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Alternative Maintenance Model

TSO PROJECT

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Disclaimer

This is a note on a maintenance model prepared to the TSO project undertaken jointly by the energy-regulators in Norway, Sweden, Finland, Denmark and Netherlands.

The contents has not been subject to any formal review, nor endorsement from the Commissionee and expresses only the viewpoint of the authors, who exclusively bear the responsibility for any possible errors.

Summary

This note gives a specification of a model to evaluate the efficiency by which different transmission companies construct, maintain and operate their physical grid. The model is an alternative to the one used in the previous Norwegian study. Although limited to its scope, the model may give valuable indication of relevant costs for the net owner's tasks. Combined with regulatory discretion and carefully designed incentives for the TSO service, the model has sound properties.

The note is illustrated with a stylized three-firm example.

1. Introduction

Objective

1.01 We intend to develop a model to evaluate the efficiency by which a TSO

- constructs,
- maintains and
- operates

a physical grid but *not* the efficiency with respect to

- net-losses,
- investment level and structure, nor
- systems operations.

1.02 To accommodate differing regulatory needs, the model should be flexible and make only minimal assumptions on technology and incentives.

1.03 The model is an ECOM model, i.e. it looks at construction, operations and maintenance. It is *not* an EOM model, i.e. a model focusing solely on operations and maintenance. In particular, a firm having bought its capital equipment too expensively will be inefficient. So will a firm running with excessive operating costs or a firm for which the maintenance expenditure does not translate into stable or decreasing operating costs.

Outline of the note

1.04 The note first introduces the model with necessary definitions. Then the ability of the model to capture different inefficiencies is explored and its application in regulation is indicated. Finally, we illustrate the functioning of the model in a simple example using a spread-sheet-like organization of the necessary calculations.

2. Model

2.01 The overall idea of the model is sketched in Figure 2-1. The physical infrastructure (grid, transformers etc) is established via investments and maintained and operated via operations expenses. An investment can be represented via its associated sequence of depreciations of the investment.

Figure 2-1 Alternative Maintenance Model

Base variables

2.02 To formalize the model let us denote firms by $f = 1,\ldots,F$ and investment goods by $g = 1,..,G$. The number of units of asset type g bought by firm f in period s is n_{fgs}. The catalog price today ($s = t$) of good g is w_g, and its standardized lifetime is T_g. The total investment (payment) by firm f in asset g at time s is Inv_{fgs}. Let $\varepsilon(u,T) = 1$ if $u \le T$ and $\varepsilon(u,T) = 0$ otherwise. Hence, ε is an indicator variable showing whether an asset of type g with lifetime T and age u is still in live. Finally, let PI_{st} be a price index transforming period s prices to period t prices (values). It could be the average increase in prices at retailer or consumer (RPI or CPI).

Operations: Opex

2.03 Operation expenses cover the running cost associated with installation, operation and maintenance of the net. We denote the variable installation, operations and maintenance costs by *Opex*:

$Opex_{fs}$ = installation, operations and maintenance of net by firm f in period s.

Depreciation: Depr

2.04 Deprecation is the nominal proxy for the costs of wear and tear of the capital equipment. We use a standardization corresponding to a linear depreciation of the actual investments across a lifetime T_a. The standardized depreciation in firm *f* in time period *t* is therefore:

$$Depr_{ft} = \sum_{g=1}^{G} \sum_{s=t-T_g}^{t} \varepsilon\left(t-s, T_g\right) PI_{st} \frac{Inv_{tgs}}{T_g}$$

Costs

2.05 A firms total costs of establishing, operating and maintaining its capital is denoted by *Cost* and given by

$$Cost_{ft} = Opex_{ft} + Depr_{ft}$$

Capital Stock: Replacement Value RV

2.06 The value of the stock is evaluated at the prices of today, i.e. time t, and corrected for age:

$$RV_{ft} = \sum_{g=1}^{G} \sum_{s=t-T_g}^{t} n_{fgs} w_g \varepsilon\left(t-s, T_g\right)\left(1-\frac{s}{T_g}\right)$$

Note that like on the cost side, we linearly depreciate the physical goods with the same estimated lifetime as used to allocate investment costs to different periods.

