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Predictability and strategic behavior under frontier regulation[☆]

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ABSTRACT

Frontier-based yardsticks, as applied in European energy network regulation, are not immune to strategic behavior. Under yardstick regulation, the regulator gauges the operator against a cost target set by the other firms in the sector. Many regulators have implemented frontier-based yardsticks where the cost function is defined by the most efficient firms (peers). This paper demonstrates that when it is possible to predict peers in advance, firms can manipulate the frontier to their advantage. We single out horizontal mergers as a plausible means to achieve such strategic objectives and develop a measure to identify strategic mergers ex ante. Using data from the electricity distribution sector in Norway that is subject to stable frontier-based regulation allows us to identify firm behavior that is consistent with our predictions. The paper contributes to the modern yardstick literature as existing evidence of strategic behavior in related regulatory settings is either based on anonymized questionnaire responses from regulatory authorities or relies on simulations using unidentified firms that are not actually exposed to such benchmarking in practice. The paper concludes by discussing policy implications.

1. Introduction

Frontier regulation is a form of yardstick competition (Shleifer, 1985) where firms are evaluated relative to the most efficient firms in the industry (peers). It is commonly applied to regulate industries that exhibit natural monopoly characteristics, and is particularly popular in electricity distribution (Agrell and Niknazar, 2013). Frontier regulation is a prime example of modern incentive (performance-based) regulation that encourages productivity improvements and innovation (Agrell et al., 2005). A long-standing criticism raised against frontier regulation is, however, that its efficiency benchmarks are unstable, which creates uncertainty over future cost targets (Sexton, 1986; Cronin and Motluk, 2007a).

Predictability is generally viewed as an important enabler for investments (Dixit and Pindyck, 1994), which are of particular relevance in a capital-intensive sector such a electricity distribution. Not surprisingly, a stable and predictable regulatory framework is routinely mentioned as best-practice to encourage investments in the context of the energy transition (Gordijn and Akkermans, 2007; Montes et al., 2007; San Román et al., 2011) and beyond (Stern and Holder, 1999). Against this background, Norway – a pioneer in the development and application of frontier regulation (Edvardsen et al., 2006; Bjørndal et al., 2010) – amended its yardstick regime for the electricity distribution sector. As a result, it became increasingly predictable which firms would be on the frontier (see Section 2.5).

This paper shows that the Norwegian reform came with a trade-off: it increased the scope for strategic behavior in the form of regulatory gaming (Jamasb et al., 2003, 2004). Firms motivated by profit maximization are now endowed with a new strategic option. In addition to minimizing their own costs, they can also take horizontal mergers involving one or several of the peers can make firms *appear* more efficient by changing the frontier against which the firms are compared.

The paper develops and estimates a measure of such peer effects and explicitly identifies one frontier firm whose recent merger is consistent with strategic behavior. This is an important empirical contribution as existing evidence of strategic behavior in related regulatory settings is either based on anonymized questionnaire responses from regulatory authorities (Jamasb et al., 2003) or relies on simulations using unidentified firms that are not actually exposed to such benchmarking in practice (Jamasb et al., 2004). In addition, the measure developed in this paper is policy relevant because the regulator or competition authority could employ it to screen mergers involving peers and apply the

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appropriate remedies. The conclusions discuss the policy implications of the paper.

2. Background

2.1. Regulatory gaming

In competitive markets, strategic firm behavior is a well-known phenomenon. Firms may collude with their rivals to increase company profits, e.g. by fixing prices above competitive levels (Tirole, 1986). In addition, it may be rational for firms to propose mergers even in the absence of any merger-related efficiency gains because the transaction allows them to exercise market power and to raise prices (unilateral effects) or because mergers facilitate collusion (coordinated or pro-collusive effects). Such strategic merger effects are thoroughly studied in theory (e.g. Williamson (1968), Farrell and Shapiro (1990)) and routinely estimated empirically (Ivaldi and Verboven, 2005; Werden and Froeb, 2008).

In regulated markets, such as energy network operation, firms cannot abuse their market power in the conventional sense because tariff setting, service and volume are constrained by regulation. Seeking to minimize information rents, the regulator may apply a method of the cost-recovery type (e.g. cost-plus/ rate-of-return) or incentive/ performance-based regulation (PBR). The prior, low-powered regimes generally provide low incentives for productivity improvements.[1] High-powered regimes (revenue or price-caps), on the other hand, typically provide better incentives for efficient operation, but productivity gains are not necessarily shared with consumers.

While advanced yardstick methods, such as frontier regulation (Agrell et al., 2005), will extract more rent from the firms than static high-powered regimes, including *ad-hoc* revenue caps, they also critically depend on the regulator having access to a sufficient number of comparable and independent firms to implement the mechanism. The theoretical literature therefore emphasizes that firms subject to yardstick competition may collude or merge, not to improve efficiency, but to limit rent extraction by the regulator (Auriol and Laffont, 1992; Tangerås, 2002; Dijkstra et al., 2017; Teusch, 2018).

Three published studies provide empirical evidence for the existence of regulatory gaming under yardstick or benchmarking techniques. First, Jamasb et al. (2003) carry out a survey among eight major electricity regulators that have experience with benchmarking techniques. Three out of the surveyed regulators that are not identified in the paper indicate potential issues with strategic mergers. Second, Jamasb et al. (2004, p. 826) "illustrate strategic issues that a Public Utility Commission overseeing few electric utilities may encounter when using frontier-based benchmarking methods in incentive regulation". Their hypothetical simulations include strategic mergers, but the firms used for the simulations remain unidentified, and never actually exposed to a frontier regulation in practice[2] Third, Agrell et al. (2015) expose a flaw in the pre-2007 Norwegian regulation and find some corroboratory evidence for strategic mergers exploiting the flawed regulatory cost function in their ex-post analysis of mergers implemented between 1995 and 2004. Thus, there is an open empirical question as to what extent yardstick methods are subject to regulatory gaming.

[1] For example, there is evidence that many jurisdictions under low-powered regulation support firms at an inefficient scale of operation (see e.g. Filippini (1998) for electricity distribution in Italy and Filippini et al. (2004) for Slovenia).

[2] Similarly, Nillesen and Pollitt (2010) warn managers of holding companies that individual firms have such possibilities.

