2 choses : l'actionnabilité du gestionnaire sur son réseau (qu'est-ce qu'il peut faire) et d'autres part de toute une série de nouveaux services qui viennent avec la transition. Ces nouveaux services viennent avec de nouvelles responsabilités, des échanges d'informations/données, des flux d'informations. Tout ça ce sont des nouvelles choses à définir. Par exemple, la flexibilité ou le stockage.

Est-ce que le gestionnaire de réseau peut prétendre à la fourniture de ces nouveaux services ? Ou bien est-ce que ça doit être des entreprises privées ?

La responsabilité des nouveaux types d'acteurs ? Est-ce que ces nouveaux services doivent être ouverts à la concurrence ou bien monopole comme le GRD ?

Dimitri : Il faut aussi s'interroger sur comment maintenir la confidentialité. Par ailleurs, il ne faut pas oublier que les gestionnaires de réseau sont des monopoles régulés donc si tu étends la sphère, il faut s'interroger sur la question de légitimité du monopole qui accède à toutes ces données procurées par des entités soumises à la concurrence.

Ce qui serait intéressant dans ton mémoire c'est de savoir le modèle qu'on définit à priori et comment on applique ce modèle-là dans un environnement qui évolue avec de nouveaux services. Est-ce que le monopole va avoir tendance à s'étendre pour le motif de la sécurité du réseau ?

Nouveaux Services

Quentin : Le stockage, la flexibilité.

Des entreprises pourraient offrir un service de flexibilité dans lequel ils contrôlent certains des processus des clients comme ça quand Elia communique que le réseau est surchargé/peu chargé, ils peuvent adapter le processus et diminuer/augmenter la demande en énergie. C'est bénéfique pour Elia car cela permet de lisser et équilibrer leur demande pour matcher correctement l'offre et la demande. Ils verseraient à l'entreprise de service un peu d'argent qu'ils peuvent ensuite redistribuer à leurs clients en gardant une petite marge.

De nos jours, on peut l'offrir au réseau de transmission (GRT) mais pas au service de distribution (GRD) sans raisons apparentes.

Par ailleurs, en lien avec le point abordé précédemment sur la possibilité de couper certaines productions. Cela coûterait plus cher de faire varier/adapter une production que de couper des choses qui sont gratuites (en d'autres termes le solaire, éolien,...)

Le stockage : une entreprise peut offrir du stockage sous forme de pile (batterie) ou de l'eau pour pouvoir utiliser l'énergie après, selon différentes échelles de temps.

Ainsi, il faudrait se demander qui doit remplir ces nouveaux services et ces nouvelles infrastructures. Est-ce que ça doit forcément être le Gestionnaire de réseau ou d'autres acteurs qui viennent renforcer les capacités

Tarification incitative

Corentin : La tarification incitative nécessite un benchmark. Avant la réforme, il y avait 15 entités. Depuis la consolidation et la décentralisation, ce nombre d'entités indépendantes sous la responsabilité du régulateur a fortement diminué.

Pensez-vous que cela devrait changer ?

Quentin : Il faut pouvoir trouver des zones géographiques comparables. La proposition lors de la conférence présentée par Agrell sur la tarification proposait de comparer la Belgique avec la Roumanie car même taille et même configuration.

Il faudrait donc partir d'une vision et comment est-ce qu'on veut transformer le réseau.

Dimitri : 2 approches

- Faire l'état du réseau et le comparer avec un optimal théorique.
- Ou bien ajouter une dimension de développement vers l'idéal. Il faut que ce réseau atteigne l'idéal dans un environnement mouvant et facilite la transition énergétique.

Actuel ➔ Optimal ou Actuel ➔ Optimal ➔ Idéal

Quentin : On réalise des scénarios de prospective.

On s'intéresse ainsi à ce que pourrait devenir les réseaux en 2030. Il pourrait ainsi être utile de s'intéresser au coût de la transition (déjà des études la dessus).

Une partie des coûts sont sur les moyens de production et une autre partie des coûts sur l'évolution du réseau.

Il serait intéressant de se donner une fourchette tolérable si on veut maîtriser l'évolution des prix d'électricité d'ici 2030 car on ne peut pas se permettre ça pour les belges. Et selon cette plage de prix, on peut calculer une plage d'efficacité.

Ex : 10 nouveaux services et augmentation des coûts de max 20%

Etudes actuelles

Quentin : On a une étude avec IWEPS (Institut Wallon des Etudes Prospectives et Statistiques) sur l'avenir des réseaux électriques wallons et particulièrement réseau de distribution.

IWEPS est un organisme public. Même si ils ne seront pas dans le temps mais tu peux demander directement des résultats préliminaires à l'IWEPS.

« Je sais qu'il y a l'étude, j'ai rencontré Climact. Est-ce que je peux disposer de résultats préliminaires de l'étude qui me seraient utile dans le cadre de mon mémoire. »

Contact : Jean-Luc Guyot

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Model quantitatif

Corentin : création d'un modèle théorique pour produire un graphe qui mesure le cout optimal (ou score d'efficacité) selon le nombre d'acteurs. Plus il y a d'acteurs, moins c'est efficace car le benchmark est complexe. Moins il y a d'acteurs, cela signifie qu'il y a des consolidations et donc des synergies qui dans ce cas la engendraient de l'efficacité.

Donc il se peut que je tombe sur un point optimal/maximal.

Quentin : La question pourrait aussi se poser sur le nombre d'acteurs différents qui interviennent dans l'activité de la gestion du réseau.

Par exemple : une personne qui va être responsable de la collecte des données, une personne responsable de la flexibilité.

Dimitri : On voit que le GRD a tendance à sortir de son carcan, non pas parce que ça lui fait plaisir mais parce qu'il y a des opportunités qui s'offrent à lui et qu'on est en transition et du renouvelable s'ajoutent.

Ainsi sur les sphères sur lesquels ils s'entendent, il faut se poser si une concurrence pourrait produire un gain d'efficacité.

Capacité et Energie

Quentin : De nos jours, des gens sont connectés au réseau et produisent en même temps de l'énergie solaire. Ces gens-là stockent en été et consomment en hiver et leur compteur tournent à l'envers. Sauf que ces personnes exploitent le réseau et ne le paie pas. Or comme ils ne le paient pas et que le réseau garde son cout, il faut répartir sur un plus petit nombre d'utilisateurs donc les autres paient plus. Il y a donc une réflexion sur volume et capacité. C'est-à-dire faire un tarif forfaitaire qui comprend simplement le fait d'être connecté au réseau (partie capacité) et ensuite un tarif variable qui dépend de la différence entre consommé et produit (partie volume). Et pour le moment la partie capacité, on ne la paie pas. En tout cas, cela part vers plus de centralisation

Dimitri : cela ne vas pas changer la façon ces couts et comment il est régulé.

Quentin : Par exemple, si tout un quartier est muni de photovoltaïque.

Le GRD doit penser à toute des infrastructures supplémentaires pour pouvoir offrir à ces gens ce service la (pallier la surtension, mettre en place du stockage, même si ils sont déconnectés ils devront s'assurer d'être fournis). Il y a donc une partie de couts qui ne sont pas facturés.

Ce ne serait pas facturé mais cela rentre dans les couts du distributeur et donc la question est de savoir qui va payer.

La transition va favoriser cette situation-là. Et la répartition va faire que ceux qui n'ont pas les moyens d'investir vont devoir supporter ces couts supplémentaires.

Inspiration d'un réseau autonome : projet NICEGRID

Projet de mettre une zone en autonomie avec du photovoltaïque et stockage.

Metering

Corentin : Qui s'occupe du comptage et de l'installation du compteur ?

Quentin : En Belgique, le GRD est le seul responsable d'installer le compteur et le compteur appartient au GRD.

Or dans d'autres pays (par exemple l'Allemagne), c'est une entreprise privée qui offre un service de comptage et ils offrent des services de visualisation.

C'est la question des smart meters (compteur intelligent).

L'Europe a demandé à ses pays membres d'évaluer si oui ou non c'était économiquement faisable de développer les compteurs intelligents. Chaque pays a fait son business case.

La question est qui paie, qui investit. Et cela pourrait être le consommateur final qui paye pour avoir un service de visualisation supplémentaire, un pouvoir de contrôle sur ses consommations.

D'un point de vue du régulateur, les performances du GRD ne sont pas sous-estimées car les volumes sont prélevés au niveau du GRD et pas du client final.

Par ailleurs, il y a des unités de production qui sont directement reliées au réseau de distribution.

Pour aller dans les exemples : YellowStorm (en Allemagne propose ce genre de metering)

Dimitri :

Il serait intéressant que tu prennes en compte l'une ou l'autre nouvelles activités qui pourraient être mise en concurrence.

Investissement

Quentin : Si il y a des travaux de rénovation, est-ce au GRD de le faire sur ce tronçon la ?

Ou au contraire faire un appel d'offre et léguer la responsabilité de l'entretien et rénovation d'un tronçon du réseau à une entreprise privée. Est-ce que ça garde du sens que le GRD continue de s'occuper de l'infrastructure.

Ex : c'est le cas de la SNCB qui a la gestion du trafic ferroviaire mais pas la gestion de la ligne (c'est Infrabel qui s'occupe des travaux).

⇒ Distinguer la gestion de l'infrastructure et gestion du trafic.

Au sein des gestionnaires de distributeur, ils font déjà la distinction.

- Gestionnaire de réseau (GRID) = gestion physiques des lignes
- Gestionnaire du système = prise de décision, gestion de l'information, power quality, ce qui circule sur le réseau.

