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Vertical Economies of Scope in Electricity Supply – Analysing the Costs of Ownership Unbundling

by

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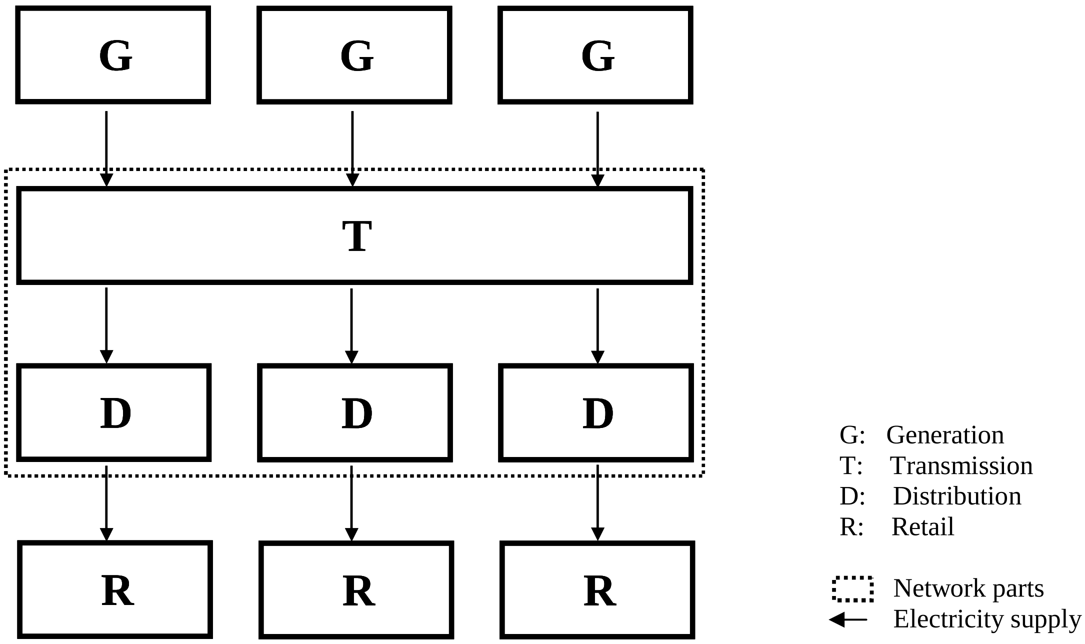
SUMMARY

Background of the study

There are couple of reasons why the electricity supply industry is fundamentally different from most other economic sectors. First of all, it is a *network industry*. This means that the transportation of electricity from the point of *generation* to the points of demand requires an interconnected system of network lines. Such a power grid typically consists of a high-voltage *transmission network* to cover long distances and a medium and low-voltage *distribution network* to serve consumers within the region they are located in. Figure 1 illustrates the supply chain and defines the four stages of electricity supply.

Figure 1: Structure of the electricity supply industry



The non-network parts of the industry are given by *generation* and *retail*. Generation refers to the “production” of electricity, which is then fed into the networks. The term retail denotes the business part of electricity supply, i.e. the sale of electricity to end consumers and related services like metering.

The network part is given by *transmission* and *distribution*. These functions represent the monopolistic sections of the industry. The reason therefore is that due to the capital intensity of building and maintaining electricity networks, it would be economically infeasible to duplicate these stages of the supply chain. Hence, both transmission and distribution networks are a classical example for a *natural monopoly* that does not allow for effective competition as a result of their cost structure. They have to be either regulated have to remain under state ownership to prevent consumers from the exhaustion of market power by these monopolies.

Another important aspect of electricity supply is the existence of strong *technological interdependencies* between the supply stages. The whole system only works reliably if voltage and frequency of the networks are balanced at each point in time. Since demand for electricity changes from season to season, from day to day, and even within seconds, the network operator is responsible for adjusting the inflow of generated electricity into the network in order to keep the system working and prevent supply interruptions or even severe damages to the equipments installed.

As a result of both the network-dependency and the technological complexities, the electricity supply industry was traditionally seen altogether as a natural monopoly ranging over all four supply stages. Accordingly, in nearly all countries, the starting point of the electricity supply industry was a vertically integrated structure with either private or state-owned utilities. The idea of liberalisation arose with the change towards a disaggregated view on the electricity industry, in particular after technological changes allowed for a larger number of small generation units. Hence, generation and retail were now considered as *competitive parts* of the electricity supply industry, while both transmission and distribution remained (naturally) *monopolistic*. The ambition of sector restructuring and liberalisation was to allow for independent generators and/or retailers to enter the market in order to establish competition at these stages of the industry. Given the predominant structure of vertical integration, however, the question was whether sufficient market entry would happen "automatically", leading to a co-existence of vertically integrated and "unbundled" suppliers (i.e. suppliers with and without network ownership). There was reason for concerns that the incumbents' monopolistic market power at the network stages could hinder market entry and, as a result, the development of competition in generation and retail. If this was the case, the *non-discriminatory network access* for independent suppliers – the first and basic step of all restructuring measures aiming to introduce competition – would only be a formal one, and a fair level-playing field could not be reached.

However, there was no general consensus among countries, whether or which additional measures would be necessary to ensure fair and equal conditions of network access, as the highly different developments among the countries within and outside Europe illustrated. While England and Wales and Norway introduced ownership unbundling right from the beginning, even before the European *First Electricity Directive* of 1996, Germany did not even establish a regulator to monitor prices and conditions of network access. The European Commission's *Second Electricity Directive* of 2003 partly acknowledged the discriminatory potential resulting from insufficient legislation and regulation and enforced regulated network access and legal unbundling, i.e. a management and operational separation of networks and competitive stages within integrated utilities. These requirements aimed to rule out cross-subsidisation ("raising rivals' costs" by socialising competitive costs through network charges) and other forms of price or non-price discrimination.

In 2007 the EU Commission published its *Sector Inquiry* in which it criticised the slow developments of competition and the internal market in the European Union. The two main lines of arguments were that integrated companies still had the interest and possibilities to discriminate against their competitors to hinder market entry and that they had reduced incentives to invest in cross-border transmission capacities (interconnectors) required to further integrate the national energy markets. Accordingly, the Commission favoured ownership unbundling of transmission from the competitive supply stages, while for distribution it considered legal unbundling as sufficient. Later in 2007, the Commission presented an *Impact Assessment* to evaluate the effects of ownership unbundling. Like the sector inquiry, however, this assessment only covers the benefits of ownership unbundling, while it completely neglects the expected costs, namely the loss of vertical economies of scope. Nevertheless, it sufficed the Commission to support and accompany its proposal for a *Third Legislative Package* that should leave the EU member countries the choice between *ownership unbundling*, a *deep ISO (independent system operator)*, and an *ITO (independent transmission operator)*. Under the ISO option, the ownership structure remains unchanged, while operating and investment decisions are handed over to a company without commercial supply interests. This industry structure is established in many U.S. markets. The ITO solution was added as a third alternative after strong opposition, in particular by France and Germany. This option can be seen as a stricter form of legal unbundling with stronger restrictions regarding cross-ownership between the network and competitive departments of the incumbents. The Third Legislative Package was finally adopted in 2009 and will be implemented in the near future.

Looking overseas, we find a somewhat different situation in the USA. Like in Europe, electric utilities in the U.S. have been characterised by a high degree of vertical integration. Compared to Europe, however, the electricity supply industry in the U.S. has been strongly fragmented. Historically, the industry developed from small, local systems that were weakly integrated. Since most utilities fell under regulation of the states' Public Utility Commissions (PUCs), a consistent and integrated regulatory regime was missing.

Possibilities for a systematic ownership unbundling were limited for at least two reasons. First, most utilities were already under private ownership so that a divestiture policy would have raised serious constitutional problems. Second, the majority of utilities fell under state regulation, while FERC was only responsible for state-crossing companies. In particular, FERC did not have sufficient authority to enforce restructuring measures against the will of the U.S. states. Different attitudes of the states regarding the adequate choice of deregulation measures made it difficult to establish a single coherent regulatory regime (see Joskow, 2005).

As a result of this regulatory fragmentation, a general unbundling debate like in the European Union did not emerge in the United States. Further reaching unbundling policies partly took place on the state level. A couple of U.S. states provided financial incentives for vertically integrated utilities to divest generation assets. These policy measures were motivated by concerns about market power and a lack of liquidity in the wholesale markets. By splitting the generation assets and selling them to a larger number of independent companies, it was intended to create "more agents that would demand wholesale power from independent, competing generation utilities" (see Kwoka et al., 2007, p. 5). These examples show that the discussion about vertical synergies, investment incentives, and market power has been present in the U.S. as well.

Motivation for the study

There were mainly two reasons for doing this PhD study on ownership unbundling. The rather one-sided argumentation of the European Commission in favour of ownership unbundling simply required additional research putting a stronger focus on the flipside of the coin, namely the loss of vertical integration economies as a result of splitting the electricity supply stages and assigning these functions to separate companies. Furthermore, although there were a variety of studies on vertical scope economies, both theoretically and empirically, there appeared to be two basic research gaps that remained to be filled.

First, previous studies measure different effects of vertical separation, depending not only on different assumptions and geographical areas of investigation but also on the precise location of the vertical split along the supply chain. Obviously, the order of magnitude of measured scope effects depends on which of the four supply stages (generation, transmission, distribution, or retail) are separated from the remaining ones. Accordingly, a systematic categorisation of the existing literature with respect to the exact type of unbundling was needed to shed more light on the expected costs of vertical separation. This gap is filled by the first research paper presented below (see *Part One: Vertical Economies and the Costs of Separating Electricity Supply – A Review of Theoretical and Empirical Literature*)

Second, it seems that the "European Case" of transmission unbundling has not yet been adequately addressed. Most theoretical and almost all empirical studies combine transmission and distribution to one "network stage" (although mostly also including retail), while others only investigate distribution systems. The ambition of this PhD was therefore to distinguish between transmission and distribution and to provide a detailed empirical analysis of several types of unbundling, including the European option of transmission unbundling. To the author's knowledge it is the first study to analyse several unbundling options based on a single database and using two different methodologies. This allows for a deeper insight into the relative importance of the individual sources of synergies arising between the supply functions.

Like most other studies on vertical scope economies in electricity supply, the following research is based on the U.S. industry. The main reason to use U.S. data for analysing a European problem is the availability of a consistent and comparable database provided by the Federal Energy Regulatory Commission (FERC). Notwithstanding some structural differences between Europe and the U.S., the underlying economics are fairly the same. Hence, the empirical analysis also provides insightful results on vertical relations and cost complementarities for the European electricity sector.

The empirical part of this PhD contains two contributions.

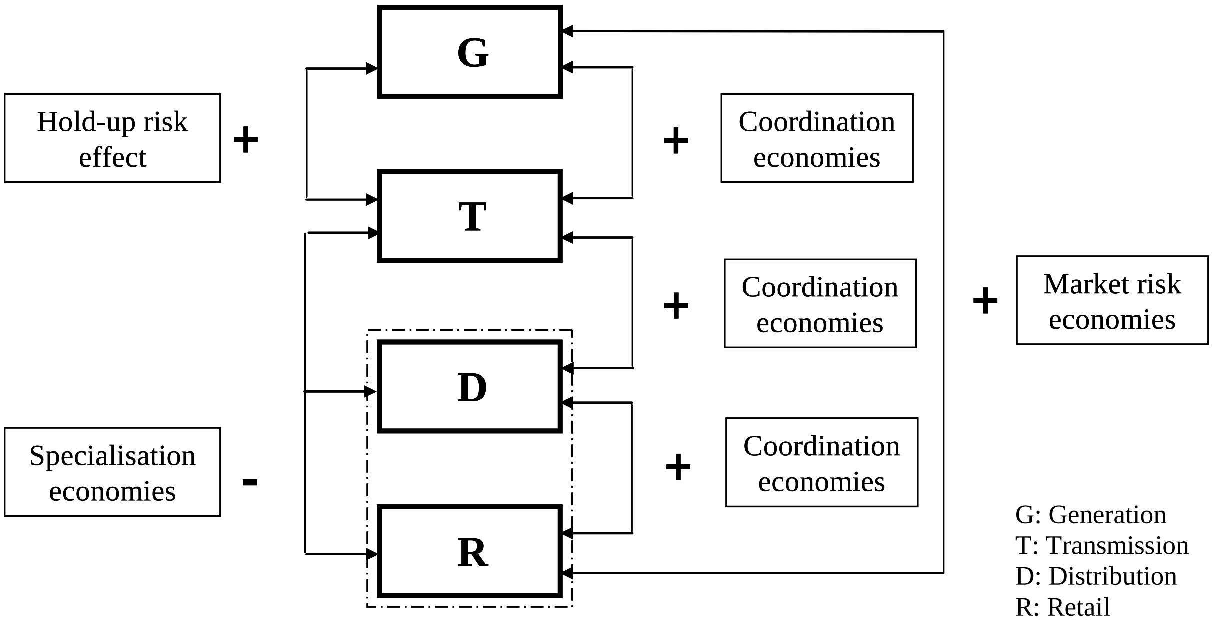
- Paper 2 estimates a *multi-stage cost function* based on which the relative cost increase of vertical separation can calculated (see *Part Two: Economies of Scope in Electricity Supply and the Costs of Vertical Separation for Different Unbundling Scenarios*).
- Paper 3 uses a *frontier benchmarking approach* directly comparing integrated and separate companies. This frontier comparison measures scope economies in terms of a "technical inefficiency" resulting from a separate compared to an integrated structure of

electricity supply (see *Part Three: Benchmarking Economies of Vertical Integration in U.S. Electricity Supply: An Application of DEA*).

Sources of vertical synergies

Figure 2 illustrates the vertical stages of electricity supply and shows between which of them scope economies or diseconomies are likely to occur. Although being interrelated, three main groups of synergies may be distinguished, namely coordination economies, market risk economies, and specialisation economies.

Figure 2: Supply stages and synergy effects



- *Coordination economies* result from the technological interdependency of electricity supply. Due to the fact that electricity supply and demand must be balanced in real-time to maintain a constant voltage and frequency in the networks, an instant coordination between all supply stages is of essential importance to keep the system working. Since the strongest interaction occurs between generation and transmission, one would expect the most significant synergies between these stages. Both information and incentive problems may occur under vertical separation (see Brunekreeft and Meyer, 2009). The necessary exchange of *information* may be organised more efficiently by hierarchical coordination within an integrated utility than between separate companies. The most obvious form of synergies appears when the separation of firms leads to a duplications of tasks, management or IT systems. Further problems arise in case of diverging *incentives* of the companies after unbundling. This is particularly the case for investment coordination when network externalities occur.

- *Market risk economies*, as a second group of vertical synergies, relate to *transaction cost economics.* Transaction costs can be interpreted as costs of using the market instead of firm-internal command and control mechanisms of an integrated company. The argument is similar to that of coordination economies described above but more directly addresses the costs of vertical arrangements (e.g. contracts or spot market transactions) as well as the resulting incentive problems. Problems arise due to the sunk character of generation and network investments which may lead to *opportunistic behaviour* of market players (the so-called *hold-up problem*). Market risk economies also play an important role between the retail and generation stage. Lacking the possibility of vertical integration, retailers have to purchase their supply needs from independent generators. If relying on wholesale spot markets, suppliers face the risk of price volatility. The same holds true on the supply side for generators. Even in the presence of financial hedging instruments in the market, the transaction costs may be significant compared to integrated "gentailers", who are better capable of predicting their own generation costs and demand.
- As a third group of scope effects, it is often claimed that there may also be negative synergies due to a *specialisation advantage.* The underlying argument is that a separation of supply stages may lead to efficiency gains due to a better management focus on specific tasks compared to a multi-product company. The European Commission uses this argument and claims that "experiences of full ownership unbundling suggest that it significantly changes the behaviour of the network undertaking: fully unbundled Transmission System Operators (TSOs) and Distribution System Operators (DSOs) will no longer have the incentive to favour affiliated companies – since there are none –, but can focus on optimising the use of the networks" (EC, 2007, p.160f).

Concepts and Measurement of scope economies

There is a broad range of empirical literature on vertical synergies in electricity supply. However, studies differ with respect to the underlying concepts to measure or indicate scope economies. The most direct concept is that of *economies of scope*. The degree of economies of scope is the relative cost increase if two or more products are produced by separate firms compared to integrated production. Another concept is that of *cost* *complementarities* between supply stages. If these exist, the marginal costs of serving one supply stage decrease, as the outputs at all other supply stages increase. Cost complementarities are a sufficient condition for the existence of economies of scope, but they are not necessary (see Baumol et al., 1982). Both concepts are empirically implemented by estimating a multi-stage cost function, while only the latter one provides a numerical estimate of synergies.

A third group of studies is based on a single-stage cost function and investigates *cost separability* from the other stages. This is a mathematical concept that tests whether a multi-stage cost function can be divided into separate *independent* cost functions. If cost separability is rejected, the stages cannot be analysed independently from one another due to technological externalities. A lack of separability indicates – but does not proof – the existence of vertical economies of scope.

Finally, *subadditivity* is a more general concept of scope economies. Subadditivity is given if *any* distribution of outputs among separate companies leads to higher costs compared to integrated production. Accordingly, economies of scope are a special case of subadditivity where orthogonal output vectors, i.e. a full specialisation of companies, is assumed. Subadditivity is a much stricter concept than scope economies, since it renders the whole industry a *natural monopoly*. Economies of scope, however, may still exist even in the absence of subadditivity.

The following analysis predominantly focuses on direct estimates of vertical scope economies. Following the general definition of Baumol et al. (1982), economies of scope relative to a product T are

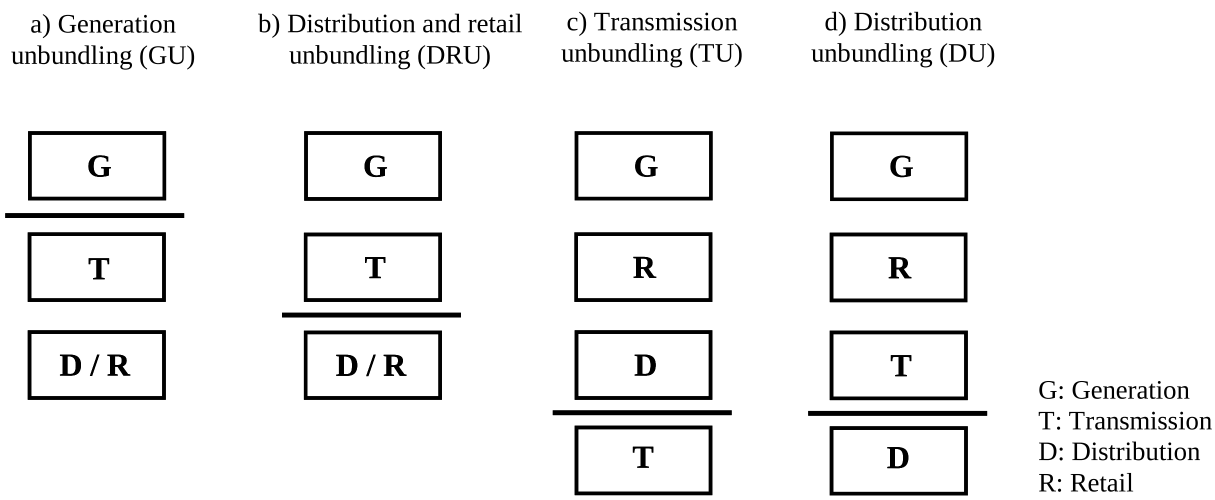
$$SC_T = \frac{\left[C(Y_T) + C(Y_{-T}) - C(Y)\right]}{C(Y)}, \qquad (1)$$

where C(Y) gives the costs of producing the complete output vector Y, while $C(Y_T)$ and $C(Y_{-T})$ are the stand alone costs of separately producing T (i.e. Y_T) and all products except for T (i.e. Y_{-T}), respectively. Accordingly, scope economies exist, if the costs of separate production by specialised firms $[C(Y_T)+C(Y_{-T})]$ are higher than the costs of integrated production C(Y). To this end, vertical scope economies measure the costs of separating the production along the vertical supply chain. These measures differ according to the precise location of the vertical split defined by the respective option of unbundling.

Options of unbundling

There appear to be four main unbundling options that most closely correspond to unbundling policies that have been or are going to be implemented in electricity markets around the world. Figure 3 illustrates these unbundling options and shows between which of the supply stages the line of separation is drawn.

Figure 3: Reference scenarios of unbundling



a) Generation unbundling (GU). This option refers to a separation of the generation stage from the two network stages (transmission and distribution) and the retail function.

b) Distribution and retail unbundling (DRU). The DRU scenario there is no split between generation and transmission. Instead, the distribution part (including retail) is separated from these upstream stages.

c) Transmission unbundling (TU). The TU option corresponds to the European option of ownership unbundling, separating the transmission stage from the remaining (in particular the competitive) supply stages.

d) Distribution unbundling (DU). DU refers to a separation of distribution from the competitive functions, generation and retail. So far, the Netherlands have been the only country in Europe to implement distribution unbundling – in addition to transmission unbundling which is already in place.

The first two scenarios, a) and b), correspond to electricity markets that did not introduce retail competition, which among others is the case for several U.S. states. In other words, the retail function is assumed to remain in the hand of the distributor that is serving its protected franchise area. Accordingly, these unbundling cases include a separation of retail activities from generation. Due to the fact that available data do not allow distinguishing between distribution and retail output, the majority of studies focuses on these two scenarios in figure 3 and use the term distribution for both downstream stages.

The latter two unbundling options, c) and d), more closely reflect the European discussion, since they make a distinction between the competitive businesses, generation and retail, on the one hand and the monopolistic network stages, transmission and distribution, on the other hand. The retail function is not regarded as an integral part of distribution. The most topical debate is on *transmission unbundling (TU)* pursued by the European Commission. For the case of *distribution unbundling (DU)* two examples can be found in the Netherlands and New Zealand.

Previous studies on economies of scope (see Part One)

This section analyses vertical scope economies based on previous theoretical and empirical literature. Results are presented for all four unbundling options shown in figure 3. Table 1 provides an overview of previous results including the econometric study of this PhD research.