2.2. Preliminaries on frontier analysis

Frontier analysis in regulation is based on the idea that information about technical and cost-efficient production can be obtained from the best practice (frontier) units. Formally, each of n operators i in an index set Ω transform m_x controllable inputs in a vector $x \in \mathbb{R}_+^{m_x}$ into m_y outputs $y \in \mathbb{R}_+^{m_y}$. The prices, if existing, on the controllable inputs are $w^i \in \mathbb{R}_+^{m_x}$. The observations are drawn from a homogeneous set of structurally comparable operators, which form the production possibility set T of all feasible input–output combinations:

$$T = \{(x, y) | x \text{ can produce } y\} \tag{1}$$

T is typically assumed to satisfy free disposability, convexity and r returns to scale (Agrell and Tind, 2001). When the observations relate to a given time t, this is indicated through a superscript, e.g (x^t, y^t); the reference set excluding a unit k is denoted Ω_{-k}.

To estimate the frontier, regulators tend to either rely on Stochastic Frontier Analysis (SFA) (Aigner et al., 1977) or, more commonly, on non-parametric Data Envelopment Analysis (DEA) (Charnes et al., 1978; Banker et al., 1984), as in Norwegian electricity distribution (Edvardsen et al., 2006; Bjørndal et al., 2010)[3]

DEA constructs a minimal hull around the production set T from the observations using linear programming without requiring any imposed functional relationship between inputs and outputs (Cooper et al., 2007; Bogetoft and Otto, 2011). The radial technical input-efficiency score for (x, y) against the reference set Ω under r-returns to scale is $D(x, y|\Omega, r) : \mathbb{R}_0^{m_x} \times \mathbb{R}_0^{m_y} \to \mathbb{R}_0$ defined as

$$D(x, y|\Omega, r) = \begin{array}{ll} \min_{\theta,\lambda} & \theta \\ \text{s.t.} & \theta x \geq \sum_{i\in\Omega} \lambda_i x_i \\ & y \leq \sum_{i\in\Omega} \lambda_i y_i \\ & \lambda \in \Gamma(r) \end{array} \tag{2}$$

where $\Gamma(r = \text{crs}) = \mathbb{R}_0^n, \Gamma(r = \text{vrs}) = \left\{\lambda \in \mathbb{R}_0^n | \sum_i \lambda_i = 1\right\}$.

The general cost model for individual exogenous input prices w is given by

$$\hat{C}(y|w) = \min_x \{wx | (x, y) \in T\}. \tag{3}$$

For the special case of equal prices across operators and full cost controllability, a single-input model with total expenditure (c_i) as input can be used and a *cost efficiency* measure CE is obtained from (2) as

$$CE(c_i, y_i|\Omega, r) = \frac{\hat{C}(y_i|w)}{c_i} = D(c_i, y_i|\Omega, r). \tag{4}$$

An operator (x_i, y_i) is defined as *technically input-efficient* if and only if the corresponding score $D(x_i, y_i|\Omega, r) = 1$. The efficient observations form the *efficient frontier* forming the best-practice cost function. The optimal multipliers λ^i from (2) for a firm i form the combinations of the efficient units (or the *peers*). As the multipliers are not bounded under constant returns to scale (crs), the relative importance of a peer k in the target for a firm i can be obtained by the normalized weight $\rho_{i,k}$:

Definition 1. Relative importance of peer k: $\rho_{i,k} = \frac{\lambda_k^i}{\sum_j \lambda_j^i}$.

2.3. Norwegian network regulation

The electricity supply chain is vertically constituted by generation, retail, transmission, regional transmission, and (local) distribution. The latter three stages are natural monopolies subject to tariff- and access regulation to curb the risk for market abuse, excessive rents and/or

[3] A combination of the two approaches, stochastic semi-nonparametric envelopment of data (StoNED), is used in Finnish electricity distribution (Kuosmanen et al., 2013).

market distortions for the unregulated segments (cross-subsidies, unequal connection conditions, etc.)[4]

The regulation is designed, monitored and enforced by the Norwegian Water Resources and Energy Directorate (NVE). Under this regime, NVE determines the allowed annual revenue for operator i in year t according to the following formula:

$$R^t(c_i^{t-2}, y_i^{t-2} | \Omega^{t-2}, \text{crs}) = \alpha\ \hat{C}(c_i^{t-2}, y_i^{t-2} | \Omega^{t-2}, \text{crs}) + (1-\alpha)\ c_i^{t-2}, \tag{5}$$

where R^t is the annual revenue cap in year t, α is the weight attributed to the cost norm $\hat{C}$ based on DEA, c_i is the actual cost incurred by the firm and Ω^{t-2} is the reference set of DSOs under regulation. While α was originally set to 0.5, in 2009 it was raised to 0.6 to increase the firms' incentives to reduce costs. The lag in the formula is explained by the need to base the assessment on audited costs, available only *ex post*.

2.4. Cost norms under the Norwegian regime

The cost norms are determined in a two-stage procedure that was last reformed in 2013 (see Section 2.5). The first-stage is traditional DEA, whereby NVE assumes constant return to scale (r = crs). The idea behind the crs assumption is to encourage firms that are not operating at efficient scale to merge or split until they reach efficient scale. The fact that the regulator imposes crs does not imply that there are no economies of scale in the real world. The recent paper by Kuosmanen and Johnson (2017, p. 794) elaborates on this point as follows: "Clearly, the descriptive interpretation of CRS is unrealistic. However, we often find the normative interpretation of CRS appealing... evaluated firms cannot plea for diseconomies of scale either due to too small or too large scale of operation. In incentive regulation, imposing CRS for the benchmark technology gives firms an incentive to merge or divest, or more generally, operate at the most productive scale size".

The DEA model only contains one input, total expenditure (totex), which includes operation and maintenance, value of lost load, network losses (physical losses multiplied by the volume-weighted average wholesale price), capital depreciation and return on capital (NVE, 2012).[5]

On the output side, NVE uses multiple outputs to account for the multidimensional task profile of DSO—who are obliged to serve all customers in their concession area. As of 2013, these outputs are limited to the number of customers, the length of high-voltage lines as well as the number of substations. These outputs are thought of as proxies for cost drivers related to the size and consumer density of the concession area.

Table 1 reports 2011–2015 averages of all input and output variables as well as the resulting technical efficiency estimates.[6] A cursory

Table 1
Summary statistics (2011–2015 averages).

	Mean	Median	Min	Max	N
Totex (in 2015-kNOK)	120,525	48,729	9,873	1,961,915	112
Customers (#)	26,405.0	7,164	1,043	689,215	112
Substations (#)	1,134.6	383.5	61	17,940	112
HV lines (km)	899.2	350.5	58	11,781	112
$CE(x,y)$	0.72	0.71	0.44	1.00	112

Table 2
Reference rate of return by year.
Source: NVE.

Year	Reference rate (in %)
2013	6.9
2014	6.61
2015	6.32
2016	6.32
2017	6.12
2018	6.10
2019	5.73 (preliminary)

look at the summary statistics reveals that the distribution of firms is skewed towards small firms—whereas the average firm has more 24,000 customers, the median firm has only around 7000. No similar trend can be observed for the distribution of firms' efficiency scores as the average and the median firms are virtually identical.