Transfert fédéral vers régional

Dimitri : c'est une raison politique et cela a été demandé par la Flandre.

Appendix 8: Interview with Bruno Vandezande

Date: 9th May 2017

Interlocutor: Bruno Vandezande, Energy expert at Agoria.

Méthodologie tarifaire en Belgique

Pour analyser le coût du transfert de compétence, il faudrait comparer le dernier tarif de distribution régulé par la CREG avant la régionalisation et le premier tarif régulé par la CWaPE après la régionalisation. La CWaPE est en train de valider sa nouvelle méthodologie tarifaire pour 2019-2023. Cette proposition est à consultation et est présent sur le site de la CWaPE pour consultation. Donc le transfert s'est déroulé en 2014. Il y a eu une première période régulatoire de 2015 – 2018, coupée en 2. Lors de cette période dites de transition, la CWaPE n'a rien changé en termes de méthodologie. Par rapport à ce que faisait la CREG, elle a favorisé la continuité.

En Flandres, la VREG a également choisi la continuité. Par contre, en Flandre, il y avait pas mal de solde régulatoire. En effet, il y a eu un gel des tarifs de distribution pendant plusieurs années et le solde régulatoire c'est tout ce qui s'accumule sans pouvoir être reporté sur les tarifs. Le dégel a eu lieu juste après le transfert de compétences. Par conséquent, ce solde régulatoire, particulièrement présent en Flandre, doit être étalé dans le temps.

Raisons du transfert de compétence

Comme toutes les compétences belges, elles ont été soumises à la nouvelle réforme de l'Etat du gouvernement Di Rupo. Il fallait donc qu'il y ait un pot suffisamment copieux des matières transférées pour arriver à un accord. Il n'y a pas vraiment de bénéfices économiques (pareil pour la sécurité routière) mais c'est purement politique. Mise à part de la volonté des régionalistes d'avoir la main sur une partie plus importante des compétences. Cette volonté vient exclusivement de la part de la Flandre mais ce qui est particulier c'est que les organismes fédéraux à l'origine étaient déjà très flamands. Ce qui est paradoxal c'est que la volonté vient de la Flandre mais ceux qui gagnent le plus à la décentralisation sont les wallons. Parce qu'ils récupèrent vraiment la main sur la gestion des réseaux, lorsque que la CREG était déjà exclusivement flamands.

Dimensions des conséquences de la régionalisation

Je m'étonnais un peu de ton hypothèse que tu poses comme quoi la décentralisation/régionalisation est un coût. Ce que tu dis est vrai, mais de là à dire que cette variable de « perte d'efficacité » a pris le contrôle et que c'est elle qui impose, là je pense que tu vas un peu vite en besogne.

Il y a une autre chose à prendre en compte c'est que la configuration wallonne et la configuration flamande ne sont pas les mêmes sur le territoire : les densités de populations ne sont pas les mêmes. C'est évident que même en Wallonie, il y a des différences entre le réseau de

distribution du sud du Luxembourg et le Brabant Wallon ou à Liège, tout simplement le cout des réseaux n'est pas le même et la densité de population n'est pas le même.

La Wallonie est exclusivement distribuée par ORES mais il existe quelques petits distributeurs (tels que Régie de Wavre, AIEG) mais qui sont pour une raison historique. Un enjeu important en Wallonie est que les ménages et entreprises dans la province du Luxembourg sont pénalisés car les couts de réseaux sont distribués sur un panier plus réduit de consommateur. Il y a donc une volonté politique de davantage mutualiser les couts, ce qui serait intelligent d'un point territoriale. Il y a donc une spécificité géographique en Wallonie vs. la Flandre lié à la densité de population et donc au cout des réseaux par entités connectées qui fait que ça peut avoir un sens d'avoir une méthodologie plus adapté aux besoins wallons. C'est donc une autre variable à coté de ce que tu exprimes.

Donc, première dimension : efficacité

Deuxième dimension : spécificité territoriale

Troisième dimension : politique de partage en les ménages et les entreprises. Comment les couts du réseau sont redistribuées entre les résidentiels, les grosses entreprises, les PME, le tertiaire, le petit manufacturier. La question est donc de savoir comment ces couts sont répercutés

Les obligations de services publics

Ce n'est pas simplement le cout du réseau qui est répercutés. Le service de transmission Elia et les distributeurs ont des obligations de services publics (OSP). Ex : protéger un certain nombre de population (sociaux), obligation de service public de racheter les certificats verts à 65€ porté par le transporteur en Wallonie et porté par le distributeur en Flandre. Ces obligations de service public portent sur une part non négligeable du cout.

Ainsi, si le régulateur fonctionne dans un système politique de droite (plus ambiance que idéologique), les entreprises vont être davantage protégés et le résidentiel va devoir davantage porter le cout. Cela a été le cas pour l'ancien ministre de l'Energie, Annemie Turtleboom qui a démissionné à cause de la Turtle Tax. Cette taxe, c'est précisément le cout du photovoltaïque qui avait été exclusivement porté par le résidentiel. En Wallonie, les choses sont différentes car le paysage politique est plus rouge de dire qu'on protège davantage le pouvoir d'achat des ménages et cela veut dire que les entreprises paient davantage (effet des vases communicants).

Ainsi, il y a des régions en Belgique où le gros industriel est protégé au détriment du petit industriel et du consommateur. De l'autre extrême, en Wallonie, on protège un peu tout le monde.

En Allemagne par exemple, les gros sont très protégés, c'est le cas pour la sidérurgie. Tous ceci sont des questions politiques qui ne sont pas blancs ou noirs mais en tout cas à la fin cela intervient

Challenges pour assurer la transition énergétique

Dans le cas de la transition énergétique, il faut évidemment regarder les challenges pour les différents acteurs. Le challenge du transporteur est énorme : comment l'Europe est interconnectée et comment assurer la sécurité d'approvisionnement. La Belgique est fortement interconnectée avec ses voisins mais il faut encore que nos voisins soient en mesure de nous fournir en électricité. La Belgique est dans un cas particulier car elle était dans une position importatrice il y a quelques années et est devenu maintenant exportatrice. Cela est dû notamment au politique de sortie du nucléaire. Cela fait 15 ans qu'on balance en Belgique pour oui/non sortir du nucléaire.

Parenthèse: La sortie du nucléaire

C'est important de développer le renouvelable de manière volontariste. Après, le nucléaire est là en Belgique et on ne construit pas de rien. Le vrai problème, c'est qu'on a besoin d'un base-load pour alimenter le réseau 24/24. Chaque technologie n'est pas à même d'assurer une base-load. Les technologies renouvelables font de la production en intermittent, cela ne produit aucun base-load. La base load ne peut provenir qu'une énergie de type combustible (ou Uranium) Alors que les énergies de type flux (vent solaire) sont par nature intermittente.

Il n'a que 3 types de technologie qui peuvent permettre de produire la baseload : le nucléaire, le fossile (le charbon qui est le plus sale et le moins cher et les turbines TGV au gaz avec très au rendement) et la biomasse (parfois un peu absurde car contient beaucoup de perte lorsqu'on brûle du bois pour faire de l'électricité, lorsqu'on pourrait directement brûler du bois pour faire de la chaleur) Vu qu'en Belgique, on a déjà le nucléaire, il faut s'appuyer là-dessus et en même temps derrière, il faut développer des solutions renouvelables.

Challenges pour assurer la transition énergétique (suite)

Les grands challenges pour la distribution sont :

- l'intégration de l'intermittence des nouveaux moyens de production
 - l'intégration de la décentralisation des nouveaux moyens de production
- ➔ Le fait de passer d'une centrale électrique (qui comme le dit son nom sont dans une situation centralisée) vers des centaines d'installation décentralisée.

En réalité les particuliers qui produisent de renouvelables ne sont jamais autonomes. Ils sont reliés au réseau et l'électricité qu'ils produisent est directement réinjecté sur le réseau. Le réseau joue le rôle de stock. Le panneau photovoltaïque n'alimente pas directement la maison mais il injecte sur le réseau et le compteur tourne à l'envers. C'est très différent comme modèle. C'est donc cela qui pose problème car les coûts de distribution ne sont pas supportés par les entités autonomes.

L'objectif pour 2050 est de diminuer de 80% les émissions de CO₂. La question est de savoir comment va-t-on réussir à dé-carbonner aussi fortement.

La responsabilité chez Agoria est de trouver et de proposer des solutions énergétiques aux grosses entreprises. L'idée est d'électrifier au maximum les processus ; les déplacements avec les moyens de transport électriques (voitures électriques) ; les processus industriels. Mais l'électrique n'est pas un miracle, c'est simplement un déplacement de la consommation et au lieu de consommer du fossile, on consomme de l'électrique. Mais il faut regarder d'où provient l'électrique.

Il y a donc un enjeu d'un point de vue du distributeur. On s'attend à ce que les coûts de distribution pour l'intégration du renouvelable ne cesse d'augmenter.

Une autre manière de gérer l'intermittence, c'est de gérer intelligemment la consommation, c'est le Demand-Side-Management (DSM). C'est donc de consommer au même moment où l'on produit. Plutôt que de lancer une machine à laver n'importe quand en faisant confiance à ton réseau, elle est lancée suite à des signaux qui indiquent qu'il y a beaucoup de vents ou soleil et que c'est le bon moment. C'est déjà comme ça sur le marché direct de l'électricité. Le prix de l'électricité entre les gros acteurs (sidérurgiste, pays,...) peut varier énormément sur le BelPex. Il y a eu un moment où les prix devenaient négatifs → il y avait tellement de vent et la consommation étaient tellement basses qu'on payait les entreprises pour consommer.

