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GENERAL & APPLIED ECONOMICS | RESEARCH ARTICLE

Investment and revenue cap under incentive regulation: The case study of the Norwegian electricity distributors

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Abstract: Electricity distribution operators are regulated as monopolies around the world. Incentive regulation is further applied to relate their allowed revenues (revenue cap) to cost efficiency and investment. Incentive regulation varies cross countries and has evolved over time for individual countries. Norway is one of the first countries reforming the network distributors by incentive regulation. Using the long time series data, we evaluated the impact of the Norwegian regulation regimes on firms' investment. The panel data model includes common time-varying factors to control firm heterogeneity. The cross-section dependence test is further employed to test the relationship between investment and revenue cap in different regulation regimes. The empirical findings confirm a dynamic pattern of investment behavior between regimes, in terms of both the unobserved common factors and the cross-section dependence between investment and revenue cap. This study provides an interesting solution for incentive evaluation and contributes to the management accounting literature in terms of econometric techniques.

Subjects: Economics; Business, Management and Accounting; Energy Industries & Utilities

Keywords: investment; regulation incentive; electricity distribution; panel data

JEL code classifications: D21; L43; L51; C11

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PUBLIC INTEREST STATEMENT

Incentive regulation is applied to stimulate investment in electricity distribution companies in Norway (our case study) and other countries. Under incentive regulations, the annual maximal revenue (revenue cap) is calculated on the base of capital input (cost) and distribution efficiency. We explored the relationship between investment and revenue cap under the last three Norwegian incentive regulation regimes. The total investment is more closely related to revenue cap under the current regime than under the previous ones. This may attribute to the new methods used in the current regime, for example, a flexible base period for cost calculation and incorporation of the actual and normalized cost in the formula. For components of the total investment, reinvestment is more strongly correlated to revenue cap than new investment. As new investment is more important to improve distribution efficiency, regulators should raise weight of cost that relates to new investment in the regulatory incentive.

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1. Introduction

As Chirinko (1993) stated, the fundamental problems of fixed investment research are the consistency of theoretical models and the interpretation of econometric evidence using non-experimental data with limited and noisy variation. According to Jorgenson's neoclassical model (Jorgenson, 1971), profit-maximizing firms' investment behavior depend on whether the sum of the expected returns is higher than the incurred cost of capital. However, firms may choose capital stock, other inputs, and production levels simultaneously. This makes it difficult to isolate the individual impacts of determinants on investment decisions. Based on an imperfect market, the theoretical framework and econometric approaches of investment analysis become either simpler or more complicated. In this study, we explore the relationship between investment decisions and revenue caps under various incentive regulations, with a case study of Norwegian electricity distribution networks.

Electricity distribution networks around the world are regulated as natural monopolies in order to avoid overinvestment in the same regions. At the same time, incentive regulation of natural monopolies has been implemented to prevent a decline in capital equipment costs in a situation of rapid technological change (Biglaiser & Riordan, 2000). Current regulatory incentives of electricity distribution networks generally use revenue caps as a tool to spur sufficient investment to modernize the grid. The total revenue of each electricity distribution company is constrained by the maximal revenue, which is set by the regulators. The calculation of the revenue cap is based on the company's *previous* capital costs and other inputs, efficiency scores, and geographic features. This means that the direction of causality may be from revenue cap to investment. In the long run, increased capital input leads to technical progress and high distribution efficiency, which in turn guarantees sufficient payoffs.

Norway has implemented a power sector reform since the early 1990s, the second country in Europe to do so after the UK (Poudineh & Jamasb, 2016a). The long data period can help us compare the efficacy of incentives under different regulation regimes by testing structural changes in the investment behavior of network companies. The potential structural changes in investment behavior may be attributed to the observed driving forces like regulation regimes and other unobserved heterogeneity between firms. The advanced statistical techniques of panel models are applied to explore the dynamics of investment decisions. This is further related to the evaluation of various regulatory incentives.