In the second-stage analysis, the regulator then regresses the technical efficiency estimates, CE, on environmental factors to account for differences in operating conditions. The environmental variables include the share of underground and submarine cables, the percentage of overhead lines going through difficult terrain, connections of small hydro plants, islands in the concession area as well as climate and weather-related factors.[7]

Finally, the regulator normalizes the efficiency scores such that the industry as a whole earns the reference rate of return (RoR), which is based on a weighted average cost of capital model.[8] Table 2 shows that the reference rate was mostly around 6% in recent years.

2.5. Impact of the regulatory reform on peer predictability

The Norwegian cost model was changed in the 2013-reform, finalized in 2012 (NVE, 2012). Two changes to the DEA model used to assess the performance of Norwegian distribution companies were critical. First, as shown in Table 3, the number of outputs used to assess the firms was reduced by five. Importantly, three of the variables that were dropped – 'delivered energy',[9] 'snow' and 'coast' (which includes wind speeds) – tend to vary substantially by year and region because of changing weather conditions. Second, before the reform, firms were compared to yearly observations from their peers; with the reform the regulator switched to relying on five-year averages.

Since the 2013 reform, there are relatively few frontier firms, and there was little variation in frontier firms over the years, as illustrated in Fig. 1. Specifically, the 112 firms in the industry were compared to a total of seven frontier firms only. Four firms were on the frontier in

[4] In Norway, the distribution system covers voltage levels up to 22kV. To the extent that the Norwegian distribution system operators (DSOs) are also active in other segments of the electricity supply chain, the firms at least need to have separated accounts for their local distribution activities. As of 2021, strict separation of all generation and distribution companies will be required (Mydland, 2019).

[5] If costs and age of capital were diverging across the industry, efficiency estimates could thus be biased.

[6] Whereas NVE uses yearly data for firm i's input and outputs vectors (x_i and y_i on the left-hand side of the constraints), the input and output observations against which firms are compared ($\Sigma_i x_i$ and $\Sigma_i y_i$ on the right-hand side of the constraints) are based on five-year averages from all firms in the industry (including firm i). As a consequence, some frontier firms may have scores greater than 1. By contrast, we work with five-year averages on both sides of the constraints to avoid conceptual confusion and increase the robustness of our results—averaging avoids biased estimates due to measurement error or idiosyncratic time-dependent shocks. This is also what NVE does to assess merger gains (NVE, 2015), replicated in Section 5.

[7] We do not perform the second-stage analysis for the calculation of the peer effects, as the focus of this paper is on frontier regulation—and only the first stage is based on a frontier methodology. While this is a limitation of our analysis, adding an additional layer of complexity would complicate the estimation and interpretation of our results. However, the analysis of the cost efficiency scores pre and post merger in Section 5 is based on the official benchmarking results from the regulator and thus includes the second-stage corrections.

[8] This paper also normalizes efficiency scores (Proposition 1).

[9] Electric heating is a major driver of electricity demand in Norway and to a large extent determined by climatic conditions.

Table 3
Outputs used in the Norwegian DEA models 2007-.
Source: NVE (2012).

Variable	Unit of measurement	2007–2009	2010–2012	2013+
Delivered energy	MWh	X	X	
Customers - cottages	#	X	X	
Customers - residential	#	X	X	
Customers - total	#			X
High-voltage (HV) lines	km	X	X	X
Substations	#	X	X	X
Transformers	Weighted measure	X		
Forest	Forest index × HV overhead lines	X	X	
Snow	Snow index × HV overhead lines	X	X	
Coast	Coast index × HV overhead lines	X	X	

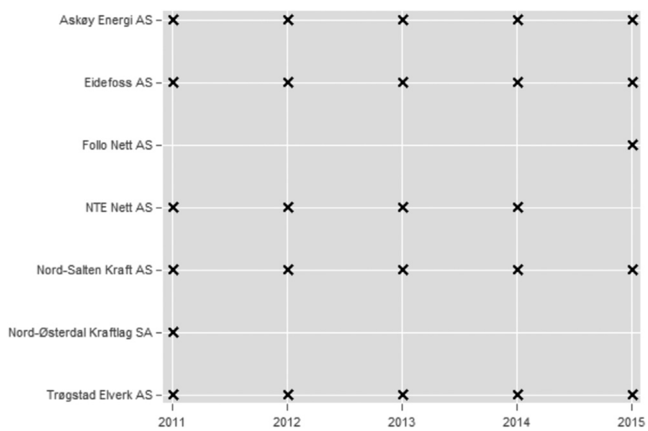

Fig. 1. Frontier firms, 2011–2015.

every single year (shown by a black x), an additional firms was on the firm in all but one year. The frontier was thus fairly concentrated.

Before the 2013 reform, on the other hand, DEA efficiency scores varied substantially across years in a largely unpredictable fashion and the frontier was notoriously unstable, making it difficult for firms to predict who they would be compared to in subsequent years. As we cannot measure predictability directly, we use peer stability as a proxy. For each DSO i, define the set of peers at time t as $\Psi_i^t \subseteq \Omega^t$. Then, let us define a *stable* peer for i as a firm j that is a peer during two consecutive periods $(t-1,t)$; $j \in \Psi_i^{t-1} \cap \Psi_i^t$. A measure of peer stability for i is then the weighted share of stable peers:

Definition 2. Peer stability for firm i: $PS_i^t = \frac{1}{2}\sum_{j\in\Psi_i^{t-1}\cap\Psi_i^t}(\rho_{i,j}^{t-1} + \rho_{i,j}^t)$

where t indexes the time period, j indexes all firms that serve as firm i's stable peers i and $\rho_{i,j}^t$ is the normalized weight from Definition 1 for the importance of peer j on firm i's reference set in year t. For any optimal solution to (2) for any DSO i, $\lambda^i > 0$ (Bogetoft and Otto, 2011); it then follows directly that $\rho_{i,j}^t > 0$ for all i, t and $j \in \Psi_i^{t-1} \cap \Psi_i^t$.

Fig. 2 shows that peer stability has indeed increased remarkably as a result of the reform—it roughly doubled. In addition, the reduction in outputs decreased the number of peers the average firm is compared to in a given year (on the second y-axis). Notice that the 2013 reform affects the frontier retroactively as of 2011 (indicated by the vertical dotted line) because cost norms are based on performance data from two years back (see Section 2.3).