Tout cela, il va bien falloir le distiller au niveau du particulier, et cela arrive sous le concept de SmartGrid. Tout cela va être intégré dans le coût réseau.

Nouveaux services pris en charge par le distributeur ou acteurs indépendants en concurrence?

Au final, cela revient à rajouter des intermédiaires. Vu qu'à la base, cela repose sur un réseau physique qui est de toute façon pris en charge par le distributeur. Cela rejoindra ce qu'il se passe avec le réseau télécom qui possède un seul réseau physique avec des acteurs qui se développent sur ce réseau.

Ces acteurs se développent pour pallier au manque d'intelligence ou au manque de volonté de s'impliquer et d'investir. Cela requiert énormément d'investissement de la part du distributeur, or la façon dont les distributeurs sont régulés de nos jours ne contribuent pas à leur donner des incitations à investir sur ces sujets.

Pour rappel, la CWaPE a décidé d'assurer la continuité sans changer la méthode de régulation pour la période 2014-2018, ni pour la période 2019-2023. En revanche, la suivante (2024-2028) va être une période clé pour ces questions d'incitation à l'investissement.

Il y a donc l'investissement classique pour augmenter la capacité du réseau et l'investissement pour le réseau intelligent/smartgridding. La façon dont le distributeur va pouvoir valoriser des investissements vers un réseau intelligent est une question clé. Avec Agoria, on plaide pour qu'un € investit sur des solutions intelligentes soient valorisé différemment par rapport à un € investit dans l'accroissement de capacité.

On prône donc pour aller vers un avantage octroyé pour les investissements smartgridding, ce qui n'est pas du tout le cas aujourd'hui.

De plus, le coût d'innovation va être réparti sur un plus gros nombre de clients pour les gros distributeurs, à l'inverse des petits distributeurs pour qui les tarifs vont être plus élevés. Ceci se trouve encore dans la méthodologie tarifaire et comment on mutualise les choses. Par ailleurs, le coût capacitaire dans la province de Luxembourg est beaucoup plus fort que le coût capacitaire à Bruxelles. L'assiette de consommateur qui peut être relié à un km de câble et qui peut donc participer à son coût est plus importante à Bruxelles que dans la province de Luxembourg.

Stockage

Pour le moment, le stockage ne fait pas partie des obligations de services publics. Mais il faut bien se rendre compte qu'aujourd'hui le réseau fait office de moyen de stockage. C'est un stockage virtuel mais un stockage financier pour le petit producteur ; tout ce qu'il ne consomme pas, il peut le réinjecter dans le système.

Par ailleurs, il existe déjà des unités de stockages comme c'est le cas pour la centrale de Coo. C'est une centrale hydraulique mise en place en même temps que Tihange. En effet, le nucléaire produit toujours 24/24, 7/7. Tout ce qui est produit la nuit et pas utilisé, permet de remonter l'eau de la centrale qui fait office de stockage d'énergie.

L'intérêt d'une centrale hydraulique est qu'il suffit d'ouvrir les vannes pour avoir de l'énergie. En faisant cela, on utilise le baseload non-utilisé pendant la nuit. Ainsi, l'intérêt est de décorrélérer la production et la consommation en créant des buffers, tampons de stockage telle que l'usine de Coo.

Ainsi, il y aurait un coût de stockage mais ce coût de stockage ne sera pas à charge du distributeur mais à charge du fournisseur.

Conclusion

Tous ces services intelligents tels que le stockage, la flexibilité, les compteurs intelligents changent les business model des acteurs existants. Le problème du fournisseur électrique aujourd'hui est qu'il livre une commodité (un électron). Pour arriver à se différencier, c'est impossible de jouer sur la qualité du produit mais bien sur les services complémentaires offerts par le fournisseur.

Pour le moment les compteurs sont gérés par les distributeurs car ceux savent bien que ce qui est plus valorisable sont les services et pas les produits. Du coup, ce qui risque d'arriver dans le futur c'est que le régulateur dise que le réseau est une sorte d'actif collectif sur lequel vient se greffer d'autres acteurs (comme c'est le cas pour les telecoms).

Ainsi pour tous ces nouveaux services, la question à se poser est qui va les développer ? Les distributeurs, les fournisseurs ou une tierce-partie.

Il y a des enableurs physiques qui sont nécessaires et dans ce cas-là c'est le distributeur qui va s'en charger. Ainsi, le régulateur a intérêt à créer des incitations pour l'investissement.

Et en contrepartie, des nouveaux services se développent sur ces enableurs physiques. Dans ce cadre-là, le régulateur doit s'assurer que les enableurs (le réseau physique) soit disponible pour tous les créateurs de services sans discrimination (Dans le monde des Telecoms, Proximus a

son réseau et développe ses propres services sur son réseau, mais il a l'obligation d'ouvrir son réseau à tout fournisseur de service concurrent).

Appendix 9: Full dataset – 164 DSOs in Sweden (2012) + DEA results

	REL	Name	x.OPEX (kSEK)	x.Capital (kSEK)	y.Connections	y.Circuit (km)	y.Power (MW)	Ownership	CE	Optimal cost (kSEK)
1	REL00001	Ale Elförening ek för	29200	228563	12097	1051	116	e	0.494	20308
2	REL00002	Alingsås Energi Nät AB	22279	122184	13928	765	105	k	0.665	19031
3	REL00004	Alvesta Elnät AB	10687	87438	4795	497	48	k	0.547	8328
4	REL00005	Arvika Teknik AB	15142	79653	10273	730	74	p	0.797	15378
5	REL00007	Bengtsfors Energi Nät AB	3798	21505	2311	179	28	k	0.745	3662
6	REL00008	Bergs Tingslags Elektriska AB	24433	151470	7171	1265	118	k	0.637	20589
7	REL00010	Bjäre Kraft ek för	23005	170164	12571	1443	99	e	0.749	23867
8	REL00011	Bjärke Energi ek för	12155	63077	4845	1029	46	e	0.989	15269
9	REL00012	Upplands Energi ek för	26456	223697	12767	2176	138	e	0.864	32897
10	REL00015	Bodens Energi Nät AB	30507	123024	16057	2160	200	k	0.975	35973
11	REL00016	Boo Energi ek för	18154	139419	12694	813	119	e	0.737	18714
12	REL00017	Borgholm Energi Elnät AB	7987	32986	4355	353	33	k	0.689	6683
13	REL00018	AB Borlänge Energi Elnät	34682	301006	28394	1948	200	k	0.866	43594
14	REL00019	Borås Elnät AB	51233	435657	41440	1567	290	k	0.788	58237
15	REL00020	Brittedals Elnät ek för	11642	43425	3630	873	39	e	0.926	12872
16	REL00021	Bromölla Energi & Vatten AB	7772	50650	4013	266	38	k	0.552	5740
17	REL00023	C4 Elnät AB	30895	327668	27904	1406	197	k	0.802	38445
18	REL00025	Degerfors Energi AB	6710	52805	4544	428	45	k	0.792	7493
19	REL00026	Elektra Nät AB	13658	81209	3969	506	38	p	0.429	7665
20	REL00030	Eksjö Elnät AB	7143	35373	6128	403	54	k	0.974	8746
21	REL00031	Emmaboda Elnät AB	11742	76090	3144	447	34	p	0.410	6442
22	REL00033	Halmstads Energi & Miljö Nät AB	46115	474901	39738	1699	327	k	0.831	58861
23	REL00035	Eskilstuna Energi & Miljö Elnät AB	52555	422782	46262	1825	349	k	0.900	67095
24	REL00037	Falbygdens Energi Nät AB	38422	234387	16853	2214	182	k	0.712	36056
25	REL00038	Falkenberg Energi AB	14423	158381	13538	784	127	k	0.852	19312

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	REL	Name	x.OPEX (kSEK)	x.Capital (kSEK)	y.Connections	y.Circuit (km)	y.Power (MW)	Ownership	CE	Optimal cost (kSEK)
26	REL00039	Falu Elnät AB	41551	480590	30779	3242	287	k	0.893	59404
27	REL00040	Filipstad Energinät AB	7114	67762	3182	224	35	k	0.453	4814
28	REL00043	Gislaved Energi AB	10176	69715	4917	509	61	k	0.651	8981
29	REL00044	Gotlands Energi AB GEAB	51190	1108095	40445	5918	376	s	0.887	96530
30	REL00049	Grästorps Energi Ek för	9825	93424	4168	952	42	e	0.959	14086
31	REL00062	Göteborgs Energi Nät AB	440180	2090667	253981	7028	1438	k	0.896	492043
32	REL00064	Habo Kraft AB	10352	61248	4440	465	54	k	0.593	8033
33	REL00069	Hedemora Energi AB	15005	157599	9083	985	75	k	0.712	16516
34	REL00071	Öresundskraft AB	75884	712013	68960	2559	374	k	0.885	99980
35	REL00072	Herrljunga Elektriska AB	10583	40407	5164	853	48	k	0.991	12565
36	REL00073	Hjo Energi AB	4695	39355	3477	198	45	k	0.834	5619
37	REL00075	Hofors Elverk AB	11394	82500	6549	682	58	k	0.736	11548
38	REL00077	Härnösand Elnät AB	33069	165248	13585	1581	157	k	0.656	27311
39	REL00078	Härryda Energi AB	30385	192339	13365	1078	142	k	0.552	22288
40	REL00080	Höganäs Energi AB	23757	159271	14361	1295	142	k	0.775	24819
41	REL00083	Jukkasjärvi Sockens Belysningsförening	11846	52533	2395	539	11	e	0.531	7740
42	REL00085	Jämtkraft Elnät AB	138965	2362551	60724	8401	750	k	0.604	158091
43	REL00086	Jönköping EnergiNät AB	56354	613477	54099	3060	510	k	1	88255
44	REL00087	Kalmar Energi Elnät AB	28489	152961	22279	761	154	p	0.801	29174
45	REL00088	Karlsborgs Energi AB	7531	42593	3838	423	37	k	0.698	6803
46	REL00089	Karlshamn Energi AB	10481	53031	8208	318	44	k	0.799	10571
47	REL00090	Karlskoga Elnät AB	33904	160635	15195	1728	203	k	0.742	31352
48	REL00091	Affärsverken Karlskrona AB	29428	211157	19436	1156	184	k	0.711	28746
49	REL00092	Karlstads Elnät AB	34154	366911	33736	1338	262	k	0.893	47538
50	REL00093	Tekniska Verken Katrineholm Nät AB	24314	235997	17613	1907	195	k	0.932	34115
51	REL00094	E.ON Elnät Kramfors AB	13119	48475	4958	426	57	p	0.521	8145
52	REL00098	Kristinehamns Elnät AB	17705	168334	10710	986	88	k	0.681	18015
53	REL00100	Kungälv Energi AB	31567	436593	21610	1923	201	k	0.686	37250

