Total cost benchmarking at RIIO-ED1 – Phase 2 report – Volume 2

A REPORT PREPARED FOR OFGEM

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1 Introduction

In the summer of 2012 Frontier Economics was commissioned by a group of DNOs, led by UKPN, to undertake an assignment to demonstrate the feasibility of totex benchmarking for the electricity distribution companies regulated by Ofgem. Since the conclusion of that first study, Frontier has worked with Ofgem and the DNOs to take forward our work on totex benchmarking.

Given the leading role that Ofgem has played in supporting the work, and the potential importance of totex benchmarking in the RIIO-ED1 review, Ofgem has now formally taken control of the Frontier totex study, with input from the DNOs through regular meetings of the Cost Assessment Working Group (CAWG). Ofgem has commissioned a second phase of work to address a range of issues left outstanding by the initial work.

This document is Volume 2 of our final report. It provides details of our investigation into a range of topics that we have concluded should not be controlled for in our preferred model specification. Full details of other aspects of our study are described in full in Volume 1.

The remainder of this report comprises the following sections.

- In Section 1, an investigation into the available data on **asset condition** and whether asset condition should be controlled for in our preferred models.
- In Section 2, an investigation into potential differences in **investment cycle** between the DNOs.
- In Section 3, a consideration of **asset related outputs** (such as network length and/or MEAV), which might be included in our models, including an assessment of the rationale for their inclusion and whether the relevant effects are already captured by other variables.
- Finally, in Section 4, an assessment of the merit of accounting for the impact of **voltage structure** in our preferred models.

2 Accounting for asset condition

2.1 Phase 1

Our Phase 1 model did not include a variable to capture potential differences in asset condition. While we tested the scope to include Ofgem's Health Index variable, there was no econometric support for doing so. In discussion with Ofgem and the DNOs this was considered a cause for concern. The concern was related to the potential for asset condition to cause changes in expenditure flows that might be considered justifiable. If this logic was accepted, it would follow that it would be necessary to try to control for asset condition in our model.

2.2 Phase 2 approach

Frontier agreed to consider further the scope and rationale for including asset condition in our preferred specification. A range of regulatory issues arise in doing so that require careful consideration. We also note that asset condition is endogenous (within the control of the companies) and a consequence a comprehensive treatment of asset condition in our preferred model would give rise to technical challenges in estimation. We review these considerations briefly below, before setting out our approach to empirical work during Phase 2.

2.2.1 Asset condition and regulatory incentives

Asset condition differs from the core output variables included in the model. While customers will attach a value to reliability (as measured through interruptions and minutes lost), customers do not value asset condition directly. For example, a network operator might choose to operate with its network assets in "poor" condition (relative to other DNOs) but manages the possible effect of this on quality by other means, e.g. such as increased remote sensing and automation. A second network operator might instead choose to have assets in "good" condition and configure its network accordingly (e.g. with less remote sensing automation). The customer would be indifferent as to the approach, and would judge purely on the basis of the cost and the level of reliability offered. As set out in Volume 1, we already propose to take account of quality of service in our model through an adjustment to totex.

These stylised examples also reveal a further important feature. It is not clear that there is an unambiguously ideal level of asset condition. Companies might simply choose to manage their networks differently and might consequently have assets with varying levels of "health". Each of these approaches could be entirely justifiable and efficient.

Similarly, unlike the other core outputs included in the model, an ever higher measure on the asset condition variable (where higher implies better condition) is not unambiguously consistent with efficiency. Indeed very high levels of asset condition might be regarded as a sign of inappropriate asset management policies, where assets are replaced too soon and/or maintained too frequently, leading to inefficiently high costs borne by customers. "Poor" asset condition could equally be associated with an efficient business, although again it is clearly possible to construct a hypothetical example where this will not be the case.

Given this analysis, coupled with the fact that quality of supply is already accounted for in the model, it is not clear that there is a strong motivation for including asset condition in our totex model. Indeed, there is a concern that if it played a role in a totex model, then it could provide perverse incentives to enhance asset condition where there would otherwise be no reason to do so.

This should not be understood to imply, however, that there is no wider rationale for monitoring asset condition. A prudent regulator might wish to monitor asset health in order to:

- provide an early warning system to protect customers, by have a leading indicator of the potential for future deterioration in the quality of supply; and
- create the ability to monitor whether activity committed to at the time of a price control has been delivered.

The analysis set out above should not, therefore, be interpreted as supporting the view the there is no merit in measuring asset condition.

In any event, notwithstanding these observations, we have investigated whether there is evidence to suggest that differences in asset condition might help to explain totex.

2.2.2 Phase 2 estimation approach and challenges

As the discussion above made clear, asset condition differs materially from the other core outputs we have included in the model. Asset condition is endogenous[1] and given this, it might be considered inappropriate to include it directly in our regression model. In such circumstances the ideal approach to estimation would be to specify and estimate a system of equations. However, an approach of this kind is complex and challenging. In the light of the paucity of data available on asset condition (i.e. a single year of data over which we understand there are concerns over comparability of data across DNOs), it is not

1 Asset condition is within the control of the company. More technically, asset condition can be understood to be simultaneously determined with totex and both will be driven by the unobservable level of managerial efficiency, which is the main focus of our estimation.

clear that there is merit in seeking to develop an estimation procedure of this kind.

Consequently, we have chosen to adopt a pragmatic two step approach to estimation that puts to one side concerns over endogeneity.

- First, we have simply added a number of candidate asset condition variables to our cost function in order to assess whether they are potentially significant.

- Second, we have considered whether asset condition might be correlated with our efficiency scores, in order to assess whether there is evidence that asset condition might play a significant role in determining DNO's efficiency scores derived from a (potentially multi-equation) model with an asset condition variable.

As we set out below, the results of this investigation have yielded results that suggest there is no merit in pursuing the more sophisticated system of equations approach outlined above.