3. Methodology

3.1. Peer effects of mergers

Whenever a frontier firm merges, the firms that were previously compared to this firm will be assessed with reference to one or several new peer(s). This could be either the merged entity or other firm(s) from the reference set. This section suggests to measure the impact of this peer effect by comparing a firm's efficiency score under the new reference set to the corresponding score under the old reference set.

First some additional notation for the case of merger between h units in an index set Υ^M. As before Ω^t is the index set of units prior to the merger. $\Omega^M = \{1, 2, \dots, M, \dots, n-(h-1)\}$ denotes the post-merger index set, where the insiders are included as one pooled entity M where $x_M = \sum_{m\in\Upsilon^M} x_m$ and $y_M = \sum_{m\in\Upsilon^M} y_m$. Technical efficiency scores under this new reference set can simply be calculated by solving (2) to obtain $D(x_i, y_i|\Omega^M, r)$ for all $i \in \Omega^M$. This allows us to express the peer effect of a merger, ω^M, as the ratio of the efficiency score firms receive when assessed against the old reference set over the corresponding score based on the new set:

Definition 3. Peer effect of merger M: $\omega_i^M = \frac{D(x_i,y_i|\Omega^t,r)}{D(x_i,y_i|\Omega^M,r)}$, $i \in \Omega^M$.

$0 \leq \omega_i^M \leq 1$ indicates[10] by how much the efficiency of firm $i \in \Omega^M$ changes after the merger. $\omega_i^M < 1$ implies that the observed efficiency increases, whereas $\omega_i^M = 1$ signals absence of peer effect on i. Note that we use the same observations for both ex-ante and ex-post effects; the only difference is that the insiders' inputs and outputs are pooled in the ex-post scenario as the unit M. Hence, the peer effect ω is a pure reference set effect—by construction no actual efficiency improvement can take place. What is the impact of such peer effects on the firms' revenue and profit?

Proposition 1. *Ceteris paribus, firm i's profit increases if and only if* $\tilde{\omega}_i^M > \omega_i^M$, $i \in \Omega^M$, *where* $\tilde{\omega}_i^M \equiv \frac{\sum_{j\neq i} c_j^*}{\sum_{j\neq i} c_j^*/\omega_j^M}$ $\forall i \in \Omega^M$. *Profitability is monotonously increasing in* $\tilde{\omega}_i^M - \omega_i^M$.

The proof is presented in Appendix A.

Profit-maximizing firms then have incentives to propose any mergers with $\tilde{\omega}_i^M > \omega_i^M$, even when they do not foresee any efficiency effects from the transaction. In fact, if the peer gains, $\tilde{\omega}_i^M - \omega_i^M$, are large enough, even mergers with efficiency losses could be firm-level rational. In order to identify such strategic mergers when they are proposed it is therefore important to also estimate the efficiency effect *ex ante*.

Due to the calibration performed by the Norwegian regulator only relative efficiency improvements matter (see Section 2.4 and Proposition 1). If all firms benefit equally from the frontier shift, firm profitability will not change, *ceteris paribus*. To see this, consider the simple numerical example with one inout x and one output y provided in Table 4.

In the example, visualized in Fig. 3, Firm 1 is the industry's most efficient firm ($D(x_i, y_i|\Omega, \text{crs}) = 1$), meaning it is on the frontier under the crs assumption (indicated by the solid black line in the figure), followed by Firm 2, with Firm 3 being the laggard. If Firm 1 and Firm 2

[10] Follows from $D(x_i, y_i|\Omega^t, \text{crs}) \leq D(x_i, y_i|\Omega^M, \text{crs})$ for all $i \in \Omega^M$.

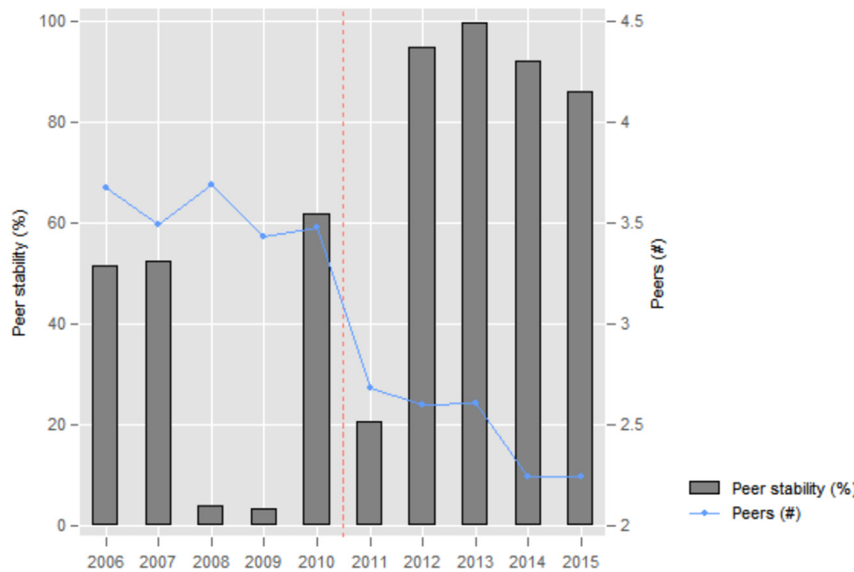

Fig. 2. Average peer stability, PS_i^t 2006–2015.

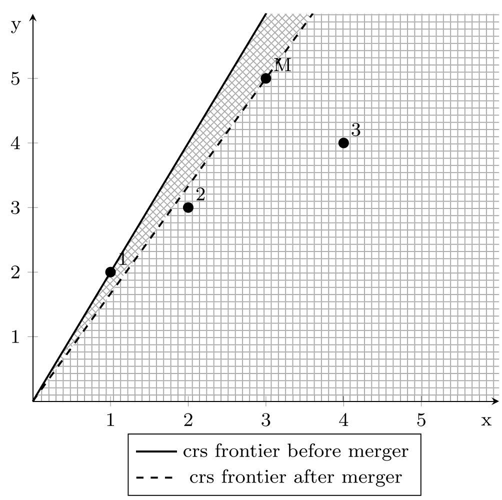

Fig. 3. Graphical illustration of frontier shift with one output.

Table 4
Numerical example of frontier shift with one output.

	i	x_i	y_i	$D(x_i, y_i \mid \Omega, \text{crs})$	$D(x_i, y_i \mid \Omega_M, \text{crs})$	ω_i^M	$\tilde{\omega}_i^M$
Ω:	1	1	2	1.00			
Ω:	2	2	3	0.75			
Ω:	3	4	4	0.50			
Ω_M:	M	3	5	0.83	1.00	0.83	0.83
Ω_M:	3	4	4	0.50	0.60	0.83	0.83

merge, all firms' efficiency scores increase. Nevertheless, in this simple one-dimensional example, firms do not benefit from this peer effect because all firms were compared to the same frontier before M benefit equally from the frontier shift caused by the merger.