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	REL	Name	x.OPEX (kSEK)	x.Capital (kSEK)	y.Connections	y.Circuit (km)	y.Power (MW)	Ownership	CE	Optimal cost (kSEK)
54	REL00102	Kvänumbygdens Energi ek för	12692	109030	3848	1141	44	e	0.925	16990
55	REL00103	Landskrona Energi AB	34000	365844	18632	657	143	k	0.449	23784
56	REL00106	Lerum Energi AB	24267	235403	16598	1268	151	p	0.722	26368
57	REL00109	Lidköpings kommun	27896	204408	21189	2235	167	f	1	38525
58	REL00110	Linde Energi AB	19466	143654	10533	1390	114	k	0.827	22281
59	REL00111	Tekniska Verken Linköping Nät AB	71254	669981	72990	3810	502	k	1	106093
60	REL00112	Ljungby Energinät AB	9933	117606	8738	527	60	k	0.760	12198
61	REL00113	Ljusdal Elnät AB	11742	71547	6980	780	55	k	0.828	12799
62	REL00118	Luleå Energi Elnät AB	60137	374867	39571	3419	374	k	0.895	71294
63	REL00121	LEVA i Lysekil AB	17274	160052	10060	942	81	k	0.666	17035
64	REL00123	Malungs Elnät AB	32203	246471	14285	1959	193	k	0.736	33153
65	REL00126	Mellersta Skånes Kraft ek. för.	7810	21239	2393	561	17	e	0.906	8078
66	REL00127	Mjölby Kraftnät AB	30779	185579	12287	1335	119	k	0.570	23046
67	REL00128	Mölnadal Energi Nät AB	24198	142157	21346	803	166	k	0.879	27758
68	REL00130	Nacka Energi AB	49956	232714	26858	1063	282	k	0.707	43901
69	REL00133	Norrtälje Energi AB	33315	187717	14431	1235	150	k	0.571	24602
70	REL00135	Nossebroortens Energi ek för	7381	32656	2628	510	24	e	0.803	7295
71	REL00136	Öresundskraft Nordvästra Skåne AB	25370	215748	9406	975	87	k	0.462	16902
72	REL00137	Nybro Elnät AB	15765	89951	8191	787	60	k	0.683	13969
73	REL00138	Nynäshamn Energi AB	33061	168292	15551	1250	126	k	0.592	24755
74	REL00139	Näckåns Elnät AB	3329	21853	2240	323	29	p	1	4465
75	REL00141	Nässjö Affärsverk Elnät AB	8931	117035	9423	414	67	k	0.807	12111
76	REL00143	Olofströms Kraft Nät AB	16998	267549	13365	2047	135	k	1	30911
77	REL00146	Oskarshamn Energi Nät AB	15581	188171	12182	833	79	p	0.711	18026
78	REL00147	Oxelö Energi AB	10555	41371	7302	418	45	k	0.784	9964
79	REL00148	Partille Energi Nät AB	27319	232151	13815	688	115	k	0.463	18254
80	REL00149	AB PiteEnergi	27137	387119	22371	2750	273	p	1	47267
81	REL00152	Ronneby Miljö & Teknik AB	21113	113871	11778	936	94	k	0.686	18556

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	REL	Name	x.OPEX (kSEK)	x.Capital (kSEK)	y.Connections	y.Circuit (km)	y.Power (MW)	Ownership	CE	Optimal cost (kSEK)
82	REL00156	Rödeby Elverk ek för	10354	43205	4171	798	42	e	0.930	11720
83	REL00157	Sala- Heby Energi Elnät AB	15979	150164	13237	1372	109	k	0.996	23702
84	REL00158	Sandhult-Sandared Elektriska ek för	4302	39117	3339	315	25	e	0.856	5425
85	REL00159	Sandviken Energi Elnät AB	35586	164602	20205	1534	185	k	0.730	32231
86	REL00160	SEVAB Nät AB	26599	223013	16571	1583	162	k	0.772	29492
87	REL00163	Sjogerstads Elektriska Distributions	4827	28601	2640	439	27	e	0.982	6204
88	REL00164	Sjöbo Elnät AB	16502	140523	7597	1191	82	k	0.747	17778
89	REL00165	Skara Energi AB	12411	100253	7289	433	60	k	0.572	10074
90	REL00167	Skurups kommun	4480	62592	3770	255	29	f	0.690	5336
91	REL00169	Skånska Energi Nät AB	26163	309528	18136	1667	193	p	0.764	32279
92	REL00170	Skövde kommun	15463	173940	19203	839	157	f	1	24508
93	REL00171	Smedjebacken Energi Nät AB	5428	19187	3535	247	24	f	0.786	5051
94	REL00173	Sollentuna Energi AB	28291	334939	27580	1339	289	p	0.989	45185
95	REL00175	Staffanstorps Energi AB	9109	82986	7052	505	116	k	0.959	12877
96	REL00178	Sundsvall Elnät AB	52167	352290	27811	1735	367	k	0.847	59687
97	REL00181	Dala Elnät AB	9031	133896	7360	1006	63	p	0.966	15452
98	REL00182	Sävsjö Energi AB	6493	39163	3406	370	37	k	0.697	5944
99	REL00183	Söderhamn Elnät AB	12038	72825	9295	578	71	k	0.831	13154
100	REL00184	Södra Hallands Kraft ek för	36314	238716	19057	2691	205	e	0.882	42994
101	REL00185	Sölvesborgs Energi & Vatten AB	7425	76969	5391	339	53	k	0.678	7752
102	REL00186	Telge Nät AB	53893	1036146	49930	2898	368	k	0.693	74668
103	REL00187	Tibro Energi AB	10838	47843	5236	502	50	f	0.658	8773
104	REL00189	Tranås Energi AB	16688	129135	10137	761	110	k	0.697	16318
105	REL00190	Trelleborgs kommun	30101	185108	16903	948	145	f	0.593	23547
106	REL00191	Trollhättan Energi Elnät AB	28240	203226	24894	1414	171	k	0.911	35370
107	REL00195	Uddevalla Energi Elnät AB	36625	290097	25545	1633	174	k	0.733	37924
108	REL00196	Ulricehamns Energi AB	13259	129069	8275	979	80	k	0.800	15967
109	REL00200	Vaggeryds kommun Elverket	10951	70574	3896	700	47	f	0.699	10224

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	REL	Name	x.OPEX (kSEK)	x.Capital (kSEK)	y.Connections	y.Circuit (km)	y.Power (MW)	Ownership	CE	Optimal cost (kSEK)
110	REL00201	Vallebygdens Energi ek för	4344	49944	2641	483	29	e	0.991	6880
111	REL00202	Elverket Vallentuna AB	43219	287392	13952	1245	106	p	0.400	23247
112	REL00203	Vara Energi ek för	10570	37200	4404	585	44	e	0.706	8823
113	REL00204	Varberg Energi AB	40106	233848	20277	1311	196	k	0.596	31166
114	REL00205	Varbergssortens Elkraft	28209	140677	10727	1919	127	e	0.815	28946
115	REL00230	Vetlanda Energi & Teknik AB Vetab	11350	106257	8520	621	96	k	0.804	13567
116	REL00232	Vimmerby Energi & Miljö AB	8361	40427	4824	342	41	k	0.672	7031
117	REL00235	Värnamo Elnät AB	17424	95231	10373	783	130	k	0.780	17443
118	REL00239	Västerviks Kraft Elnät AB	16376	115281	12131	934	107	k	0.850	19006
119	REL00242	Västra Orusts Energitjänst	10761	55766	5351	539	35	e	0.674	9202
120	REL00243	Växjö Energi Elnät AB	43185	346029	32624	1369	214	k	0.733	44865
121	REL00244	Ystad Energi AB	16788	235442	13477	734	97	k	0.632	18347
122	REL00246	Ålem Energi AB	7822	52154	3282	369	31	k	0.553	5822
123	REL00250	Öresundskraft Ängelholm AB	27757	297553	17719	1170	138	k	0.602	26041
124	REL00255	Östra Kinds Elkraft ek för	7976	60734	2822	606	32	e	0.788	8770
125	REL00257	Övik Energi Nät AB	26403	188454	8886	670	102	k	0.399	14448
126	REL00267	Mälaren Energi Elnät AB	93840	1435776	103282	5950	790	k	1	168500
127	REL00332	Tidaholms Elnät AB	11997	91374	6606	796	72	k	0.774	12959
128	REL00364	Österlens Kraft AB	11233	67409	7282	636	142	e	1	14738
129	REL00509	Fortum Distribution AB	178029	3357569	119468	13152	1281	p	0.857	302351
130	REL00570	Västerbergslagens Elnät AB	52320	475278	26448	3022	228	s	0.676	52083
131	REL00571	E.ON Elnät Stockholm AB	130559	2260240	120884	7562	1104	p	1	248091
132	REL00572	Vattenfall Eldistribution AB	219688	3844107	113897	25521	1377	s	1	419582
133	REL00576	Härjeåns Nät AB	79231	522193	26763	5821	351	p	0.837	89033
134	REL00583	Vattenfall Eldistribution AB	956080	20669320	746132	83969	7405	s	1	2030885
135	REL00584	Umeå Energi Elnät AB	96747	786519	57454	4814	597	k	0.823	113299
136	REL00585	Götene Elförening ek för	20406	249128	7389	1217	133	e	0.627	20918
137	REL00594	VänerEnergi AB	17286	146138	14191	1029	106	k	0.867	21579