Depreciation Policy

2.07 Above, we have assumed that the wear and tear of the capital equipment is linear. Alternatively, we can depreciate with a given percentage of the equipment and use this as the basis for depreciations and lifetime adjustments. A possible advantage of this is that the efficiency measures to be proposed below may become more stable over time. With linear depreciation, the depreciation compared to the value of the capital equipment is increasing.

Notes on Labor Content, Quality, Climate and Topology

2.08 In the absence of reliable data on the labor contents of subcontracted investments, we have chosen not to postulate its proportions. If a component is installed by a subcontractor as part of an investment package, we include the labor costs etc of the sub-contractor as part of the investment. The labor costs covered by the firm's own employees, if reported separately, could also be added to the investment for comparability. For simplicity, however, we leave them as part of *Opex*. This implies that the costs *Cost* for a TSO using mainly in-house labor may vary more than for TSOs relying on subcontracted work that is depreciated over a longer period of time.

2.09 The quality of the network and the resulting transmission may not be accounted for in the catalog prices. On the other hand, the quality should not be higher than what is motivated by associated decline in *Opex* – or by associated benefits to consumers. The latter issue is, however, not explicitly assessed in this model.

2.10 Climate and topology are not taken into account. The obvious possibility is to adjust investment levels for the relative difficulty of making investments under different climatic or topologic conditions. Adjustments should be made if the necessary quality improvement, the extra labor qualifications needed etc are due to tougher conditions that are not reflected in the catalog prices. In such cases, we propose an adjustment of the catalog prices with severance factors γ_{ft} for firm f at time t

$$RV_{ft} = \gamma_{ft} \sum_{g=1}^{G} \sum_{s=t-T_g}^{t} n_{fgs} w_g \varepsilon(t-s, T_g)\left(1 - \frac{s}{T_g}\right)$$

3. Efficiency Measures

3.01 Below, we give the definition, derivation and interpretation of some relevant efficiency metrics. The metrics are numerically illustrated in an example in section 5.

Maintenance Unit Costs

3.02 Using the above variables, we can calculate the maintenance unit costs of firm *f* in period *t* as

$$M_{ft} = (Cost_{ft}) / RV_{ft}$$

3.03 The best (lowest) maintenance unit costs will be denoted M_t^*

$$M^*_t = \min\{M_{ft} | f \in F\}$$

It represents the least cost policy observed to operate and maintain $1 of capital goods.

M-efficiency

3.04 The M(aintenance)-Efficiency is the best maintenance unit costs in relation to the maintenance unit costs of operator *f*:

$$ME_{ft} = M^*_t / M_{ft}$$

3.05 We see that *ME* is always less than or equal to 1. We say that firm f is maintenance efficient in period *t* if $ME_{ft} = 1$ (or 100%), i.e. if firm *f* has the lowest cost per unit of normalized capital value. Analogously, an M-efficiency $ME_{ft} = 0.70$ would indicate that 70% of the cost correspond to efficient expenditure, the rest has to be accounted for by deviations from the least cost operator.

M-efficient Costs

3.06 The M-efficient cost level of operator *f* is denoted $Cost^*_{ft}$ and given by

$$Cost_{ft}^* = M^*_t \bullet RV_{ft}$$

It is the cost level firm *f* would have realized if it were efficient in the installation, operation and maintenance of the capital.

M-efficient WACC

3.07 Assuming that firm *f* in time period *t* extracts revenue of R_{ft}. We can then calculate the M-efficient weighted average cost of capital $WACC_{ft}^*$ as

$$WACC^*_{ft} = (R_{ft}\text{-}Cost^*_{ft})/RV_{ft}$$

The M-efficient *WACC* is the return on capital that the firm would be able to extract if it were efficient in its establishment, operations and maintenance of the grid, transformers etc.