- *Generation unbundling (GU)* turns out to be the most costly unbundling option, since it increases both coordination costs and market risks. According to most studies, synergy losses exceed 15 percent of total costs, which is a significant cost increase.
- *Distribution and retail unbundling (DRU)* involves mainly market risks, since generation and transmission remain vertically integrated. Only distribution and retail are separated from the combined generation and transmission stage. According to the majority of studies, this scenario leads to synergy losses between 5 and 9 percent.
- Both *transmission unbundling (TU)* and *distribution unbundling (DU)* only separate the respective network part from all other supply stages, resulting in synergy losses between 2 and 5 percent due to coordination costs.

These results indicate that coordination losses appear to be a minor part of the expected costs of unbundling. Market risk effects are much more important. This is good news for the ambition of transmission unbundling, since market risk is not affected by this unbundling option.

Table 1: Economies of scope for fully integrated utilities (in fractions of total costs)

Output all stages (million MWh)	**1 – 10**	**10 – 15**	**15 – 20**	**20 – 40**	**40 – 50**
Generation Unb. (GU)					
Kaserman & Mayo (1991)	<0.19	0.19–0.54	0.54–0.89	-	-
Kwoka (2002)	<0.43	0.43–0.75	0.75–1.04	-	-
Arocena et al. (2008)	-	0.04–0.10	0.04–0.10		
Meyer (2010)	<0.22	0.17–0.22	0.16–0.22	0.16–0.17	0.17–0.19
Dist. & Retail Unb. (DRU)					
Arocena (2008)	<0.04	0.04–0.05	0.04–0.05	0.04–0.05	0.04–0.05
Fraquelli et al. (2005)	>0.16	-	-	-	-
Jara-Díaz (2004)	~0.08	~0.08	-	-	-
Meyer (2010)	<0.09	~0.04	~0.04	~0.04	~0.05
Transmission Unb. (TU)					
Meyer (2010)	<0.09	0.04–0.05	0.03–0.04	0.03–0.04	~0.04
Distribution Unb. (DU)					
Deloitte (2005)[1]	0.04–0.05	0.04–0.05	0.04–0.05	-	-
Roland Berger[1]	0.03–0.04	0.03–0.04	0.03–0.04		
CPB (2005)[1]	~0.01	~0.01	~0.01	-	-

[1] Based on ex-ante welfare analysis

Cost function estimation and results on economies of scope (see Part Two)

Data for both empirical studies stem from FERC form 1 data for U.S. electric utilities. We use pooled panel data for the period of 2001 to 2008. In order to reduce the number of estimated coefficients, the sample is restricted to relatively homogenous generation companies with a focus on steam and nuclear power production.

The econometric study on scope economies is based on the estimation of a multi-stage quadratic cost function for the three main supply stages, generation (G), transmission (T) and distribution (D). As mentioned above, distribution also includes retail. Accordingly, the major part of the costs depends on the linear and quadratic terms for the three outputs considered and the interaction terms between them. Furthermore, the cost function is extended by control variables to capture influences of input prices and structural parameters on the firms' costs. We include input prices for generation fuel, labour, and capital. Price of fuel is calculated as fuel costs divided by generation output. Price of labour is the sum of salaries and wages per full-time employee. Price of capital is a weighted average for the price of proprietary capital and long-term debt. We include the interaction terms between input prices and outputs to cover progressive influences of prices with varying output quantities. Finally, there are variables to control for the share of nuclear power production and the average residential sales per customer in linear and quadratic form. The latter serve as substitutes for distribution density, which could not be calculated due to missing data on distribution network length.

For the purpose of this study, three unbundling scenarios are analysed, g*eneration unbundling (GU)*, *distribution and retail unbundling (DRU)*, and *transmission unbundling (TU)*. After estimating the complete cost function, we calculate vertical integration economies according to these unbundling options for various output combinations. This leads to the following results:

- *Generation unbundling* reveals the highest synergies ranging from 12 percent to 17 percent on average. The reason is that both *coordination losses* and the *market risk effect* contribute to the increase in costs as a result of vertical separation.
- In case of *distribution and retail unbundling*, generation and transmission remain integrated and only the distribution stage (including retail) is vertically separated. This scenario leads to a 4 to 7 percent loss of synergies due to *market risk*, while *coordination* between generation and transmission can still be realised firm internal.
- The lowest cost increase arises under *transmission unbundling* with 4 percent on average. This scenario corresponds to the option of ownership unbundling as part of the European Third Legislative Package. A separation of transmission from the remaining supply stages involves a loss of *coordination economies* between generation and transmission, but there is no increase in *market risk*, since generation and distribution (more precisely: retail) remain vertically integrated.

Benchmarking economies of scope (see Part Three)

Frontier approaches are well suited for a comparison of companies that do not necessarily produce on the efficient frontier. The common characteristic of frontier benchmarking models is that the efficiency values are derived as a relative measure compared to the sample group. We use *data envelopment analysis (DEA)*, which is a non-parametric approach that uses a linear programming technique to calculate the efficient frontier based on a sample of firms. This is done by constructing a piece-wise surface over all observations. The advantage of DEA is that no functional assumption of the underlying production technology is required and it is possible to deal with the limited number of observations that are often the most serious restriction in analysing the energy sector. Due to the fact that no information on input and output prices is used, the analysis is restricted to measuring technical – instead of economic – efficiency.

This paper analyses the sources and magnitudes of vertical scope economies in electricity supply. We use the same database as in the econometric study described above, containing pooled data of U.S. electric utilities from 2001 to 2008. Based on a bootstrapping data envelopment analysis (DEA), two types of vertical unbundling are analysed, namely *generation unbundling* and *transmission unbundling*.

As in the econometric estimation, I restrict the sample to relatively homogenous generation companies with a focus on steam and nuclear power production. I use total costs (TOTEX), i.e. the sum of operating and capital costs, as the only input variable. The four output variables are generation (G), transmission (T), distribution (D) and transmission network length (NL). I apply a variable returns to scale (VRS) model.

The results are as follows:

- *Generation unbundling* is – similar to the cost function results – the most costly option with an average cost increase of 17.9 percent due to risk and coordination effects.
- The second scenario, *transmission unbundling*, shows an average cost increase of 1.4 percent, which is mainly due to coordination losses between the transmission and generation stages.

For the average company size, both scenario results are comparable to previous cost function studies (see table 1 above). In case of the TU option vertical synergies are somewhat lower. This may indicate that a direct frontier comparison of integrated and separate companies reveals a specialisation advantage which is not fully captured by cost function estimations.

These results confirm that *market risk* seems to be of larger importance for economies of vertical integration than *coordination effects*. Analysing the structure of scope effects reveals for both generation and transmission unbundling that synergy losses are higher for small utilities and for those companies with a relatively strong focus on *transmission* compared to generation and distribution (measured by the respective output ratios). Put differently, stand-alone generation and distribution firms may be less cost efficient than larger ones and should rather remain vertically integrated.

Conclusions

Economic theory predicts two main sources of synergies, namely *coordination economies* and *market risk economies*. Furthermore, empirical evidence suggests that an opposite effect in terms of a *specialisation advantage* may occur, reducing the expected costs of unbundling at least in the long run. Empirical results are presented for four different unbundling options.

Generation unbundling (GU) refers to a separation of the generation stage from the two network stages (transmission and distribution) and the retail function. This turns out to be the most costly unbundling option, since it increases both coordination costs and market risks. Synergy losses can be expected to make up more than 15 percent of total costs depending on firm size and output structures.

Distribution and retail unbundling (DRU) involves lower coordination losses, since generation and transmission remain vertically integrated. Accordingly, only distribution and retails are separated from the combined generation and transmission stage. This scenario leads to synergy losses between 5 and 9 percent.

Both *transmission unbundling (TU)* and *distribution unbundling (DU)* only separate the respective network part from all other supply stages, resulting in synergy losses between 2 and 5 percent. In case of the benchmarking results, the TU option shows somewhat lower cost increases. This may indicate that a direct frontier comparison of integrated and separate companies reveals a specialisation advantage which is not fully captured by cost function estimations. Both empirical approaches indicate that *market risk effects* seem to be more important for economies of vertical integration than *coordination effects*.

What conclusions can be drawn for the unbundling discussion in general and the development within the European Union in particular?

First, *transmission unbundling* does not come without a cost as it results in coordination losses between generation and transmission. Both theoretical and empirical literature indicates that network externalities may hinder efficient investment coordination unless a market mechanism – like a form of local network pricing – is established that internalises these external effects. Great Britain and Norway are examples for European countries that have gained experience with locational network charges, and the discussion has already started to extend to other European countries as well.

Second, although there is no direct empirical assessment of the *ISO* option, this may turn out to be the "golden mean". Coordination losses are most probably lower compared to ownership unbundling, given that optimisation takes place from a more integrated perspective. A critical issue is that of investment incentives, in particular the necessary split between decision-maker and risk-bearer, as required for a deep-ISO. This analysis, however, is beyond the scope of this survey (see Balmert and Brunekreeft, 2009).

Third, although the European debate focuses on transmission unbundling at the moment, *distribution unbundling* may become an issue in the near future. Given the current developments towards *smart grids*, the question whether distribution unbundling favours or hinders innovations on the distribution level has moved into the focus of discussion. New Zealand and the Netherlands provide examples for distribution unbundling.

Fourth, the analysis shows that market risk effects play an important role in vertical relations of the electric industry, in particular between the generation and retail stage. Both scenarios *generation unbundling* and *distribution and retail unbundling* correspond to electricity markets that did not establish retail competition. In other words, distributors still serve protected franchise areas as it was the case prior to liberalisation. In such an environment, the separation of generation from distribution, as analysed in both scenarios, results in a higher market risk, since distributors have to purchase electricity for their retail supply on the wholesale markets, and are subject to price volatility and face the risk of opportunistic behaviour of other players that may be able to exhaust market power.

Fifth, concluding on these market risk arguments, a lesson for Europe is that – given retail competition in Europe is established – vertical integration between generation and retail may increase if distribution unbundling should be implemented in future. The re-integration between these stages that has taken place after distribution unbundling in New Zealand and the UK confirms the importance of the risk hedging effect of integration.

Finally, it should be noted that a measurement of scope economies only covers one side of the coin, namely the cost effects of unbundling. For an overall assessment of unbundling one has to consider the expected effects on competition. The disciplining effect of increased competition on cost effectiveness may or may not outweigh the costs of unbundling.

The cost benefit analysis of Brunekreeft (2008) indicates that the net effect of ownership unbundling may be positive but probably small (see Brunekreeft, 2008).

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PART ONE

Vertical Economies and the Costs of Separating Electricity Supply – A Review of Theoretical and Empirical Literature

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Abstract

Motivated by the European policy of electricity network unbundling, this paper reviews theoretical and empirical literature on vertical synergies in electricity supply. In the analysis a clear distinction is made between four different unbundling options leading to different forms and magnitudes of synergy losses. Apart from *coordination economies* a main source of scope economies results from a *market risk effect* if generation and retail are separated. Accordingly, the European policy of network unbundling results in synergy losses between 2 and 5 percent due to coordination losses, while an unbundling option that separates retail and generation may lead to a permanent cost increase of 15 percent and more due to a risk increase.

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1 Introduction

Traditionally, the electricity supply industry (ESI) was dominated by vertically integrated electric utilities, due to large sunk costs in generation and networks and coordination requirements between the supply stages. Both transmission and distribution networks have remained monopolistic up to now, since it would be economically infeasible to duplicate them. For generation, however, the situation has changed. Technological developments lowered the minimum efficient scale of generators (see Christensen and Greene, 1976). In particular, combined cycle gas turbine (CCGT) technology allowed for a larger number of small-scale power producers. In combination with an increase in market demand over time, this supported the idea of competition in generation (see e.g. Joskow, 1998). Furthermore, developments in information technology have improved possibilities to coordinate generation and transmission between separate firms (see e.g. IEA, 1999). Nevertheless, there appears to be a trade-off between enhancing competition and exhausting economies of vertical integration. Accordingly, vertical relations have remained to be in the focus of the liberalisation discussion.

This paper reviews theoretical and empirical literature on sources and magnitudes of vertical synergies in the electricity sector. Section two shortly analyses the structural characteristics and major steps of liberalisation in Europe and the U.S., as these markets reveal fundamentally different philosophies and developments in restructuring and unbundling. Section three analyses the sources of vertical synergies according to theoretical literature. Four basic options of unbundling will be defined that closely reflect implemented and discussed unbundling options in practice. The analysis shows that the precise location of the vertical split along the supply chain determines the resulting synergy losses. Section four reviews empirical studies on scope economies, and relates the numerical results to the four reference scenarios. Section 5 concludes.

2 Liberalisation

2.1 Liberalisation and vertical relations in the European Union

The starting point for liberalisation on the European level was the First Electricity Directive of 1996 (see EC, 1996).[2] This first step of liberalisation aimed to allow independent generators to gain access to the grids required for electricity supply on a fair and non-discriminatory basis. After a period of transition, final customers should be allowed to choose their electricity supplier, so that the protected supply area of the incumbent firms was given up in favour of retail competition. After a promising start of the liberalisation process with market entries of independent suppliers and decreasing retail prices, the development slowed down, and prices started to increase again. The traditionally high market shares of the incumbent supply companies did not decline considerably, and it was questioned whether the playing field for all competitors could be levelled as long as network owners and operators still have own supply interests. Accordingly, the European Commission's Second Electricity Directive in 2003 contained a package of unbundling requirements, referred to as *legal unbundling*. In detail, this package includes the following unbundling rules (see EC, 2003):

- *Legal Separation*: the utility's network section had to be transformed into a separate legal entity with separate bookkeeping (*accounting separation*). This requirement is met, for instance, if the network business is organised as an affiliate within a holding structure.
- *Management Separation*: the management and staff of the network business were no longer allowed to be active or to have financial interests in the competitive businesses.
- *Operational Separation*: this unbundling requirement aimed to increase the independence of the network part with respect to operational decisions. This also included an *informational separation* between network and supply business. By implementing *Chinese Walls*, it should be prevented that confidential information about competitors, collected for the purpose of network operation, is handed over to the affiliated supply business that could misuse this information to gain a relative advantage.

In 2007, the European Commission criticised the weak development of competition in Europe in its *Sector Inquiry* on the energy markets (see EC, 2007b). Since then, two aspects are in the focus of discussion, and for both of them vertical integration has been identified as the main source of problems.

[2] England & Wales and Norway were the first countries in Europe that started the restructuring process as early as 1990/91. For an overview of the development of EU Policy in the energy sector, see e.g. Kreis (2004). Joskow (2003) gives a description of the transition processes in the U.S.

First, the Commission argues that even under legal unbundling the incumbents – that mostly have remained vertically integrated – have both incentives and the ability to hinder market entry and competition in favour of their own commercial supply interests. The key point is the dependence of supply on the monopolistic networks that may give their owners the possibility of vertical foreclosure (see e.g. Beard et al., 2001). This could take the form of *price discrimination*, if incumbents are able to charge higher network prices for competitors than for its own affiliates to squeeze their profit margins and render market entry unattractive. Even though a direct discrimination in network access charges is prohibited, vertically integrated firms may cross-subsidise their competitive business by shifting costs into their network part. Given imperfect and cost-based regulation, these costs are passed through to all network users. This leads to a distortion of competition, since for incumbents the increased network charges are a pure cost shift. For independent network users, however, these reflect real costs, leaving them with a relative cost disadvantage (see Joskow, 1996). This practice is known in the literature as *raising rivals' costs*.[3] Furthermore, incumbents may use *non-price discrimination* like delays in network connection or administrative burdens to consumer switching to frustrate the level playing field for competitors.[4]

In a second line of arguments, the Commission is concerned about insufficient incentives for network investments, especially across borders. Electricity markets have largely remained national in scope, as network congestions at most borders indicate. The European Commission argues that incumbents may lack sufficient incentives to invest in cross-border network connections, as a relief of congestion to lower-cost countries intensifies domestic competition and runs counter to their own profit interests.[5]

As a consequence of these arguments, the Commission regards the current state of legal unbundling as insufficient and considers that "transmission ownership unbundling is the most effective tool to promote investments in infrastructure in a non-discriminatory way, fair access to the grid for new entrants and transparency in the market" (see EC, 2007b).

[3] A general discussion of discrimination and sabotage is provided by Perry (1978); Krattenmaker and Salop (1986); Beard et al. (2001). For the electricity industry, Brunekreeft (2003) gives an excellent overview.

[4] However, at least for the electricity sector, these problems seem well addressed by regulatory rules after some years of practical experience and may nowadays play a minor role in the discussion (see Brunekreeft, 2008a).

[5] Although this argument holds in principle, it should be noted that cross-border connections involve two network firms, one of which may well have an interest in a capacity increase if supply interests exits; namely the one in the low-cost country that heads for export opportunities in the neighbouring country (see Brunekreeft, 2008a).

In September 2007, the European Commission presented an *Impact Assessment* that aimed to measure the expected effects of unbundling on the electricity markets (see EC, 2007a). This study was heavily criticised for methodological reasons by many observers, since it neglects the cost aspects of unbundling, while the assessment of its benefits is based on simple comparisons of market shares and investments between countries with legal and ownership unbundling. Nevertheless, it sufficed the Commission to support and accompany its proposal for a Third Legislative Package that should leave the EU member countries the choice between *ownership unbundling*, a *deep ISO (independent system operator)*, and an *ITO (independent transmission operator)*. Under the ISO option, the ownership structure remains unchanged, while operating and investment decisions are handed over to a company without commercial supply interests. This industry structure is established in many U.S. markets.[6] The ITO solution was added as a third alternative after strong opposition, in particular by France and Germany. This option can be seen as a stricter form of legal unbundling with stronger restrictions with regard to cross-ownership between the network and competitive departments of the incumbents.[7] The Third Legislative Package was adopted in 2009 (see EC, 2009).

All European unbundling options refer to a separation of transmission from the competitive stages generation and retail. Although retail competition is implemented in Europe, the discussion did not yet expand to ownership unbundling of distribution from generation and retail; up to now, only legal unbundling applies. However, given that the Netherlands have recently started to implement distribution unbundling, the extension of the debate to the European distribution level may only be a question of time.

It should be noted that the new unbundling legislative applies to the gas market as well, although this paper will focus on electricity only.[8]

2.2 Liberalisation and vertical relations in the United States

Many studies on vertical scope economies in electricity supply are based on the U.S. industry. Accordingly, it is advisable to review the main similarities and differences between

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[6] It should be noted that both ownership unbundling and the deep ISO involve severe constitutional problems if electricity companies are already privatised (see Pielow and Ehlers (2008) and Ehlers (2010)).

[7] The remainder of this paper will focus on strict ownership unbundling. For an analysis of the ISO option see Balmert et al. (2008), and Balmert and Brunekreeft (2009). A discussion of the ITO solution, also known as *Effective and Efficient Unbundling (EEU)*, is provided by Säcker (2008).

[8] For a discussion of unbundling and its impacts on the gas industry, see Growitsch et al. (2008).

the U.S. and Europe in terms of the industry structure.[9] Like in Europe, electric utilities in the U.S. have been characterised by a high degree of vertical integration. Prior to liberalisation, regulated retail rates were "bundled" prices for generation, transmission, and distribution.

Compared to Europe, however, the electricity supply industry in the U.S. has been strongly fragmented. Historically, the industry developed from small, local systems that were weakly integrated. In 2000, there were 140 control areas within the three synchronized AC systems. Since most utilities fell under regulation of the states' Public Utility Commissions (PUCs), a consistent and integrated regulatory regime was missing. Hence, incentives for transmission investments to enlarge and integrate control areas were rather low. Interconnections between the transmission networks were mainly constructed for reliability reasons based on cooperative agreements between utilities. Open access to transmission networks was only granted "voluntarily" to allow municipal distributors to gain access to generators outside of the control area they were embedded in (see Joskow, 2005). The weak integration of the U.S. transmission areas may explain why the discussion on deregulation and unbundling has rather been motivated by the aim to strengthen investment incentives to increase supply security than to lower supply costs by granting access to remote generators.

Although open access to transmission networks was already implemented with the *Public Utility Regulatory Policy Act* (PURPA) in 1978, many complaints about discriminatory behaviour remained, for instance due to refusals of transmission capacity by integrated firms in favour of own supply requirements.

This led to the implementation of *Order 888* in 1996 that required a *functional separation* of the transmission stage from generation to prevent discriminatory behaviour of integrated utilities. In detail it involved the separation of administrative units, transparent pricing, and rules of conduct that should reduce the scope for anticompetitive behaviour (see Kwoka et al., 2007). Although this unbundling measure is comparable to management and operational unbundling as implemented in Europe within the Second Electricity Directive in 2003, it seems far less strict, since it neither required the separation of operational decisions nor the installation of firewalls to exclude the exchange of confidential information on competitors.

[9] See Joskow (2005) for a detailed description of the institutional and regulatory developments in the United States.

Possibilities of stricter unbundling measures were limited for at least two reasons. First, most utilities were already under private ownership so that a divestiture policy would have raised serious constitutional problems. Second, the majority of utilities fell under state regulation, while FERC was only responsible for state-crossing companies. In particular, FERC did not have sufficient authority to enforce restructuring measures against the will of the U.S. states. Different attitudes of the states regarding the adequate choice of deregulation measures made it difficult to establish a single coherent regulatory regime (see Joskow, 2005). Some states, for instance, have been reluctant to establish retail competition. In these cases, distributors remain as franchised suppliers in their geographic areas.[10] As a result of this regulatory fragmentation, a general unbundling debate like in the European Union did not emerge in the United States.

The alternative solution was to leave the ownership structure unchanged and separate *ownership* and *operation* of transmission systems. With *Order 2000*, FERC initiated the creation of ISOs that independently operated electricity transmission networks, integrated over large geographic areas. These companies, referred to as RTOs (*regional transmission organizations)* in the official terminology, fall under FERC regulation. According to Joskow (2005) the establishment of these RTOs seemed to be the most ambitious goal that could be achieved by FERC to expand and unify regulatory conditions in the U.S. electricity industry.