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	REL	Name	x.OPEX (kSEK)	x.Capital (kSEK)	y.Connections	y.Circuit (km)	y.Power (MW)	Ownership	CE	Optimal cost (kSEK)
138	REL00601	E.ON Elnät Sverige AB	123889	2194818	81000	15495	1019	p	1	238020
139	REL00615	E.ON Elnät Sverige AB	921861	20583095	800590	102492	7286	p	1	1992182
140	REL00824	Skellefteå Kraft Elnät AB	132526	1323289	63552	10995	830	k	0.909	183025
141	REL00860	Fortum Distribution AB	149722	3467699	101492	14147	1003	p	0.751	247851
142	REL00861	Fortum Distribution AB	225235	5497965	131858	24553	1569	p	0.812	414864
143	REL00869	Dala Energi Elnät AB	41985	556840	24882	3039	200	k	0.714	50686
144	REL00884	Fortum Distribution AB	581719	10283076	544811	12327	2902	p	1	1116439
145	REL00885	Gävle Energi AB	65308	342103	45810	2630	375	k	0.845	70229
146	REL00886	Kraftringen Nät AB	159041	1460770	99607	8681	770	k	0.801	188316
147	REL00003	Almnäs Bruk AB	1417	1330	310	103	4	p	0.700	1041
148	REL00014	Blåsjön Nät AB	4602	34085	1528	411	13	p	0.906	5773
149	REL00034	Envikens Elnät AB	2104	17634	1171	167	10	p	0.725	2192
150	REL00067	Hallstaviks Elverk Ek för	3315	18180	1803	85	17	e	0.601	2563
151	REL00068	Hamra Besparingsskog	1719	8191	518	137	7	e	0.729	1563
152	REL00074	Hjärtums Elförening Ek För	3805	18746	1941	287	14	e	0.817	3904
153	REL00101	Kviinge El AB	3184	16313	969	138	8	e	0.438	1766
154	REL00104	Larvs Elektriska Distributionsförening	344	699	168	60	2	e	1	380
155	REL00115	LJW Nät HB	420	137	158	10	1	p	0.890	380
156	REL00140	Närkes Kils Elektriska ek för	4760	22322	1224	256	15	e	0.573	3392
157	REL00144	Olseröds Elektriska Distributionsförening	3775	11453	1719	285	13	e	0.880	3845
158	REL00193	Töre Energi ek för	1724	29112	966	176	14	e	0.675	2186
159	REL00231	Viggafors Elektriska Andelsförening Upa	467	1733	290	36	2	e	0.960	535
160	REL00234	Vinninga Elektriska Förening	1283	9007	808	127	9	e	0.871	1526
161	REL00245	Åkab Nät & Skog AB	4910	12857	1873	281	20	p	0.683	3808
162	REL00249	Årsunda Kraft & Belysningsförening upa	3979	12384	1500	214	23	e	0.670	3099
163	REL00252	Österfärnebo El ek för	1613	9819	816	169	7	e	0.968	2055
164	REL00590	LKAB Nät AB	3018	6096	619	157	42	s	1	3335

Notes: km = 1000m, kSEK = 1000 Swedish crowns (SEK)

Price vector: (1, WACC) WACC=5.2%

Appendix 10: Results for random and geographic partition

N	Absolute social cost (kSEK)				Relative social cost				Hypothesis test	
	Random partition			Geographic Partition	Random partition			Geographic partition	t-test 95%	
	Mean	Confidence interval			Mean	Confidence interval			p-value	Reject?
1	0	0	0	0	0	0	0	0	/	/
2	305503	286762	324243	349995	2.61%	2.45%	2.78%	3.00%	1.54E-05	TRUE
3	492896	477351	508441	405225	4.22%	4.09%	4.35%	3.47%	2.19E-15	TRUE
4	596625	577136	616114	560636	5.11%	4.94%	5.27%	4.80%	4.94E-04	TRUE
5	687071	666206	707936	640322	5.88%	5.70%	6.06%	5.48%	3.82E-05	TRUE
6	761513	745079	777947	731831	6.52%	6.38%	6.66%	6.26%	6.36E-04	TRUE
7	812672	793320	832023	772650	6.96%	6.79%	7.12%	6.61%	1.20E-04	TRUE
8	866828	851009	882646	869393	7.42%	7.28%	7.55%	7.44%	7.44E-01	FALSE
9	892799	872771	912827	907358	7.64%	7.47%	7.81%	7.77%	1.48E-01	FALSE
10	951960	937897	966023	986183	8.15%	8.03%	8.27%	8.44%	1.02E-05	TRUE
11	985417	969136	1001699	1015449	8.43%	8.29%	8.57%	8.69%	5.01E-04	TRUE
12	1015050	999923	1030177	1026714	8.69%	8.56%	8.82%	8.79%	1.26E-01	FALSE
13	1045146	1032027	1058265	1064748	8.94%	8.83%	9.06%	9.11%	4.01E-03	TRUE
14	1059594	1044163	1075024	1078119	9.07%	8.94%	9.20%	9.23%	1.90E-02	TRUE
15	1089536	1077047	1102024	1095169	9.32%	9.22%	9.43%	9.37%	3.66E-01	FALSE
16	1112657	1097294	1128020	1115975	9.52%	9.39%	9.65%	9.55%	6.64E-01	FALSE
17	1113402	1100871	1125933	1115975	9.53%	9.42%	9.64%	9.55%	6.80E-01	FALSE
18	1140700	1128024	1153375	1129431	9.76%	9.65%	9.87%	9.67%	7.85E-02	FALSE
19	1141195	1126997	1155393	1139922	9.77%	9.65%	9.89%	9.76%	8.57E-01	FALSE
20	1169449	1157207	1181692	1148564	10.01%	9.90%	10.11%	9.83%	1.17E-03	TRUE
21	1195001	1181297	1208705	1160207	10.23%	10.11%	10.34%	9.93%	4.92E-06	TRUE
22	1199989	1189384	1210594	1165387	10.27%	10.18%	10.36%	9.97%	2.82E-08	TRUE
23	1221894	1209628	1234161	1165956	10.46%	10.35%	10.56%	9.98%	2.82E-12	TRUE
24	1226272	1211027	1241517	1201571	10.50%	10.36%	10.63%	10.28%	1.95E-03	TRUE
25	1234421	1221126	1247716	1204119	10.56%	10.45%	10.68%	10.31%	2.94E-05	TRUE
26	1265254	1255823	1274685	1222516	10.83%	10.75%	10.91%	10.46%	3.43E-12	TRUE
27	1267832	1255614	1280051	1244717	10.85%	10.75%	10.96%	10.65%	3.72E-04	TRUE
28	1276628	1265312	1287944	1262339	10.93%	10.83%	11.02%	10.80%	1.39E-02	TRUE
29	1277653	1265430	1289875	1269621	10.93%	10.83%	11.04%	10.87%	1.90E-01	FALSE
30	1295307	1284269	1306345	1269621	11.09%	10.99%	11.18%	10.87%	2.13E-05	TRUE
31	1313986	1303715	1324258	1274338	11.25%	11.16%	11.33%	10.91%	3.85E-10	TRUE
32	1312738	1302714	1322761	1305776	11.24%	11.15%	11.32%	11.18%	1.67E-01	FALSE
33	1328140	1317933	1338347	1305776	11.37%	11.28%	11.45%	11.18%	5.32E-05	TRUE
34	1333804	1323778	1343830	1310718	11.42%	11.33%	11.50%	11.22%	2.51E-05	TRUE
35	1345893	1335682	1356105	1318679	11.52%	11.43%	11.61%	11.29%	2.03E-06	TRUE
36	1343714	1335152	1352277	1319858	11.50%	11.43%	11.57%	11.30%	8.63E-07	TRUE
37	1353681	1345920	1361442	1340811	11.59%	11.52%	11.65%	11.48%	1.56E-03	TRUE
38	1357341	1348583	1366100	1345324	11.62%	11.54%	11.69%	11.51%	7.83E-03	TRUE
39	1368030	1358406	1377653	1346674	11.71%	11.63%	11.79%	11.53%	4.41E-05	TRUE
40	1358800	1348033	1369568	1348756	11.63%	11.54%	11.72%	11.54%	6.53E-02	FALSE
41	1372749	1364102	1381396	1351604	11.75%	11.67%	11.82%	11.57%	9.44E-06	TRUE
42	1376740	1367023	1386456	1358166	11.78%	11.70%	11.87%	11.62%	3.29E-04	TRUE
43	1380759	1371052	1390465	1358166	11.82%	11.73%	11.90%	11.62%	2.12E-05	TRUE
44	1386342	1377040	1395644	1360322	11.87%	11.79%	11.94%	11.64%	7.97E-07	TRUE
45	1390524	1381758	1399289	1362339	11.90%	11.83%	11.98%	11.66%	3.97E-08	TRUE
46	1392840	1384055	1401625	1362339	11.92%	11.85%	12.00%	11.66%	6.25E-09	TRUE
47	1405414	1397385	1413442	1363525	12.03%	11.96%	12.10%	11.67%	3.36E-14	TRUE
48	1414209	1405734	1422685	1365933	12.10%	12.03%	12.18%	11.69%	1.54E-15	TRUE