2.3 Data

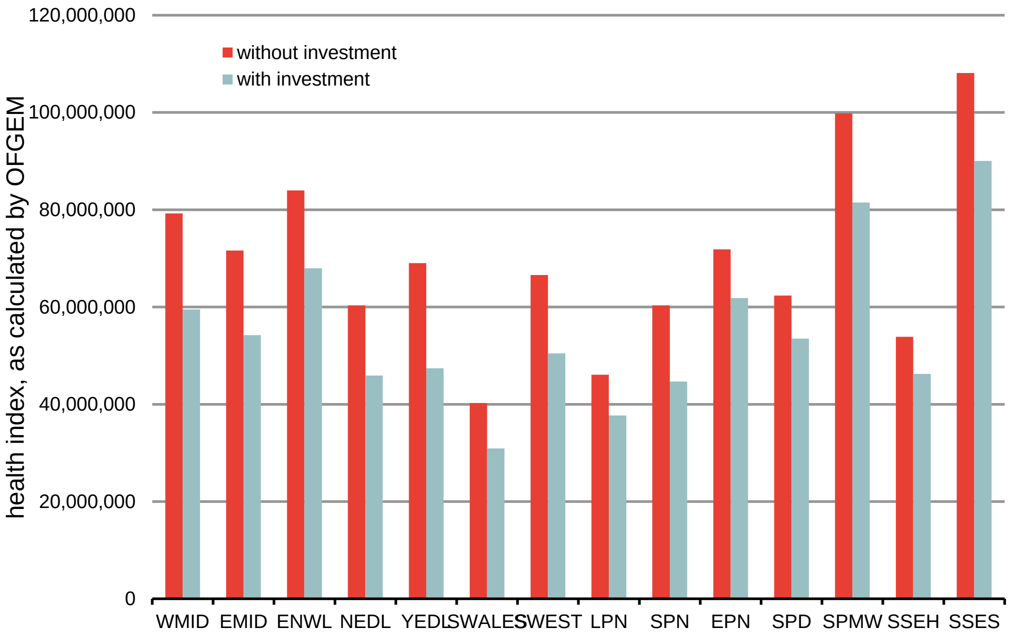
We have investigated two different indicators of the asset condition of a network:

- The **average asset age,** which might reflect the asset condition of a network simply by counting the average age of assets. We were given the asset registers from Ofgem, which allowed us to construct a measure of average asset age by company. This measure is the simple average of the average asset ages of the different asset classes (for example, if poles had an average age of 10 and lines had an average age of 15, we would come to 12.5). Given the data made available to us it was not possible to construct a weighted average asset age, taking account of for example the relative value of each asset class.

- The **network asset replacement health index** is a new composite measure which Ofgem constructed in the course of the consultations around DPCR5. This index is based on underlying data on the condition of network assets, as measured by each DNO. We understand that development of the health index is ongoing.

Figure 1 shows the Health Index, which is only available at present for a single year. The red column shows the index as measured at DPCR5, while the blue column shows the index given the future planned investment programmes of the companies.

Figure 1. Network health index



Source: Ofgem

2.4 Results

2.4.1 Adding condition variables to our regression model

Both variants of the network health index, with and without DPCR5 investments, were added to both base specifications of our preferred model, to assess whether they have a significant impact on costs. The output of the resulting four regression models can be seen in **Table 1**. We find the network health index is typically insignificant.

Table 1. Regression results when adding network health index with and without investments to base models

Variable	Regional wage specification		National wage specification	
	Health index without investments	Health index with investments	Health index without investments	Health index with investments
Customers	0.440***	0.436***	0.540***	0.539***
Peak	0.322**	0.306**	0.189	0.166
Regional wage (SIC 35)	0.322***	0.321***		
National wage (SIC 35)			0.557***	0.565***
Price of capital[2] (BEAMA)	0.678	0.679	0.443	0.435
Phase 1 density measure	-0.062*	-0.055	-0.031	-0.023
Health index	0.106	0.138	0.173	0.210*
Constant	-9.53***	-9.94***	-10.78***	-11.240***
R^2 [3]	0.8895***	0.8930***	0.8838***	0.8905***

The table reports the estimated coefficient for each variable and the confidence intervals using a 95% probability.[4]

*** Significant at 1% ** Significant at 5% *Significant at 10%

Source: Frontier Economics

2 Due to the imposition of homogeneity of degree +1 in input prices, we can infer the coefficient for the capital price as 1-coefficient on wages.

3 The table reports the overall R^2 in the Random Effects and the Pooled OLS regression. We use ***, **, * to indicate the overall goodness of fit using the p-value of the Chi-square test for Random Effects and the p-value of the F test for Pooled OLS.

4 The intervals report that with 95% probability the estimated coefficient will be within the confidence interval. The intervals are calculated using the variances of the estimated coefficient, the higher the variance the less precise are the estimates of the coefficients and the wider the confidence intervals.

We regard the results of including the health index variable as insufficiently robust to be considered further. Moreover we note that normally significant core outputs (peak and density) become insignificant following the addition of asset condition.

We also examined likelihood ratio tests for all combinations and in all cases we reject the null hypothesis that using the HI provides a better fit.

We note that it was not possible to econometrically test for endogeneity of asset quality, as this variable is only available for one year.

Checking correlation between efficiency scores and condition variables

Table 2 shows that there is only a very weak correlation between the time invariant residuals (the efficiency measure in our panel context) and the variables indicating asset condition. This suggests that DNO efficiency scores and asset condition are only very weakly related and again provides no evidence to suggest that asset condition should be controlled for in our models.

Table 2. Correlations between condition variables and efficiency scores

	Health index without investments	Health index with investments	Residuals* of specification 1	Residuals* of specification 2
Health index without investments	100%			
Health index with investments	97%	100%		
Residuals* of specification 1	**12%**	**18%**	100%	
Residuals* of specification 2	**26%**	**32%**	88%	100%

Source: Frontier Economics

* time invariant residuals

2.5 Conclusion

There is limited data available on asset condition. Perhaps as a consequence of this, we have been unable to find a statistically significant relationship between the asset condition and totex. In one case we did find a statistical relationship that was borderline significant, but this did not result in a viable model specification and the likelihood ratio test rejected this expansion of the model.

We find limited correlation between our efficiency scores (derived from regression models that do not include any condition variable) and condition variables.

As a consequence of this, and perhaps more importantly because of the regulatory and incentive concerns we have identified above, we recommend that this variable is not included in our totex model.

3 Accounting for investment cycle

3.1 Phase 1

At the conclusion of our Phase 1 report we identified a potential concern over differences in investment cycle between companies, which arises as a consequence of the totex measure that is the focus of this study. Included within totex are flows of capex expenditure and it is acknowledged that these expenditures can be lumpy over time. As we describe in Volume 1 of this report, this lumpiness can be addressed through the use of a Random Effects estimation approach, which allows us to estimate performance over the period covered by our panel and reduces the risk that the timing of capex programmes will strongly influence estimates of efficiency. However, this would not necessarily address more significant and potentially justifiable differences in capex flows that might arise as a result of large differences in investment cycle. This gives rise to a concern that our totex model might find a firm to be inefficient simply because it must undertake a large volume of asset replacement sooner than peers.

We agreed to investigate this concern further during Phase 2.

3.2 Phase 2 approach

In Phase 2 we have considered investment cycle further. We have focused our attention on assessing whether there is evidence to suggest that there are substantive differences between the DNOs in respect of their position in the investment cycle. If such differences were identified, we would then consider how we might control for this appropriately.

This approach recognises the possibility that investment cycle could be important in principle, but not in practice. If the position of each DNO in the investment cycle is similar to each other, then the efficiency estimates should not be significantly influenced or biased.

In the following sections we describe the evidence we have reviewed to inform on potential differences in investment cycle and on which we have based our recommendation.

3.3 Evidence

In order to assess whether there are material differences between DNOs in respect of their position in the investment cycle it is necessary to look at evidence on investments made over a long period of time. We have considered various data sets and sources.