Further reaching unbundling policies partly took place on the state level. A couple of U.S. states provided financial incentives for vertically integrated utilities to divest generation assets. These policy measures were motivated by concerns about market power and a lack of liquidity in the wholesale markets. By splitting the generation assets and selling them to a larger number of independent companies, it was intended to create “more agents that would demand wholesale power from independent, competing generation utilities” (see Kwoka et al., 2007, p. 5).

These examples show that the discussion about vertical synergies, investment incentives, and market power has been present in the U.S. as well. However, the diversity of market structures complicates the analysis of scope economies and limits the possibilities to transfer the results of U.S.-based studies to Europe. This refers particularly to the impact of outsourcing operating activities to RTOs on the amount of scope economies that vertically

[10] As will be discussed below, it makes an important difference for the measurement and interpretation of scope economies, whether the term distribution covers only the *network* function or includes *retail* activities. A lack of retail competition may significantly increase the market risk of vertical splintering of the supply stages.

integrated companies are able to realise. Furthermore, as Joskow and Schmalensee (1983) emphasise, electric utilities in the U.S. are characterised by a large number of horizontal and vertical arrangements, ranging from contracts and cooperatives over joint ventures to full integration. Accordingly, it is not possible to draw a precise line between integrated and separate firms; there is rather a continuum of in-betweens.

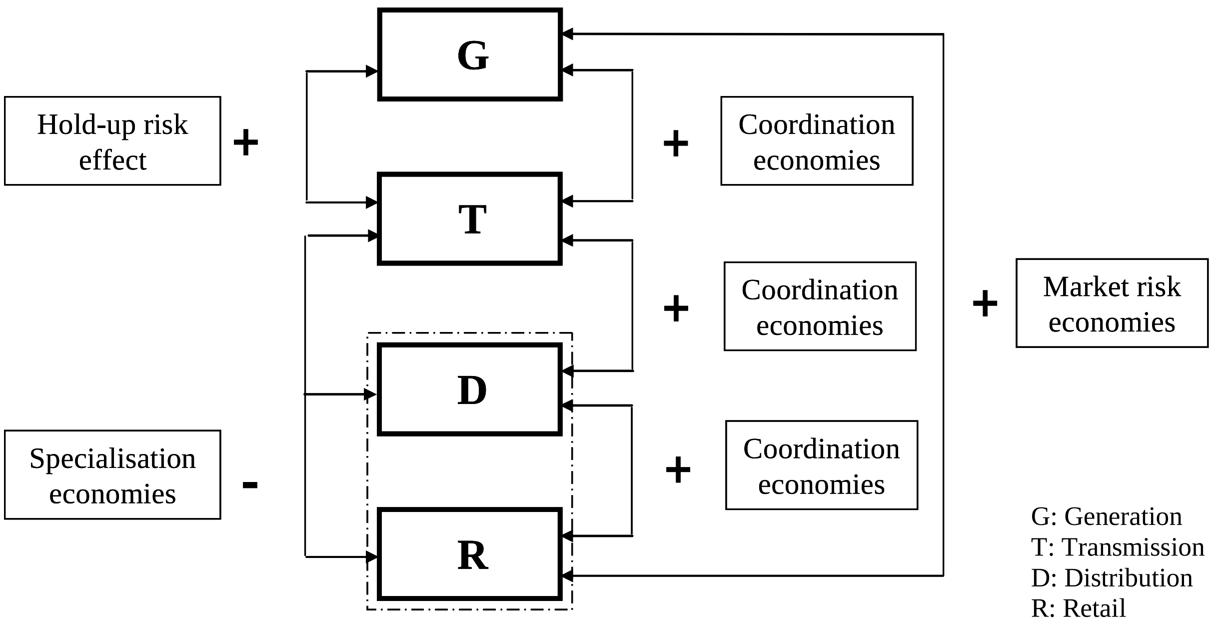
3 Economies of scope

3.1 Source of vertical synergies

The previous section reviewed the restructuring process in Europe and the U.S. and outlined the main arguments for unbundling. However, there is another side of the story. There are important technological aspects of the ESI that favour vertical integration between the supply stages. The arguments against ownership unbundling arise from the existence of vertical scope economies.

Figure 1 illustrates the vertical stages of electricity supply and shows between which of them scope economies or diseconomies are likely to occur.

Figure 1: Supply stages and synergy effects



Although being interrelated, three main groups of synergies may be distinguished, namely coordination economies, market risk economies (including hold-up risks), and specialisation economies.

Coordination economies result from the technological interdependency of electricity supply. Due to the fact that electricity supply and demand must be balanced in real-time to maintain a constant voltage and frequency in the networks, an instant coordination between all supply stages is of essential importance to keep the system working. Since the strongest interaction occurs between generation and transmission, one would expect the most significant synergies between these stages.

Both information and incentive problems may occur under vertical separation (see Brunekreeft and Meyer, 2009). The necessary exchange of *information* may be organised more efficiently by hierarchical coordination within an integrated utility than between separate companies (see Joskow and Schmalensee, 1983). The restructuring process may lead to a duplication of tasks and, accordingly, increase both operational and capital costs. Furthermore, information flows are more complicated to handle as more market players are involved, and may become available at too short notice for the network operator to efficiently organise flow paths for electricity. This may happen in cases when generators are shut down for maintenance reasons. As long as it only concerns the technical organisation of *information flows*, the problem is less severe. In these cases, coordination in the form of costless signals by the involved market players may suffice to achieve an efficient outcome. This simple form of coordination is known as “cheap talk” in the literature (see Brunekreeft and Friedrichsen, 2010). However, the central problem arises from diverging *incentives*. This is especially the case for investment coordination. Competitive firms may for instance hold back information on generation investments plans for strategic reasons or may at least not be truth telling with respect to relevant details needed for efficient long-term network capacity planning. In such cases “cheap talk” may not suffice as an efficient coordination mechanism.[11] Since operation and construction costs of the network clearly depend on the location of generators feeding into the network, a generator being placed at the wrong location or the wrong point in time affects the whole system flows of electricity in a costly way. In an unbundled world, power producers typically do not care about the effects on network costs, as long as these costs are paid by all network users. This is a network externality. As a consequence, generators are too often simply connected “one after another”, leaving no room for a joint transmission optimisation to minimise overall system costs (see Baldick and Kahn, 1993). Only a vertically integrated company takes overall costs into account and therefore internalises those network externalities by a joint decision making over all supply stages (see Nemoto and Goto, 2004).

[11] See Brunekreeft and Friedrichsen (2010) for an analysis of a *cheap talk model* of investment coordination.

Furthermore, there is a substitutive relation between building a nearby generator and extending or reinforcing transmission lines to connect to a more distant generator. Vertical integration ensures a coherent investment strategy that is needed to find the most efficient system configuration (see Chao et al., 2005). The degree of synergy losses depends on how efficiently a decentralised market mechanism can replace firm internal coordination.[12] For investment coordination, a market-based solution is to implement locational pricing to send efficient long-term investment signals to generators (see Brunekreeft et al., 2005).

Market risk economies, as a second group of vertical synergies, relate to *transaction cost economics* as developed by Oliver Williamson.[13] Transaction costs can be interpreted as costs of using the market instead of firm-internal command and control mechanisms of an integrated company. The argument is similar to that of coordination economies described above but more directly addresses the costs of vertical arrangements (e.g. contracts or spot market transactions) as well as the resulting incentive problems. A major characteristic of the electricity supply industry is the complexity of its vertical relations and the dependencies on other market players' investment and operational decisions, and – not the least – on the regulatory framework. Both generation and network assets are highly specific and irreversible investments with a long construction and operating duration. The *sunk costs* character of these investments fully exposes an investor to this risk of uncertainty. While this risk is fairly manageable under the integrated optimisation of investment decisions within a single utility, separate market players with opposing interests face a small-numbers bargaining problem.

Accordingly, vertical arrangements in terms of long-term contracts are necessary to alleviate the investment risk. However, given the complexity of the industry in face of demand fluctuations, network and generator availability, these contracts inevitably remain incomplete. This gives rise to *opportunistic behaviour* of the market players which can be described as "the tendency for people to violate the spirit of agreements in pursuit of self-interest" (Joskow and Schmalensee, 1983, p.27). Anticipating this *hold-up risk,* independent investors may hesitate to invest, as they cannot be sure to recover their investment costs adequately.[14] On the generation level, this may be a serious problem for ancillary services. Peak load generators providing spinning reserves, for instance, may only generate electricity

[12] See Joskow and Schmalensee (1983) for a discussion of how a decentralised system should optimally behave. From a more technical point of view, Künneke and Fens (2006) and Künneke (2008) investigate the institutional challenges for the electricity sector resulting from deregulation and unbundling.
[13] For the theory of transaction costs see Williamson (1971, 1975, and 1979) and Hart (1995).
[14] For an analysis of asset specificity and hold-up problems see the seminal paper of Klein et al. (1978).

in a small fraction of the day but are important for system stability. For those generators to 'jump in' in cases of emergency or balancing needs, it is particularly important that these services are adequately (and ex-ante credibly) valued. Vertical integration reduces the risk for a generator to be held-up by the transmission system operator as soon as the investment is made. However, the hold-up risk similarly applies to networks. The profitability of building or upgrading transmission lines requires reliable information on generation investment plans. If the realisation of those plans fails (or a generator's capacity exceeds or falls short of the expected capacity), a transmission company may be left with *stranded costs* that cannot be recovered by ordinary network charges.

Market risk economies also play an important role between the retail and generation stage. Lacking the possibility of vertical integration, retailers have to purchase their supply needs from independent generators. If relying on wholesale spot markets, suppliers face the risk of price volatility. Even in the presence of financial hedging instruments in the market, the transaction costs may be significant compared to integrated retailers, who are better capable of predicting their own generation costs. In particular, market power aspects become very important under vertical unbundling. As both Mansur (2007) and Bushnell et al. (2008) argue, integrated firms have reduced incentives to set higher market prices, as long as these were merely transfer prices that shifted profits between their integrated generation and retail stages. By contrast, a separate generator does indeed have incentives to exhaust market power in order to increase its profits relative to retailers.

If vertical integration is prohibited, there are two alternatives for retailers to alleviate market risks. *Market transactions* as provided by forward markets or financial option markets may help to hedge against price volatility. There is indeed theoretical evidence that these market instruments can increase market efficiency (see Allaz and Vila, 1993; Willems, 2005). However, such hedging instruments involve transaction costs and do not cover all risk aspects, notably in markets that lack sufficient liquidity. As an alternative, retailers can opt directly for *(long-term) contracts* with generators. However, demand fluctuations and opposing interests between market players generally hinder a complete elimination of market risks. As Chao et al. (2005) note, both generators and suppliers have a common interest to fix *prices*, but differ with respect to fixing *volumes*. While generators aim for a constant utilisation of their capacity, retailers prefer contracts with flexible energy volumes due to load fluctuations in order not to rely on spot markets. Accordingly, at least one – if not both – contract parties are left with some remaining market risk. The complexity and dynamics of the ESI make it impossible to foresee all possible future events and environmental conditions. Therefore, contracts necessarily remain incomplete, or it would involve exorbitant transaction costs to negotiate and control the fulfilment of these contracts (see e.g. Landon, 1983). Nevertheless, lacking the possibility to vertically integrate, there is no doubt about the importance of alternative vertical arrangements to alleviate market risks.

However, there are two sides of the coin. In its Sector Inquiry, the European Commission argues in the opposite direction. Long-term contracts are criticised for reducing liquidity in spot markets and therefore causing (instead of reducing the risk of) price volatility and market power issues (see EC, 2007b). Indeed, the only difference between a long-term contract over 20 to 40 years (corresponding to the lifetime of a generator) and vertical integration is that the former lacks “direct investment and operational management and control” (Chao et al., 2005, p12). In both cases, wholesale markets are by-passed and market entry of new competitors may be hampered.

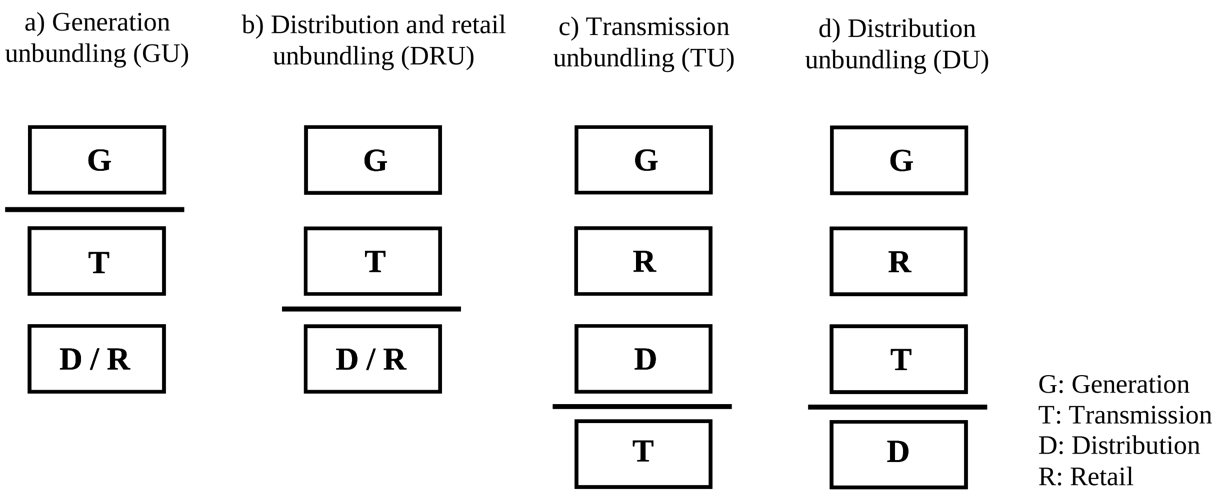
As a third group of scope effects, it is often claimed that there may also be negative synergies due to a *specialisation advantage.* The underlying argument is that a separation of supply stages may lead to efficiency gains due to a better management focus on specific tasks compared to a multi-product company. The European Commission uses this argument and claims that “experiences of full ownership unbundling suggest that it significantly changes the behaviour of the network undertaking: fully unbundled Transmission System Operators (TSOs) and Distribution System Operators (DSOs) will no longer have the incentive to favour affiliated companies – since there are none –, but can focus on optimising the use of the networks” (EC, 2007b, p.160f). The specialisation argument contains two aspects. First, there appear to be significant differences in network and supply operation. Different requirements in personnel skills and organisational structures may thus give rise to specialisation advantages if a company focuses on one group of activities. This argument has also been applied in the discussion on distribution unbundling in the Netherlands (see CPB, 2005). Indeed, it seems quite unlikely that a company after a vertical split would continue to behave as if nothing happened. Instead it would rather seek to compensate for the loss of vertical synergies by organisational restructuring. Empirically, both Ida and Kuwahara (2004) and Meyer (2010) confirm the existence of a specialisation effect in the longer run.

3.2 Reference scenarios of unbundling

Vertical economies of scope are defined as the percentage cost increase of separate production compared to vertical integration (see Baumol et al., 1982). Hence, they provide a measure for the costs of vertical unbundling. Obviously, these costs depend on where exactly the line of separation is drawn along the vertical supply chain. As the liberalisation discussion above showed, there is a large diversity of deregulation policies that have been pursued by different countries and states including the question whether or which kind of unbundling measures should be taken to ensure the most cost efficient and reliable power system.

There appear to be four main unbundling scenarios that most closely correspond to unbundling policies that have been or are going to be implemented in electricity markets around the world. Figure 2 illustrates these unbundling options and shows between which of the supply stages the line of separation is drawn.

Figure 2: Reference scenarios of unbundling



The first two scenarios correspond to electricity markets that have not introduced retail competition, as is the case for several U.S. states. In other words, the retail function is assumed to remain in the hand of the distributor that is serving its protected franchise area. Accordingly, these unbundling cases include a separation of retail activities from generation. The theoretical implication of this separation has been discussed above. We will come back to this issue below when discussing the empirical results.

Due to the fact that available data do not allow distinguishing between distribution and retail output, these two stages are combined in most empirical studies. As a consequence, the majority of studies focus on the first two scenarios in figure 2, namely *generation unbundling* (GU) and *distribution and retail unbundling* (DRU). In case of GU, transmission and distribution are often combined to one "network" stage, although containing retail as well.

The latter two unbundling options more closely reflect the European discussion focusing on the network businesses excluding retail. The most topical debate is on *transmission unbundling (TU)* pursued by the European Commission. For the case of *distribution unbundling (DU)* two examples can be found in the Netherlands and New Zealand.[15]

3.3 Concepts of vertical synergies

There is a broad range of empirical literature on vertical synergies in electricity supply. However, studies differ with respect to the underlying concepts to measure or indicate scope economies. Before turning to empirical results, a short summary of related concepts will be provided.

The most direct concept is that of *economies of scope*. The degree of economies of scope is the relative cost increase if two or more products are produced by separate firms compared to integrated production. Following the general definition of Baumol et al. (1982), economies of scope relative to a product T can be written as

$$SC_T = \frac{\left[C(Y_T) + C(Y_{-T}) - C(Y)\right]}{C(Y)}, \qquad (1)$$

where C(Y) gives the costs of integrated production of the complete output vector Y, while $C(Y_T)$ and $C(Y_{-T})$ are the stand alone costs of separately producing product T and all products except for T (i.e. Y_{-T}), respectively. Accordingly, scope economies exist, if the costs of separate production by specialised firms $[C(Y_T)+C(Y_{-T})]$ are higher than the costs of integrated production C(Y). To this end, vertical scope economies measure the costs of separating the production along the vertical supply chain.

[15] It should be noted that both the Netherlands and New Zealand have implemented ownership unbundling on the transmission level as well. Hence, it would be more precise to add another line of separation in figure 2 between retail and transmission. We simplified the graph in order to emphasize that the main focus of the DU scenario is on the single effect of separating distribution.

Another concept is that of *cost complementarities* between supply stages. If these exist, the marginal costs of serving one supply stage decrease, as the outputs at all other supply stages increase. Cost complementarities are a sufficient condition for the existence of economies of scope, but they are not necessary (see Baumol et al., 1982). Both concepts are empirically implemented by estimating a multi-stage cost function, while only the latter one provides a numerical estimate of synergies.

A third group of studies is based on a single-stage cost function and investigates *cost separability* from the other stages. This is a mathematical concept that tests whether a multi-stage cost function can be divided into separate *independent* cost functions. If cost separability is rejected, the stages cannot be analysed independently from one another due to technological externalities. A lack of separability indicates – but does not proof – the existence of vertical economies of scope.

Finally, *subadditivity* is a more general concept of scope economies. Subadditivity is given if *any* distribution of outputs among separate companies leads to higher costs compared to integrated production. Accordingly, economies of scope are a special case of subadditivity where orthogonal output vectors, i.e. a full specialisation of companies, is assumed (see Baumol et al., 1982). Subadditivity is a much stricter concept than scope economies, since it renders the whole industry a *natural monopoly*. Economies of scope, however, may still exist even in the absence of subadditivity.[16]

4 Empirical studies

Before turning to an analysis of the unbundling scenarios defined above, we shortly review some empirical studies on related concepts of scope economies.

Following a proposal by Evans and Heckman (1984), Gilsdorf (1995) uses a local test for *subadditivity* over the observed range of outputs, based on a multi-stage cost function.[17] He does not find evidence for subadditivity that would render the electricity supply industry a natural monopoly. Also Fraquelli et al. (2005) do not find evidence for a subadditive cost structure of the Italian electricity supply industry. However, as mentioned above, scope economies may exist even in the absence of subadditivity. In an earlier study, Gilsdorf (1994)

[16] For a more formal and more general discussion on these cost concepts see Baumol et al. (1982).

[17] Note that a global test for subadditivity is difficult, as one would have to test for all possible combinations of output quantities to decide whether joint production is more or less cost efficient than separate production.

tests for *cost complementarities* between the electricity supply stages, using a multiproduct translog cost function.[18] His results show that, for the average firm, marginal costs tend to increase slightly with increasing output at related stages, providing evidence against cost complementarity. In contrast, a study by Piacenza and Beccio (2004) does indeed find evidence for cost complementarity for the Italian electricity industry. Also Ida and Kuwahara (2004) confirm cost complementarities for Japan's electric power industry. According to their panel estimation, values tend to decrease over time. This indicates some kind of adjustment process after specialisation that reduces the quantitative importance of scope effects over time.

Roberts (1986) tests and rejects *separability* of the distribution stage from generation and transmission, indicating technological externalities. Thompson (1997) additionally tests for separability of generation from the network parts. Both kinds of separability are strongly rejected. Hayashi et al. (1997) reject separability of the transmission and distribution cost function from the generation stage. They find that *electricity prices* have an influence on the design of networks, thereby affecting its costs. Nemoto and Goto (2004) find negative externalities of *generation capital* on both network stages that would only be internalised if investment decisions are optimised from an overall perspective within an integrated utility. However, the explanatory power of their approach is limited to verifying the existence of network externalities. The conclusion of Nemoto and Goto (2004) that separating investment decisions leads to an overcapitalisation at the generation stage only holds if other aspects – like market risk effects of unbundling – are left aside, as these would rather argue in favour of a possible under- than overinvestment in generation assets.

Lee (1995) tests for the opposite causality of externalities, and finds that electricity costs depend on *network capital*. This result indicates the effect of network design and investments on generation costs, for instance by influencing the possibilities of capacity utilisation.

To summarise, all studies confirm the interaction between electricity supply stages, showing that these stages cannot be treated separately. Accordingly, centralised decision-making may be more efficient in finding "an optimal substitution between local generation and transmission to access distant generation" (Chao et al., 2005).

[18] As a consequence of this specification, a direct test of scope economies is not possible, since a translog function cannot handle zero values necessary for a comparison of orthogonal production vectors.

Analysing the impact of unbundling on investments, Nardi (2009) does not find a significant effect apart from enlargements at the peripheries. However, his study reveals a negative effect on quality of supply. Reversing this argument, the same level of supply quality would obviously require *more* investments. In this sense, Nardi's finding does indeed confirm a negative effect of vertical separation on network costs and additionally raises questions, whether an adequate level of investments is provided if the vertical supply chain is separated. These concerns are confirmed by Arocena (2008) who finds a negative effect of unbundling on supply security.