49	1402015	1392733	1411297	1365933	12.00%	11.92%	12.08%	11.69%	3.17E-10	TRUE
50	1412509	1403648	1421369	1365933	12.09%	12.01%	12.16%	11.69%	2.60E-14	TRUE
51	1416507	1407658	1425355	1372121	12.12%	12.05%	12.20%	11.74%	1.28E-13	TRUE
52	1424024	1415416	1432631	1372192	12.19%	12.11%	12.26%	11.74%	2.01E-16	TRUE
53	1429819	1422573	1437066	1372192	12.24%	12.18%	12.30%	11.74%	3.59E-21	TRUE
54	1429096	1421645	1436546	1387230	12.23%	12.17%	12.29%	11.87%	2.50E-15	TRUE
55	1434821	1426470	1443173	1387230	12.28%	12.21%	12.35%	11.87%	1.51E-15	TRUE
56	1447583	1442326	1452841	1390113	12.39%	12.34%	12.43%	11.90%	3.98E-27	TRUE
57	1437614	1430228	1445000	1390113	12.30%	12.24%	12.37%	11.90%	1.69E-17	TRUE
58	1443292	1434947	1451636	1396278	12.35%	12.28%	12.42%	11.95%	2.27E-15	TRUE
59	1442907	1434908	1450907	1403029	12.35%	12.28%	12.42%	12.01%	1.57E-13	TRUE
60	1449952	1443496	1456407	1403029	12.41%	12.35%	12.46%	12.01%	1.40E-19	TRUE
61	1446163	1438682	1453644	1403029	12.38%	12.31%	12.44%	12.01%	9.89E-16	TRUE
62	1448203	1442112	1454293	1403156	12.39%	12.34%	12.45%	12.01%	6.95E-20	TRUE
63	1451299	1445329	1457268	1403156	12.42%	12.37%	12.47%	12.01%	2.01E-21	TRUE
64	1455745	1449882	1461607	1403156	12.46%	12.41%	12.51%	12.01%	2.26E-23	TRUE
65	1457079	1450507	1463651	1404615	12.47%	12.41%	12.53%	12.02%	3.06E-21	TRUE
66	1457407	1450622	1464193	1404615	12.47%	12.42%	12.53%	12.02%	8.86E-21	TRUE
67	1462388	1457039	1467738	1404615	12.52%	12.47%	12.56%	12.02%	6.80E-27	TRUE
68	1463961	1458895	1469028	1407791	12.53%	12.49%	12.57%	12.05%	2.11E-27	TRUE
69	1465313	1458557	1472069	1408973	12.54%	12.48%	12.60%	12.06%	4.98E-22	TRUE
70	1465323	1459582	1471065	1408973	12.54%	12.49%	12.59%	12.06%	4.64E-25	TRUE
71	1467504	1461645	1473363	1408973	12.56%	12.51%	12.61%	12.06%	2.13E-25	TRUE
72	1470917	1466181	1475653	1408973	12.59%	12.55%	12.63%	12.06%	1.18E-30	TRUE
73	1473199	1468632	1477766	1408973	12.61%	12.57%	12.65%	12.06%	4.18E-32	TRUE
74	1471007	1465067	1476948	1408973	12.59%	12.54%	12.64%	12.06%	3.03E-26	TRUE
75	1477566	1473150	1481983	1408973	12.65%	12.61%	12.68%	12.06%	4.14E-34	TRUE
76	1478149	1473435	1482863	1408973	12.65%	12.61%	12.69%	12.06%	5.83E-33	TRUE
77	1481132	1477746	1484518	1408973	12.68%	12.65%	12.71%	12.06%	1.32E-40	TRUE
78	1484294	1480827	1487761	1408973	12.70%	12.67%	12.73%	12.06%	5.20E-41	TRUE
79	1481410	1477022	1485797	1412071	12.68%	12.64%	12.72%	12.09%	1.84E-34	TRUE
80	1482261	1478206	1486317	1414490	12.69%	12.65%	12.72%	12.11%	1.34E-35	TRUE
81	1486976	1483454	1490498	1414490	12.73%	12.70%	12.76%	12.11%	6.93E-40	TRUE
82	1487904	1484833	1490974	1418479	12.73%	12.71%	12.76%	12.14%	7.77E-42	TRUE
83	1488946	1486516	1491375	1418479	12.74%	12.72%	12.76%	12.14%	4.80E-47	TRUE
84	1491800	1489963	1493637	1418900	12.77%	12.75%	12.78%	12.14%	1.20E-53	TRUE
85	1489327	1486445	1492210	1418900	12.75%	12.72%	12.77%	12.14%	1.86E-43	TRUE
86	1488975	1485760	1492191	1418900	12.74%	12.72%	12.77%	12.14%	4.49E-41	TRUE
87	1490331	1488081	1492580	1418900	12.76%	12.74%	12.77%	12.14%	6.02E-49	TRUE
88	1490831	1488711	1492951	1419477	12.76%	12.74%	12.78%	12.15%	3.59E-50	TRUE
89	1491267	1489018	1493517	1419477	12.76%	12.74%	12.78%	12.15%	4.71E-49	TRUE
90	1491140	1489087	1493192	1419477	12.76%	12.74%	12.78%	12.15%	6.10E-51	TRUE
91	1491246	1489525	1492967	1419477	12.76%	12.75%	12.78%	12.15%	1.09E-54	TRUE
92	1490820	1488211	1493429	1419786	12.76%	12.74%	12.78%	12.15%	1.02E-45	TRUE
93	1490691	1488576	1492806	1419786	12.76%	12.74%	12.78%	12.15%	4.35E-50	TRUE
94	1491112	1487854	1494369	1423780	12.76%	12.73%	12.79%	12.19%	5.68E-40	TRUE
95	1493514	1492131	1494897	1449814	12.78%	12.77%	12.79%	12.41%	7.78E-49	TRUE
96	1490174	1487810	1492538	1449814	12.75%	12.73%	12.77%	12.41%	4.86E-36	TRUE
97	1491619	1489529	1493708	1467479	12.77%	12.75%	12.78%	12.56%	3.32E-28	TRUE
98	1489794	1486668	1492920	1467479	12.75%	12.72%	12.78%	12.56%	2.88E-19	TRUE
99	1489924	1487561	1492288	1467479	12.75%	12.73%	12.77%	12.56%	1.94E-24	TRUE
100	1491252	1489111	1493392	1467479	12.76%	12.74%	12.78%	12.56%	1.96E-27	TRUE
101	1492002	1489894	1494110	1467479	12.77%	12.75%	12.79%	12.56%	2.44E-28	TRUE
102	1493264	1491613	1494914	1467479	12.78%	12.77%	12.79%	12.56%	3.15E-34	TRUE