Panel models are a powerful tool in the econometric analysis of investment decisions, which are hugely heterogeneous across firms. A panel model can eliminate heterogeneity bias and its explanatory power generally exceeds that of cross-sectional models. Henderson and Kaplan (2000) compared different modeling techniques when evaluating the determinants of audit report lags in the bank industry. They found that the cross-sectional estimate was subject to omitted-variable bias and that the panel model with firm-specific intercepts provided consistent estimates. Nunes, Serrasqueiro, and Sequeira (2009) used a static panel model and dynamic estimator to investigate the determinants of the profitability of Portuguese service industries. Few studies have applied panel models to explore investment decisions under regulatory incentives, although, researchers have applied other econometric methods to evaluate investment decisions under incentive-based regimes, in the context of Norway (Poudineh & Jamasb, 2016a, 2016b) and other countries (Cambini, Fumagalli, & Rondi, 2016; Cullmann & Nieswand, 2016; Kinnunen, 2006). Poudineh and Jamasb (2016b) used Baysian techniques to assess the impact on investment behavior of various driving forces, i.e. demand factors, characteristics of distribution networks, and quality-driven factors. Unlike Poudineh and Jamasb (2016b), we directly test how the regulatory incentives affect firms' investment behavior. Regulatory incentives are based on efficiency measures and hence account for the various driving forces behind investment behavior. Consequently, the revenue cap can be treated as a compound of variables, i.e. the drive forces behind investment decisions. Simple modeling techniques of management accounting are more cost-effective than their complex counterparts (Macintosh & Scapens, 1991; Scapens, 1994).

Most of cited studies on electricity distribution networks have restricted themselves to evaluating methods of calculating efficiency measures and to providing suggestions about how to improve these methods. Researchers have provided *ex ante* evidence regarding the design of incentive regulations, especially frontier-based efficiency measures. However, distribution companies are expected to respond to actual incentives rather than any other *ex-ante* simulated results. Thus, the *ex post* evidence of the impact of the actual incentive regulations on investment is worthy of researchers' attention.

This paper is organized as follows. In Section 2, we discuss relevant literature on investment decisions under incentive regulations. We then present background information for the present study, i.e. the historical context of Norwegian electricity distributors. In Section 4, the data and methodology are described, followed by a discussion of the empirical findings in Section 5. Finally, we conclude with a summary and potential policy implications.

2. Literature review

In the spirit of Jorgenson (1971) and his numerous collaborators, management accounting models have been derived by researchers to evaluate discounted flow of profits, delivery lags, and other adjustment costs. Return on investment or cash flows are then calculated to compare with accrued cost. These traditional models were later modified to reflect value-based management and strategic management accounting (Seal, 2010). For firms under government regulation, Averch and Johnson (1962, p. 1052) defined the "fair rate of return" criterion as: "… After the firm subtracts its operating expenses from gross revenues, the remaining net revenues should be just sufficient to compensate the firm for its investment in plant and equipment." The revenue cap, as a useful regulatory tool, is directly consistent with this criterion and is broadly applied to improve the investment incentives of regulated firms.

Incentive designs can be made by either shareholders or regulators. For internal incentive designs, Ortner, Velthuis, and Wollscheid (2017) theoretically illustrated how to design incentive systems to ensure multi-period investment decisions under unknown preferences in risky situations. For firms where earning management is determined by external agents, the internal investment decisions are still affected by the management (McNichols & Stubben, 2008).

As documented by Wagenhofer (2003), considering accruals relative to cash flow for performance measurement was useful, even if an agent could manipulate depreciation methods. Investment decisions play a role in the design of incentive regulations through annual depreciation, depending on the regulation intervals. For the energy distribution industry, the depreciation and maintenance fees from the last years are used to calculate the efficiency scores and the allowed revenues in later periods. This implies that revenue cap, which is mainly based on costs incurred in the last periods, should lead to capital expenditures. Biglaiser and Riordan (2000) highlighted that, for an industry with an incentive regulation, the incentives for replacement investments may increase if the new equipment improves production techniques.