Although all of these studies indicate the existence of scope economies, they do not provide a direct measure for the loss of synergies due to unbundling. In the following, direct cost estimations will be presented and categorised according to the four unbundling scenarios defined above.

a) Generation unbundling (GU)

Generation unbundling (GU) shall denote a separation of generation from all remaining supply stages. Since no distinction is made between retail and distribution, this unbundling scenario corresponds to electricity markets that did not introduce retail competition. As discussed above, an important implication is that the generation stage is fully separated from retail leading to a *market risk effect* for distributors, as these have to purchase their supply requirements on the wholesale markets.

The following papers estimate a multi-stage quadratic cost function for U.S. electric utilities and combine transmission and distribution (including retail) to a single supply stage. Kaserman and Mayo (1991) show a cost increase of almost 12 percent due to separate production for the average company with a generation output (G) of 9 million MWh and transmission, distribution and retail output (T=D=R) of 7.3 million MWh. The values appear to increase strongly with the size of firms and are most significant for almost completely integrated companies, where most of the distribution output is self-generated. Kwoka (2002) uses a similar approach and finds a cost increase of almost 37 percent for the median firm (G=8.2 million MWh, and T=D=R=9.6 million MWh).[19] When scaling the outputs to a fully integrated company with 16 million MWh at all output stages, both Kaserman and Mayo

[19] Precisely, Kwoka (2002) measures the cost *savings* of vertical integration. His average value of 27 percent corresponds to a cost *increase* of 37 percent when moving from integrated to a separate production.

(1991) and Kwoka estimate scope economies as high as 72 and 75 percent. However, these values seem way too high to provide a plausible measure of the costs of unbundling. At least the strong increases of synergy effects cast serious doubt on the underlying model specifications. A more recent U.S. study of Arocena et al. (2009) estimates lower vertical synergies ranging from 4.3 to 9.7 percent.

Meyer (2010) further distinguishes transmission and distribution output to calculate scope economies for three different forms of unbundling. Here, the GU scenario shows lower values compared to Kaserman and Mayo (1991) and Kwoka (2002): a fully integrated company with a symmetric output of 16 million MWh reveals synergies of 17 percent.

Fetz (2008) analyses vertical synergies for the Suisse electricity industry. Depending on the estimation model used, the author calculates integration economies between 10 and 26 percent for the average company (G=0.2 million MWh, and T=D=R=0.6 million MWh). Similar to the studies mentioned above, scope values increase with a higher degree of vertical integration. Within his range of outputs, however, synergies first decrease with company size, while they start to increase again for larger utilities.

A detailed analysis of the scope effects in Meyer (2010) confirms that both *coordination economies* and *market risk economies* are significant in case of generation unbundling. However, results also indicate that there might be a *specialisation effect* for network companies that divested their generation assets. The existence of this specialisation advantage, which is also confirmed by Ida and Kuwahara (2004), indicates that the costs of unbundling may be significantly lower in the long run, as soon as firms are able to realise efficiency gains from restructuring.

b) Distribution and retail unbundling (DRU)

Scope estimations for the DRU case are obtained when only the distribution and retail stages are separated from generation.[20] There are some examples for studies on European markets. Fraquelli et al. (2005) estimate economies of scope for Italian distribution utilities, excluding the transmission activity. Results for the average firm (G=0.3 million MWh and D=R=0.6 million MWh) show a cost increase of 3 percent. These vertical economies also

[20] Empirically, this means that the vertical relation between transmission and the other stages either remains unchanged (as for Fraquelli et al.2005) or transmission costs are not regarded at all (as for the Spanish studies, Arocena (2008) and Jara-Díaz et al. (2004)).

increase with firm size up to a value of 79 percent (G=2.4 million MWh and D=R=4.8 million MWh).

Jara-Díaz et al. (2004) measure integration economies for the Spanish electricity industry. Since transmission networks in Spain are owned and operated by the independent company REE, only costs of generation and distribution are included in their cost estimation. For an average firm (G= 8.2 million MWh, D=R=11.35 million MWh) vertical synergies make up 8 percent. In a non-parametric DEA approach, Arocena (2008) calculates about 4 percent for a similar firm size. In general, vertical integration economies for the Spanish ESI range from 1.7 percent to 5.3 percent.[21] Applying the DRU scenario on the U.S. cost estimation, Meyer (2010) calculates synergies of 5 percent for a company size comparable to those of the Spanish estimations.

Kwoka et al. (2007) focus on the effect of unbundling on distribution network costs. Using a DEA approach for U.S. distribution companies, an average efficiency loss of 4 percent for the time period of 5 years after unbundling is estimated. Within this time frame, however, efficiency losses appear to increase from 4.1 percent in the second year after divestiture up to 15.3 percent in year five. Thus, an adjustment process due to specialisation could not be observed. However, Kwoka et al. (2007) only measure the network cost and do not take account of cost effects that may occur at the generation stage.

Summarizing these studies, it is noticeable that the estimated scope economies differ strongly depending on the specific markets that are analysed and the way the transmission stage is treated. Focusing on the studies that leave the transmission stage aside, synergies between 4 and 8 percent can be expected for a distribution company with an average output of 10 million MWh in generation and distribution.

It should be noted that these studies may overestimate the costs of unbundling for markets with retail competition. Lacking the possibility to empirically separate distribution from retail in cost function estimations ignores the fact that part of the synergies may be preserved if an integration of generation and retail is still possible and only the distribution *networks* are separated from the competitive stages. A more adequate analysis of markets with retail competition is provided by the two following scenarios.

[21] A short description of the DEA approach to calculate scope economies is given in the annex.

c) Transmission unbundling (TU)

To the best of the author's knowledge, there is only one cost function approach measuring vertical synergies for a pure *transmission unbundling (TU).* Meyer (2010) calculates vertical integration economies between 3 and 5 five percent for the U.S. industry. The estimated values decrease with company size up to an output of 28 million MWh, and slightly increase with larger outputs.

A couple of further studies investigate *price* and *efficiency effects* of transmission unbundling. Instead of vertical synergies, these studies rather estimate an overall effect, including possible efficiency gains due to an increase in competitive pressure. Steiner (2000) was the first author to provide an international comparison of electricity markets and measures the impact of several regulatory and liberalisation policies, one of which is transmission unbundling. Although results hint towards a price reduction for industrial users, they are statistically not significant. In a re-estimation of Steiner's results, Hattori and Tsutsui (2004) find a price reduction due to ownership unbundling which also lacks statistical significance. A study of Copenhagen Economics (2005a; 2005b) investigates the impact of several indicators of market opening on industrial prices. For transmission unbundling they confirm the results above since they do not find a significant influence on prices. The same holds true for the study of Growitsch et al. (2008) on ownership unbundling in the gas industry. To the author's knowledge, only one study does indeed find a significant price effect: Schober and Weber (2009) apply a regression model similar to Steiner (2002) to nine South American countries. Their results show a price decreasing effect of ownership unbundling amounting to 2 US-cents per kWh.

The fact that most of the market studies do not find significant price effects is not surprising. Due to the large number of different deregulation measures taken by countries, and given the uncertainty about their respective time-lags, an econometrical separation of the individual influences of liberalisation policies is problematic. As Joskow (2006, p73) puts it, "It is difficult to disentangle the effects of privatization, restructuring and incentive regulation".

d) Distribution unbundling (DU)

Finally, *distribution unbundling (DU)* illustrates a scenario where only the distribution business is separated from all other supply stages, while retail remains to be integrated with generation. For this scenario, no cost function approach could be found to provide a direct measurement of scope economies. Hence, we have to fall back on a couple of bottom-up studies to get an idea of the costs of distribution unbundling. With the Netherlands and New Zealand we find two examples that have been analysed empirically.

The Netherlands recently decided to implement ownership unbundling of distribution networks until 2011. In an *ex ante* welfare analysis, Deloitte (2005) estimates permanent synergy losses ranging between 350€ and 460€ million. The major part of these costs appears on the holding level and is attributed to IT systems, finance, personnel, and organisation. Roland Berger (2005) calculates somewhat smaller costs between 285€ and 400€ million. The Dutch Minister of Economic Affairs (MEA) estimates permanent restructuring costs of 150€ million, arguing that unbundling would simplify contracts and the billing system, since it would allow for a capacity-based network fee. However, no detailed breakdown of these figures is provided to underpin the argument (see De Nooij and Baarsma, 2009).

CPB (2005) emphasises that most of the synergy losses already result from the step to legal unbundling, which has been implemented on the distribution level in 2005. Accordingly, they expect further losses of an additional step to ownership unbundling to be only 100€ million.

Relating these values to the overall industry costs of the Netherlands of about 10€ billion, scope economies of distribution unbundling can be expected to roughly lie in the range of 2 to 5 percent, which is comparable to the results of transmission unbundling.[22]

For New Zealand, Nillesen and Pollitt (2008) found only temporary effects of distribution unbundling in terms of reduced commercial prices. While generation costs are not directly analysed, a decrease of network operating costs of about 17 percent was found. However, as the authors note, this effect can not undoubtedly be attributed to unbundling, but could have resulted from other deregulation policies and a so-called "regulatory threat". The latter refers to efficiency increases due to an (implicit) threat of the government that a regulator – which did not exist in New Zealand before 2003 – would be implemented in case the performance was too weak. Indeed, the discussion about establishing a regulation authority was ongoing since 1999. New Zealand's distribution utilities may have had incentives to increase their efficiency to avoid their profits to be regulated away (see

[22] These values are indeed very high. As a consequence, a social cost-benefit analysis of De Nooij and Baarsma (2007) draw a negative conclusion on the welfare effects of *distribution* unbundling.

Brunekreeft, 2003). Nevertheless, this strong decrease in network costs is surprising, given that it seems to contradict almost all theoretical and empirical findings so far.

Table 1 categorises the estimated scope economies for each unbundling scenario based on the empirical studies discussed above. Results have been transferred to fully integrated companies. However, it should be noted that these numbers can only give a rough approximation, and not all of the studies cover the full output range. Figure 3 compares the first three scenarios according to the cost function estimation of Meyer (2010).

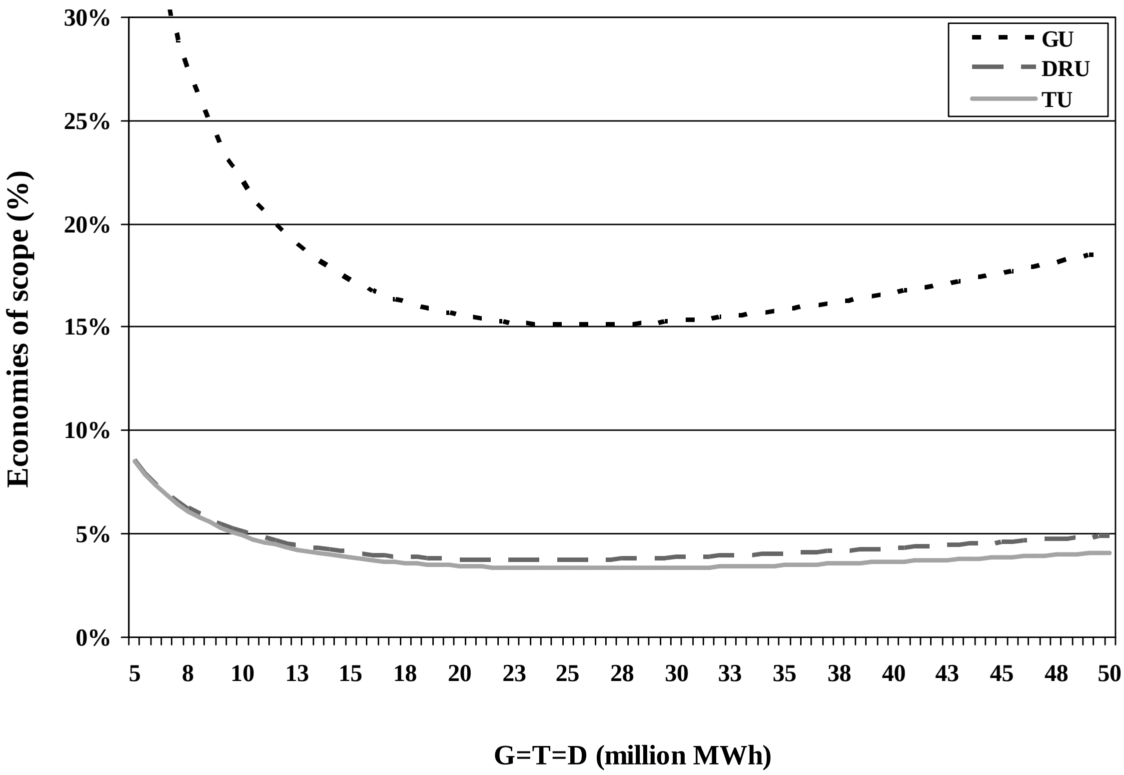
Table 1: Economies of scope for fully integrated utilities (in fractions of total costs)

Output all stages (million MWh)	**1 – 10**	**10 – 15**	**15 – 20**	**20 – 40**	**40 – 50**
Generation Unb. (GU)					
Kaserman & Mayo (1991)	<0.19	0.19–0.54	0.54–0.89	-	-
Kwoka (2002)	<0.43	0.43–0.75	0.75–1.04	-	-
Arocena et al. (2008)	-	0.04–0.10	0.04–0.10		
Meyer (2010)	<0.22	0.17–0.22	0.16–0.22	0.16–0.17	0.17–0.19
Dist. & Retail Unb. (DRU)					
Arocena (2008)	<0.04	0.04–0.05	0.04–0.05	0.04–0.05	0.04–0.05
Fraquelli et al. (2005)	>0.16	-	-	-	-
Jara-Díaz (2004)	~0.08	~0.08	-	-	-
Meyer (2010)	<0.09	~0.04	~0.04	~0.04	~0.05
Transmission Unb. (TU)					
Meyer (2010)	<0.09	0.04–0.05	0.03–0.04	0.03–0.04	~0.04
Distribution Unb. (DU)					
Deloitte (2005)[1]	0.04–0.05	0.04–0.05	0.04–0.05	-	-
Roland Berger[1]	0.03–0.04	0.03–0.04	0.03–0.04		
CPB (2005)[1]	~0.01	~0.01	~0.01	-	-

[1] Based on ex-ante welfare analysis

As table 1 indicates, empirical studies differ widely with respect to the estimated degree of scope economies for all scenarios. While the estimations show comparable values for their respective sample means, large differences occur as soon as results are transferred to larger companies. In particular, the estimations of Kaserman and Mayo (1991) and Kwoka (2002) for "large" utilities (beyond an output of 15 million MWh) seem way too high as a measure for the expected costs of unbundling. It should further be noted that all studies have in common that they cannot (and do not aim to) take account of the adjustment processes taking place after vertical separation. Although Meyer (2010) indicates the existence of such *specialisation effects*, a precise measurement of long-run effects is beyond the scope of a static cost function estimation. Furthermore, the efficiency gains resulting from *increased competition*, which in fact are a major argument for vertical unbundling, are not measured in these studies. Accordingly, the "net costs" of unbundling can be expected to be generally overestimated, while the net effect might be positive but probably small (see Brunekreeft, 2008b).

Figure 3: Economies of scope for fully integrated utilities



However, these restrictions do by no means weaken the important insights into the cost structure of electricity supply and its vertical relations that the empirical studies provide.

A major conclusion it that both *coordination economies* and *market risk economies* are important and should be considered in case of vertical restructuring. In particular, the market risk effect by splitting generation and retail appears to have a significant influence. Evidence from New Zealand, where a strong re-integration between these stages took place after distribution unbundling, confirms the importance of the risk hedging effect: by 2000, only one independent retailer remained in the market (see Bertram, 2006).[23] An important conclusion of these results seems to be that the introduction of retail competition, in the sense of granting open access to the distribution networks, is important to avoid an increase in market risks when vertical unbundling of the distribution stage from the generation level is applied. Pure network unbundling options, like transmission and distribution unbundling that still allow for an integration of the competitive supply stages, show a significantly lower loss of scope economies between 2 and 5 percent. Nevertheless, these values are still high. For the purpose of comparison: Newbery and Pollitt (1997) estimate an efficiency increase of 5 percent for the *whole* liberalisation and restructuring process in Great Britain.

It should be kept in mind, however, that the scenarios analysed are polar cases, and market structures observed in practice tend to lie in between. Comparing the GU and DRU scenario in figure 3 indicates, for instance, that the transmission stage makes an important difference. In the GU scenario, transmission is *fully separated* from generation. Accordingly, coordination losses between generation and transmission lead to higher efficiency losses compared to the DRU scenario, where these stages remain *fully integrated*. The ISO solution – that is quite common in the U.S. and is one of the European options of the third legislative package as well – represents an intermediate case, where neither full integration nor full separation is given. By outsourcing operational (and to some degree investment) decisions, much of the coordination economies may be preserved, and one might end up with significantly lower costs of unbundling compared to a strict ownership separation.

5 Conclusions

This paper reviews theoretical and empirical literature on sources and magnitudes of vertical synergies in the electricity sector as an indicator for the costs of unbundling.

Economic theory predicts two main sources of synergies, namely *coordination economies* and *market risk economies*. Furthermore, empirical evidence suggests that an opposite effect in terms of a *specialisation advantage* may occur, reducing the expected costs of unbundling at least in the long run.

Empirical results are presented for four different unbundling options. *Generation unbundling (GU)* refers to a separation of the generation stage from the two network stages

[23] For the same risk arguments, Trevino (2009) considers vertical integration, in terms of self-generation, as a business model for energy intensive consumers.

(transmission and distribution) and the retail function. This turns out to be the most costly unbundling option, since it increases both coordination costs and market risks. Synergy losses can be expected to make up 17 percent of total costs for the average company. *Distribution and retail unbundling (DRU)* involves lower coordination losses, since generation and transmission remain vertically integrated. Accordingly, only distribution and retail are separated from the combined generation and transmission stage. This scenario leads to synergy losses below 5 percent. Similar results apply to pure network unbundling. Both *transmission unbundling (TU)* and *distribution unbundling (DU)* only separate the respective network part from all other supply stages, resulting in synergy losses between 2 and 5 percent.

What conclusions can be drawn for the unbundling discussion in general and the development within the European Union in particular?

First, *transmission unbundling* does not come without a cost as it results in coordination losses between generation and transmission. Both theoretical and empirical literature indicates that network externalities may hinder efficient investment coordination unless a market mechanism – like a form of local network pricing – is established that internalises these external effects. Great Britain and Norway are examples for European countries that have gained experience with locational network charges, and the discussion has already started to extend to other European countries as well.

Second, although there is no direct empirical assessment of the *ISO* option, this may turn out to be the "golden mean". Coordination losses are most probably lower compared to ownership unbundling, given that optimisation takes place from a more integrated perspective. A critical issue is that of investment incentives, in particular the necessary split between decision-maker and risk-bearer, as required for a deep-ISO. This analysis, however, is beyond the scope of this survey (see Balmert and Brunekreeft, 2009).

Third, although the European debate focuses on transmission unbundling at the moment, *distribution unbundling* may become an issue in the near future. Given the current developments towards *smart grids*, the question whether distribution unbundling favours or hinders innovations on the distribution level has moved into the focus of discussion. New Zealand and the Netherlands provide examples for distribution unbundling.

Fourth, the analysis shows that market risk effects play an important role in vertical relations of the electric industry, in particular between the generation and retail stage. Both scenarios *generation unbundling* and *distribution and retail unbundling* correspond to electricity markets that did not establish retail competition. In other words, distributors still serve protected franchise areas as it was the case prior to liberalisation. In such an environment, the separation of generation from distribution, as analysed in both scenarios, results in a higher market risk, since distributors have to purchase electricity for their retail supply on the wholesale markets. Accordingly, they are subject to price volatility and face the risk of opportunistic behaviour of other players.

Fifth, concluding on these market risk arguments, a lesson for Europe is that – given retail competition in Europe is established – vertical integration between generation and retail may increase if distribution unbundling should be implemented in future. The re-integration between these stages that was observed both in the UK and New Zealand after distribution unbundling confirms the importance of the risk hedging effect of integration. However, as the ex-ante cost benefit studies of distribution unbundling in the Netherlands indicate, synergy losses may still be significant even if the risk effect is avoided.

Since most studies are based on the U.S. electricity industry, one should consider the structural differences between the U.S. and Europe when interpreting the empirical results. It should be noted that in Europe a *legal unbundling* restriction has already been established. This requires a functional and management separation of network and competitive businesses. Accordingly, the additional step towards ownership separation is a smaller one, compared to fully integrated systems.

Finally, it should be noted that a measurement of scope economies only covers one side of the coin, namely the cost effects of unbundling. For an overall assessment of unbundling one has to consider the expected effects on competition. The disciplining effect of increased competition on cost effectiveness may or may not outweigh the costs of unbundling. The cost benefit analysis of Brunekreeft (2008) indicates that the net effect of ownership unbundling may be positive but probably small (see Brunekreeft, 2008).