103	1490748	1488618	1492878	1467479	12.76%	12.74%	12.78%	12.56%	4.07E-27	TRUE
104	1491823	1490001	1493644	1467479	12.77%	12.75%	12.78%	12.56%	4.41E-31	TRUE
105	1490172	1487051	1493292	1473618	12.75%	12.73%	12.78%	12.61%	1.90E-14	TRUE
106	1490576	1488378	1492775	1473618	12.76%	12.74%	12.78%	12.61%	1.25E-20	TRUE
107	1493890	1492622	1495158	1473618	12.79%	12.77%	12.80%	12.61%	1.07E-34	TRUE
108	1489987	1487583	1492392	1473618	12.75%	12.73%	12.77%	12.61%	1.89E-18	TRUE
109	1491191	1488920	1493462	1473618	12.76%	12.74%	12.78%	12.61%	1.10E-20	TRUE
110	1490675	1488174	1493176	1473618	12.76%	12.74%	12.78%	12.61%	1.74E-18	TRUE
111	1491591	1489569	1493613	1473618	12.77%	12.75%	12.78%	12.61%	3.35E-23	TRUE
112	1490390	1487765	1493016	1473618	12.76%	12.73%	12.78%	12.61%	2.20E-17	TRUE
113	1492002	1489728	1494275	1473618	12.77%	12.75%	12.79%	12.61%	1.79E-21	TRUE
114	1492087	1489273	1494901	1473618	12.77%	12.75%	12.79%	12.61%	7.73E-18	TRUE
115	1492371	1490131	1494612	1473618	12.77%	12.75%	12.79%	12.61%	4.27E-22	TRUE
116	1492238	1490255	1494221	1475161	12.77%	12.75%	12.79%	12.63%	1.29E-22	TRUE
117	1494133	1493002	1495265	1475161	12.79%	12.78%	12.80%	12.63%	1.15E-35	TRUE
118	1491162	1487453	1494871	1476025	12.76%	12.73%	12.79%	12.63%	8.00E-11	TRUE
119	1492066	1489788	1494345	1476025	12.77%	12.75%	12.79%	12.63%	4.97E-19	TRUE
120	1493738	1492100	1495376	1476025	12.78%	12.77%	12.80%	12.63%	6.40E-27	TRUE
121	1493529	1491747	1495311	1476025	12.78%	12.77%	12.80%	12.63%	4.46E-25	TRUE
122	1494581	1493398	1495765	1476025	12.79%	12.78%	12.80%	12.63%	2.64E-34	TRUE
123	1490568	1488381	1492756	1476025	12.76%	12.74%	12.78%	12.63%	4.71E-18	TRUE
124	1493666	1491745	1495587	1476025	12.78%	12.77%	12.80%	12.63%	8.31E-24	TRUE
125	1491521	1488962	1494080	1476025	12.77%	12.74%	12.79%	12.63%	1.64E-16	TRUE
126	1493554	1491726	1495382	1476025	12.78%	12.77%	12.80%	12.63%	1.28E-24	TRUE
127	1493794	1491889	1495700	1476025	12.78%	12.77%	12.80%	12.63%	4.29E-24	TRUE
128	1494881	1493559	1496202	1476025	12.79%	12.78%	12.81%	12.63%	2.16E-32	TRUE
129	1494922	1493913	1495931	1476025	12.79%	12.79%	12.80%	12.63%	6.23E-38	TRUE
130	1494925	1493496	1496354	1476025	12.79%	12.78%	12.81%	12.63%	7.08E-31	TRUE
131	1494730	1493452	1496008	1476025	12.79%	12.78%	12.80%	12.63%	6.56E-33	TRUE
132	1494370	1493038	1495701	1476025	12.79%	12.78%	12.80%	12.63%	1.09E-31	TRUE
133	1495626	1494904	1496347	1488480	12.80%	12.79%	12.81%	12.74%	3.10E-25	TRUE
134	1494936	1493593	1496279	1488480	12.79%	12.78%	12.81%	12.74%	5.19E-13	TRUE
135	1494399	1492853	1495946	1488480	12.79%	12.78%	12.80%	12.74%	4.83E-10	TRUE
136	1494730	1493106	1496353	1488480	12.79%	12.78%	12.81%	12.74%	4.14E-10	TRUE
137	1495133	1494064	1496202	1488480	12.80%	12.79%	12.81%	12.74%	5.92E-17	TRUE
138	1494567	1493016	1496117	1488480	12.79%	12.78%	12.80%	12.74%	2.42E-10	TRUE
139	1494689	1493212	1496165	1488480	12.79%	12.78%	12.81%	12.74%	3.35E-11	TRUE
140	1493487	1491846	1495129	1488480	12.78%	12.77%	12.80%	12.74%	1.30E-07	TRUE
141	1493046	1491260	1494832	1488480	12.78%	12.76%	12.79%	12.74%	4.36E-06	TRUE
142	1494884	1493429	1496340	1488480	12.79%	12.78%	12.81%	12.74%	8.54E-12	TRUE
143	1495806	1494887	1496726	1488480	12.80%	12.79%	12.81%	12.74%	3.34E-21	TRUE
144	1495927	1494989	1496865	1488480	12.80%	12.79%	12.81%	12.74%	3.90E-21	TRUE
145	1495411	1494098	1496725	1488480	12.80%	12.79%	12.81%	12.74%	2.28E-14	TRUE
146	1495159	1493514	1496804	1488480	12.80%	12.78%	12.81%	12.74%	9.25E-11	TRUE
147	1494466	1492743	1496189	1489179	12.79%	12.78%	12.81%	12.75%	1.15E-07	TRUE
148	1495814	1494594	1497034	1489179	12.80%	12.79%	12.81%	12.75%	7.91E-15	TRUE
149	1495770	1494635	1496904	1496979	12.80%	12.79%	12.81%	12.81%	3.61E-02	TRUE
150	1495042	1493575	1496510	1496979	12.80%	12.78%	12.81%	12.81%	1.03E-02	TRUE
151	1494215	1491603	1496827	1496979	12.79%	12.77%	12.81%	12.81%	3.75E-02	TRUE
152	1495788	1494623	1496952	1496979	12.80%	12.79%	12.81%	12.81%	4.40E-02	TRUE
153	1496027	1494918	1497136	1496979	12.80%	12.79%	12.81%	12.81%	8.90E-02	FALSE
154	1496504	1496108	1496900	1496979	12.81%	12.80%	12.81%	12.81%	1.92E-02	TRUE
155	1496873	1496767	1496978	1496979	12.81%	12.81%	12.81%	12.81%	4.72E-02	TRUE
156	1496029	1495052	1497006	1496979	12.80%	12.80%	12.81%	12.81%	5.51E-02	FALSE

157	1496505	1496116	1496894	1496979	12.81%	12.80%	12.81%	12.81%	1.72E-02	TRUE
158	1495564	1494371	1496757	1496979	12.80%	12.79%	12.81%	12.81%	2.04E-02	TRUE
159	1496585	1496138	1497033	1496979	12.81%	12.80%	12.81%	12.81%	8.18E-02	FALSE
160	1496658	1496324	1496993	1496979	12.81%	12.81%	12.81%	12.81%	5.84E-02	FALSE
161	1496919	1496798	1497040	1496979	12.81%	12.81%	12.81%	12.81%	3.22E-01	FALSE
162	1496979	1496979	1496979	1496979	12.81%	12.81%	12.81%	12.81%	/	FALSE
163	1496893	1496719	1497067	1496979	12.81%	12.81%	12.81%	12.81%	/	FALSE
164	1496979	1496979	1496979	1496979	12.81%	12.81%	12.81%	12.81%	/	FALSE

Note: kSEK = 1000 Swedish crowns (SEK)

95% t-test:

$$H_0: \mu_{random} = \mu_{geo}$$

$$H_1: \mu_{random} \neq \mu_{geo}$$

Appendix 11: Results for scale partition

Threshold $\bar{s}$	Size Ω_1	Size Ω_2	Balance φ	Sum target cost (kSEK)	Social cost	
					Absolute (kSEK)	Relative
0	0	164	0.000	11684184	0	0.000%
158	1	163	0.006	11684231	47	0.000%
168	2	162	0.012	11687546	3362	0.029%
290	3	161	0.019	11689544	5359	0.046%
310	4	160	0.025	11689557	5372	0.046%
518	5	159	0.031	11689741	5557	0.048%
619	6	158	0.038	11690174	5989	0.051%
808	7	157	0.045	11694665	10481	0.090%
816	8	156	0.051	11700228	16044	0.137%
966	9	155	0.058	11700263	16078	0.138%
969	10	154	0.065	11701274	17090	0.146%
1171	11	153	0.072	11702303	18118	0.155%
1224	12	152	0.079	11703673	19488	0.167%
1500	13	151	0.086	11703689	19504	0.167%
1528	14	150	0.093	11702534	18350	0.157%
1719	15	149	0.101	11701789	17605	0.151%
1803	16	148	0.108	11701791	17607	0.151%
1873	17	147	0.116	11702704	18519	0.158%
1941	18	146	0.123	11702755	18571	0.159%
2240	19	145	0.131	11714486	30301	0.259%
2311	20	144	0.139	11716283	32099	0.275%
2393	21	143	0.147	11716797	32613	0.279%
2395	22	142	0.155	11723575	39391	0.337%
2628	23	141	0.163	11719292	35108	0.300%
2640	24	140	0.171	11721286	37102	0.318%
2641	25	139	0.180	11729430	45246	0.387%
2822	26	138	0.188	11729478	45293	0.388%
3144	27	137	0.197	11737133	52948	0.453%
3182	28	136	0.206	11741232	57047	0.488%
3282	29	135	0.215	11744627	60443	0.517%
3339	30	134	0.224	11748811	64626	0.553%
3406	31	133	0.233	11736706	52521	0.450%
3477	32	132	0.242	11735969	51785	0.443%
3535	33	131	0.252	11741605	57420	0.491%
3630	34	130	0.262	11737142	52958	0.453%
3770	35	129	0.271	11739013	54829	0.469%
3838	36	128	0.281	11739612	55428	0.474%
3848	37	127	0.291	11740771	56587	0.484%
3896	38	126	0.302	11743966	59782	0.512%
3969	39	125	0.312	11752017	67833	0.581%
4013	40	124	0.323	11753441	69256	0.593%
4168	41	123	0.333	11745545	61361	0.525%
4171	42	122	0.344	11744264	60080	0.514%
4355	43	121	0.355	11742336	58152	0.498%
4404	44	120	0.367	11744258	60073	0.514%
4440	45	119	0.378	11747130	62946	0.539%
4544	46	118	0.390	11741725	57541	0.492%
4795	47	117	0.402	11747203	63019	0.539%
4824	48	116	0.414	11748684	64500	0.552%