- A data set collated by Phil Burns and Professor Tom Weyman-Jones covering the period 1971 to 1993[5].
- RAV additions taken from Ofgem's DPCR5 Financial Model.
- Expert reports published at previous price control.

3.3.1 Long run analysis from 1971 to 1993

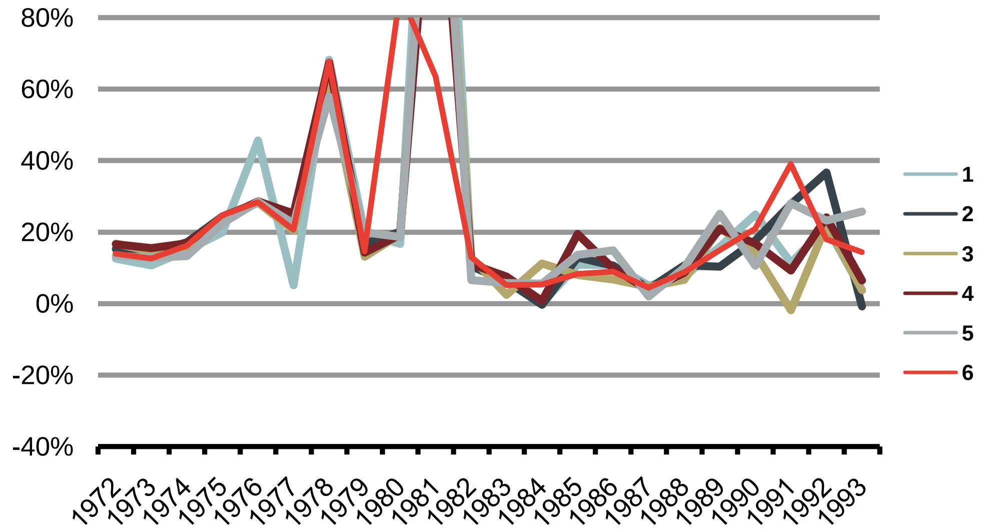
We have considered data on the Electricity Area Boards in England and Wales between 1971 and 1993.[6] While data on capital expenditure was not available in this dataset, we have been able to analyse data on depreciation. Since depreciation is proportional to the size of the asset base, tracking depreciation over time (and changes in depreciation) does provide us with a view on the growth in the asset base over time and consequently, this can provide guidance on whether there might be significant differences in historic investment patterns (and hence investment cycle).

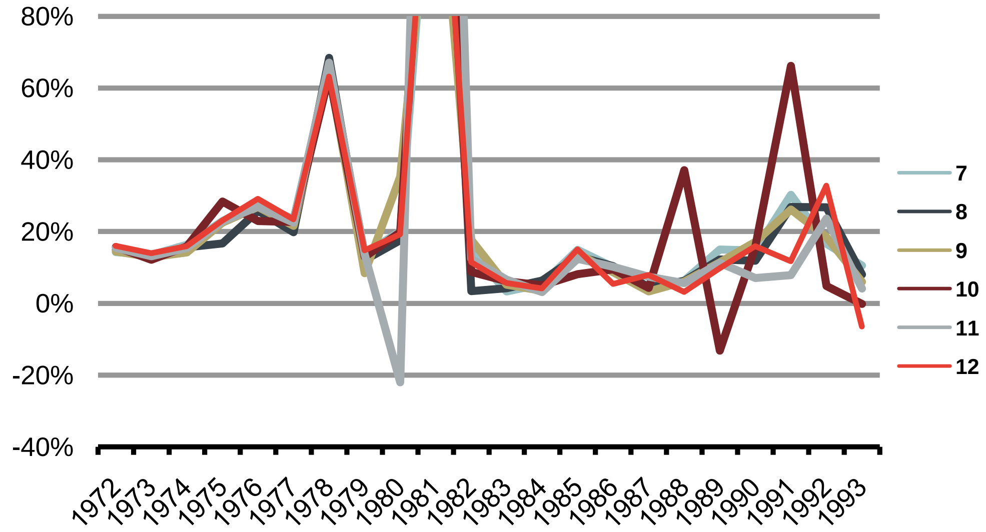
We have calculated the year on year change in depreciation and these are presented in **Figure 2**. This analysis reveals growth in the asset base of the Area Boards over the entire period. We observe some very large changes in depreciation over time, but consider that these are likely to reflect difficulties in collecting consistent data from varying sources over time. For example, there is a known structural break in the data from 1981.

5 Data from the accounts of the Area Boards and UK DUKES (1971-1993)

6 Data for the Scottish Area Boards were not available in this data set. Clearly, data is for the then newly vested DNOs from 1990 onwards.

Figure 2. Percentage change in annual depreciation by the 12 Electricity Area Boards in England and Wales





Year 1981 identifies a possible structural change in the way depreciation amount are calculated.

Source: Frontier Economics using data from the accounts the Area Boards and UK DUKES

Through the 1970s we see growth in depreciation of approximately 20% per year, slightly below that level during the early seventies and then slightly above from the mid-seventies onwards. Such large growth in depreciation would have been associated with very large investment flows. However, this pattern appears reasonably common to all of the DNOs. During the 1980s growth in depreciation slowed and generally fell between 5% and 10%. Again, rates of growth appears common to all DNOs.

This analysis of depreciation suggests that underlying capex was broadly synchronized across Area Boards for the period leading to vesting, with high correlation between each DNOs depreciation growth and average growth across the DNOs. The evidence from this data suggests that DNOs are likely to have been in similar position with respect to their investment cycle for the period up to privatization.

In the period following vesting we observe what appears to be a marked increase in volatility. We set out further analysis of this period below.