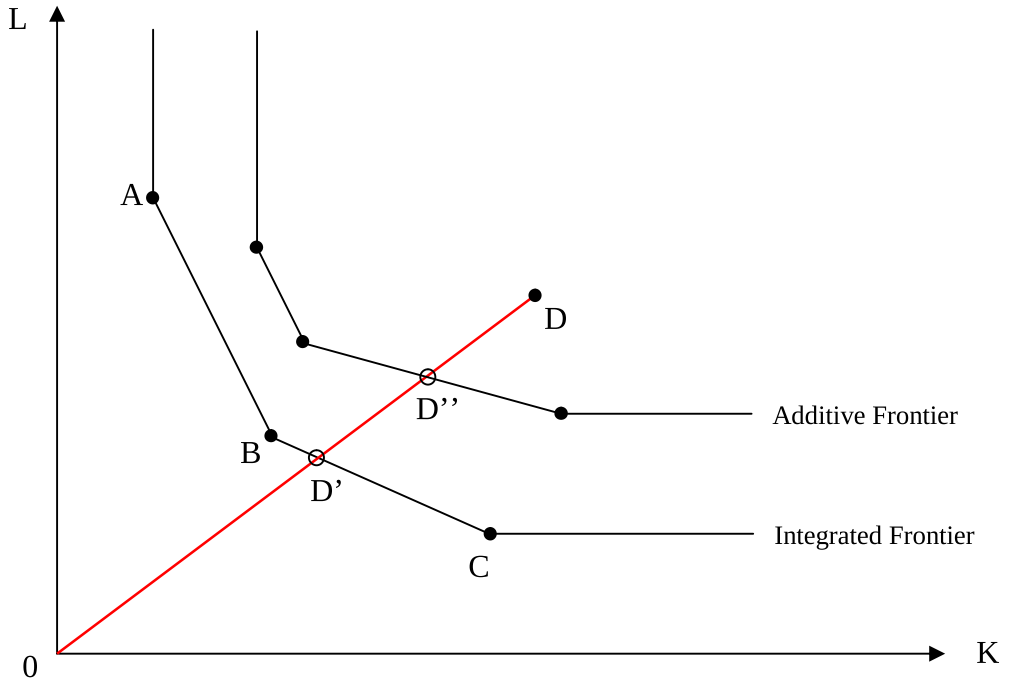
Annex

Arocena (2008) uses the non-parametric DEA approach to calculate vertical economies of scope for the Spanish ESI.[24] Based on a method introduced by Färe (1986), Arocena (2008) calculates different frontiers for integrated and separate companies, as figure 1 illustrates.

[24] There is a broad literature on parametric and non-parametric frontier approaches. See for instance Coelli et al. (2005). A comprehensive analysis of the DEA method is given by Cooper et al. (2007).

In a first step, Arocena (2008) calculates the 'integrated' frontier comparing integrated firms to their own best practice firms. In figure A1, the efficiency score of firm D is the ratio 0D'/0D. In a second step, "hypothetically integrated" firms are constructed by pairwise combining specialised generation and distribution companies, i.e. adding up costs and outputs. Comparing firm D with best practice firms under separate production ('additive' frontier), results in an efficiency score of 0D''/0D according to figure A1. Firm D turns out to be more efficient with regard to the additive than its own frontier, implying the existence of economies of vertical integration. The fact that the additive frontier lies above the integrated one indicates that even the most efficient firms perform weaker if they are vertically separated. This implies the existence of vertical economies of scope. The degree of synergies is then given by the ratio (0D'/0D) / (0D''/0D) = 0D'/0D'', where values smaller than unity imply advantages of joint production.

Figure A1: Data envelopment analysis with different frontiers (based on Arocena, 2008)



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PART TWO

Economies of Scope in Electricity Supply and the Costs of Vertical Separation for Different Unbundling Scenarios

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Abstract

Motivated by the movement towards vertical unbundling in Europe this study measures economies of scope between the electricity supply stages based on a multi-stage cost function. The paper analyses three unbundling options. Separating generation from networks and retail appears to be the most costly alternative with an average cost increase of 12 to 17 percent. If generation and transmission remain integrated but are separated from distribution and retail, average scope economies still reach up to 7 percent. A split between the transmission level and the remaining supply stages leads to a cost increase of approximately 4 percent as a result of coordination losses.

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1 Introduction

Since the beginning of the liberalisation process in the electricity sector in the 90s of the last century, the whole industry has been subject to a large number of structural changes. Although the policy measures differ strongly between countries, all of them share the common goal of promoting competition and providing sufficient investment incentives in both generation and networks to ensure efficient and secure energy supply.

One of the controversial regulatory discussions is that of a vertical ownership unbundling and its alternatives to separate the competitive functions of the industry (generation and retail) from the monopolistic network stages (transmission and distribution). The main idea is to prevent discriminatory behaviour of network owners and to enhance market entry and competition. The controversy about unbundling results from the highly interdependent structure of electricity supply. Due to non-storability of electricity and the need for real-time balancing of supply and demand, supply stages require strict coordination. This may be handled more efficiently within integrated firms than between separate companies. Furthermore, risk economies play an important role, since independent suppliers rely on long-term contracts and wholesale spot markets to purchase their electricity supply needs. Thus they are exposed to the risk of opportunistic behaviour of other market participants and the volatility of wholesale prices.

The key concept behind the arguments against strict unbundling policies is that of vertical integration economies, or economies of scope. The central question is how much unbundling costs compared to its benefits for competition.[1]

Accordingly, different philosophies of liberalisation as well as different initial conditions of the industry between countries led to a large diversity of vertical separation policies. The most noticeable discussion has taken place in the European Union, where three legislative packages enforced a movement over *legal unbundling* (including a functional and management separation) to *ownership unbundling* to be implemented in the near future.[2] The European unbundling option refers to a separation of transmission from the competitive stages

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[1] Apart from the economic analysis there are a number of constitutional issues, at least as far ownership intervention in privately owned companies is required. This discussion will not be part of this study. See Ehlers (2010) for an analysis of legal frameworks and constitutional issues for the cases of Germany, Great Britain, and the Netherlands.

[2] Alternatively, European member states have been offered the choice of implementing an independent system operator (ISO) or an independent transmission operator (ITO) (see EC, 2009). Both alternatives will not be analysed in this paper. For the underlying legislative packages of the European Commission, see EC (1996), EC (2003), and EC (2009).

generation and retail. Although retail competition is implemented in Europe, the discussion did not yet expand to ownership unbundling of distribution from retail; up to now, only legal unbundling applies.[3]

This study empirically analyses economies of scope between the vertical stages of electricity supply based on U.S. electric utility data. Following up on previous studies on vertical synergies, the paper contributes to the discussion by distinguishing between the network stages *transmission* and *distribution* instead of combining them to one network stage. This distinction allows for analysing three different unbundling scenarios comparable to policies that have been implemented or discussed in practice. The calculations are based on the estimation of a total cost function for U.S. electric utilities with varying degrees of vertical integration between generation, transmission, and distribution.

Section 2 reviews the sources of vertical economies of scope between the stages of electricity supply. In section 3, the basic unbundling options are defined. Section 4 describes the empirical methodology and the data base. The cost function estimation is presented in section 5, while the results of the unbundling scenarios are discussed in section 6. Section 7 concludes.

2 Sources of vertical economies

Vertical economies of scope exist if there is a cost advantage for firms to be engaged in two or more supply stages of an industry instead of serving only one function. The electricity sector is a classical example, where those synergies have been confirmed both theoretically and empirically.

Figure 1 illustrates the vertical stages of electricity supply and shows between which of them scope economies or diseconomies are likely to occur.

Although being interrelated, three main groups of synergies may be distinguished, namely coordination economies, market risk economies (including hold-up risks), and specialisation economies.

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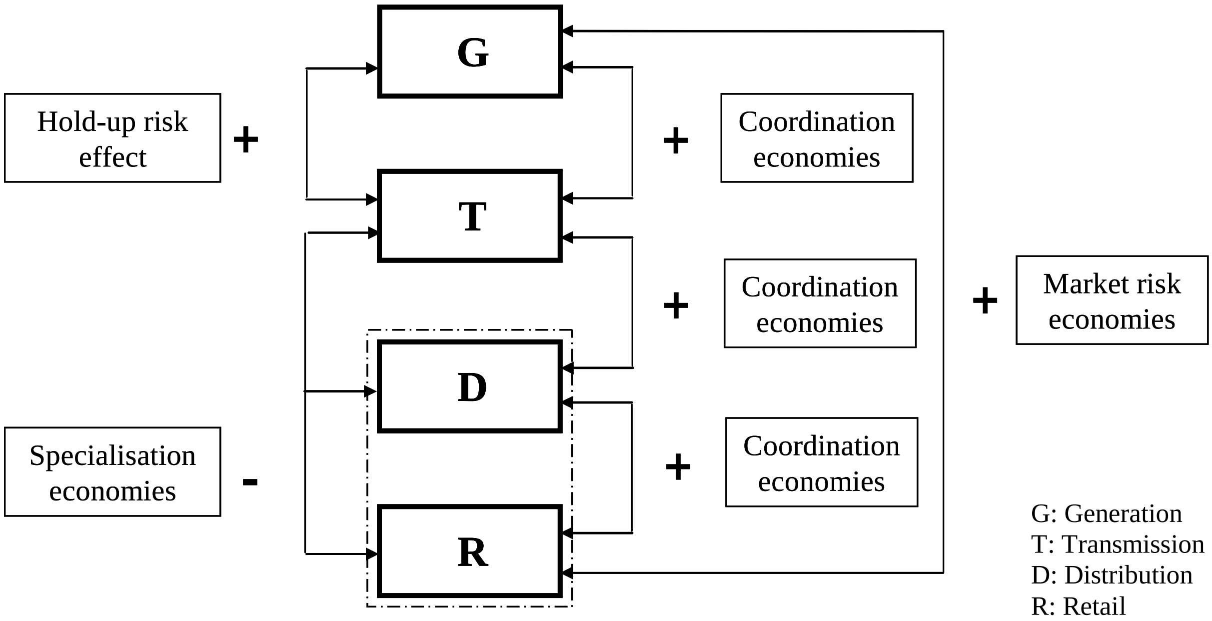
[3] However, the implementation of ownership unbundling in the Netherlands and some countries outside Europe may have paved the way for this discussion as well.

Figure 1: Supply stages and synergy effects



Coordination economies result from the technological interdependency of electricity supply. Both information and incentive problems may occur under vertical separation (see Brunekreeft and Meyer, 2009). Due to the fact that electricity supply and demand must be balanced in real-time to maintain a constant voltage and frequency in the networks, an instant coordination between all supply stages is of essential importance to keep the system working. Since the strongest interaction occurs between generation and transmission, one would expect the most significant synergies between these stages. The main argument is that the necessary exchange of *information* may be organised more efficiently by hierarchical coordination within an integrated utility than between separate companies (see Joskow and Schmalensee, 1983). The most obvious form of synergies appears when the separation of firms leads to a duplications of tasks, management or IT systems. Further problems arise in case of diverging *incentives* of the companies after unbundling. This is particularly the case for investment coordination when network externalities occur.

Market risk economies, as a second group of vertical synergies, relate to *transaction cost economics* as developed by Oliver Williamson.[4] Transaction costs can be interpreted as costs of using the market instead of firm-internal command and control mechanisms of an integrated company. Two aspects are important. First, both generation and network assets are

[4] For the theory of transaction costs see Williamson (1971, 1975, and 1979) and Hart (1995).

highly specific and irreversible investments with a long construction and operating duration. The *sunk costs* character of these investments fully exposes an investor to the risk of uncertainty and opportunistic behaviour of other market players with opposing interests. Market risks result from the incompleteness of contracts in the face of uncertain future developments, technological interdependencies and unforeseeable demand fluctuations. Second, market risk economies play an important role between the retail and generation stage. Lacking the possibility of vertical integration, retailers have to purchase their supply needs from independent generators. If relying on wholesale spot markets, suppliers face the risk of price volatility. Even in the presence of financial hedging instruments in the market, the transaction costs may be significant compared to integrated retailers, who are better capable of predicting their own generation costs.

As a third group of scope effects, it is often claimed that there may also be negative synergies due to a *specialisation advantage.* The underlying argument is that a separation of supply stages may lead to efficiency gains due to a better management focus on specific tasks compared to a multi-product company. This argument was used both by the European Commission in its Sector Inquiry (see EC, 2007) and in the discussion about distribution unbundling in the Netherlands.[5]

Several empirical studies confirm the existence and importance of vertical scope economies. Kaserman and Mayo (1991), Kwoka (2002) and Arocena et al. (2008) estimate multi-stage cost functions for the U.S. electricity industry and find significant cost savings for companies with vertical integration of generation and network output, of which the latter combines transmission and distribution. Similar estimations for Europe have been carried out by Jara-Díaz et al. (2004), Fraquelli et al. (2005), and Arocena (2008). These studies focus on distribution rather than transmission companies.[6]

Following the approaches of Kaserman and Mayo (1991) and Kwoka (2002), this paper presents a multi-stage cost function estimation. However, we refine the analysis by distinguishing between the transmission and distribution stage to provide a more detailed description of the cost function. This refinement allows for analysing three different unbundling scenarios corresponding to policy measures that have been taken in several electricity sectors around the world. Based on the cost function estimations, vertical scope

[5] For a deeper analysis of the theoretical arguments see Meyer (2010).
[6] Meyer (2010) reviews previous studies on vertical scope economies.

economies are calculated for each scenario indicating the costs of these unbundling options in terms of synergy losses.

3 Measuring scope economies

The degree of economies of scope is the relative cost increase if two or more products are produced by separate firms compared to integrated production. Following the general definition of Baumol et al. (1982), economies of scope relative to a product T are

$$SC_T = \frac{[C(Y_T) + C(Y_{-T}) - C(Y)]}{C(Y)}, \qquad (1)$$

where C(Y) gives the costs of producing the complete output vector Y, while $C(Y_T)$ and $C(Y_{-T})$ are the stand alone costs of separately producing T and all products except for T (i.e. Y_{-T}), respectively. Accordingly, scope economies exist, if the costs of separate production by specialised firms $[C(Y_T)+C(Y_{-T})]$ are higher than the costs of integrated production C(Y).

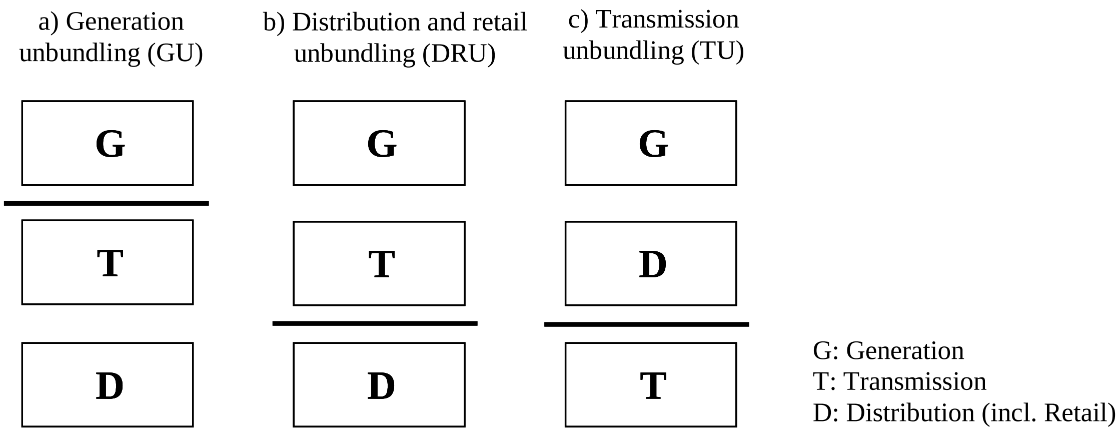
To this end, vertical scope economies measure the costs of separating the production along the vertical supply chain. Depending on which of the supply stages to be separated, scope economies can be calculated for different unbundling options. The four relevant stages of electricity supply are generation, transmission, distribution, and retail. Unfortunately, our data does not allow for an empirical distinction between distribution and retail so that both functions have to be combined in our analysis. For the simplicity of notation we mostly refer to these two supply stages as distribution. However, a distinction between distribution and retail is important for understanding the sources of vertical scope economies. When analysing the scope effects and interpreting the results, we will disentangle these downstream stages on the basis of economic theory with regard to their expected contribution to the measured scope economies.

For the purpose of this study, three unbundling scenarios are defined.

- *Generation unbundling (GU)*
- *Distribution and retail unbundling (DRU)*
- *Transmission unbundling (TU)*

Figure 2 schematically illustrates the unbundling scenarios and shows the precise location of the ownership split along the vertical supply chain.

Figure 2: Unbundling scenarios



The term *generation unbundling (GU)* shall be used for an unbundling policy, where generation is separated from both network stages and retail. Accordingly, the economies of vertical integration (EVI) are calculated as

$$EVI_{GU} = \frac{[C(G,0,0) + C(0,T,D)] - C(G,T,D)}{C(G,T,D)}. \tag{2}$$

The square brackets give the total costs under the unbundling scenario, summing up the costs of a stand-alone generator C(G,0,0) and the costs of a network and retail provider C(0,T,D). Subtracting total costs under vertical integration C(G,T,D) gives the cost increase resulting from unbundling. Following the standard definition, we measure the *relative cost increase* of this vertical split by relating the cost difference to the total costs of integrated production.

The DRU scenario is defined as a separation of distribution and retail from generation and transmission. Analogously to the formula above, scope economies result as

$$EVI_{DRU} = \frac{[C(G,T,0) + C(0,0,D)] - C(G,T,D)}{C(G,T,D)}. \tag{3}$$

Finally, we regard the TU option, where the transmission networks are separated from all other supply stages. Accordingly, scope economies are given as

$$EVI_{TU} = \frac{[C(G,0,D) + C(0,T,0)] - C(G,T,D)}{C(G,T,D)}. \tag{4}$$

A more detailed analysis of the political relevance of the unbundling options will be given in section 6, along with the empirical results.

4 Cost function and data

Calculating economies of scope for the scenarios defined above requires the estimation of a multi-stage cost function for the electricity sector. As in most previous studies a quadratic cost function is applied.[7] Neglecting other than output variables for the moment, the main part of the cost function can be written as

$$C(G,T,D) = \alpha_0 + \beta_1 G + \beta_2 T + \beta_3 D + \gamma_1 G^2 + \gamma_2 T^2 + \gamma_3 D^2$$

$$+ \delta_{12} GT + \delta_{13} GD + \delta_{23} TD \,. \tag{5}$$

Accordingly, the major part of costs depends on the linear and quadratic terms for the three outputs considered, generation (G), transmission (T), and distribution (D). As mentioned above, however, distribution actually includes retail. The last three terms of (5) are the interaction variables between the supply stages. Each of these terms denotes whether for two stages costs increase or decrease if a firm produces both outputs. A negative sign of δ_{12} for GT, for instance, indicates economies of scope between the generation and transmission stage. The value of scope economies for the three unbundling scenarios is calculated by applying formulas (2), (3), and (4) to the estimated cost function, respectively.

The complete cost function is given by equation (6). Therein, $C(G,T,D,\mathbf{Z})$ is total costs (TOTEX), defined as operating (OPEX) and capital costs (CAPEX). More precisely, OPEX includes operating cost, maintenance costs, and depreciation. CAPEX is calculated as the price of capital (as defined below) multiplied by the value of net utility in service. All monetary values are in U.S. dollars at constant prices according to the U.S. consumer price index. The vector of control variables is denoted as **Z**.

An important adjustment has been made with respect to the interaction term between transmission and distribution. Data analysis revealed differences in the firms' cost structures regarding the relationship between these supply stages. Therefore, two dummy variables have been defined. For those companies being integrated over all supply stages ("generating firms"), the cost interaction is captured by TD_{GEN}. For transmission and distribution utilities without generation ("network firms"), the same effect is covered by the parameter TD_{NET}.

[7] The most prominent alternative, a translog cost function, cannot be applied here, since it does not allow for zero-values in outputs.

$$C(G,T,D,\mathbf{Z}) = \alpha + \alpha_{NET} + \beta_1 G + \beta_2 T + \beta_3 D + \gamma_1 G^2 + \gamma_2 T^2 + \gamma_3 D^2 + \delta_{12} GT + \delta_{13} GD$$
$$+ \delta_{23} TD_{GEN} + \delta'_{23} TD_{NET} + \mu_1 PFUEL + \mu_2 PLABOUR + \mu_3 PCAPITAL$$
$$+ \omega_{11} GPFUEL + \omega_{12} GPLABOUR + \omega_{13} GPCAPITAL + \omega_{22} TPLABOUR + \omega_{23} TPCAPITAL$$
$$+ \omega_{32} DPLABOUR + \omega_{33} DPCAPITAL + \theta_1 NUCSHARE + \theta_2 RSC + \theta_3 RSC^2 + \theta_4 t, \quad (6)$$

with:

α: constant
α_{NET}: dummy for network firms
G: GEN [MWh]
T: TRANS [MWh]
D: DIST (incl. retail) [MWh]
GT: GEN × TRANS [MWh^2]
GD: GEN × DIST [MWh^2]
TD_{GEN}: TRANS × DIST [MWh^2]
(dummy for generating firms)
TD_{NET}: TRANS × DIST [MWh^2]
(dummy for network firms)
PFUEL: price of fuel [$/MWh]

Plabour: price of labour [$/FTE/year]
Pcapital: price of capital
GPFUEL: GEN × PFUEL [$]
GPLABOUR: GEN × PLABOUR [$MWh/FTE/y]
GCAPITAL: GEN × PCAPITAL [MWh]
TPLABOUR: TRANS × PLABOUR [$MWh/FTE/y]
TPCAPITAL: TRANS × PCAPITAL [MWh]
DPLABOUR: DIST × PLABOUR [$MWh/FTE/y]
DPCAPITAL: DIST × PCAPITAL [MWh]
NUCSHARE: share of nuclear generation
RSC: Residential sales per customer [MWh]
t: time index; t=1,…,8

Furthermore, the cost function is extended by control variables to capture influences of input prices and structural parameters on the firms' costs.

- We include input prices for generation fuel, labour, and capital. Price of fuel is calculated as fuel costs divided by generation output. Price of labour is the sum of salaries and wages per full-time employee. Price of capital is a weighted average for the price of proprietary capital and long-term debt.[8]
- Following Kwoka (2002), we include the interaction terms between input prices and outputs to cover progressive influences of prices with varying output quantities.
- Finally, there are three variables to control for the share of nuclear power production (*NUCSHARE*) and the average residential sales per customer in linear and quadratic form (*RSC*, RSC^2). The latter serve as substitutes for distribution density, which could not be calculated due to missing data on distribution network length.

[8] The price of proprietary capital is the sum dividends for common and preferred stock and retained earnings divided by proprietary capital. The price of long-term debt is the interest on long-term debt divided by long-term debt outstanding. The calculation of capital prices is based on Kolbe and Read (1986).

Data stem from FERC form 1 data for U.S. electric utilities for the period of 2001 to 2008 with varying degrees of vertical integration. In order to reduce the number of estimated coefficients, the sample is restricted to relatively homogenous generation companies with a focus on steam and nuclear power production. Table 1 describes the database.