However, in Norwegian regulatory practice, the regulator gauges firm performance against three output variables (Section 2.4). As a consequence, there are several frontier firms, and individual firms are compared to different frontier firms. This implies that the peer effect will differ across firms, which creates opportunities for strategic mergers. Table 5 provides a simple numerical example of such a peer effect for a strategic merger with one input x and two outputs, y^1, y^2.

Table 5
Numerical example of frontier shift with two outputs.

	i	x_i	y_i^1	y_i^2	$D(x_i, y_i \mid \Omega, \text{crs})$	$D(x_i, y_i \mid \Omega_M, \text{crs})$	ω_i^M	$\tilde{\omega}_i^M$
Ω:	1	1	1	3	1.00			
Ω:	2	1	1	2	0.75			
Ω:	3	1	2	2	1.00			
Ω:	4	1	1	1	0.50			
Ω_M:	M	2	2	5	0.88	1.00	0.88	1.00
Ω_M:	3	1	2	2	1.00	1.00	1.00	0.90
Ω_M:	4	1	1	1	0.50	0.50	1.00	0.92

In this two-dimensional example, illustrated graphically in Fig. 4, Firms 1 and 2 merge, which shifts the frontier inwards. This benefits the newly merged entity which is now on the frontier (previously only Firm 1 was on the frontier, while Firm 2 was inefficient). Firms 3 and 4 remain independent. Given that Firm 3 was already on the frontier before the merger, and Firm 4 is compared to Firm 4, their efficiency scores remain unaltered—these firms do not benefit from a peer effect. However, Firms 3 and 4 are now relatively less efficient, and will thus receive a smaller share of industry profits, whereas profitability of the merged firms increases.

3.2. Efficiency effects of mergers

In an industry with essentially inelastic demand, such as electricity distribution, the efficiency effects of mergers are a reasonable approximation of the welfare effects of mergers (Teusch, 2018). Mergers increase social welfare if they increase input efficiency (it costs firms less to produce a given level of output), and vice versa.

The merger effects under DEA can be decomposed using the Bogetoft and Wang (2005) model into learning, scope (harmony) and scale (size) related gains (see Appendix B). The methodology is widely used in network regulation (e.g Bagdadioglu et al. (2007)) and beyond, including the German water industry (Zschille, 2015) and Danish hospitals (Kristensen et al., 2010).

4. Data

Since peer stability first increased at the 2013 regulatory reform (see Section 2.5), the opportunity to game the system by strategically merging with one's peers is relatively recent in the Norwegian context. Consequently, we only study mergers that took place after the 2013

Table 6
Mergers and takeovers ($2011 \leq t \leq 2015$).
Source: NVE, Company register and DSO websites.

Merged firm ($t+1$)	Constituent firms (t)	Year (t)
TrønderEnergi Nett AS	Malvik Everk AS, **TrønderEnergi Nett AS**, Tydal KF	2012
Mørenett AS	Tafjord Kraftnett AS, Tussa Nett AS	2013
Hafslund Nett AS	Fortum Distribution AS, **Hafslund Nett AS**	2013
Nordlandsnett AS	Dragefossen Kraftanlegg AS, **Nordlandsnett AS**	2013
Eidsiva Nett AS	**Eidsiva Nett AS**, Elverum Nett AS	2014
Fosen Nett AS	Fosen Kraft AS, Rissa Kraftlag SA	2014
ISE Nett AS	Fauske Lysverk As, Sørfold Kraftlag AS	2014
Nordvest Nett AS	Ørskog Energi AS, Vestnes Energi AS	2014
Glitre Energi Nett AS	EB Nett AS, Hadeland Energinett AS, Lier Nett AS	2015
Haugaland Kraft Nett AS	**Haugaland Kraft Nett AS**, SKL Nett As	2015
Nordlandsnett AS	**Nordlandsnett AS**, Rødøy-Lurøy Kraftverk AS	2015
Norgesnett AS	Askøy Energi AS, Follo Nett AS, Fredrikstad Nett AS	2015
TrønderEnergi Nett AS	Selbu Energiverk AS, **TrønderEnergi Nett AS**	2015

Note: In case of a takeover, the acquiring firm is marked in bold.

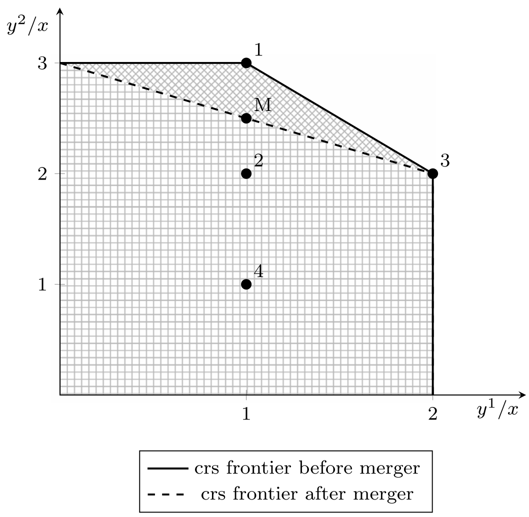

Fig. 4. Graphical illustration of frontier shift with two outputs.

regime change.[11] Table 6 lists all mergers and takeovers that were implemented from 2013 to 2016 (no mergers took place in 2012). As the performance data is available from 2007–2015, we have information on the inputs and outputs of the constituent firms—which is necessary to calculate our ex-ante measures of peer and efficiency effects. Descriptive statistics of the mergers are reported in Appendix C, Table A.1.

Of particular interest to this work is the Norgesnett merger in 2016, as two of the three merging firms were on the frontier in the year prior to the merger (see Fig. 1). Contrastingly, none of the firms in any of the other mergers was on the frontier in the years prior to the merger. Other potential targets for strategic mergers that were not carried out were Eidefoss AS, Nord-Salten Kraft AS and Trøgstad Elverk AS.

Fig. 5 shows the distribution of the merging parties across Norway. As is standard in the Norwegian context (Agrell et al., 2015), virtually all mergers take place between geographically adjacent or close firms. This makes intuitive sense in electricity distribution since merger-specific efficiency gains generally are expected as resulting from economies of scope and scale in maintenance, customer service and billing as well as research and development (Yatchew, 2000; Kumbhakar et al., 2015; Saastamoinen et al., 2017), many of which have an important spatial dimension.[12] The Norgesnett merger is thus atypical in that the merging parties are not adjacent but are scattered across the country.

[11] For an analysis of earlier mergers, see Agrell et al. (2015).