Single or Multiple Periods Evaluations

3.08 The evaluations above can be undertaken in the final period – or in each of the historical periods, i.e. one can let *t* = 2000,1999,1998,... Note, however, that the final period evaluation contains information about some of the past mistakes, namely too expensive acquisitions of the equipment. If the regulator also wants to extract possibly excessive cost reimbursements (or WACC payments) from the past, he can backtrack the efficient cost levels and calculate possible surplus payments to the firm over the time periods.

Regulatory Applications

3.09 The TSO study will be used by regulators with different regulatory policies and we will therefore not suggest specific models tying efficiency evaluations to revenue caps. It is worthwhile to note however that efficient cost levels are derived as $Cost^*_{ft}$ above and that the efficient WACC levels are given by $WACC^*_{ft}$ above.

4. Model Control

4.01 To understand and test the model, a few comparative statics can be useful.

Effects of Gold Plating

4.02 If the firm has paid too much for the equipment, the price adjusted investments $Inv_{fs} \bullet P_{st}$ will be high compared to the replacement value. Depreciations will therefore seem high and the firm inefficient.

Operational and Maintenance Slack

4.03 Excessive use of operations and maintenance will increase *Opex*, and hereby lead to a small M-efficiency as desired.

Substitution between Operations and Capital

4.04 If a firm buys better than average equipment, the depreciation costs will be high. The replacement value may not increase if the quality of the equipment is not reflected in the catalog. On the other hand, one most expect less than average operations and maintenance of such equipment and the evaluation may therefore not be adversely affected.

4.05 Over-investment in capital, e.g. installment of lines and transformers that are under-utilized, leads to a higher replacement value with a corresponding higher depreciation level. However, such behavior will most likely also reduce the operations costs and the firms may look too favorable. The problem is that the model does not correct for the appropriateness of the capital installed. The service model is intended for this purpose.

Nominal and Efficient WACC

4.06 Given the nominal asset base of firm *f* at time *t*, K_{ft}, enables us to determine the relationship between the nominal WACC, i.e. the factor such that

$$R_{ft} = WACC_{ft} \bullet K_{ft} + Cost_{ft}$$

and the E-efficient $WACC^*_{ft}$ defined above. We have

$$WACC^*_{ft} = (WACC_{ft}+(Cost_{fr}-Cost^*_{ft})/K_{ft})\bullet(K_{ft}/RV_{ft})$$

Hence, firm *f* can increase its efficient WACC by introducing slack in the operations and maintenance as well as by assessing its capital basis above the replacement value. In addition, the firm can affect the efficient WACC by its choice of depreciation policy – but it can only do so temporarily and the effect will be counteracted in later periods.

4.07 On the other hand, given an efficient WACC of $WACC^*_{ft}$, one can determine the nominal WACC as

$$WACC_{ft} = (WACC^*_{ft}-(Cost_{fr}-Cost^*_{ft})/RV_{ft})\bullet(RV_{ft}/K_{ft})$$

We see that the firms nominal WACC is the efficient WACC decreased by the payment rate taken out as operational slack and increased by the extend to witch capital acquisition is under-valued.

5. Example

5.01 To illustrate the properties of the method, consider the following fictitious example.

5.02 We assume that the market consists of three TSOs, $f = \{A,B,C\}$, with a time horizon of ten years under study. Note, however, that the results generalize to *F* firms without loss of detail. For simplicity, all assets are of the asset class with depreciation period T_g = 30 years. The firms have adopted various depreciation schemes due to differing national accounting practices and regulation. The firms are supposed to have supplied information on gross investments per asset class Inv_{fgs} and year, operating expenditure $Opex_{fs}$ and actual revenues R_{fs}.

5.03 The regulator has determined replacement values for the assets w_g and a price index Pi_{st}. Below, *Opex* and revenues have been discounted to allow for intertemporal comparisons. However, the M-efficiency has been calculated only on annual estimates to safeguard against possible general output changes. The latter is not a general recommendation but subject to regulatory discretion.