Table 1: Overview of database

Variable (scale)	Average	Min	Max
TOTEX (10^6 $)	653.12	0.26	5,219.06
GEN (10^6 MWh)[1]	16.06	0	93.15
TRANS (10^6 MWh)[1]	24.59	0	194.61
DIST (10^6 MWh)[1]	15.79	0	87.06
STEAMSHARE	0.54	0	1.00
NUCSHARE	0.12	0	1.00
HYDROSHARE	0.01	0	0.09
PFUEL ($/MWh)	19.00	2.76	97.91
PLABOUR (10^3 $ / FTE)	85.12	29.62	390.05
PCAPITAL	0.11	0.02	0.73
RSC	8.49	0	19.38
No. of observations	971		

[1] only firms active on respective supply stage

5 Estimation

The total costs are regressed on the linear and quadratic outputs, interaction terms and control variables according to equation (6). The Prais-Winsten Regression was performed to cope with the panel typical autoregression of disturbance terms and heteroscedasticity (see Prais and Winsten, 1954). Two estimation models have been applied. Model (a), covers our complete data set. As mentioned above, the scope effects between transmission and distribution are captured by two dummy variables depending on whether the company is engaged in generation or not. Model (b) uses a reduced sample that excludes sole transmission and distribution companies in favour of a single scope parameter for the network stages. Table 2 shows the estimation results.

Table 2: Estimation results

	Model (a)		Model (b)	
Variable (scale)	Coefficient	z-value	Coefficient	z-value
CONSTANT (10^6)	29.50	1.99**	41.80	1.50
$CONSTANT_{NET}$ (10^6)	81.10	4.56**		
GEN	13.50	5.06**	12.20	4.15**
TRANS	1.69	1.08	-0.36	-0.19
DIST	13.80	5.75**	14.20	3.67**
GENSQ (10^{-6})	0.18	2.63**	0.18	2.94**
TRANSSQ (10^{-9})	1.58	0.15	-6.01	-0.54
DISTSQ. (10^{-9})	-0.83	-1.16	0.41	1.00
GEN × TRANS (10^{-6})	-0.18	-3.66**	-0.15	-2.65**
GEN × DIST (10^{-6})	-0.19	-2.23**	-0.29	-4.93**
TRANS × DIST (GEN) (10^{-6})	0.15	2.74**	0.22	4.31**
TRANS × DIST (NET) (10^{-6})	-0.08	-2.07**		
PFUEL (10^6)	0.18	0.97	0.18	0.97
PLABOUR (10^3)	-0.34	-2.01**	-0.25	-0.96
PCAPITAL (10^6)	77.20	1.33	105.00	0.73
GEN × PFUEL	0.86	14.59**	0.84	11.78**
GEN × PLABOUR (10^{-6})	2.91	0.16	-11.40	-0.39
GEN × PCAPITAL	41.00	5.83**	49.20	3.35**
TRANS × PLABOUR (10^{-6})	32.60	1.87*	37.20	1.93*
TRANS × PCAPITAL	-16.90	-2.56**	-12.40	-1.80*
DIST × PLABOUR (10^{-6})	-34.30	-1.48	1.41	0.05
DIST × PCAPITAL	69.00	6.38**	47.90	2.90**
NUCSHARE (10^9)	0.17	4.47**	0.23	5.67**
RSC (10^6)	-0.63	-0.15	1.86	0.31
RSCSQ (10^6)	-0.57	-2.24**	-0.75	-2.03**
t (10^6)	4.55	1.58	2.24	0.67
R^2		0.981		0.983
No. of observations		971		745

** significant at 5% level
* significant at 10% level

Most of the estimated coefficients appear to have plausible signs and values. The estimator for *GEN* is relatively low, since it averages marginal costs of fossil and nuclear production. On the other hand, the higher fixed costs of nuclear generation are controlled for by *NUCSHARE*. Furthermore, the parameter for *TRANS* lacks significance in both models. For the generation stage diseconomies of scale are observed, while the transmission and distribution stages neither show economies nor diseconomies of scale. However, distribution costs appear to decrease with an increase of demand density, as shown by the negative coefficient for the squared values of residential sales per residential customer (RCSSQ).

Turning to the vertical scope effects, the four interaction terms are of particular interest. The negative coefficient *GEN* × *TRANS* indicates vertical synergies between the generation and the transmission stage. This result can be attributed to a *coordination effect* in the sense of transaction cost theory: firm internal coordination is expected to be more efficient than market coordination as a result of costly, incomplete and/or inflexible contracts of market participants pursuing different or opposing interests.

A second scope effect can be observed between the generation and the distribution stage as the negative parameter for *GEN* × *DIST* indicates. For an explanation it is important to recall that distribution in our data includes retail. As the majority of generation assets are not directly connected to the distribution wires, one would not assume significant synergies between these functions. However, generation and retail activities are strongly related, since retailers without own generation assets have to purchase their supply needs from the market. Vertical integration may serve as an efficient way to hedge against the market risk caused by the volatility of wholesale prices. This argument also relates to transaction cost theory and stresses the importance of suitable market instruments to alleviate what we refer to as the *market risk effect*. [9] Table 2 reveals that this effect is larger for model (b) than for model (a).

A third group of synergy effects relates to the transmission and distribution stage. In our complete model (a), we used two interaction terms to capture the cost relations between these stages. Results show a significant difference between companies that are integrated over all supply stages and those that specialised on transmission and distribution. The first group will be referred to as *generating firms* (GEN) and the latter group as *network firms* (NET) in the following.

For generating firms, a positive parameter for *TRANS* × *DIST (GEN)* indicates diseconomies of scope. While such an effect can hardly apply to the network services, the explanation may again concern the retail function as part of distribution.

One could argue for a kind of *specialisation effect*, when a firm's management focuses either on the transmission network business or the supply and marketing tasks that are required for the retail business. Differences in network and supply operation may favour different organisational structures and personnel skills, and may thus give rise to

[9] The market risk argument plays a central role in the liberalisation discussion. The question to what extent long-term contracts or financial contracts can alleviate this problem is beyond the scope of this study. For an economic analysis of the importance of vertical arrangements for market performance see Bushnell (2004), Bushnell et al. (2004), and Willems (2005).

specialisation advantages.[10] Furthermore, integrated firms are likely to have distorted incentives in favour of their more profitable supply business. Depending on the degree of regulatory oversight, network operation may degrade to a strategic means to favour own supply interests while disfavouring competitors. Integrated firms may accept certain efficiency losses in network operation in favour of increased profits in generation or supply. Empirically, this may explain the appearance of a negative scope effect.

It is interesting to observe that for network firms without generation, the negative sign for the dummy variable *TRANS × DIST (NET)* reveals the opposite effect compared to generating firms: these utilities tend to realise economies of scope between the downstream activities. As both interaction dummies are clearly significant, this seems to provide empirical evidence for a different cost structure for generating and network firms. Following the argumentation above, a transmission and distribution utility without generation assets may adjust both its organisational structure and its strategic behaviour such that it is able to exhaust scope economies between its supply stages, while a completely integrated utility may be willing to sacrifice these economies for strategic reasons in favour of higher supply profits. Alternatively, it could be argued that the different sign of TD_{NET} results from a selection bias. Obviously, a network firm realising diseconomies between its only two businesses would either decide to fully split into separate companies or try to acquire generation assets to at least exhaust scope economies to the upstream stage. As a consequence, only those network firms that are able to realise scope economies between the downstream stages, would remain in the market.

As an alternative, we added a reduced model (b) that excludes the separate network companies from the sample. What remains then is a negative coefficient for *TRANS × DIST*, indicating diseconomies of scope that are even larger than the respective parameter in model (a). A comparison of both model results can be useful for at least two reasons. First, in case of a selection bias one might prefer model (b) as a more adequate approximation of the industry's cost structure. This is equivalent to interpreting the network firms as kind of outliers. Second, the difference in cost coefficients may indeed indicate a different cost structure resulting from a (long-term) adjustment process.

[10] This argument corresponds to the European Commission's claim of an improved management focus on network operation under ownership unbundling (see EC, 2007, p.160f). See also Meyer (2010) for a review of the Commission's arguments.

6 Results and interpretation

a) Generation unbundling (GU)

Generation unbundling (GU) refers to a separation of generation from both networks and retail. In practice, such an industry structure can be historically grown or can be the result of a divestiture policy. Some U.S. states like California pursued a divestiture of generation assets to strengthen the wholesale market. The idea is that a larger part of retail supply requirements should be traded over the wholesale market instead of self generation to increase liquidity of the market, aiming to reduce volatility of market prices and market risk. Market entry of independent generators is supposed to enable efficiency gains through increased competition. Our GU scenario assumes that transmission ownership and operation remain under control of distribution utilities.[11] Tables 3a and 3b show the calculated scope economies for different output combinations for model (a) and (b), respectively. Each cell in the table shows the percentage cost increase of stand-alone production compared to vertical integration. The values are calculated by applying formula (2) to the estimated cost function. Figure 3 gives a graphical representation for the case of fully integrated companies, i.e. utilities with the same output at all supply stages are used as reference for the calculation of scope economies.

[11] This is indeed a difference to many U.S. markets (including California) in which Independent System Operators (ISOs) are in charge of operating the transmission networks. One could make the point that in an ISO system coordination efficiency between generation and transmission may be higher than under a completely separate structure. In this case, our scenario results would overestimate the costs of a stand-alone generation stage.

Table 3a: GU scenario: relative cost increase for model (a)

T=D \ G	5	10	15	20	25	30	35	40	45	50
5	0.38	0.25	0.20	0.19	0.18	0.19	0.21	0.22	0.24	0.26
10	0.31	0.22	0.19	0.18	0.18	0.19	0.20	0.22	0.24	0.26
15	0.25	0.20	0.17	0.17	0.17	0.18	0.20	0.21	0.23	0.25
20	0.21	0.17	0.16	0.16	0.16	0.17	0.19	0.21	0.23	0.25
25	0.17	0.15	0.14	0.14	0.15	0.16	0.18	0.20	0.22	0.24
30	0.14	0.13	0.12	0.13	0.14	0.15	0.17	0.19	0.21	0.23
35	0.11	0.10	0.10	0.11	0.12	0.14	0.16	0.18	0.20	0.22
40	0.09	0.08	0.09	0.10	0.11	0.13	0.15	0.17	0.19	0.21
45	0.06	0.06	0.07	0.08	0.10	0.11	0.13	0.15	0.18	0.20
50	0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.19

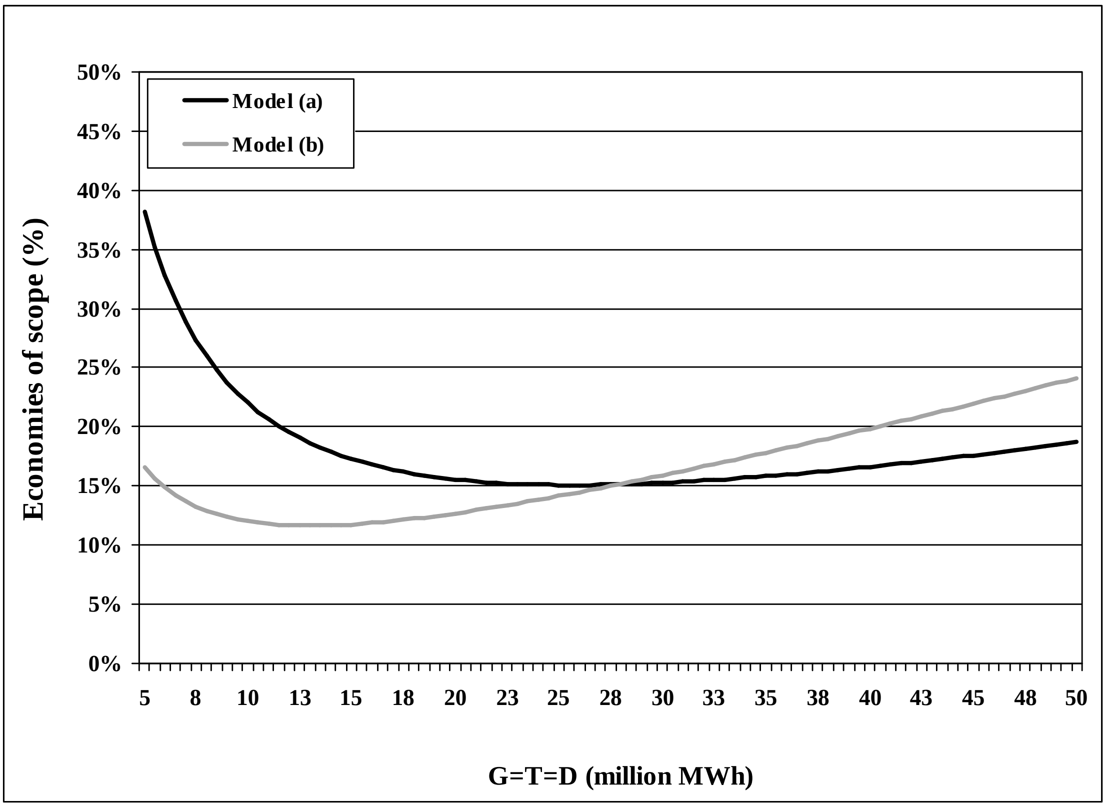
G: generation output (million MWh)
T=D: transmission and distribution output (million MWh)

Table 3b: GU scenario: relative cost increase for model (b)

T=D \ G	5	10	15	20	25	30	35	40	45	50
5	0.17	0.13	0.12	0.13	0.14	0.16	0.17	0.19	0.21	0.24
10	0.14	0.12	0.12	0.13	0.14	0.16	0.18	0.20	0.22	0.24
15	0.13	0.12	0.12	0.13	0.14	0.16	0.18	0.20	0.22	0.24
20	0.12	0.11	0.12	0.13	0.14	0.16	0.18	0.20	0.22	0.24
25	0.11	0.11	0.12	0.13	0.14	0.16	0.18	0.20	0.22	0.24
30	0.11	0.11	0.11	0.13	0.14	0.16	0.18	0.20	0.22	0.24
35	0.10	0.10	0.11	0.13	0.14	0.16	0.18	0.20	0.22	0.24
40	0.10	0.10	0.11	0.12	0.14	0.16	0.18	0.20	0.22	0.24
45	0.09	0.10	0.11	0.12	0.14	0.16	0.18	0.20	0.22	0.24
50	0.09	0.10	0.11	0.12	0.14	0.16	0.18	0.20	0.22	0.24

G: generation output (million MWh)
T=D: transmission and distribution output (million MWh)

Figure 3: GU scenario: integration economies for fully integrated utilities



The GU scenario appears to be the most costly unbundling option as both the *coordination effect* (by separating generation from transmission) and the *market risk effect* (by separating generation from distribution) arise. For a utility that produces an output of 16 million MWh on all stages, which is relatively close to the average company in the sample, scope economies range from 12 percent (model (b)) to 17 percent (model (a)). The differences result from the fact that in model (a) the dummy variable indicates higher fixed costs for network firms dominating the costs up to an output of 28 million MWh. On the other hand, non-generating firms in model (a) do not face diseconomies of scope between transmission and distribution. Therefore, the increase in scope economies with increasing firm size appears to be smaller in model (a) than in model (b). There is reason to be sceptical about the strong increase of values in model (b). On the other hand, both Kaserman and Mayo (1991) and Kwoka (2002) estimate even stronger increases of scope economies with firm size for a comparable scenario.[12]

[12] Taking the average company of our sample as benchmark, these studies estimate cost increases of 72 percent and 80 percent, respectively.

b) Distribution and retail unbundling (DRU)

The DRU scenario leaves generation and transmission integrated and only separates distribution and retail from the upstream stages. Tables 4a and 4b give the empirical results for both models, while figure 4 gives a graphical representation.

Scope economies appear to be lower compared to the GU scenario, since there are no *coordination losses* between generation and transmission. As before, however, there remains the *market risk effect* of splintering generation from the downstream supply stages. For the average company, scope economies range from 4 to 7 percent. The higher values in model (b) for all company sizes is an indirect effect of the different specification, since the market risk effect turns out to be higher in the reduced model compared to model (a).

Table 4a: DRU scenario: relative cost increase for model (a)

D \ G=T	5	10	15	20	25	30	35	40	45	50
5	0.09	0.06	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02
10	0.07	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02
15	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
20	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03
25	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
30	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
35	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
40	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
45	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05
50	0.03	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05

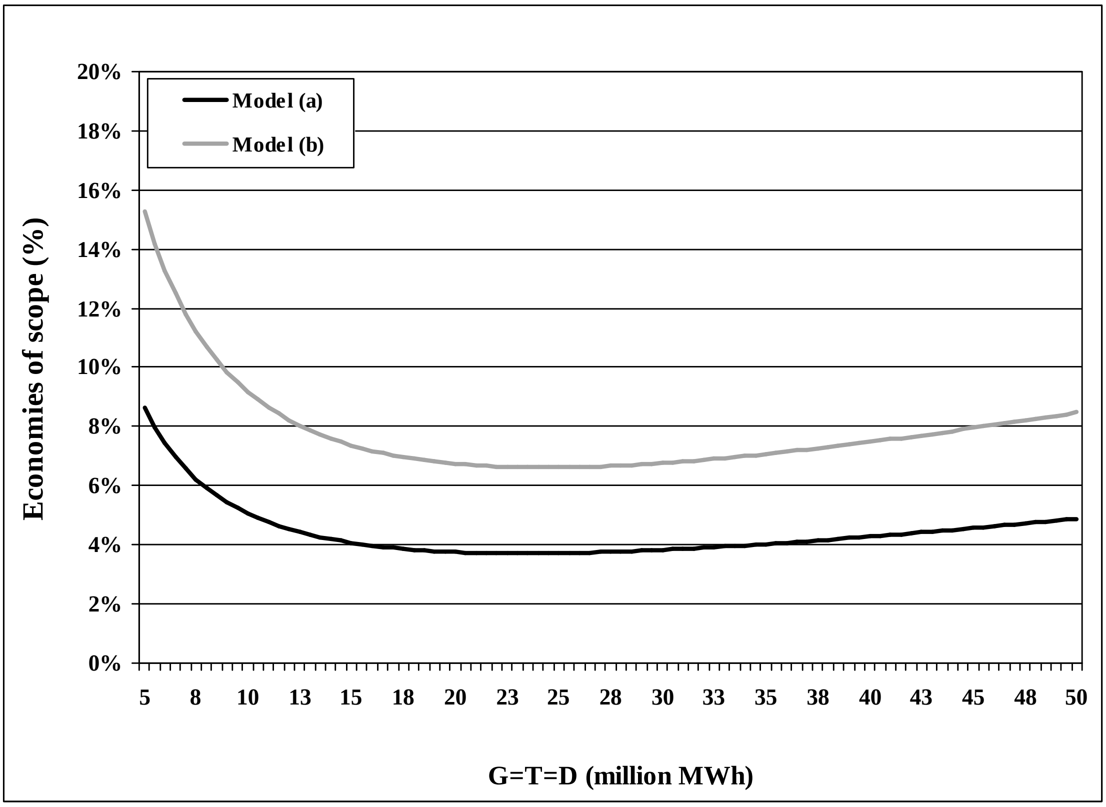
G=T: generation and transmission output (million MWh)
D: distribution output (million MWh)

Table 4b: DRU scenario: relative cost increase for model (b)

D \ G=T	5	10	15	20	25	30	35	40	45	50
5	0.15	0.10	0.08	0.07	0.06	0.05	0.04	0.04	0.04	0.04
10	0.12	0.09	0.08	0.07	0.06	0.05	0.05	0.05	0.04	0.04
15	0.10	0.08	0.07	0.07	0.06	0.06	0.06	0.05	0.05	0.05
20	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
25	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
30	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
35	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
40	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08
45	0.05	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.08	0.08
50	0.05	0.06	0.06	0.07	0.07	0.08	0.08	0.08	0.08	0.08

G=T: generation and transmission output (million MWh)
D: distribution output (million MWh)

Figure 4: DRU scenario: integration economies for fully integrated utilities



c) Transmission unbundling (TU)

In the TU scenario, the transmission stage is separated from all other supply stages. As the results in table 5a and 5b reveal, it appears to be the least costly unbundling alternative. In practice, it is equivalent to the option of strict ownership unbundling as part of the European Third Legislative Package (see EC, 2009).[13]

Although there are *coordination losses* between the generation and transmission stage, this unbundling option avoids the effect of *market risk* that would result from a split between generation and retail as well as the diseconomies to be expected between transmission and retail due to the *specialisation effect*. Tables 5a and 5b give the numerical results, while figure 5 shows the scope effects graphically.