The increasing importance of distribution network investment is mostly due to the requirement of having to improve efficiency and achieve carbon-free generation. This draws researchers' attention to evaluating the determinants of investment decisions under incentive regulations. For example, Cullmann and Nieswand (2016) derived an investment model including micro- and macro-variables to explore investment behavior of German electricity distributors before and after incentive regulation. They confirmed that the implementation of incentive regulation had a significantly positive impact on distributors' investment rates. Although firm-specific factors were incorporated in their model specification to control for firm heterogeneity, unobserved heterogeneity was ignored. Poudineh and Jamasb (2016b) applied investment models with variables based on economic theory, Norwegian regulatory models, and technical grid characteristics. Bayesian Model Averaging (BMA) techniques were applied to evaluate these variables' contributions to the model's explanatory power. Although Poudineh and Jamasb (2016b) provided detailed evidence for determinants of

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investment decisions, there is no evidence of the direct relationship between investments and regulatory incentives. Moreover, exactly how the various Norwegian regulatory models affect distributors' investment was not specified.

3. Norwegian incentive regulations

Since the 1990s, power sector reforms have been implemented throughout European counties, including Norway (Poudineh & Jamasb, 2016a). The electricity distribution industry, as a national monopoly, is regulated by incentives to encourage new investments and to protect consumers from market power. For distribution operators, investment decisions depend on market mechanisms, institutional constraints, and firms' characteristics. Of these, institutional constraints became a dominant driving force as the traditional rate-of-return regulation was replaced with various incentive regulations (Cullmann & Nieswand, 2016).

From 1993 to 1996, Norway used a traditional rate-of-return regulation and set the price to cost of distribution. As argued in the literature, this traditional regulation may have led to a lack of incentives for cost efficiency (Poudineh & Jamasb, 2016a). Since then, a more effective incentive-based regulation, the revenue cap (*RC*) regulation, has been implemented in Norway. Generally speaking, for a company operating, all cost variables incurred are aggregated to a single index, which is then benchmarked against peers in order to calculate efficiency scores (Miguéis, Camanho, Bjørndal, & Bjørndal, 2012; Poudineh & Jamasb, 2016b). The efficiency scores are further used to derive a norm cost. The allowed revenue for each distributor is calculated through a combination of actual and norm costs.

The Norwegian revenue cap regulation has evolved over time. It can be separated into three distinct versions: 1997–2001; 2002–2006; and 2007-onwards. Below, we introduce the latest version of the incentive scheme. We then summarize the differences between the current and previous schemes, with particular attention paid to regulation schemes' impacts on investment decisions.

The 2007-onwards version of Norwegian incentive regulations takes the form:

$$RC_t = (1 - \lambda)C_t + \lambda C_t^* \tag{1}$$

where RC_t is revenue cap of the network companies; C_t represents inflation-adjusted actual cost; C_t^* is the normalized cost based on the Data Envelopment Analysis (DEA) model; λ is the weight set between the actual cost and the norm cost. Currently, the regulator set λ equals 60%. Both the inflation-adjusted actual cost and the normalized cost are based on historic data year before last. For λ, a higher value means a more important influence of norm cost on allowed revenue.

The 2002–2006 incentive regulation applied the costs for the 1996–1999 period to estimate networks' operation scores and then compute the norm cost (C_t^*). The period for the base cost was 1994–1995 for the incentive regulation in 1997–2001. Unlike the current version, the two previous incentive regulations fixed the period for the base cost. Moreover, they applied a longer period than the new version when calculating the norm cost. Both the fixed intervals of revenue caps and the base years chosen play a substantial role in investment decisions and timing (Cullmann & Nieswand, 2016). When the fixed period for the cost base is applied, the regulated companies invested immediately after the regulatory review in order to maximize excess profit in the regulatory period (Sweeney, 1981). In addition to bases, the three regimes differ from each other in terms of the methods used to include the realized cost of current or adjacent years in the revenue caps. As one can see from Equation (1), the new incentive regulation directly incorporates the realized cost to calculate the revenue cap and uses a weight to adjust the relative importance of the realized cost (and the norm cost). The 2002–2006 regime took the depreciation that occurred in the last year as one of the elements in the formulations. In the *RC* formula used in 1997–2001, the change in energy distributed in the current year and last year was included in the model to reflect recent cost changes.