5.04 The full calculations are given in the attached spreadsheet ECAM_example2.xls that is also available until 1.12.2001 at www.sumicsid.com under "Regulation".

Nominal terms

5.05 The two firms B and C have a nominal WACC of 7.5% and 15%, respectively.

5.06 The nominal data for the two firms are given in Tables 1 and 2.

Table 1. TSO A nominal data

	TSO A						
Year	Nominal investment	Book value	Nominal depreciation	Opex	Nominal Costs	Revenue	Nominal WACC
s	*Inv(g,s)*	*K(s)*	$K(s)/T_g$	*Opex(s)*		*R(s)*	*WACC*
1	600	4950	384	873	2183	0.19	600
2	700	5548	383	944	2225	0.16	700
3	1000	6517	381	1 014	2268	0.13	1000
4	450	6722	379	1 085	2310	0.13	450
5	490	6957	378	1 156	2352	0.12	490.1
6	630	7298	415	1 090	2280	0.11	630
7	600	7541	344	1 521	2772	0.12	600
8	1080	8245	352	1 318	2312	0.08	1080
9	1307	9226	350	1 409	2307	0.06	1307
10	998	9844	404	1 499	2724	0.08	998

Table 2. TSO B nominal data.

	TSO B						
Year	Nominal investment	Book value	Nominal deprec.	Opex	Nominal Costs	Revenue	Nominal WACC
s	*Inv(g,s)*	*K(s)*	$K(g,s)/T_g$	*Opex(s)*		*R(s)*	*WACC*
1	870	2430	81	510	798	0.09	870
2	650	2959	122	621	994	0.09	650
3	450	3261	148	685	1110	0.09	450
4	1245	4343	163	912	1444	0.09	1245
5	560	4685	217	984	1599	0.09	560
6	470	4921	234	1 033	1686	0.09	470
7	890	5565	246	1 169	1888	0.09	890
8	1320	6607	278	1 387	2227	0.09	1320
9	600	6876	330	1 444	2359	0.09	600
10	510	7043	344	1 479	2421	0.09	510

Table 3. TSO C nominal data.

	TSO C						
Year	Nominal investment	Book value	Nominal deprec.	Opex	Nominal Costs	Revenue	Nominal WACC
s	*Inv(g,s)*	*K(s)*	$K(g,s)/T_g$	*Opex(s)*		*R(s)*	*WACC*
1	390	3786	126	681	1376	0.15	390
2	560	4157	189	748	1561	0.15	560
3	750	4699	208	846	1758	0.15	750
4	530	4994	235	899	1883	0.15	530
5	1310	6054	250	1 090	2248	0.15	1310
6	1090	6842	303	1 231	2560	0.15	1090
7	870	7369	342	1 326	2774	0.15	870
8	650	7651	368	1 377	2702	0.13	650
9	450	7718	383	1 389	2737	0.13	450
10	1245	8577	386	1 544	3002	0.13	1245

Real and Replacement Value Adjustments

5.07 The adjusted values for the firms are given in Tables 4, 5 and 6. Note that the estimated replacement value, given in current value at t = 10, occasionally is both higher and lower than the actual investment, adjusted with the price index. Without any loss of generality, we assume that the value of incumbent assets (bought before t = 0) is equal to the nominal value at t = 0. The $Cost_s$ term is adjusted to present value to allow comparisons.

Table 4. TSO A real and adjusted data.

	TSO A					
Year	Price index (s,10)	Real investment	Replacement value	Real depreciation	Real Costs	Cost/RV
s	$PI_{s,10}$	*w(g)*	*RV(g,s)*	$Depr_{ft}$	*PICost(s)*	*M(s)*
1	1.45	900	5 250	156	1 823	0.35
2	1.4	1000	6 094	189	1 857	0.30
3	1.35	1300	7 205	234	1 884	0.26
4	1.3	500	7 472	253	1 904	0.25
5	1.25	700	7 919	274	1 917	0.24
6	1.2	800	8 445	299	1 806	0.21
7	1.15	700	8 846	322	2 145	0.24
8	1.1	1100	9 624	361	1 837	0.19
9	1.05	1300	10 563	407	1 847	0.17
10	1	1000	11 156	440	1 903	0.17

Table 5. TSO B real and adjusted data.