Table 5a: TU scenario: relative cost increase for model (a)

T \ G=D	5	10	15	20	25	30	35	40	45	50
5	0.09	0.05	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01
10	0.08	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02
15	0.08	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02
20	0.08	0.05	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02
25	0.08	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
30	0.08	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03
35	0.08	0.06	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03
40	0.08	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.03
45	0.08	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04
50	0.08	0.06	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04

G=D: generation and distribution output (million MWh)
T: transmission output (million MWh)

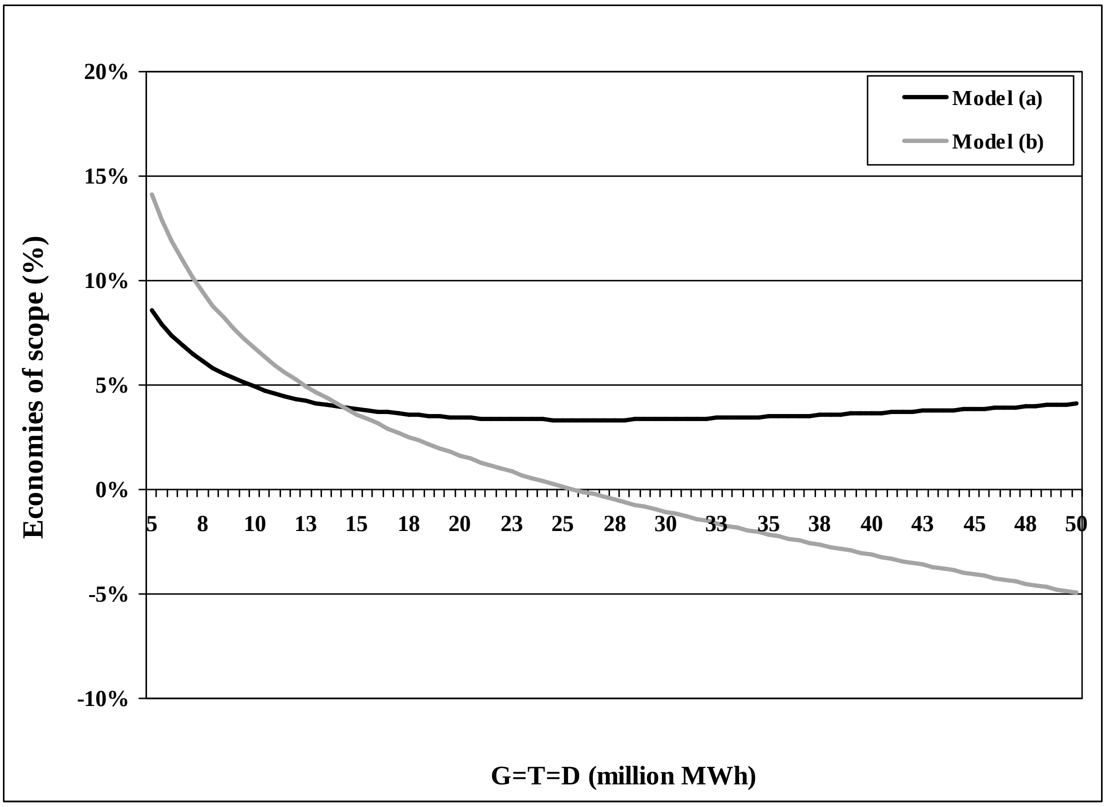
[13] A main difference to the European practice is that the starting point in Europe is that of *legal unbundling*. This means that management and accounting separation already applies (including the application of firewalls). The costs of an additional step from legal to ownership separation are therefore overestimated by our results. Furthermore, one has to keep in mind that the analysis is based on the U.S. industry which structurally differs from the European electricity markets. Therefore, a direct transfer of numerical results is not possible.

Table 5b: TU scenario: relative cost increase for model (b)

T \ G=D	5	10	15	20	25	30	35	40	45	50
5	0.14	0.07	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01
10	0.13	0.07	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.00
15	0.12	0.06	0.04	0.02	0.01	0.01	0.01	0.00	0.00	0.00
20	0.12	0.05	0.03	0.02	0.01	0.00	0.00	0.00	-0.01	-0.01
25	0.11	0.05	0.02	0.01	0.00	0.00	-0.01	-0.01	-0.01	-0.02
30	0.10	0.04	0.02	0.00	0.00	-0.01	-0.01	-0.02	-0.02	-0.02
35	0.09	0.03	0.01	0.00	-0.01	-0.02	-0.02	-0.02	-0.03	-0.03
40	0.09	0.03	0.00	-0.01	-0.02	-0.02	-0.03	-0.03	-0.03	-0.04
45	0.08	0.02	0.00	-0.01	-0.02	-0.03	-0.03	-0.04	-0.04	-0.04
50	0.08	0.02	-0.01	-0.02	-0.03	-0.04	-0.04	-0.04	-0.05	-0.05

G=D: generation and distribution output (million MWh)
T: transmission output (million MWh)

Figure 5: TU scenario: integration economies for fully integrated utilities



For a utility of average size, scope economies are 4 percent. However, there is a large difference between the two model specifications regarding size effects. For model (a) the results are relatively stable according to firm size, while scope economies in model (b) strongly decrease with increasing outputs and turn into diseconomies beyond an output of 27 million MWh. Econometrically, this size effect results from a smaller coefficient for coordination losses between generation and transmission that dominates the results for larger outputs. From an economic point of view it seems questionable though whether such a large size effect is plausible. However, one should be cautious anyway about interpreting the results for companies that are significantly larger than the sample average. Interpreting the results locally, both models predict an average synergy loss of 4 percent.

7 Conclusions

This study empirically analyses economies of scope between the supply stages of the electricity industry based on a multi-stage total cost function for U.S. data from 2001 to 2008. Following up on previous studies on vertical synergies, the paper contributes to the unbundling discussion by providing a separation of the network stages transmission and distribution which allows for analysing three different unbundling scenarios, generation unbundling (GU), distribution and retail unbundling (DRU), and transmission unbundling (TU). The GU option refers to a separation of the generation stage from both network stages transmission and distribution, where distribution includes the retail function. Generation unbundling reveals the highest synergies ranging from 12 percent to 17 percent on average. The reason is that both *coordination losses* and the *market risk effect* contribute to the increase in costs as a result of vertical separation.

In the DRU option, generation and transmission remain integrated and only the distribution stage (including retail) is vertically separated. This scenario leads to a 4 to 7 percent loss of synergies due to *market risk*, while *coordination* between generation and transmission can still be realised firm internal.

The lowest cost increase arises under the TU scenario with 4 percent on average. This scenario corresponds to the option of ownership unbundling as part of the European Third Legislative Package. A separation of transmission from the remaining supply stages involves a loss of *coordination economies* between generation and transmission, but there is no increase in *market risk*, since generation and distribution (more precisely: retail) remain vertically integrated.

Differences appear between the two models applied. There is empirical evidence that for separate network firms scope economies between transmission and distribution are present, while diseconomies occur for generating firms. Model (a) controls for this effect by dummy variables, while model (b) uses a reduced sample excluding sole network companies

The results confirm previous studies in concluding that significant economies of scope exist between the stages of electricity supply. Qualitatively, the results are in line with economic theory and indicate that a complete decentralisation of the industry due to ownership separation does not come without a cost.

What conclusions can be drawn for the unbundling discussion in general and the development within the European Union in particular?

First, vertical economies resulting from market risk compensation between generation and retail play an important role as our scenario of *distribution and retail unbundling* shows. This should be distinguished from a pure *distribution unbundling* like in New Zealand and the Netherlands, where the retails part is still allowed to integrate with generation. The re-integration between these stages that has taken place after distribution unbundling in New Zealand confirms the importance of the market risk effect. If in Europe distribution unbundling becomes an issue for the future, a stronger vertical integration of retailers with generators may results for the European market as well and should, according to our results, not be prohibited. The cost increase of a sole distribution unbundling is supposed to be moderate, if risk compensation between the competitive stages is not hindered.

Second, *transmission unbundling* leads to coordination losses and market transaction costs. For the European Union, the loss of scope economies should be even lower, as a functional and management unbundling is already established, and the additional step towards ownership separation is a smaller one, compared to fully integrated systems as in empirical studies on the U.S. markets. However, one should not take the numerical values too literally, since structural differences between the U.S. and the European electricity markets are significant.

Third, it should be noted that a comprehensive assessment of ownership unbundling is beyond the scope of this paper. Estimations of scope economies only give an idea of the costs of unbundling, but do not measure its benefits. If competition increases as a result of preventing discriminatory behaviour and providing a level playing field, efficiency effects may compensate for the synergy losses from vertical disintegration. Furthermore, empirical cost estimates only give a snapshot of which cost effects unbundling has on integrated companies. Separate companies may find alternatives to compensate for missing vertical synergies; market and regulatory experience will increase and may lower transaction costs as well as market risk over time.

Finally, a remaining issue is that of investment coordination in an unbundled world. Whether or to what extent network externalities can efficiently be internalized between separate companies by market mechanisms remains to be an open question and needs further research with a more detailed view on market characteristics.

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PART THREE

Benchmarking Economies of Vertical Integration in U.S. Electricity Supply: An Application of DEA

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Abstract

This study applies a frontier benchmarking approach to measure economies of scope between the vertical stages of electricity supply in the U.S. electricity industry. By comparing different frontiers for integrated and separate provision of electricity based on a bootstrapping DEA, two types of vertical unbundling are analysed. Separating the generation stage from networks and retail appears to be the more costly alternative with an average cost increase of 18 percent. Our second scenario, covering one of the options of transmission unbundling to be implemented in the European Union, shows an average cost increase below 2 percent.

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1 Introduction

Since the beginning of the liberalisation process in the electricity sector in the 90s of the last century, the whole industry has been subject to a large number of structural changes. Although the policy measures differ strongly between countries, all of them share the common goal of promoting competition and providing sufficient investment incentives in both generation and networks to ensure efficient and secure energy supply.

One of the controversial discussions is that of a vertical ownership unbundling and its alternatives to separate the competitive functions of the industry (generation and retail) from the monopolistic network stages (transmission and distribution) that aims to prevent discriminatory behaviour of network owners in favour of their own supply interests. The most noticeable discussion has taken place in the European Union, where three legislative packages enforced a movement over *legal unbundling* (including a functional and management separation) to *ownership unbundling* of transmission from the competitive supply stages to be implemented in the near future.[1]

The controversy about unbundling results from the highly interdependent supply stages in terms of coordination requirements and network externalities. Theory and empirical evidence indicate that investment coordination and operative coordination may be handled more efficiently within integrated firms than between separate companies. Furthermore, risk economies play an important role, since independent suppliers rely on long-term contracts and wholesale markets to purchase their electricity supply needs.

The key concept behind the arguments against strict unbundling policies is that of vertical integration economies, or economies of scope. The central question is how much unbundling costs compared to its benefits for competition.[2]

This paper analyses the sources and magnitudes of vertical scope economies in electricity supply. Unlike most previous research that is based on cost function estimations, this study applies a frontier benchmarking approach to empirically analyse economies of

[1] Alternatively, European member states have been offered the choice of implementing an independent system operator (ISO) or an independent transmission operator (ITO) (see EC, 2009). Both alternatives will not be analysed in this paper. For the underlying legislative packages of the European Commission, see EC (1996), EC (2003), and EC (2009).

[2] Apart from the economic analysis there are a number of constitutional issues, in particular when ownership intervention in privately owned companies is required. This discussion will not be part of this study. See Ehlers (2010) for an analysis of legal frameworks and constitutional issues for the cases of Germany, Great Britain, and the Netherlands.

scope between the vertical stages of electricity supply in the U.S. electric industry. By comparing different frontiers for integrated and separate provision of electricity based on a bootstrapping data envelopment analysis (DEA), two types of vertical unbundling are analysed, reflecting the fact that the precise location of the vertical split along the supply chain determines the resulting synergy losses. Results show that the magnitude of scope economies strongly depends on whether generation and retail are separated. This confirms that risk economies play an important role in electricity supply and should be adequately addressed in the restructuring process.

The outline of this paper is as follows. Section two describes the sources of vertical synergies in the electricity supply industry and defines the unbundling options that will be analysed in the study. In section three, the methodology of our benchmarking approach and the data base are described. Section four provides a discussion of the results. Section 5 concludes.

2 Vertical unbundling and scope economies

2.1 Sources of vertical synergies

Economies of scope exist if there is a cost advantage of integration in the sense that it is less costly to have two or more supply stages served by a single firm instead of separate firms. The electricity sector is a classical example, where those synergies have been confirmed both theoretically and empirically.

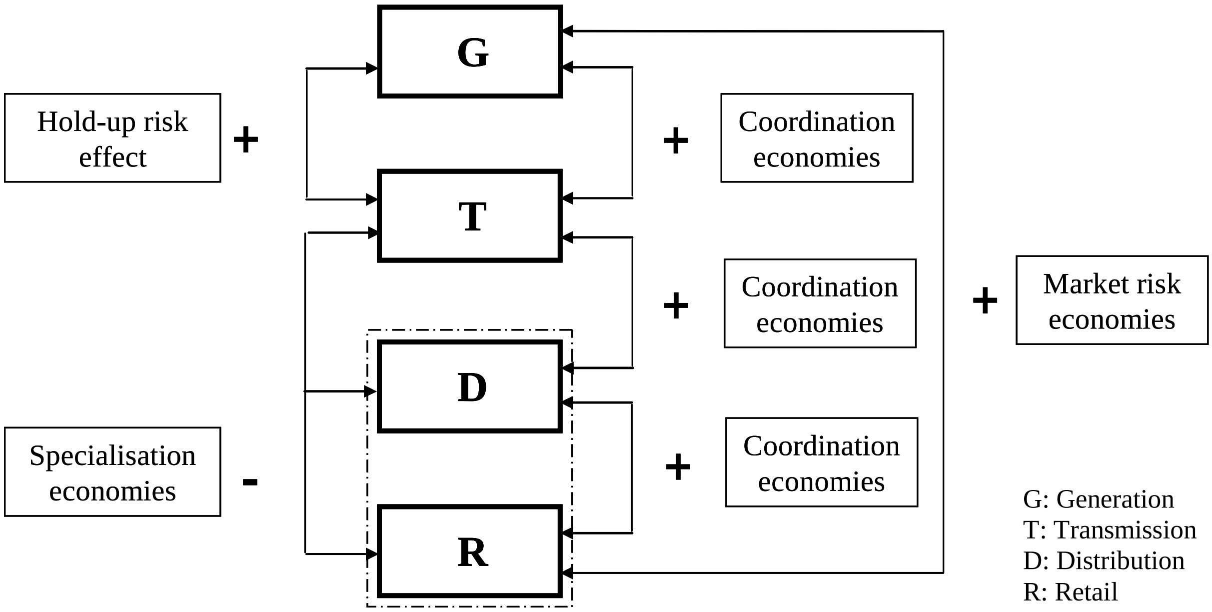
Formally, economies of scope are measured as the relative cost increase if two or more products are produced by separate firms in contrast to integrated production. Following the general definition of Baumol et al. (1982), economies of scope relative to a product T are

$$SC_T = \frac{[C(Y_T) + C(Y_{-T}) - C(Y)]}{C(Y)}, \quad (1)$$

where C(Y) gives the costs of producing the complete output vector Y, while $C(Y_T)$ and $C(Y_{-T})$ are the stand alone costs of separately producing T (i.e. Y_T) and all products except for T (i.e. Y_{-T}), respectively. Accordingly, scope economies exist, if the costs of separate production by specialised firms $[C(Y_T)+C(Y_{-T})]$ are higher than the costs of integrated production C(Y).

To this end, vertical scope economies measure the costs of separating the production along the vertical supply chain. Figure 1 illustrates the vertical stages of electricity supply and shows between which of them scope economies or diseconomies are likely to occur.

Figure 1: Supply stages and synergy effects



Although being interrelated, three main groups of synergies may be distinguished, namely coordination economies, market risk economies (including hold-up risks), and specialisation economies.

Coordination economies occur due to the requirement of real-time balancing of supply and demand and with respect to network externalities (see Brunekreeft and Meyer, 2009). The main argument is that information flows can be handled more efficiently within vertically integrated companies than between separate firms. The latter may involve high market transaction costs as a result of both asymmetric information and diverging incentives.[3] In particular, efficient investment coordination may be foiled by network externalities if generators do not take network expansion costs of their investment decisions into account. Additional coordination costs due to vertical separation may also result from the duplication of tasks, departments and personnel.

[3] Transaction costs can be interpreted as costs of using the market. For the theory of transaction costs see Williamson (1971, 1975, and 1979) and Hart (1995).

Market risk economies involve two main aspects. First, both generation and network assets are highly specific and irreversible investments with a long construction and operating duration. The *sunk costs* character of these investments fully exposes an investor to this risk of uncertainty and opportunistic behaviour of other market players with opposing interests. Accordingly, market risks may result from the incompleteness of contracts in face of uncertain market developments, technological interdependencies and unforeseeable demand fluctuations. Second, market risk economies play an important role between the retail and generation stage. Lacking the possibility of vertical integration, retailers have to purchase their supply needs from independent generators. If relying on wholesale spot markets, suppliers face the risk of price volatility. Even in the presence of financial hedging instruments in the market, transaction costs may be significant compared to integrated retailers, who are better capable of predicting their own generation costs.

As a third group of scope effects, it is claimed that there may also be negative synergies due to a *specialisation advantage.* The underlying argument is that a separation of supply stages may lead to efficiency gains due to a better management focus on specific tasks compared to a multi-product company. This argument was used both by the European Commission in its Sector Inquiry (see EC, 2007) and in the discussion about distribution unbundling in the Netherlands.[4]

2.2 Types of unbundling

As a consequence of the various relations between the electricity supply stages, the costs of unbundling depend on which of the vertical supply stages are separated. Figure 2 schematically illustrates the unbundling options which are analysed in this study and shows the precise location of the ownership split along the vertical supply chain.

Generation unbundling (GU) shall denote a separation of generation from both network stages, high-voltage transmission and low- and medium-voltage distribution, and the retail function. As discussed above, an important implication is that a *market risk effect* is expected to arise for distributors, as these have to purchase their supply requirements on the wholesale markets or via bilateral contracts. Furthermore, *coordination losses* may result from separating generation and transmission.

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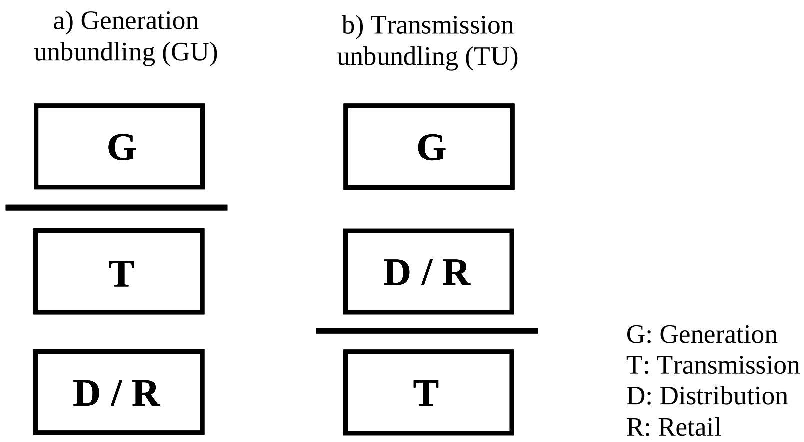
[4] For a deeper analysis of the theoretical arguments see Meyer (2010b).

Figure 2: Unbundling scenarios



In the case of *transmission unbundling (TU)*, corresponding to the European option of ownership unbundling according to the third legislative package, the transmission network is separated from the remaining supply stages. In contrast to the alternative option of generation unbundling, generation and retail remain vertically integrated. As a result one would not expect a significant risk increase under this unbundling scenario.[5]

Several empirical studies confirm the existence and importance of vertical scope economies. A majority of studies is based on cost function estimations and analyses U.S. markets. Kaserman and Mayo (1991), Kwoka (2002), Arocena et al. (2009), and Meyer (2010) estimate quadratic multi-stage cost functions for the U.S. electricity industry and find significant cost savings for companies with vertical integration of generation and network output, of which the latter combines transmission and distribution. Similar estimations for Europe have been carried out by Jara-Díaz et al. (2004) and Fraquelli et al. (2005). These studies focus on distribution rather than transmission companies.

However, there are a couple of drawbacks of such cost function estimations. First, they assume that electric utilities produce their outputs under the same production and cost structure, no matter whether they are integrated or serve only parts of the supply stages. As Meyer (2011) indicates, separate companies may behave differently compared to integrated

[5] Note that in most empirical studies (including this one), retail is subsumed under distribution since data do typically not allow for a distinction of these functions. However, many retail markets have been fully opened to competition. In the case of Europe many distributors are even subject to legal unbundling (see EC, 2003). Nevertheless, as our main focus is on generation and transmission, we do not expect a significant influence of this data limitation on our results.

ones and may realize specialisation advantages that compensate for the lack of vertical scope economies. Second, the underlying assumptions of a cost function estimation are that the observed companies are efficient and follow a cost minimizing approach. These assumptions may be violated in a network industry that is partly characterised by imperfect competition (generation stage) and regulated or state-owned monopolies (transmission and distribution stages). Instead of the traditional cost function approach this study therefore uses frontier benchmarking to estimate vertical economies of scope.

3 Methodology and data

3.1 Data Envelopment Analysis

Frontier approaches are well suited for a comparison of companies that do not necessarily produce on the efficient frontier. The common characteristic of frontier benchmarking models is that the efficiency values are derived as a relative measure compared to the sample group. One of the most prominent benchmarking approaches for analysing regulated industries is *data envelopment analysis (DEA),* which is also used for regulatory purposes to derive efficiency performance targets.[6] The DEA method is a non-parametric approach that uses a linear programming technique to calculate the efficient frontier based on a sample of (comparable) firms. This is done by constructing a piece-wise surface over all observations. The advantage of DEA is that no functional assumption of the underlying production technology is required and it is possible to deal with the limited number of observations that are often the most serious restriction in analysing the energy sector. Due to the fact that no information on input and output prices is used, the analysis is restricted to measuring technical – instead of economic – efficiency.

Figure 3 illustrates the general DEA procedure graphically for one composite output (y) and one input (x), assuming variable returns to scale.[7]

Firms A, B, and C are considered efficient, since they require the least amount of inputs to produce their outputs among all observable firms. By contrast, firm D uses the input in excess of the efficient level, and its *technical inefficiency* can be calculated according to the

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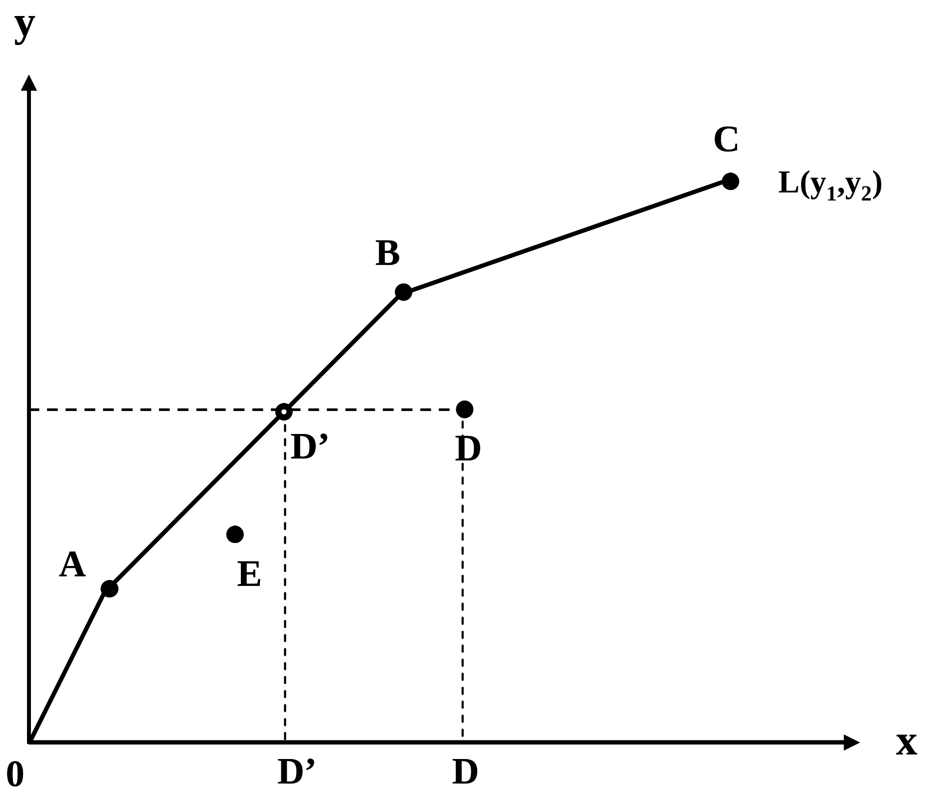
[6] See Jamasb and Pollitt (2001, 2003) for an overview of international experiences with benchmarking in regulation. Coelli et al. (2005) give an overview of different frontier benchmarking approaches.