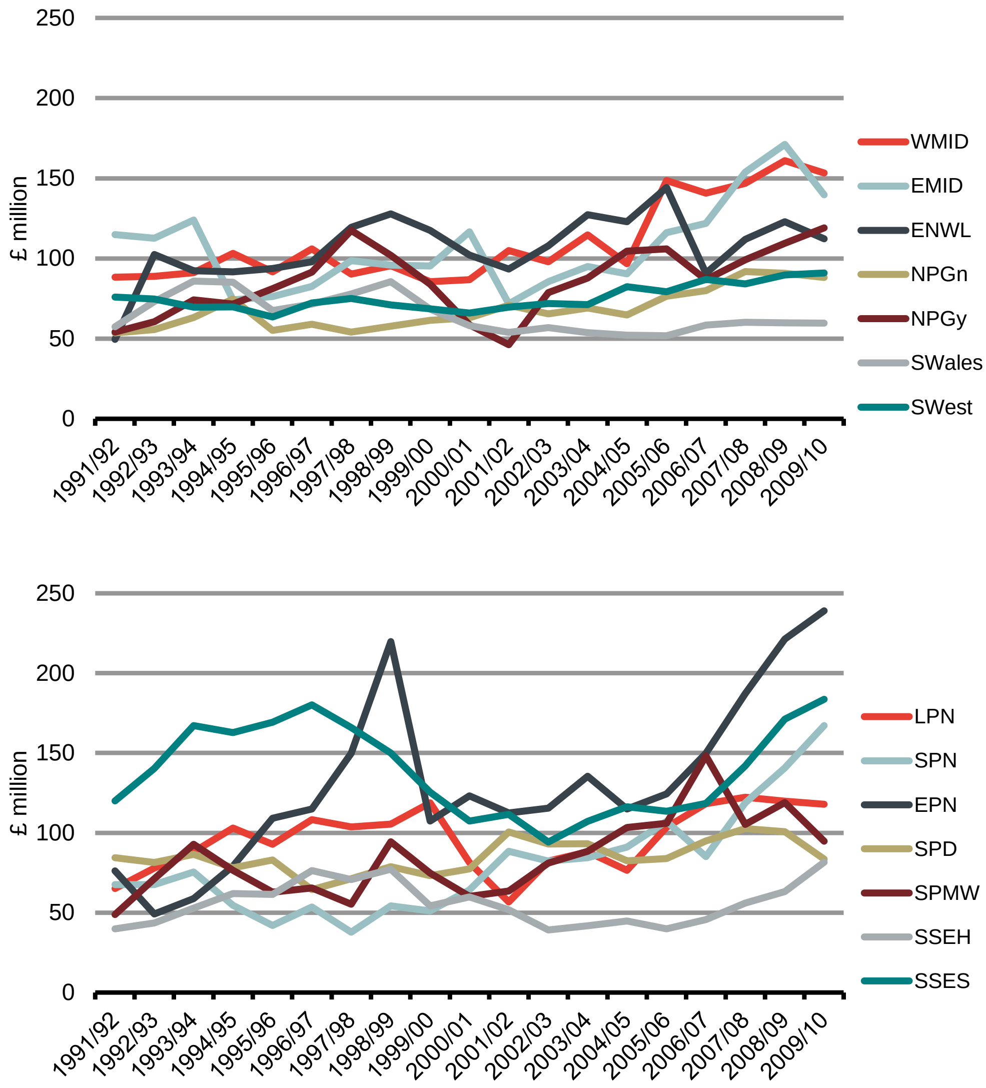
3.3.2 RAV additions since vesting

Having reviewed a proxy for investment through the seventies and eighties, it would be informative to consider capex since vesting. In this context we have analysed RAV additions as recorded in Ofgem's financial model for DPCR5[7] covering the period since privatization. These data are shown in **Figure 3** below.

We recognise that RAV additions are likely to be influenced by a number of changes to regulatory accounting rules in respect of which expenditures have been capitalised by the DNOs, and in particular that not all DNOs will have followed precisely the same policies in this respect in any given year and over time. We might therefore anticipate that this data will be noisy over time and might not necessarily reflect accurately the accumulation of fixed assets in the business over time.

7 Ofgem, Electricity Distribution Price Control Review Final Proposals – Financial model, Excel file, December 2009

Figure 3. RAV additions (£m 2007/08)



Source: Ofgem

There appears to be considerably more volatility in capex flows and less consistency of pattern than we observed in the depreciation data. This might be consistent with a more diverse set of management approaches being adopted by the newly vested DNOs. However, as noted above, it would also be consistent with a multiplicity of approaches to capitalisation. Consequently, it is difficult to draw clear conclusions from this evidence.

3.3.3 Expert assessment of asset age at DPCR4

We have also considered expert reports prepared at previous price control reviews conducted by Ofgem. In particular, we have found some qualitative evidence that is relevant in the reports prepared by PB Power for Ofgem at DPCR4.[8]

In its assessment of capital allowances, PB Power concluded that at the beginning of DPCR4, there were no material differences in the asset ages across DNOs for the main asset classes[9]. This evidence suggests that for the period covered by the sample, following the DPCR4 decision which covered the period from April 2005, DNOs' network assets were of broadly similar age, with any departures not sufficiently material to warrant differences in forecast expenditure.

3.4 Conclusion

We have considered whether the specification proposed to estimate totex efficiency should also take account of the position of DNOs in the investment cycle.

Our assessment of depreciation data (which can be used to understand growth in fixed asset) for the Area Boards (the predecessors of the DNOs) suggests that all DNOs constructed and expanded their networks with broadly similar growth rates over the course of the seventies and eighties.

Evidence on investment since vesting is relatively noisy and could suggest that there have been differences in network investment approaches over the 20+ years since vesting. However, given known differences in capitalisation policy, it is difficult to draw strong conclusions in this respect.

Expert assessment undertaken at DPCR4 did not identify any material differences in underlying asset age, at least none that would justify differences in allowances.

Consequently, on balance our conclusion in relation to investment cycle is that there is no need to control for this in assessing the relative efficiency of DNOs total expenditures.

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8 Ofgem, Electricity Distribution Price Control Review PB Power Reports on Capital Expenditure, January 2005.

9 See for example, Ofgem, NEDL, DPCR4 – FBPQ analysis and capex projections, October 2004, Forward section, fourth paragraph.

4 Including asset related outputs

4.1 Phase 1

In line with the economic theory that underpins our approach, our total cost function specification depends on outputs, inputs prices and environmental factors. Asset related outputs, such as network length, have not hitherto been included.

Discussion with Ofgem and the DNOs highlighted the desire on the part of certain DNOs to undertake a more thorough review of asset related outputs. This was therefore considered to be an important topic for further research during Phase 2.

4.2 Phase 2 approach

During meetings with Ofgem and the DNOs, Frontier has set out its view on the merit of including asset related outputs in our benchmarking exercise. In short, Frontier does not consider asset related output measures such as network length and MEAV to be suitable cost drivers for the following reasons.

- **Assets are not outputs:** DNOs' customers value the electricity delivered to them and the absence of service interruptions. They are indifferent to the length of the DNO's network or the underlying value of its asset base. Hence, network length and MEAV are not outputs but rather inputs (or intermediate inputs) by means of which electricity can be delivered.

- **Efficiency is not correctly measured.** The lengths of distribution networks, as well as the volume of other assets used, are discretionary choices made by the companies that have a large impact on total expenditure. It follows that if such variables are included in the model as cost drivers, the error term that explains managerial efficiency would not be capturing how efficient are DNOs at designing and building optimal networks. While such an approach could be considered appropriate if one was interested in how efficient DNOs are at maintaining their networks (e.g. with opex as the dependent variable), we do not consider it to be valid if the exercise is focused on totex.

- **Poor incentive properties:** Including asset related outputs in a benchmarking exercise can cause perverse incentives. Holding everything else equal, DNOs with larger networks will appear more efficient, which will consequently provide DNOs with incentives to have larger networks where other design choices might be better. At the margin, this could encourage

DNOs to make operational choices that involve the installation of more assets, when alternatives and overall lower cost solutions exist.