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Above all, there are substantial differences between the three Norwegian regulation schemes used in 1997–2001, 2002–2006, and 2007-onwards. These differences may cause structural changes in the impact of revenue caps on investment decisions.

4. Data description and methodology

4.1. Data description

Accounting data from the electricity distribution networks are provided by the Norwegian Water Resource and Energy Directorate (https://www.nve.no/). The sample period is from 1997 to 2012. The original data-set is an unbalanced panel as a number of small distribution operators exited from the market, as a result of mergers and acquisitions among the network companies. A reduction in the number of operators may lead to changes in scale economy and affects the relationship between investment and revenue cap. Accordingly, in this study we use a balanced panel data-set by selecting samples that have existed through the entire period. This can facilitate relating the potential structural changes in investment behavior to firms' behavior rather than capacity changes after mergers.

For the model with total investment and revenue cap, the balanced panel data-set is composed of 89 distribution operators, all of which are observed in all 16 years. As of 2002, operators are required to report new investment and reinvestment. Thus, the model with new investment and reinvestment uses the balanced panel data-set from 2002 to 2012, a total of 11 years and 89 operators. Data description for revenue cap, investment, and depreciation is reported in Table 1.

Table 1 indicates that the average revenue cap increases by 27.5% in 2002–2006 and 51.9% in 2007–2012, relative to the base period 1997–2001. The corresponding growths of total investments

Table 1. Data summary					
Year	Revenue cap (RC)	Investment (IN)		Reinvestment	Depreciation
		Total	New investment		
1997	3,968,382	808,977			553,411
1998	4,376,344	928,209			620,042
1999	4,714,314	721,107			654,640
2000	4,610,708	782,992			684,324
2001	5,102,221	646,662			698,172
1997–2001	4,554,394	777,589			642,118
2002	5,497,387	957,121	728,851	228,270	728,663
2003	5,889,131	795,656	615,149	180,507	746,498
2004	5,785,126	905,662	618,054	287,608	773,961
2005	5,734,775	1,166,573	881,494	285,079	796,439
2006	6,123,949	833,626	651,902	181,724	835,936
2002–2006	5,806,074	931,728	699,090	232,638	776,299
2007	5,915,091	990,946	703,178	287,768	860,632
2008	6,116,288	1,069,608	704,781	364,827	890,621
2009	6,231,084	1,153,786	719,181	434,605	925,704
2010	8,136,988	1,188,438	788,120	400,318	958,907
2011	7,844,918	1,484,051	866,774	617,277	1,074,185
2012	7,256,583	1,864,003	1,173,524	690,479	1,109,999
2007–2012	6,916,825	1,291,805	825,926	465,879	970,008

Note: Unit: 1000 Norwegian kroner.

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are 19.9 and 66.1%, respectively. The share of investment out of revenue cap is 17.1% in 1997–2001, 16.0% in 2002–2006, and 18.7% in 2007–2012. The high growth of investment in 2007–2012 and its large share out of revenue cap imply that the current incentive method has successfully stimulated the distribution networks to increase capital inputs. However, the share of depreciation value out of revenue cap only increases 0.6% between 2002–2006 (13.4%) and 2007–2012 (14.0%), although the share of total investment out of revenue cap increases 1.7% (= 18.7 − 16.0%). This may be related to the composition of total investments. For the two recent sub-periods, the share of reinvestment out of revenue cap increases from 4.01% in 2002–2006 to 6.74% in 2007–2012; however, the share of new investment out of revenue cap decreases from 12.0 to 11.9%.