Table 7
Peer effect of Norgesnett merger.

	ω_i^M	$\tilde{\omega}_i^M$
Norgesnett AS	0.96	0.99

5. Results and discussion

This section first estimates the merger effects based in the ex-ante measures developed in Sections 3.1 and 3.2. We then discuss whether firms' observed performances in the years following the mergers are consistent with the ex-ante scores.

Table 7 shows the peer effects of the Norgesnett merger. As none of the other mergers involved frontier firms, they do not come with a peer effect. The merging parties do indeed benefit from peer gains ($\omega = 0.96 < \hat{\omega} = 0.99$, cf. Proposition 1).

Naturally, mergers are not only about peer effects. Table 8 therefore reports our estimates of ex-ante efficiency effects for all mergers and acquisitions that took place over our sample period. Specifically, the table lists learning effects L, harmony effects H, and scale effects S, for each merger M, calculated based on the methodology introduced in Section 3.2.

Learning effects $L < 1$ indicate that the merging parties could improve their efficiency by catching up with the industry's best-practice firms, the table indicates that most firms do indeed have significant catch-up potentials. This applies in particular to the firms involved in the ISE Nett AS and Mørenett mergers (0.60 and 0.66, respectively). While in principle firms should be able to reap such learning gains individually, mergers, being change events, may facilitate adjustments to best practice.

Harmony effects, H, on the other hand, tend to be close to 1; meaning that such effects are rather small. The mergers thus do not appear to be primarily driven by the firms' motivation to obtain profits from the harmony effect (see Footnote).

The final column of Table 8 reports the estimates of the mergers' scale effects. Values below 1 indicate that the merger is expected to bring economies of scale; $S > 1$ implies diseconomies of scale. Taking the scores at face value, only two mergers, Fosen Nett AS and ISE

[12] Admittedly, billing and central administration-related synergies could also be obtained by geographically dispersed firms. Against the background of digitalization and outsourcing, the spatial dimension of mergers may be decreasing in importance.

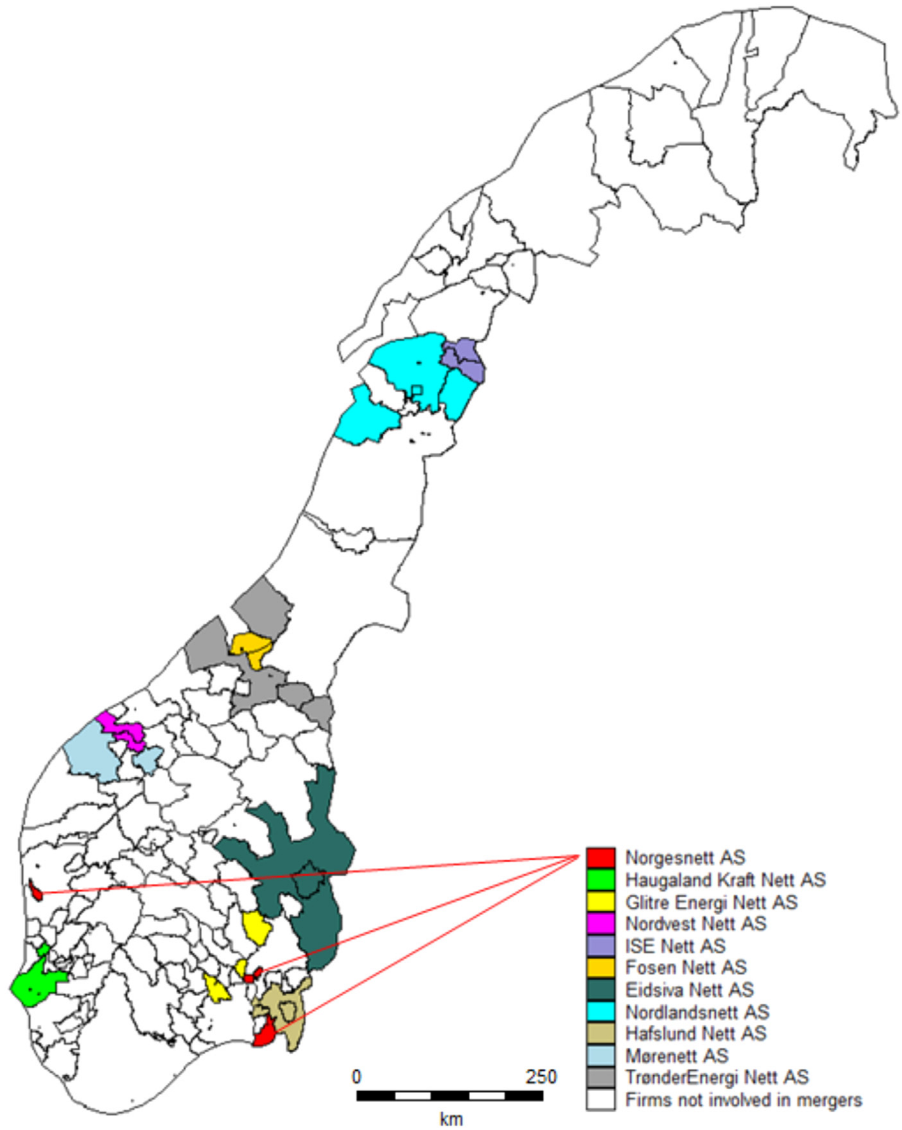

Fig. 5. Map of mergers and takeovers. Note: Geospatial data is from NVE's website.

Table 8
Efficiency effects of mergers.

	Year	L_M	H_M	S_M
TrønderEnergi Nett AS	2012	0.78	1.00	1.03
Mørenett AS	2013	0.66	0.99	1.02
Hafslund Nett AS	2013	0.94	0.98	*
Nordlandsnett AS	2013	0.78	1.00	1.03
Eidsiva Nett AS	2014	0.84	1.00	1.25
Fosen Nett AS	2014	0.80	1.00	0.98
ISE Nett AS	2014	0.60	1.00	0.95
Nordvest Nett AS	2014	0.86	1.00	1.00
Glitre Energi Nett AS	2015	0.86	0.96	1.08
Haugaland Kraft AS	2015	0.71	1.00	1.01
Nordlandsnett AS	2015	0.72	0.99	1.04
Norgesnett AS	2015	0.96	0.99	1.05
TrønderEnergi Nett AS	2015	0.84	1.00	1.01

*As Hafslund is Norway's biggest DSO, S_M is not defined under the vrs assumption.

Nett AS, bring efficiency gains (0.98 and 0.95, respectively). The other mergers, in particular the Eidsiva Nett AS transaction, would appear to cause losses.