- **Density is a better proxy:** A possible argument in favour of including network length is that it may capture geographic features of each DNO's service region that drive costs. That is, DNOs serving large, sparsely populated areas will face higher costs as they have to build and maintain larger networks per unit of core output delivered. If this feature is not controlled for, those DNOs would appear as inefficient when there is an objective justification for their apparently excess cost. However, customer density is a better variable to control for those effects, as it is not within the control of the company and therefore does not create perverse incentives and/or technical difficulties in estimation.

Conversely, it might be reasonable to consider taking account of network length (or MEAV) as a short run fixed input that we use to condition our estimation of totex and hence efficiency. However, in the light of the incentive properties of such a model, its use would need to be considered carefully.

Notwithstanding our in principle position on the inclusion of asset related variables, we have tested the effect of including such variables in our model. In the following subsections we consider the appropriateness of including such variables in the total cost function. As we set out, we have considered a wide range of potential approaches. We present the conclusions that we draw from an initial exploration of the available data in Sections 4.3 and 4.4. We then present econometric results in Section 4.5, before presenting our conclusions in 4.6.

4.3 Analysis of network length

If there are geographical factors that affect the amount of network length per unit of output delivered, and the intensity of these factors is heterogeneous across DNOs, then an argument for including network length as a cost driver could be made.

In this section we present evidence that supports this hypothesis. However, we will show that connection density can also explain such differences and given its properties we consider its inclusion to be a superior approach.

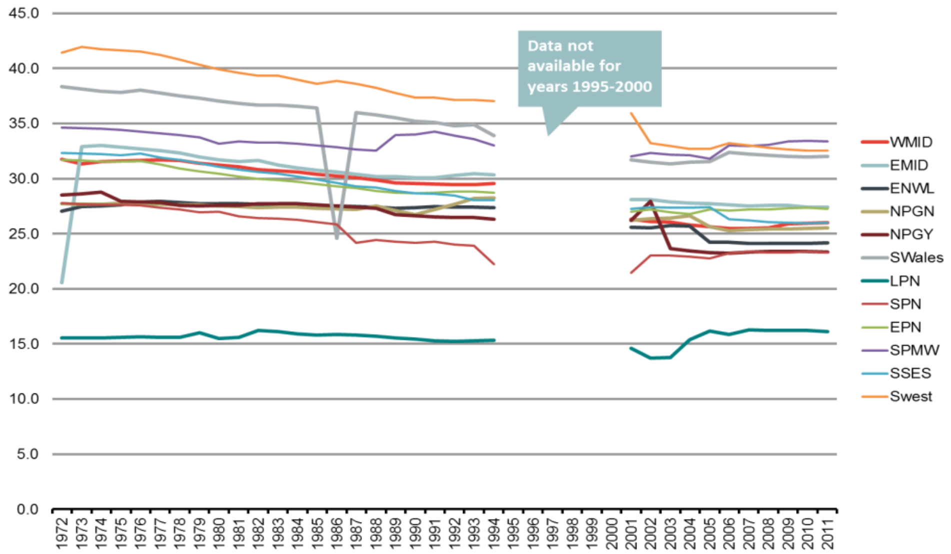
We have considered data on network length, energy delivered, customers supplied, and peak load from the 1970s up to date. We use the data set that underpinned our analysis of potential differences in investment cycle (see Section 3) from 1970 to 1993. We use data from Ofgem for the period 2001 to 2011. We do not have data for the period between 1993 and 2001. Note that the two Scottish distributors are not included in the graphs, since data over all of this time frame was not included in the historic data set.

4.3.1 Network length per unit of output

We have considered whether there is any evidence to suggest that there are intrinsic differences between DNOs in respect of the relationship between network length and the other core outputs in the model.

We show below the evolution of the relationship between network length and three core outputs (number of customers, peak load and energy delivered) over the period 1972-2011.

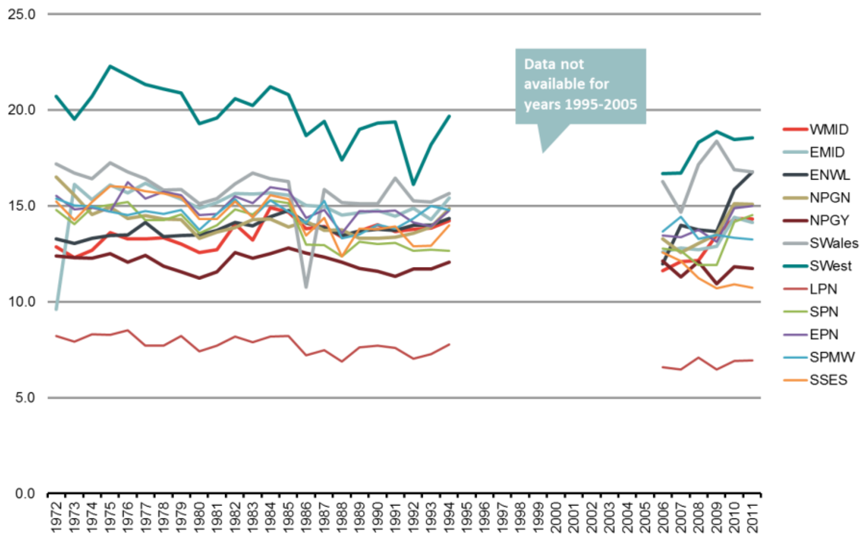
Figure 4. Network length / Number of customers (km/1000 customers)



Source: Frontier analysis using data from the accounts the Area Boards and UK DUKES (1971-1993) and Ofgem data (2001-2011).

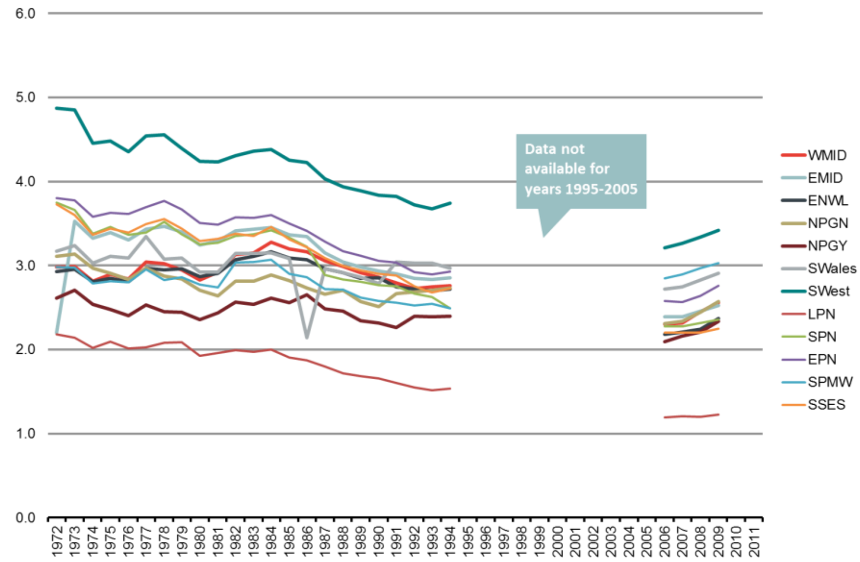
Note the two outliers, EMID in 1972 and SWales in 1986. We suspect that data for such values might be inconsistent with the rest of the series and attach no weight to those observations.