4.2. The panel data model

In panel data, individuals (network companies, in our case) are observed at several time-interval points. When estimating panel data models, a main issue is unobserved heterogeneity in the dimensions of time, individual, or both. Econometricians use dummy variables or structural assumptions on the error terms to control for unobserved heterogeneity, which is assumed constant over time. If the unobserved heterogeneity is not constant, the effect of the observed variables is not consistently estimated. For our case study, the unobserved heterogeneity may change with the updated regulatory methods. Following Bai (2004) and Bai, Kao, and Ng (2009), we apply the method of principal components to catch unobserved individual effects. Thus, the classic panel data model is modified by adding a principal estimator (*E*)

$$IN_{it} = \alpha + \delta_i + \tau_t + \beta RC_{it} + E_{it} + U_{it} \tag{2}$$

where *IN* is annual investment and *RC* is annual revenue cap; α is constant; δ_i controls individual effect; τ_t controls the time-specific effect, which affects all individuals in the same way; β is the parameter catching the impact of *RC* on IN; *E* represents the time-varying individual effect, a $n \times 1$ vector of latent factors of investments; *U* is the idiosyncratic error term.

Bai (2004) defines the specification of common time-varying factors as follows:

$$E_{it} = \sum_{m=1}^{n} \gamma_{im} F_{mt} \tag{3}$$

where γ denotes the individual factor-loading parameters and *F* represents unobserved common factors. After confirming the existence of common factors, the factor-loading parameters can be plotted in the dimension of time to reveal how the loading parameters evolve over time.

4.3. The cross-section dependence test

The existence of common factors indicates that individuals respond to certain common shocks, leading to serial correlation between individuals. Among the different tests of cross-section (*CD*) dependence, the one proposed by Pesaran (2004) is employed here to directly evaluate the correlation between the *RC* and *IN* panels. This *CD* test is valid under fairly general variety settings even with a short time period and large number of individuals, the data type closest to our data-set.

The *CD* test of Pesaran (2004) is expressed as:

$$CD\left(\frac{2T}{N(N-1)}\right)^{1/2}\left(\sum_{i=1}^{N-1}\sum_{j-i+1}^{N} \hat{\rho}_{ij}\right) \tag{4}$$

where *T* and *N* are numbers of observations and sample size; $\hat{\rho}_{ij}$ represents pair-wise correlation coefficients for each pair of cross-sectional units. The null hypothesis is no cross-sectional dependence against cross-sectional dependence. The *CD* test statistic is a nominal distribution as either time or individual dimension tends to infinity in any order (Pesaran, 2004).

5. Results and discussion

5.1. The panel data model

Equation (2) is a full representation of the panel model, with both individual and time effects. In addition to Equation (2), we also estimate various specific versions of the panel model, i.e. the model with individual effect, the model with time effect, and the base model without the two effects. Each model is accompanied by common time-varying factors, Equation (3). This "general-to-specific" specification search approach can reveal how model specification affects the impact of revenue cap on investment behavior. In other words, we test whether relationships between the two variables are affected by time effect and/or individual effect in the panel model. Most of the time series are stationary and, accordingly, the level variables are used in the model. An iterated least-squared approach is used to estimate the panel models. The estimation results are summarized in Table 2.

Table 2 shows that the R^2 values for the four models range from 0.917 to 0.934, indicating a remarkable goodness-of-fit. Moreover, the coefficient of RC is firmly significant in the four models. Thus, excluding fixed-time effect and/or individual effect from the panel model does not affect the explanatory power of the regressor, RC. However, the estimated coefficient of RC does vary. For the full representation of the panel model, the coefficient of RC is 0.0598, which is not substantially different from the estimate of the model with individual effect (0.0648). In contrast, estimates from the two models above are substantially different from estimates from the model with time effect (0.133) and the model without individual and time effects (0.149). One empirical issue is whether the different estimates of RC signal different dimensions of the common time-varying factors estimated from the four models. As shown in Table 2, the existence of four common factors is consistently supported by the four models. Conclusively, while the revenue cap can explain most investment changes, as evidenced by the high R^2 values, there are many unobserved common factors that contribute to investment decisions. For example, geographic feature and quality of distribution may affect both investment decisions and responses of networks operators to regulatory incentives. This is also observed in other European countries (Cambini et al., 2016).