However, as the scores are calculated using historical cost data, they may fail to reflect dynamically increasing scale economies that could result from changing service requirements, e.g. because of the transition to smart distribution systems (Jenkins and Pérez-Arriaga, 2017). Efficiency scores could be affected by falling demand, rising distributed renewables, as well as electric vehicle charging in some DSO areas. In addition, the DEA model itself may not be accurate, e.g. because it does not account properly for the age of the distribution assets (see Footnote 2.4).

Against this background, it is important to also analyze whether merged firms managed to improve their performance in practice, as measured by the regulator. Table 9 shows the merging parties' cost efficiency scores based on the original cost norms calculated by the regulator. A cost efficiency above 100% means that firms will earn more than the reference rate of return (see Section 2.4), a score below 100% indicates that they make less. The cost efficiency scores before the merger were calculated by pooling the costs and cost norms of all constituent firms.

Most firms managed to increase cost efficiency after the merger. In particular, for eight of the 13 mergers the average cost efficiency in the two years after the merger is higher than the average cost efficiency in the two years prior to the merger (column Δ).

Table 9
Measured cost efficiency of merging firms in %.
Source: Own calculations based on official benchmarking results published by NVE.

	t−1	t	t+1	t+2	Δ
TrønderEnergi Nett AS	100.55	85.80	81.02	106.34	0.50
Mørenett AS	91.57	90.58	86.21	91.53	−2.21
Hafslund Nett AS	102.36	109.33	103.23	115.34	3.44
Nordlandsnett AS	89.44	98.04	97.17	95.14	2.42
Eidsiva Nett AS	109.66	101.27	107.80	113.43	5.15
Fosen Nett AS	101.52	104.55	98.90	98.11	−4.53
ISE Nett AS	70.96	76.60	84.29	76.22	6.47
Nordvest Nett AS	108.13	108.91	121.31	113.84	9.06
Glitre Energi Nett AS	108.72	102.47	107.12	115.21	5.57
Haugaland Kraft AS	91.96	89.50	97.70	97.56	6.90
Nordlandsnett AS	98.86	95.56	104.16	89.72	−0.27
Norgesnett AS	106.63	102.37	105.82	102.52	−0.33
TrønderEnergi Nett AS	105.72	101.55	107.53	99.57	−0.08

Note: Δ denotes the percentage point difference between the average cost efficiency in the two years prior to the merger and the average cost efficiency in the two years following the merger.

In the case of the Norgesnett merger that came with a peer effect, the cost efficiency is relatively constant when comparing the two years prior to the merger to the observed performance in the two years after the merger. However, there is a notable 3 percentage point change between t and t+1, precisely when the firms' reference set changed. This is consistent with our estimate of the peer effect.

6. Conclusions and policy implications

This paper has shown that the recent regulatory reform in Norway that increased the predictability of frontier firms came with a trade-off. Firms are now able to take actions to push the frontier *inwards*. The recent merger involving two frontier firms, including Askøy, is noteworthy in this regard as it does not appear to be driven by technological efficiency motivations.[13]

The observed form of strategic behavior is however rare. Only one out of the 13 mergers that were implemented over the period under study came with a peer effect—which arises if a merger involves at least one frontier firm. The change in observed cost efficiency was also relatively low, compared to other mergers that were implemented over the period under study. Other firms that were involved in mergers saw their cost efficiency increase more over the period under study.

As a result, it would appear disproportionate to make major changes to the regulatory regime to avoid strategic behavior. Instead, the regulator could screen mergers involving frontier firms ex ante, using the measure of peer gains developed in this paper: $\tilde{\omega}_i^M - \omega_i^M$. Provided an appropriate legal basis for sanctioning strategic behavior exists, the potential for peer manipulation would then appear to be tractable. In particular as NVE already applies a similar methodology to assess the harmony effects (see Footnote), calculating peer effects would come at little additional cost. To the extent that such peer effects turn out to be significant, the regulator could then adjust post-merger revenue caps accordingly. The advantage of this approach would be that it would not require radical changes to a well-established regulatory regime that regulators and industry are familiar with.

The identified form of strategic behavior is a side effect of the transparency and predictability of the Norwegian regulatory regime. If the regulator did not provide the full data to firms (as in German electricity network regulation), the target-setting firms could not readily be identified ex ante. A less transparent regime does however make it more difficult for firms and managers to learn from the industry's best practice (Nillesen and Pollitt, 2010). Obfuscation could also facilitate regulatory capture and generally decrease the legitimacy of frontier regulation. In particular, in industries with wide-spread public and cooperative ownership such as Norwegian electricity distribution, a transparent best-practice frontier may have greater normative power to coerce owners who might not react to purely monetary incentives to improve firm performance.

The gaming opportunity is also a side effect of the frontier methodology. Under alternative benchmarking methods the influence any one peer exerts on the revenue of the other firms is lower (Teusch, 2018). This would for instance be the case under the Stochastic Frontier Analysis (Aigner et al., 1977) or the StoNED method applied in Finnish electricity distribution (Kuosmanen et al., 2013), which convincingly addresses stochastic noise in both input and output variables (Kuosmanen and Johnson, 2017). Such a radical overhaul of the Norwegian regime, which is generally performing well, is however unlikely to be justified on the basis of the opportunities for regulatory gaming identified in this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Per J. Agrell: Conceptualization, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Writing - review & editing. **Jonas Teusch:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Visualization, Writing - original draft, Writing - review & editing.

Appendix A. Proof of Proposition 1

Proof. Omit the time index and the specification of the production set (returns to scale) without loss of generality. Denote firm i's actual cost as c_i, its efficient cost as $c_i^*(\Omega)$, and the reimbursement for firm i under reference set Ω as $\hat{c}_i(\Omega)$, where

$$\hat{c}_i(\Omega) = \frac{c_i^*(\Omega)}{\sum_j c_j^*(\Omega)} \sum_j c_j$$

The static profit for firm i is increased by a merger iff $\hat{c}_i(\Omega^M) > \hat{c}_i(\Omega)$. I.e.,

$$\frac{c_i D(x_i, y_i|\Omega^M)}{\sum_j c_j D(x_j, y_j|\Omega^M)} \sum_j c_j > \frac{c_i D(x_i, y_i|\Omega)}{\sum_j c_j D(x_j, y_j|\Omega)} \sum_j c_j$$

$$\frac{c_i D(x_i, y_i|\Omega)}{\omega_i^M \sum_j c_j D(x_j, y_j|\Omega)/\omega_j^M} > \frac{c_i D(x_i, y_i|\Omega)}{\sum_j c_j D(x_j, y_j|\Omega)}$$

$$\sum_j c_j^* > \omega_i^M \left[\sum_j c_j^*/\omega_j^M\right]$$

$$\sum_j c_j^* > c_i^* + \omega_i^M \left[\sum_{j\neq i} c_j^*/\omega_j^M\right]$$

$$\frac{\sum_j c_j^* - c_i^*}{\sum_{j\neq i} c_j^*/\omega_j^M} > \omega_i^M$$

$$\frac{\sum_{j\neq i} c_j^*}{\sum_{j\neq i} c_j^*/\omega_j^M} > \omega_i^M$$

since $\sum_j c_j > 0$ and $D(x_j, y_j|\Omega^M) = D(x_j, y_j|\Omega)/\omega_j^M$.