Figure 5. Network length / Peak load (km/MW)



Source: Frontier analysis using data from the accounts the Area Boards and UK DUKES (1971-1993), and Ofgem data (2001-2011).

Figure 6. Network length / Energy delivered (km/kWh)



Source: Frontier analysis using data from the accounts the Area Boards and UK DUKES (1971-1993) and Ofgem data (2001-2011).

Certain features emerge from examination of network length per number of customers.

- The ratio of network length to customers generally decreases over time. This is likely to be due to economies of scale, as more customers are added to a fixed size service area, the DNO can exploit its already built network to serve them.

- Across DNOs, there are systematic differences in network length per customer. These differences persist over time and, importantly, were observable for the predecessor Area Boards. This suggests that DNOs are faced with environmental conditions specific to their service area that cause them to need more assets per customer.

- Network length ratios with respect to peak load and energy are more volatile and show different underlying trends. This is intuitive, since energy delivered and peak load are, per se, more volatile variables than number of customers since they will be affected by factors such as the economic environment and short term weather/climate conditions.

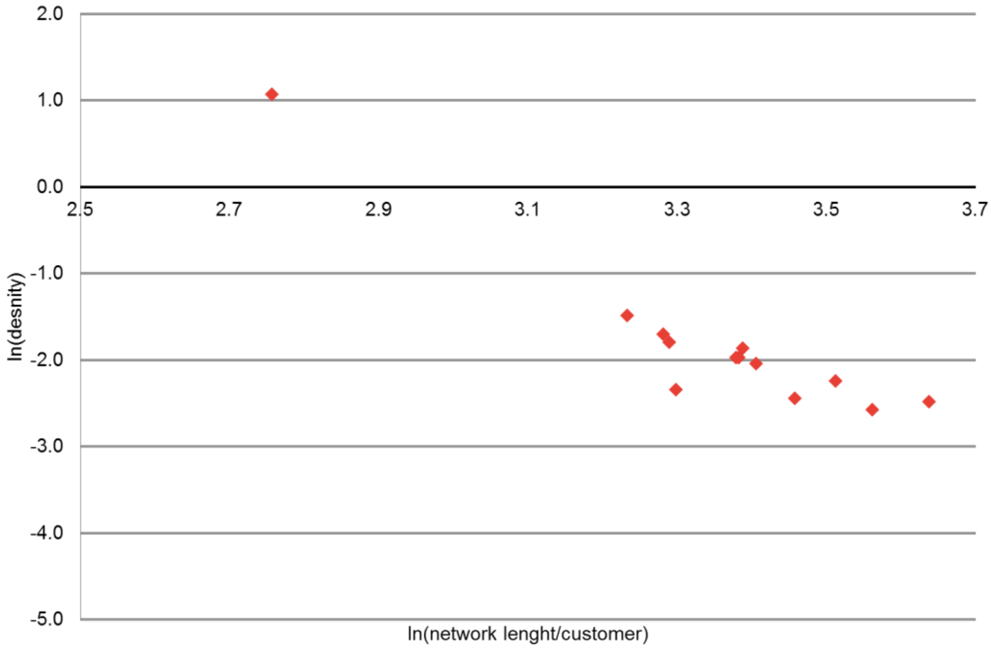
We conclude that the long run data we have analysed supports the hypothesis that there exist geographical factors that influence the lengths of DNOs' networks and that these differences are sustained over time. It also seems reasonable to presume that these differences in service region characteristics could drive justifiable differences in totex. Consequently, it is necessary for us to consider whether these factors are captured in our model if we decide not to include a measure such as network length.

4.3.2 Network length and density

In what follows, we examine whether and to what extent density appears to explain the observed dispersion in network length per customer across the DNOs.

The figure below shows the correspondence between the averages (over the period 1972-2011) of network length per customer and density (both in logarithms).

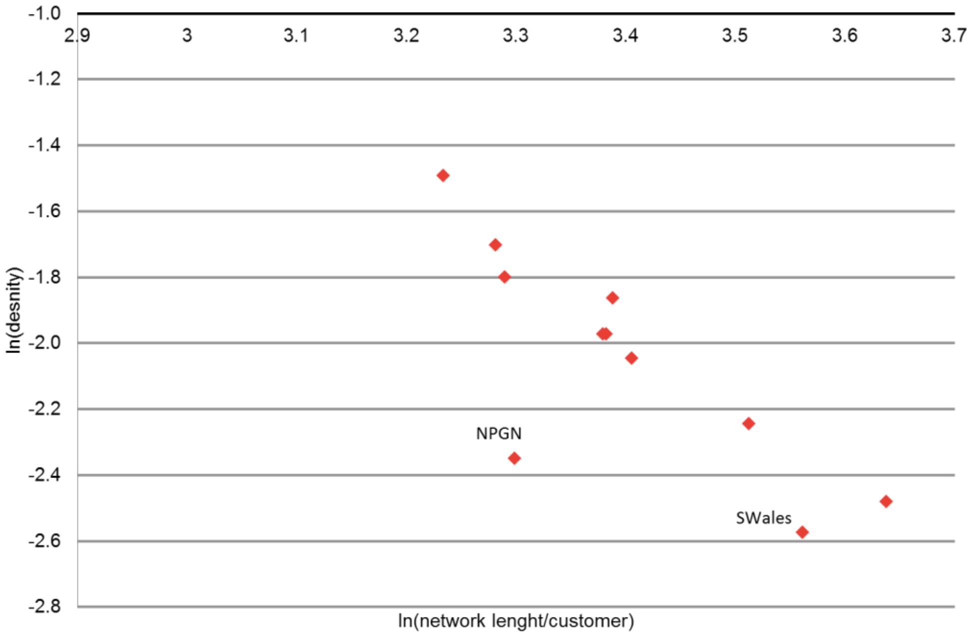
Figure 7. Scatter of density and network length/customer in logs; Averages over the period 1972-2011 for the 12 England and Wales DNOs



Source: Frontier Economics

Since the scatter is highly influenced by an outlier (LPN), below we plot again the same graph, but this time excluding LPN from the sample. We highlight two DNOs.