Before using the common factors to detect structural changes in investment behavior, we calculate the share of individual loading parameters' variances out of the total variance. The results are reported in the lower part of Table 2. Among the four time-varying common factors of investment, the first vector is the dominant one, as its share of the total variance is over 40% in all four models. Accordingly, we illustrate the first common factor estimated from the four models in Figure 1.

Table 2. Estimated coefficients and common factors of the panel model				
	Model 1 (Two-way)	**Model 2 (Individual effect)**	**Model 3 (Time effect)**	**Model 4 (Base)**
Constant	7,520* [167]	7,200* [184]	2,760* [222]	1,700* [217]
Revenue cap (*RC*)	0.0598* [0.0126]	0.0648* [0.0116]	0.133* [0.0045]	0.149* [0.0036]
Number of factors	4	4	4	4
Share out of total variance				
Factor 1	40.75	40.09	42.00	40.22
Factor 2	25.69	26.15	26.14	26.1
Factor 3	18.75	18.82	17.03	18.51
Factor 4	14.81	14.94	14.83	15.18
R^2 value	0.93	0.933	0.921	0.917

Note: Values in square bracket are standard error.

*denotes significance at the 0.01 level.

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Figure 1. The estimated first time-varying common factors of the four panel models.
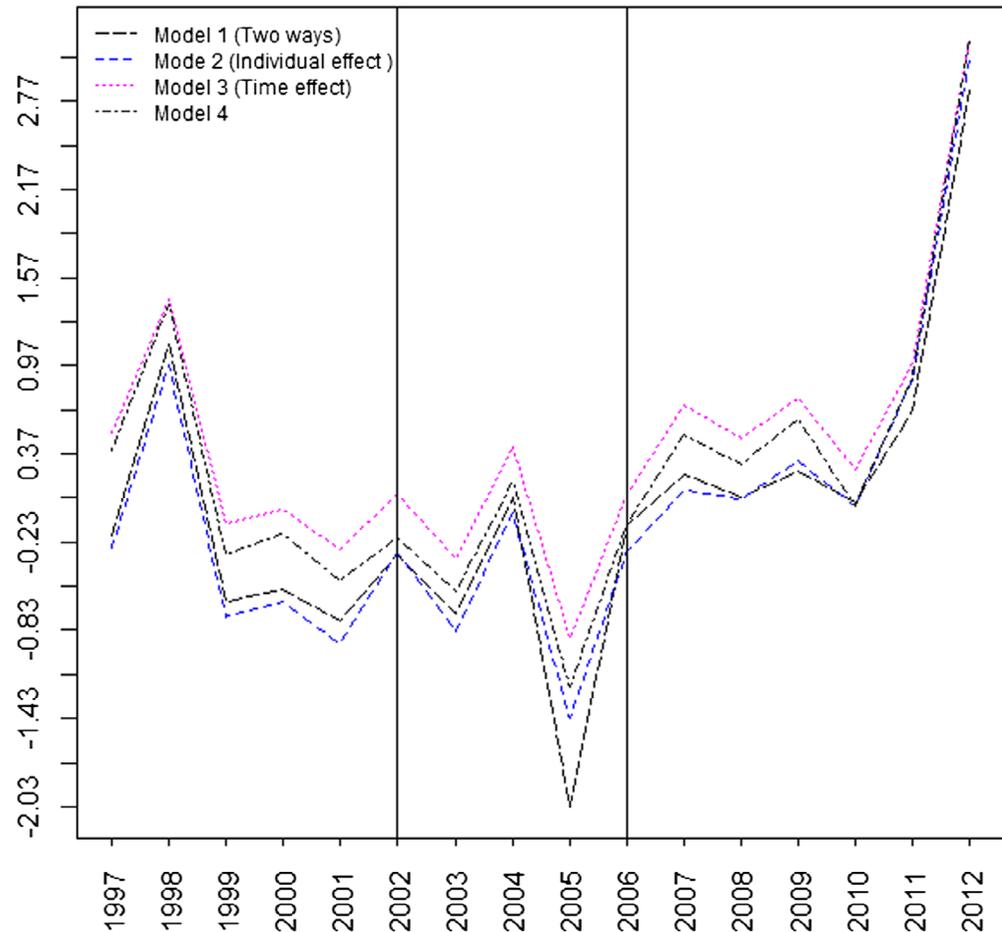
The two vertical lines in Figure 1 separate the curves into three regulatory incentive schemes, i.e. 1997–2001, 2002–2006, and 2007–2012. We see in Figure 1 that the four lines increasingly converge toward each other. At the last time points, the estimated common factors are almost the same. The pattern of these four lines interpreted as a whole reflects a high level of fluctuations through the sample period. The differences between the three regimes are clearly evidenced by the figure. While firms mainly respond negatively to the common factors in the second regime, their responses are both negative and positive in the first regime and are constantly positive in the current regime. The first two sub-periods have a more dynamic pattern than the current period where the common factors are stable in the first several time points before then showing a steep upward trend. The revealed structural changes of the unobserved factors may imply the indirect impact on distributors' investment behaviors of changes in incentive regulation, via other unobserved factors, like useful life of assets and cost of network energy loss (Poudineh & Jamas, 2016b).