Threshold $\bar{s}$	Size Ω_1	Size Ω_2	Balance φ	Sum target cost (kSEK)	Social cost	
					Absolute (kSEK)	Relative
4845	49	115	0.426	11745545	61361	0.525%
4917	50	114	0.439	11743336	59152	0.506%
4958	51	113	0.451	11749665	65480	0.560%
5164	52	112	0.464	11745750	61565	0.527%
5236	53	111	0.477	11748936	64752	0.554%
5351	54	110	0.491	11752034	67849	0.581%
5391	55	109	0.505	11750634	66450	0.569%
6128	56	108	0.519	11747507	63323	0.542%
6549	57	107	0.533	11748992	64808	0.555%
6606	58	106	0.547	11747596	63411	0.543%
6980	59	105	0.562	11746398	62214	0.532%
7052	60	104	0.577	11741083	56899	0.487%
7171	61	103	0.592	11751647	67463	0.577%
7282	62	102	0.608	11784672	100488	0.860%
7289	63	101	0.624	11788364	104179	0.892%
7302	64	100	0.640	11785002	100818	0.863%
7360	65	99	0.657	11803698	119514	1.023%
7389	66	98	0.673	11812685	128501	1.100%
7597	67	97	0.691	11814522	130338	1.116%
8191	68	96	0.708	11817044	132859	1.137%
8208	69	95	0.726	11815543	131359	1.124%
8275	70	94	0.745	11812941	128756	1.102%
8520	71	93	0.763	11820159	135975	1.164%
8738	72	92	0.783	11820287	136103	1.165%
8886	73	91	0.802	11837540	153356	1.313%
9083	74	90	0.822	11840751	156567	1.340%
9295	75	89	0.843	11838806	154622	1.323%
9406	76	88	0.864	11855242	171058	1.464%
9423	77	87	0.885	11867763	183578	1.571%
10060	78	86	0.907	11844133	159948	1.369%
10137	79	85	0.929	11844058	159873	1.368%
10273	80	84	0.952	11853291	169106	1.447%
10373	81	83	0.976	11849556	165371	1.415%
10533	82	82	1.000	11828690	144506	1.237%
10710	83	81	0.976	11832610	148425	1.270%
10727	84	80	0.952	11827237	143052	1.224%
11778	85	79	0.929	11828954	144769	1.239%
12097	86	78	0.907	11846973	162789	1.393%
12131	87	77	0.885	11829865	145681	1.247%
12182	88	76	0.864	11832478	148294	1.269%
12287	89	75	0.843	11840774	156590	1.340%
12571	90	74	0.822	11846195	162011	1.387%
12694	91	73	0.802	11840627	156443	1.339%
12767	92	72	0.783	11823500	139316	1.192%
13237	93	71	0.763	11798053	113869	0.975%
13365	95	69	0.726	11810476	126292	1.081%
13365	95	69	0.726	11810476	126292	1.081%
13477	96	68	0.708	11816849	132664	1.135%
13538	97	67	0.691	11803803	119618	1.024%
13585	98	66	0.673	11805816	121632	1.041%
13815	99	65	0.657	11820699	136515	1.168%
13928	100	64	0.640	11814365	130180	1.114%

Threshold $\bar{s}$	Size Ω_1	Size Ω_2	Balance φ	Sum target cost (kSEK)	Social cost	
					Absolute (kSEK)	Relative
13952	101	63	0.624	11845347	161163	1.379%
14191	102	62	0.608	11806759	122575	1.049%
14285	103	61	0.592	11804528	120344	1.030%
14361	104	60	0.577	11807780	123596	1.058%
14431	105	59	0.562	11822633	138448	1.185%
15195	106	58	0.547	11814543	130359	1.116%
15551	107	57	0.533	11827990	143806	1.231%
16057	108	56	0.519	11801273	117089	1.002%
16571	109	55	0.505	11806336	122152	1.045%
16598	110	54	0.491	11813232	129048	1.104%
16853	111	53	0.477	11824999	140815	1.205%
16903	112	52	0.464	11839124	154939	1.326%
17613	113	51	0.451	11821488	137304	1.175%
17719	114	50	0.439	11836887	152702	1.307%
18136	115	49	0.426	11839780	155595	1.332%
18632	116	48	0.414	11868296	184111	1.576%
19057	117	47	0.402	11846876	162692	1.392%
19203	118	46	0.390	11776096	91912	0.787%
19436	119	45	0.378	11782154	97970	0.838%
20205	120	44	0.367	11789396	105212	0.900%
20277	121	43	0.355	11805763	121579	1.041%
21189	122	42	0.344	11811717	127532	1.091%
21346	123	41	0.333	11817133	132948	1.138%
21610	124	40	0.323	11823085	138900	1.189%
22279	125	39	0.312	11823156	138971	1.189%
22371	126	38	0.302	11794349	110165	0.943%
24882	127	37	0.291	11803493	119308	1.021%
24894	128	36	0.281	11824466	140281	1.201%
25545	129	35	0.271	11828234	144050	1.233%
26448	130	34	0.262	11841483	157298	1.346%
26763	131	33	0.252	11833965	149780	1.282%
26858	132	32	0.242	11846581	162396	1.390%
27580	133	31	0.233	11823801	139616	1.195%
27811	134	30	0.224	11826226	142041	1.216%
27904	135	29	0.215	11826568	142384	1.219%
28394	136	28	0.206	11821747	137562	1.177%
30779	137	27	0.197	11823978	139794	1.196%
32624	138	26	0.188	11830929	146744	1.256%
33736	139	25	0.180	11840311	156127	1.336%
39571	140	24	0.171	11842500	158315	1.355%
39738	141	23	0.163	11845049	160865	1.377%
40445	142	22	0.155	11842265	158081	1.353%
41440	143	21	0.147	11842265	158081	1.353%
45810	144	20	0.139	11838081	153896	1.317%
46262	145	19	0.131	11822509	138325	1.184%
49930	146	18	0.123	11842027	157842	1.351%
54099	147	17	0.116	11808796	124611	1.066%
57454	148	16	0.108	11819007	134822	1.154%
60724	149	15	0.101	11914020	229836	1.967%
63552	150	14	0.093	11823618	139434	1.193%
68960	151	13	0.086	11821040	136855	1.171%
72990	152	12	0.079	11764628	80444	0.688%

Threshold $\tilde{s}$	Size Ω_1	Size Ω_2	Balance φ	Sum target cost (kSEK)	Social cost	
					Absolute (kSEK)	Relative
81000	153	11	0.072	11758496	74312	0.636%
99607	154	10	0.065	11789960	105776	0.905%
101492	155	9	0.058	11846341	162157	1.388%
103282	156	8	0.051	11859228	175043	1.498%
113897	157	7	0.045	11863165	178980	1.532%
119468	158	6	0.038	11879318	195134	1.670%
120884	159	5	0.031	11906643	222459	1.904%
131858	160	4	0.025	11902236	218052	1.866%
253981	161	3	0.019	11902236	218052	1.866%
544811	162	2	0.012	11842522	158337	1.355%
746132	163	1	0.006	11716218	32034	0.274%
800590	164	0	0.000	11684184	0	0.000%

Notes: kSEK = 1000 Swedish crowns (SEK)

$\Omega_1 = \{k \mid y_k^1 \leq \tilde{s}\}$

$\Omega_2 = \{k \mid y_k^1 > \tilde{s}\}$

y_k^1 : connections

Balance $\varphi = \min_i |\Omega_i| / \max_i |\Omega_i|$
 $i \in [1, 2]$

Appendix 12: Benchmarking usage

This appendix comes at a support of the benchmarking theory. As a reminder, the benchmarking exercise consists in observing the practices in the sector to determine the efficiency of the firm. In theory, the firms are included in a technology set T with pre-defined assumptions on convexity, scaling etc... Moreover, in multi-output/multi-input model, the firms detain some preferences, formalized as the utility function. By including the price vector and/or the revenue vector, it allows the firm to favor one output or the others (respectively input). However, the regulator faces some lack of information regarding the firms' preference and the real technology set.

In the first instance, the ignorance about the preference – the utility function $U(\cdot)$ - is bridged by the Farrell output efficiency $\tilde{F}A$ (projection on the technology set). Since in the reality, T is unknown, it is approximated in the second phase by some set T^* from other firms' performance, which is the *benchmark*.¹

Besides the theoretical interest explained above, the benchmarking is used in practice to address the allocation of tasks and/or industry restructuration. It may facilitate the *coordination*, i.e. ensuring that the right firms are producing the right products at the right time and place" (Bogetoft & Otto, 2010, p.3). Moreover, the benchmarking facilitates *incentive provision*. Indeed, it limits the *asymmetric information* and reduces *moral hazard*, explained above (Bogetoft & Otto, 2010).

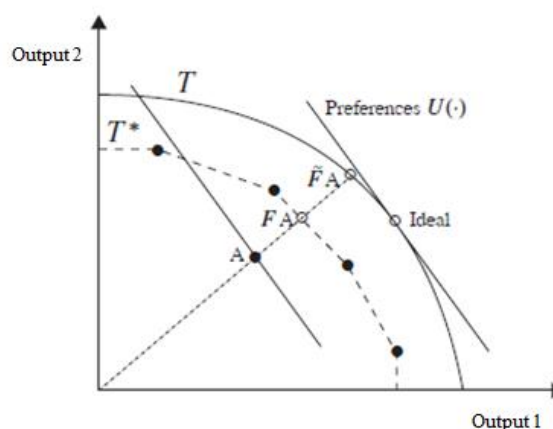


Figure 0-4 Benchmarking mechanism (Source: Bogetoft & Otto, 2010)

¹ Thus, the relative efficiency is measured instead of the absolute efficiency, since the evaluation is performed compared to sector's performance.

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