Figure 8. Scatter of density and network length/customer in logs; Averages over the period 1972-2011; LPN excluded

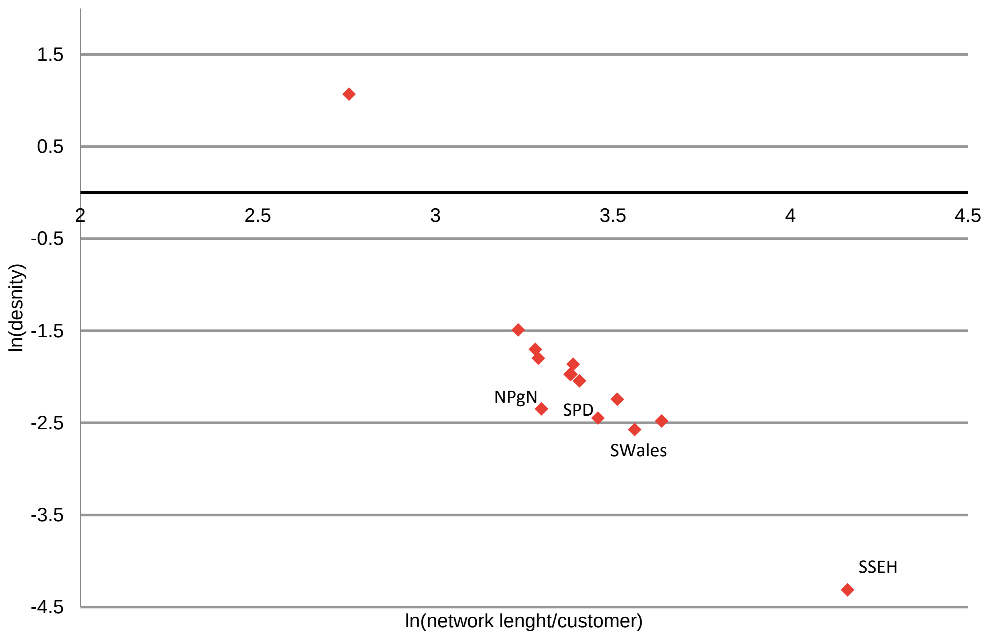


Source: Frontier Economics

As it can be seen, there is a strong linear relationship between the two variables, with two DNOs (NPgN and SWales) appearing to depart slightly from that relationship.

In order to include the two Scottish DNOs, we repeat the analysis again using data from 2006 to 2011 for those two DNOs only.

Figure 9. Scatter of density and network length/customer in logs, including averages over the period 2006-2011 for SPD and SSEH



Source: Frontier Economics

The figure reveals that, as has been the case in other elements of our analysis, both LPN and SSEH are outliers. However, SPD appears to lie well within the range spanned by the other DNOs, in particular given the inaccuracy that may arise as a consequence of the shorter period for analysis for the Scottish DNOs.

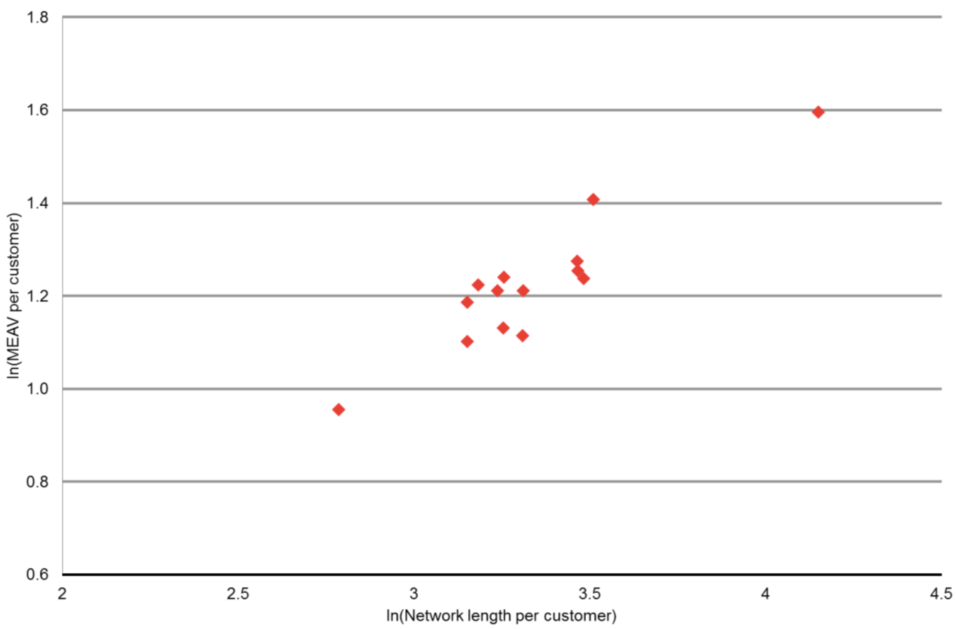
In summary, we observe an apparently close relationship between network length per customer and density. We conclude that density (simple, average density) is therefore a reasonable proxy to use for the environmental factors that cause DNOs to have larger networks per customer served. Given that density also addresses the undesirable regulatory/incentive properties associated with network length (highlighted above), and also eliminates the issue of endogeneity, these findings suggest that proceeding with a measure of density to capture potentially important environmental differences between networks is to be preferred to using a measure of network length.

4.4 Analysis of MEAV

In this section we explore the prospect of including MEAV as a cost driver. Our analysis is complicated by the fact that we only have MEAV data available for a single year, 2010. Thus, we are unable to observe the evolution of MEAV over time. However, we understand from the DNOs that MEAV changes very slowly over time and consequently consider that it is reasonable to work with the data at hand.

Since conductors are one of the main elements of the asset register, we expect MEAV to be highly correlated with network length. Indeed, we find high correlation (0.930) between MEAV per customer and network length per customer (both in logarithms) for the year 2010. We illustrate this below. We note that the figure reveals again two outliers in the sample, LPN and SSEH.

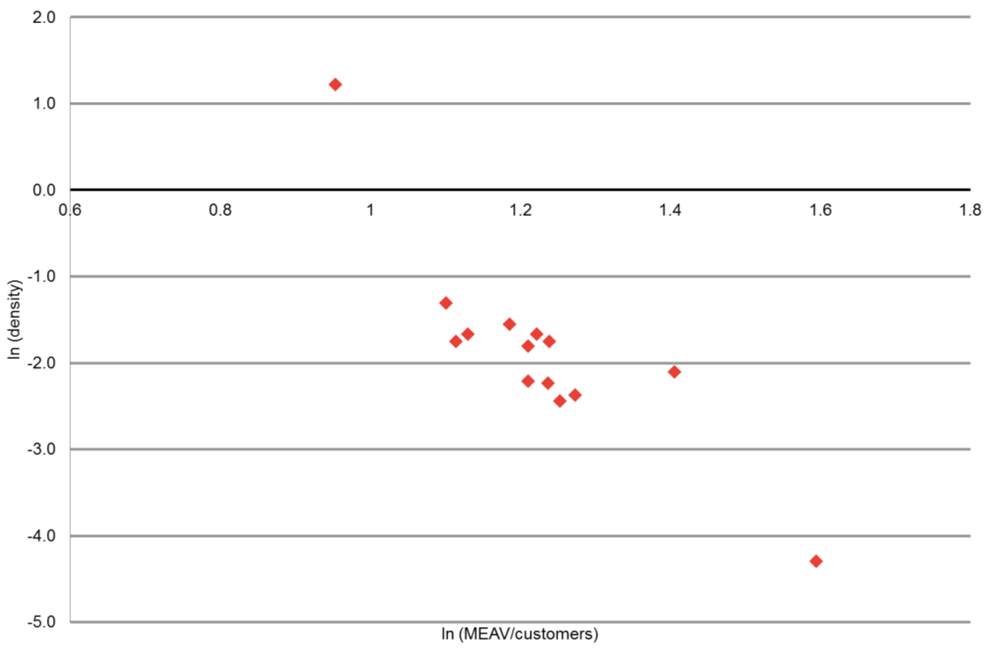
Figure 10. Scatter of network length and MEAV in logs (2010)



Source: Frontier Economics

Below we show a scatter plot of density against MEAV/customers in logarithms.