In sum, the unobserved time-varying common factors estimated from the panel models provide evidence of structure changes in the three incentive regimes. This is likely in accordance with changes in incentive regulations and is attributed to factors, which may reflect indirect effects of revenue cap.

5.2. The cross-section dependence (CD) test

Since revenue cap explains most investment changes, as revealed in the panel models, the test of structural changes in the relationship between investment and revenue cap is more relevant to investment analysis. The *CD* test is applied to the entire sample as well as the three incentive regimes. The available data for new investments and reinvestments are employed to test their correlations

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Table 3. The cross-section dependence (*CD*) test results				
	Whole sample	**1997–2001**	**2002–2006**	**2007–2012**
Total investment vs. Revenue cap				
statistic value	52.3	26.1	31.4	38.4
p-value	< 0.01	< 0.01	< 0.01	< 0.01
New investment vs. Revenue cap				
statistic value	38.0		66.0	18.5
p-value	<0.01		<0.01	<0.01
Reinvestment vs. Revenue cap				
statistic value	41.7		36.5	56.7
p-value	<0.01		<0.01	<0.01
Critical value	2.56	2.56	2.56	2.56

with revenue caps in 2002–2006 and 2007–2012. Between these two periods, while new investment increased by only 18.1%, reinvestment doubled (Table 1). The correlation between the total investment and revenue cap is probably different from the correlation between its components and revenue cap. The *CD* test results are presented in Table 3.

Table 3 shows that, for all pair-wise variables, the null hypothesis of zero cross dependence is firmly rejected at the 0.01% significance level. The results for total investment vs. revenue cap are in line with the estimated significant impact of *RC* on *IN* in the panel models. Following Pesaran (2004), the test statistic can be used to justify the closeness between the pair-wise variables. For the total investment vs. revenue cap pair, the statistic value of the *CD* test using the entire sample is as high as 52.3, which is greater than the test values in the three sub-periods. The upward trend of the test value is observed from early to later periods. The results reflect a closer link between investment and revenue cap in 2007–2012 than in the two previous sub-periods. Thus, the current regulatory incentive has a stronger influence on investment incentives than the old regulations. As the new regime do not fix the period for the normalized cost and directly incorporate the realized cost in the revenue cap, those changes may lead to an increase in the total investment.

Is this conclusion supported by the test results using the components of the total investment? The statistic value of the *CD* test for the new investment and revenue cap pair is 66.0 in 2002–2006 and 18.5 in 2007–2012. The lower value in the latter period implies a looser relationship between new investment and revenue cap in 2007–2012. This contrasts with findings for reinvestment. For the relationship between reinvestment and revenue cap, the high statistic value in 2007–2012 (56.7) compared with the one in 2002–2006 (36.5) indicates a strengthened link between these two variables. If new equipment leads to larger technical progress than reinvestment, the current regulation might not fully improve the distribution efficiency of network companies. Using different modeling techniques, empirical findings in Poudineh and Jamas (2016b) show that some regutory incentives of Norwegian regulatory models appeared to have been ineffetive.