[7] Looking ahead to our empirical implementation, one might interpret x as the total expenditures (TOTEX), while the y might be seen as a composite output consisting of generation, transmission, distribution and network length.

input distance measure. This measure indicates to what degree a firm could radially contract its inputs for a given output.[8] For simplicity of notation, we refer to firm D's *actual* input use as D as well, while its *efficient* input use (the projection on the efficiency frontier) shall be denoted as D'.

Figure 3: Data envelopment analysis



The so-called Shephard (1970) distance measure for D yields

$$\theta_D = \frac{D}{D'} \geq 1. \quad (2)$$

A value of θ_D =1.25, for instance, indicates that D is using 25 percent too much of its inputs. The respective technical efficiency would be TE =1/θ_D, or 80 percent. For the efficient firms A, B, and C, technical efficiency is equal to 1.

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[8] This is called *input-oriented* approach. One could apply also an *output-oriented* approach to analyse to what degree the output of D could be increased for the given input combination used (see e.g. Coelli et al., 2005).

For the general case, the linear programming problem for each firm i in the sample can be stated formally as

$$\begin{aligned} & max\,\theta_i \\ & st \quad -\mathbf{y_i} + \mathbf{Y\lambda} \geq \mathbf{0} \\ & \quad \mathbf{x_i}/\theta_i - \mathbf{X\lambda} \geq \mathbf{0} \\ & \quad \mathbf{\lambda} \geq \mathbf{0}. \end{aligned} \tag{3}$$

The intuition behind the optimization approach is to find the maximum amount θ_i by which firm i's input use can be radially contracted so that it still remains in the feasible input set defined by all other companies. This feasibility restriction is provided for by the constraints in equation (3) and can be interpreted as follows:

- The first constraint in equation (3) ensures that the firm's output vector y_i cannot be larger than the linear combination of all other firms' outputs (i.e. $\mathbf{y_i} \leq \mathbf{Y\lambda}$), where $\mathbf{\lambda}$ is a N×1 vector of constant weights.
- The second constraint requires that the *efficient* input use of firm i after radial contraction, ($\mathbf{x_i}/\theta$), cannot be smaller than the linear combination of all other firms' inputs (i.e. $\mathbf{x_i}/\theta \geq -\mathbf{X\lambda}$).
- Finally, the third constraint ensures that the vector $\mathbf{\lambda}$ of weights is positive.

The meaning of the $\mathbf{\lambda}$ vector is that it provides a linear combination of all observed inputs and outputs that produces a projected point ($X\mathbf{\lambda}$,$Y\mathbf{\lambda}$) on the efficiency frontier (see Coelli et al., 2005) which corresponds to the efficient production of firm i after its input use has been corrected for inefficiency by radial contraction. For the example of firm D mentioned above, this projection on the frontier is given by point D' as shown in figure 2. As part of the DEA, this linear optimisation procedure is repeated N times for all firms in the sample.

3.2 Measuring economies of scope

Measuring economies of scope based on frontier methods involves the comparison of different frontiers, namely for integrated and separate production of an output vector.

Assume we have two output vectors y_1 and y_2 which can be produced either by one integrated company supplying (y_1, y_2) or by two separate companies supplying (y_1, 0) and (0, y_2), respectively. Accordingly, there are economies of scope if the costs of integrated production, given by $C(y_{1,}\ y_2)$, are less than the costs of separate production, given by $C(y_{1,}\ 0) + C(0,\ y_2)$. However, an application of benchmarking to evaluate this kind of comparison requires two samples of firms producing the same output vector. A basic methodology for such a frontier comparison was introduced by Färe (1986). If all separate companies are combined *pairwise*, by adding up their output and inputs, one constructs a new sample of *hypothetically* integrated companies. These companies produce the same output vectors as the integrated ones, but do so under a different, namely *separate*, production technology. Figure 4 illustrates the procedure of a frontier comparison.

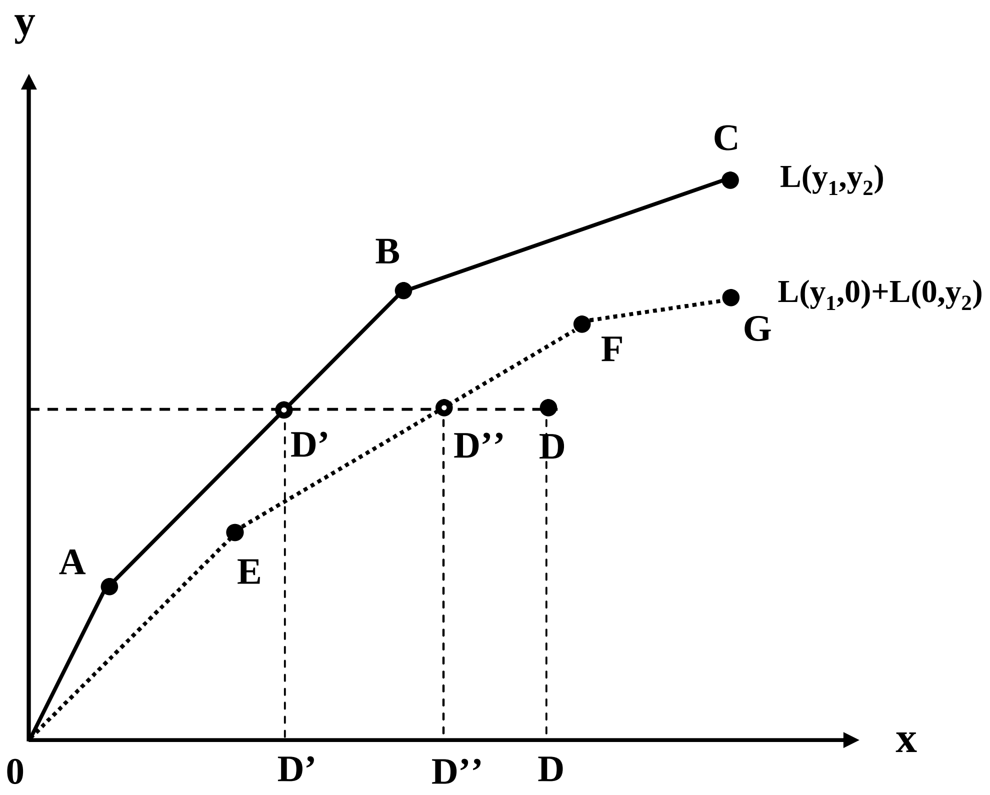
Assume firms A, B, C, and D are *real* integrated companies whose "integrated frontier" is denoted as $L(y_1,y_2)$. Firms E and F are *hypothetical* combinations of separate companies whose "separate frontier" shall be denoted as $L(y_1,0) + L(0,y_2)$.

We see directly from figure 4 that the separate frontier lies outside of the integrated one, which means that producing the same amount of outputs requires more inputs under separate compared to integrated production. The degree of scope economies (for any given output) results from the relative radial distance of both frontiers. The formal procedure involves the following two steps:

1) The integrated firms are benchmarked against their own group defining the *integrated frontier*. In case of firm D, for instance, the radial distance $\theta_D = \frac{D}{D'}$ measures the inefficiency of D with respect to this integrated frontier**.**
2) Each of the integrated firms is benchmarked against the reference set of combined separate companies defining the *additive frontier*. The radial distance $\tilde{\theta}_D = \frac{D}{D''}$ measures the *super efficiency* value of the integrated firm D with respect to the reference production technology.[9]

[9] The term *super efficiency* means that a firm's efficiency values results from a reference sample and may therefore be smaller or larger than unity.

Figure 4: Data envelopment analysis with different frontiers



Hence, scope economies with regard to products y_1 and y_2 can be calculated as the ratio of efficiency scores (ER), which for the example of firm D is given by

$$ER_D = \frac{\theta_D}{\tilde{\theta}_D} = \frac{D/D'}{D/D''} = \frac{D''}{D'}. \tag{4}$$

As can be seen from figure 4, this efficiency ratio is equivalent to the radial distance between the separate and the integrated frontier. In other word, the higher the efficiency ratio, the stronger are the economies of scope. Note that the *individual* inefficiencies of all firms cancel out, and all we measure is the "*technological*" inefficiency resulting from the separation of the production process, which are the vertical scope economies.

This approach has been applied to the estimation of scope economies in various contexts (see e.g. Grosskopf and Yaisawarng, 1990). Growitsch and Wetzel (2006) provide an application to a typical network industry, and analyze scope economies in European Railways using a bootstrapping procedure. To the best of the author's knowledge only Arocena (2008) uses the methodology to analyse the electricity industry, finding evidence for vertical synergies for Spanish distribution utilities.

3.3 Database and procedure

Our data stem from FERC form 1 for U.S. electric utilities. We use pooled panel data for the period of 2001 to 2008 containing both separate and integrated electric companies. Table 1 gives a summary statistic of the database separately for each group of company according to the output stages at which they are active. The groups are named by their scope of the company's outputs so that GTD stands for a fully integrated utility with generation (G), transmission (T) and distribution (D) output, while G, for instance, refers to a sole generator without network and retail business.

Table 1: Summary statistics; average values of costs and outputs per company group

Group	**Input**	**Outputs**				**No. obs.**
	TOTEX	**Generation (GWh)**	**Transmission (GWh)**	**Distribution (GWh)**	**Trans. Net (miles)**	
GTD	1,064,758	20,436	30,971	19,660	3038	432
G	379,688	12,312	-	-	-	38
TD	318,386	-	18,205	13,507	1279	221
GD	790,348	14,125	-	16,241	-	37
T	65,009	-	15,938	-	3065	46

Total costs (TOTEX) are defined as operating (OPEX) and capital costs (CAPEX). More precisely, OPEX includes operating cost, maintenance costs, and depreciation. CAPEX is calculated as the price of capital multiplied by the value of net utility in service. Price of capital is a weighted average for the price of proprietary capital and long-term debt.[10] All monetary values are in U.S. dollars at constant prices according to the U.S. consumer price index.

We use TOTEX as the only input variable and four output variables, generation (G), transmission (T), distribution (D) and transmission network length (NL). We apply a variable returns to scale (VRS) model.

[10] The price of proprietary capital is the sum of dividends for common and preferred stock and retained earnings divided by proprietary capital. The price of long-term debt is the interest on long-term debt divided by long-term debt outstanding. The calculation of capital prices is based on Kolbe and Read (1986).

To avoid too much heterogeneity in our sample, we restricted the observations to generators with a clear focus on steam and nuclear power production. The nuclear share turned out to have a negligible effect on the structure of our results. We therefore decided to focus on one generation parameter. Due to the well-known problem of data sensitivity of DEA, we eliminate outliers separately for each company group using the influence-function approach developed by Wilson (1993).

In the following we use the frontier comparison approach described above to measure vertical economies of scope with regard to two options of vertical unbundling, as defined in section 2.2. Accordingly, there are three frontiers to compare, one *integrated* and two *additive* frontiers. The latter two reference samples need to be constructed by pairwise combining the separate companies to hypothetically additive firms according to the underlying unbundling options:

- *Generation unbundling (GU).* This involves a combination of single generators, named as *G*, with integrated transmission and distribution companies, *TD*, by pairwise adding up outputs and costs. We refer to this constructed additive sample as *G+TD.*
- *Transmission unbundling (TU).* Similarly, we obtain a reference set containing of transmission companies *(T)* and integrated generation-distribution firms *(GD).* We will refer to this additive sample as *GD+T*.

Following Growitsch and Wetzel (2006), we apply a *bootstrapping procedure* as developed by Efron (1979) in order to obtain statistical features of the estimated results. The idea is to create a number of bootstrap samples by applying a number of random draws with replacement from the original sample. We used the common value of B=1000 draws. By repeatedly performing DEA to these samples, a set of efficiency estimates $\theta_{i1},\ldots,\theta_{iB}$ for each firm *i* is calculated that can be used to provide information on the statistical properties of the DEA efficiency measures. The assumption is that each of the randomly drawn bootstrap samples is representative for the underlying population. Following Simar and Wilson (1998; 2000), a *smoothed bootstrap method* is used to overcome the problem of biased estimates resulting from the discontinuous distribution of efficiency scores, in particular for small samples.[11]

[11] See Cummins et al. (2003) and Simar and Wilson (1998; 2000) for the problem of biased estimates and the smoothed bootstrap procedure to obtain bias-corrected efficiency measures.

4 Results

Scope economies are estimated by applying the bootstrap benchmarking procedure to the integrated firms both with respect to their own sample and the reference samples for the two unbundling cases. The measure for scope economies results from the ratio of efficiency scores.

Table 2 summarises the estimation results for both unbundling scenarios, while a deeper analysis of scope economies follows below. We observe that on average, generation unbundling (GU) leads to a permanent cost increase of 17.9 percent, while transmission unbundling (TU) results in a synergy loss around 1.4 percent.

Table 2: Bias-corrected efficiency values and scope economies[12]

	Efficiency IF (relative to own frontier)	Efficiency IF (relative to separate frontier)		Scope economies (efficiency ratios)	
	θ	$\tilde{\theta}_{GU}$	$\tilde{\theta}_{TU}$	**ER$_{GU}$**	**ER$_{TU}$**
Mean	2.028	1.904	2.114	1.179	1.014
Min	1.084	0.447	0.536	0.606	0.623
Max	9.193	9.832	8.624	2.886	3.391
Std. dev.	0.054	0.026	0.059		

IF: integrated firms (GTD)
ER: efficiency ratios (scope economies)

a) Generation unbundling

Generation unbundling (GU) refers to a separation of generation from both network stages and retail. As table 2 reveals, the average value of scope economies (ER$_{GU}$) appears to be almost 18 percent. Generation unbundling is the most costly unbundling option, since it leads to both *coordination losses* (between generation and transmission/distribution) and an increase in *market risk* (between generation and distribution/retail). Scope economies are estimated by comparing the additive sample (G+TD) with the integrated sample (GTD).

[12] All calculations are performed with the statistical programming software R, using the FEAR package developed by Paul Wilson (see Wilson, 2005).

A detailed analysis of the individual efficiency ratios shows that scope economies vary in a broad range depending on the output structures. Table 3 groups the sample of integrated firms according to the degree of vertical synergies under which they operate. For each group of scope effects the table shows the average output values and their degree of vertical integration, measured by the output ratios between generation and transmission (VI G/T), generation and distribution (VI G/D) as well as transmission and distribution (VI T/D).[13]

Although there is no monotonic size effect, the bottom row of table 3 reveals that relatively small companies compared to the sample mean (with 6 to 7 million MWh of generation and distribution and about 16 million MWh of transmission) face strong scope economies above 30 percent (i.e. an efficiency ratio $ER_{GU}>1.3$).

Table 3: GU scenario results: summary statistics per group of scope economies

Eff. ratio (ER_{GU})	**GEN (GWh)**	**TRANS (GWh)**	**DIST (GWh)**	**Net len. (miles)**	**VI G/T**	**VI G/D**	**VI T/D**	**No. obs.**
< 0.80	11,822	19,720	15,645	1,693	0.65	0.84	1.28	35
0.80 - 0.90	11,724	20,549	14,244	2,074	0.58	0.91	1.52	80
0.90 - 1.00	11,889	20,136	13,508	2,194	0.59	0.91	1.54	57
1.00 - 1.10	10,803	18,805	11,467	2,062	0.55	0.91	1.65	64
1.10 - 1.30	12,964	24,913	14,041	3,150	0.55	1.23	2.16	52
>1.30	6,189	16,280	6,905	2,486	0.45	0.88	2.19	77
TOTAL	10,607	19,820	12,199	2,294	0.55	0.94	1.75	365

b)

Furthermore, synergy losses tend to increase with transmission output *relative* to distribution, as the increasing output ratio VI T/D indicates. Similarly, though to a smaller degree, cost effects are positively correlated with the output ration VI G/T. Obviously, it is (c.p.) more costly for smaller generators (compared to transmission output) to vertically disintegrate from transmission and distribution networks. Hence, both coordination and

[13] Note that both the number of observations and the summary statistics differ from the original sample values for integrated firms given in table 1. This is a result of the variable returns to scale assumption, which reduces the number of comparable firms due to differences in size between integrated and separate firms. As a consequence, the average firm size of the remaining integrated utilities reduces compared to the full sample.

market risk economies seem to play a more important role for these "unequally sized" utilities.

Transmission unbundling (TU)

Transmission unbundling (TU) denotes the option of separating the transmission stage from all other supply stages. According to both theoretical and empirical findings, this unbundling option is expected to lead to *coordination losses* between generation and transmission, while risk compensation between generation and retail through vertical integration is still possible. The average synergy losses of transmission unbundling are about 1.4 percent. Hence, coordination economies appear to be of smaller importance compared to the risk effects of generation unbundling.

Scope effects are measured by comparing the additive sample (GD+T) with the integrated sample (GTD).

The detailed results are given in table 4. For this unbundling option, the size effects appear to be clearer. Smaller utilities are subject to stronger scope economies. Furthermore, as in the GU option above, synergy losses are higher for small distribution and generation companies compared to transmission (measured by the respective output ratios VI G/T and VI T/D). As before, a separation of *relatively* small generation and distribution companies from the transmission stage comes at a higher cost compared to utilities with a higher share of these outputs.

Table 4: TU scenario results: summary statistics per group of scope economies

Eff. ratio (ER_{TU})	**GEN (GWh)**	**TRANS (GWh)**	**DIST (GWh)**	**Net len. (miles)**	**VI G/T**	**VI G/D**	**VI T/D**	**No. obs.**
< 0.70	17,893	28,726	18,999	3,851	0.64	0.96	1.52	86
0.75 - 0.85	14,771	21,772	13,720	2,117	0.71	1.12	1.60	70
0.85 - 1.00	9,341	19,648	11,111	1,958	0.51	0.97	1.90	64
1.00 - 1.10	6,676	13,079	9,085	1,533	0.56	0.78	1.42	41
1.10 - 1.20	4,264	17,314	13,402	1,347	0.27	0.41	1.39	29
> 1.20	4,018	10,045	4,942	1,670	0.45	1.03	2.25	76
TOTAL	10,583	19,272	12,137	2,277	0.55	0.94	1.73	366

A comparison of both scenarios with previous studies based on cost function estimations shows that our estimation results lie in a comparable range. Table 5 gives an overview of previous results.

For the GU scenario, vertical synergies lie between 16 and 22 percent, which is comparable to our benchmarking estimation of 18 percent on average. In case of the TU option, Meyer (2010) provides the only comparable estimation. As table 5 shows, vertical synergies range between 5 and 9 percent, compared to an average value of 1.4 percent according to the DEA approach. This may indicate that a direct frontier comparison of integrated and separate companies reveals a specialisation advantage which is not fully captured by a cost function estimation.

Table 5: Economies of scope for fully integrated utilities based on previous cost function estimations

Output all stages (million MWh)	**1 – 10**	**10 – 15**	**15 – 20**
Generation Unb. (GU)			
Kaserman & Mayo (1991)	<0.19	0.19–0.54	0.54–0.89
Kwoka (2002)	<0.43	0.43–0.75	0.75–1.04
Arocena et al. (2008)	-	0.04–0.10	0.04–0.10
Meyer (2010)	<0.22	0.17–0.22	0.16–0.22
Transmission Unb. (TU)			
Meyer (2010)	<0.09	0.04–0.05	0.03–0.04

5 Conclusions

This study applies a frontier benchmarking approach to empirically analyse economies of scope between the vertical stages of electricity supply in the U.S. electric industry. Unlike most previous studies, this analysis allows for directly comparing different frontiers for integrated and separate provision of electricity based on data envelopment analysis (DEA).

Two unbundling options are analysed. *Generation unbundling (GU)* refers to a separation of the generation stage from transmission and distribution. This appears to be the most costly alternative with an average cost increase of 17.9 percent. The main part of vertical synergies is expected to arise from risk economies due to the separation of generation from distribution, which includes retail. The reason is that *market risk* of electricity supply increases, since retailers are subject to volatility of market prices if they have to purchase their supply needs from the wholesale markets instead of self-generation.

The second scenario, *transmission unbundling (TU)*, analyses a separation between transmission and all other supply stages, which is one of the options of the European Union's third legislative package. This type of unbundling shows an average cost increase of 1.4 percent, which is mainly due to *coordination losses* between the transmission and generation stages.

These results indicate that market risk is *more important* for economies of vertical integration than coordination effects. This may be seen as good news for the European development towards transmission unbundling as a result of the third legislative package on energy markets.

For the average company size, both scenario results are comparable to previous cost function studies. In case of transmission unbundling, synergies appear to be smaller compared to a costs function estimation based on the same data base. A reason may be that the direct comparison of separate and integrated companies reveals differences in the cost structure, or specialisation advantages, which are not captured by a cost function estimation.

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