[13] As discussed in the introduction, there are many reasons why firms merge, and not all efficiency considerations are captured by the Bogetoft-Wang methodology applied in this paper.

Appendix B. The Bogetoft-Wang methodology

To consider the overall gains in terms of input reduction by a (horizontal) merger of the firms $m \in Y^M$, first calculate the maximal radial reduction in the aggregated (pooled) inputs E_M:

$$E_M = D(x_M, y_M | \Omega^t, r) \tag{B.1}$$

where merger effects are estimated with respect to the old technology set Ω^t which is based on observations from all firms that are contained in the pre-merger reference set. This ensures that what is measured are real efficiency effects and not effects due to a changed reference set.

If $E_M < 1$, the merger could produce savings, and if $E_M > 1$, the merger would appear costly.[14] The score E_M does, however, not take into account the part of the potential savings that are merger-independent. Importantly, if some of the insiders are technically inefficient before the merger, this inefficiency is counted as a merger gain in E_M.

To adjust the overall merger gains for such a learning effect (which firms should be able to achieve on their own without the need for a horizontal merger), Bogetoft and Wang project the original firms to the production possibility frontier and use the projected plans as the basis for evaluating the remaining gains from the merger. This is done by adjusting each merging firm to technical efficiency, i.e. contracting input to

$$x_m^* = D(x_m, y_m | \Omega^t, r) \cdot x_m, m \in Y^M. \tag{B.2}$$

This controls for the individual catch-up effects, providing the adjusted overall merger gains E_M^* as

$$E_M^* = D\left(\sum_{m \in Y^M} x_m^*, \sum_{m \in Y^M} y_m | \Omega^t, r\right) \tag{B.3}$$

Setting

$$L_M = \frac{E_M}{E_M^*} \tag{B.4}$$

one obtains $E_M = L_M \cdot E_M^*$, where $L_M \in [0, 1]$ indicates what can be saved by individual technical efficiency adjustments by the different firms in M.

Assessing the harmony (or scope) effect of a merger, H_M, amounts to examining how much one can reduce the average input in the production of the average output:

$$H_M = D\left(\frac{1}{h} \sum_{m \in Y^M} x_m^*, \frac{1}{h} \sum_{m \in Y^M} y_m | \Omega^t, r\right) \tag{B.5}$$

where $h = |Y^M|$, she number of insiders involved in the merger M. The use of averaging controls for scale effects, however it assumes that the firms in M are not too different in terms of initial scale.

Finally, the scale effects S_M are captured by asking how much could have been saved by operating at full rather than average scale:

$$S_M = D\left(H_M \sum_{m \in Y^M} x_m^*, \sum_{m \in Y^M} y_m | \Omega^t, r\right) \tag{B.6}$$

The rescaling is advantageous, $S_M < 1$, if there are economies of scale, for example in procurement, staffing or from access to scarce managerial or technical resources (Roeller et al., 2006) and costly, $S_M > 1$, if there are diseconomies of scale because of information costs (Grossman and Hart, 1986; McAfee and McMillan, 1995). Efficiency-decreasing mergers appear to be surprisingly common in practice (Cronin and Motluk, 2007b; Kwoka and Pollitt, 2010). Under the crs assumption, S_M will of course always be equal to 1.

[14] $E_M \leq 1$ if $r = \text{crs}$.

Table A.1
Descriptive statistics of merged firms.

	Year	Totex	Customers	HV lines	Substations
TrønderEnergi Nett AS	2012	485,000	134,296	3,262	4,192
Hafslund Nett AS	2013	2,160,947	672,945	11,393	17,524
Mørenett AS	2013	322,413	61,963	1,779	2,497
Nordlandsnett AS	2013	165,782	33,677	1,201	1,310
Eidsiva Nett AS	2014	863,359	156,997	7,055	10,266
Fosen Nett AS	2014	61,607	11,153	619	763
ISE Nett AS	2014	58,210	7,784	383	346
Nordvest Nett AS	2014	68,646	13,894	569	857
Glitre Energi Nett AS	2015	344,677	87,947	1,944	3,467
Haugaland Kraft AS	2015	326,706	70,787	1,853	2,490
Nordlandsnett AS	2015	236,005	38,581	1,773	1,664
Norgesnett AS	2015	309,611	91,029	1,662	3,050
TrønderEnergi Nett AS	2015	500,277	142,863	3,426	4,257

Having defined the learning L_M, harmony H_M and size S_M effects, we now decompose the potential gains of a merger M on technical efficiency:

$$E_M = L_M \cdot \underbrace{H_M \cdot S_M}_{E_M^*} \tag{B.7}$$

The learning or technical efficiency measure L_M captures what can be gained by making the constituent firms efficient. The remaining potential savings, E_M^*, are created by the harmony or scope effect H_M[15] and the size or scale effect S_M.[16]

Appendix C. Summary statistics of merged firms

Table A.1 reports the pooled inputs and outputs of the constituent firms in the year before the merger was implemented.

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[15] Given the low median size of Norwegian DSOs (see Section 2.4), the Norwegian regulator does not want to discourage horizontal mergers and compensates the merged firm for the 'harmony effect'. The harmony effect results from the fact that after a merger the insiders' inputs and outputs will be pooled together as the regulator treats the merging firms as one entity. As a result of this effect, crs efficiency estimates of merged firms will first weakly decrease after a merger (before firms are actually able to reallocate resources and potentially reap these gains). To avoid that firms refrain from merging because they are afraid of losing revenue in the short term, the Norwegian regulator reimburses merged firms for the net-present value of the calculated income loss over 30 years (NVE, 2015). Against the background of strategic mergers it is noteworthy that NVE does not take the peer effect into account, meaning it does not estimate whether the merging parties gain because they face a more favorable reference set after the merger.

[16] While we generally follow NVE and estimate the effects under $r = \text{crs}$, we cannot estimate size-related efficiency gains, S_M as defined by Eq. (B.6), using a DEA model with $r = \text{crs}$ as any such effect would be ruled out by assumption. We therefore assume varying returns to scale ($r = \text{vrs}$).

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