6. Conclusion

In this study, we explored investment behavior of Norwegian electricity distribution companies, using panel data econometric techniques. The distribution companies are regulated as natural monopolies in Norway and elsewhere in order to avoid overinvestment in the same regions. At the same time, regulatory incentives are implemented to encourage network companies to increase investments, and to protect consumers from market power. This becomes more important as the electricity sector is targeted as a decarbonized industry. Differing from a perfect market where firms maximize discounted cash flow and justify expected returns that are higher than incurred costs, investment behavior in an imperfect market is probably associated with regulation incentive rather than those seen under a perfect market.

Under the regulatory incentive, firm efficiency is benchmarked against peer efficiency, which may lead to a reward or penalty. The regulatory revenue cap is expected to encourage network companies to improve distribution efficiency through capital input. The heterogeneity of distribution operators and the various measures of distribution efficiency indicate a complex relationship between investment and revenue cap. The potential structural changes of investments in various regulation regimes can be attributed to either firms' heterogeneity or changes in methods used to calculate revenue cap.

The relationship between investment and revenue cap for Norwegian distribution operators is first evaluated using panel data models. In these models, the accompanied time-varying common factors are used to test heterogeneity of distribution companies after controlling for the influences of revenue cap. The results show a significant impact of revenue cap on investment decision. Moreover, revenue cap explains most investment changes, although the existence of four common time-varying factors is verified regardless of whether individual effect and/or time effect are incorporated into the panel model. The unobserved common factors provide evidence of structural changes in investment, which coincides with the three regulation regimes and may reflect the indirect impact of regulation changes on firms' investment behaviors.

The cross-section dependence test results reveal a strengthened link between investment and revenue cap over time, implying that the current regulatory incentive is more effective in driving investment than the previous versions. The previous two regimes applied a fixed period for calculation of the normalized cost. Operators may invest immediately after the regulatory review in order to maximize economic benefit. Unlike the previous two regimes, the current regime does not use a fixed period for calculation of the normalized cost. This may lead to a gradual investment under the regime. However, for the components of total investment, the cross-section dependence test only confirms a closer relationship between reinvestment and revenue cap in the latest period compared to the last period. For the new investment and revenue cap pair, the test reflects a looser relationship in the current regime. These results are in line with changes in depreciation. Between the last two periods with different incentive frameworks, changes in the share of depreciation value out of revenue cap is negligible.

Researchers on incentive regulation focus primarily on the measurements of productivity, which are probably reflected in the evolvement of the revenue cap regulation in Norway and other countries. The investment timing and the choices between new investment and reinvestment are affected by the regulation and directly affect distribution efficiency. Investment behavior under the current regime is totally different from the previous regimes. This may relate to a flexible period for the base cost and incorporation of the realized cost in the revenue cap under the current regime. However, the new investment has less been spurred. As new investment generally leads a great depreciation. Regulators may consider to set a high weight for depreciation when calculating the realized cost.

This study contributes, first, to management accounting techniques. Traditional econometric practices focus on the estimation of the driving forces behind firms' investment behavior at the average level. Heterogeneity due to firm size, location, production level, and life time probably leads to non-classical measurement errors and/or misspecification in the model. Firm heterogeneity is explicitly accounted for in the panel models that incorporate individual effect, time effect, and common time-varying factors. Estimation results can further reveal the dynamic pattern of investment behavior. The informative results are subsequently useful for evaluating the incentive regimes of the network companies. Incentive effectiveness in driving distribution operators' investments (and hence their carbon performance) is a critical criterion when evaluating regulatory incentives. Our methods can be applied to other individual cases and to cross-country analysis regarding the incentive frameworks of electricity network industries.

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