	TSO B					
Year	Price index (s,10)	Real investment	Replacement value	Real depreciation	Real Costs	Cost/RV
s	$PI_{s,10}$	*w(g)*	*RV(g,s)*	$Depr_{ft}$	*PICost(s)*	*M(s)*
1	1.45	1200	2 760	68	857	0.31
2	1.40	900	3 592	98	1 040	0.29
3	1.35	610	4 104	119	1 124	0.27
4	1.30	1600	5 585	172	1 397	0.25
5	1.25	700	6 113	196	1 501	0.25
6	1.20	600	6 517	215	1 521	0.23
7	1.15	1000	7 302	249	1 627	0.22
8	1.10	1500	8 554	297	1 832	0.21
9	1.05	600	8 856	318	1 863	0.21
10	1.00	500	9 038	335	1 823	0.20

Table 6. TSO C real and adjusted data.

Year	TSO C					
	Price index (s,10)	Real investment	Replacement value	Real depreciation	Real Costs	Cost/RV
s	$PI_{s',10}$	*w(g)*	*RV(g,s)*	$Depr_{ft}$	*PICost(s)*	*M(s)*
1	1.45	500	3 896	120	1 171	0.30
2	1.40	800	4 576	146	1 313	0.29
3	1.35	1000	5 429	180	1 422	0.26
4	1.30	700	5 949	203	1 474	0.25
5	1.25	1600	7 346	258	1 674	0.23
6	1.20	1300	8 388	301	1 841	0.22
7	1.15	1000	9 087	335	1 919	0.21
8	1.10	700	9 452	359	1 920	0.20
9	1.05	480	9 573	374	1 860	0.19
10	1.00	1245	10 444	416	1 930	0.18

M-Efficiency Calculations

5.08 The efficiency calculations in Table 7 are made using annual updating, a choice depending on the actual comparability over time. In the example, TSO C is initially the most efficient, but TSO C catches up by making less than proportional increases in Opex when the grid size increases. As in any index calculation, the underlying technology is presumed to be linear, that is exhibiting constant returns to scale. Further, the M-efficient costs (in current value) are given in Table 7, along with the M-efficient real WACC that the companies have enjoyed. Note that TSO B in the example consistently charges the lowest tariffs, although the analysis suggests that the motivation may be more linked to low capital costs (subsidized loans?) than efficiency.

Table 7. Efficiency calculations for TSO A and B

Year	EFFICIENCY CALCULATIONS					
	M-Efficiency			M-efficient costs		
				Real efficient WACC		
s	*ME(A,s)*	*ME(B,S)*	*ME(C,S)*	*Cost*(A,s)*	*Cost*(B,s)*	*Cost*(C,s)*
1	87%	97%	100%	1 578	830	1 171
2	94%	99%	100%	1 748	1 030	1 313
3	100%	95%	100%	1 884	1 073	1 419
4	97%	99%	100%	1 851	1 384	1 474
5	94%	93%	100%	1 805	1 393	1 674
6	100%	92%	97%	1 806	1 394	1 794
7	87%	95%	100%	1 868	1 542	1 919
8	100%	89%	94%	1 837	1 633	1 804
9	100%	83%	90%	1 847	1 549	1 674
10	100%	85%	92%	1 903	1 542	1 782

Conclusion

5.09 The stylized example shows some of the properties of the measure, how it reacts to increasing costs and varying purchase efficiency. Finally, it also shows some of the information that may be utilized in regulatory settings, such as the efficiency score, the cost norm and the return on real assets.

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