Figure 11. Scatter of MEAV per customer and density in logs (2010)



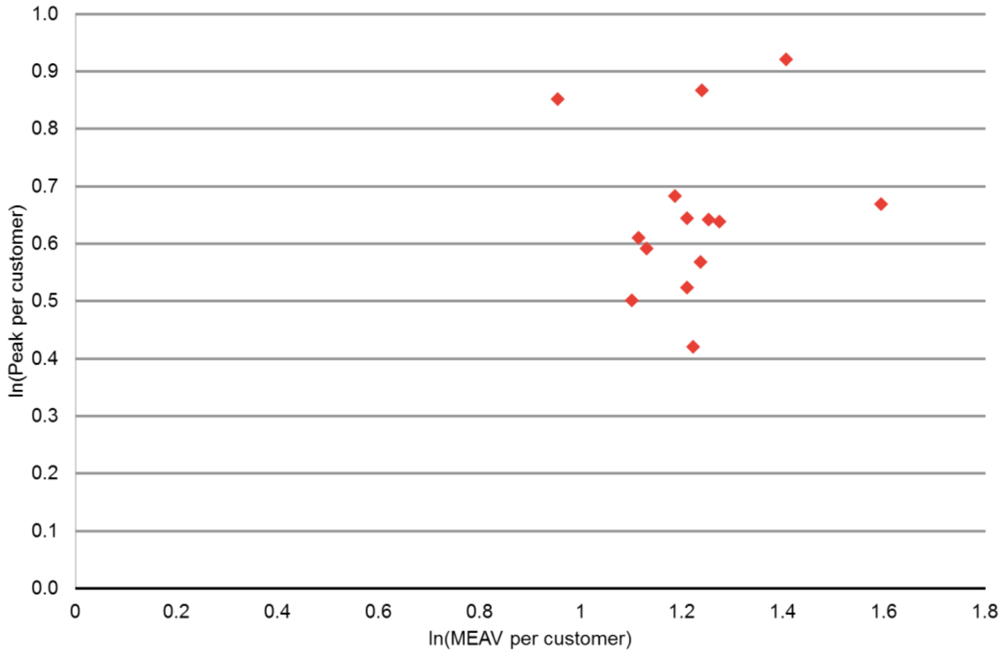
Source: Frontier Economics

While there is a seemingly clear relationship between the two measures, the correspondence is not as strong (correlation equals 0.882) as that found in **Figure 9** above, where we plotted density and network length per customer.

This slightly weaker correlation arises since MEAV is driven by more than just network length. It seems reasonable to suppose that, to some extent, MEAV will also take account of the volume and size of other assets, notably transformers. In turn we might consider that these assets are driven not only by the spatial distribution of customers, but also by their peak energy demands.

As we illustrate in **Figure 12** below, we find limited correlation (0.117) between peakload per customer and MEAV per customer.

Figure 12. Scatter of Peak per customer and MEAV per customer in logs (2010)



Source: Frontier Economics

However, when we regress network length per customer and MEAV per customer for 2010 against peak per customer and density we obtain the following results.

Table 3. Pooled OLS regression of MEAV per customer and network length per customer as a function of density and peak per customer

	MEAV/Customer	Network length/customer
density	-0.125***	-0.256***
Peak/customer	0.350***	0.450*
constant	-2.86***	0.538
R^2 [10]	0.884***	0.899***

The table reports the estimated coefficient for each variable and the confidence intervals using a 95% probability.[11]

*** Significant at 1% ** Significant at 5% *Significant at 10%

Source: Frontier Economics

This suggests that MEAV can be understood to be reasonably well described by a combination of density and peak, both of which are included directly in our preferred model. Consequently we conclude that adding MEAV to our preferred model would not result in additional insights. Furthermore, given concerns over the incentive properties of including MEAV, together with the technical issues of endogeneity that arise, we consider that a model that does not include MEAV is to be preferred.

4.5 Results

Notwithstanding the analysis and observations set out in the preceding subsections on network length and MEAV, we have nevertheless explored econometric models that include network length and MEAV as cost drivers. In this section we show the econometric results obtained under variations of our core models, Specification 1- Regional wages and Specification 2 – National wages, that include network length or MEAV as a cost drives.

4.5.1 Network length per customer as a cost driver

If we replace our density measure used in our two core specifications by network length per customer we obtain the following results.

10 See footnote 3.

11 See footnote 4

Table 4. Relationship between network length per customer and density

	Specification 1 (Regional wages, SIC35)		Specification 2 (National wages, SIC35)	
	Base Case (density)	Network length	Base Case (density)	Network length
Customer	0.469***	0.577***	0.585***	0.696***
Peak	0.351***	0.309**	0.239*	0.215*
Density	-0.078***		-0.056*	
Network length per customer		0.362***		0.339***
Wages	0.326***	0.313***	0.542***	0.567***
Price of capital[12] (BEAMA)	0.674	0.687	0.458	0.433
Constant	-8.21***	-8.54***	-8.64***	-9.076***
R^2 [13]	0.8866***	0.8975***	0.8751***	0.8981***

The table reports the estimated coefficient for each variable and the confidence intervals using a 95% probability.[14]

*** Significant at 1% ** Significant at 5% *Significant at 10%

Source: Frontier Economics

Overall, the results are broadly similar whether the model includes density or network length. As would be anticipated, the coefficient on density and that on customers per network length are different. In particular the sign changes, but this reflects the negative correlation between the two variables as highlighted in various figures above. For the other variables in the model, while it is true that we observe some variations in the coefficients, such differences are small.

Further, R^2 values suggest that the model has slightly greater explanatory power when density is substituted by network length per customer.

12 Due to the imposition of homogeneity of degree +1 in input prices, we can infer the coefficient for the capital price as 1-coefficient on wages.

13 See footnote 3.

14 See footnote 4

We do not consider that this is evidence to suggest that network length should replace density in our model. Our objective is to capture how efficient DNOs are at managing costs given the required volume of outputs they are asked to serve and the nature of their service region. In an exercise of this kind, including network length per customer as an explanatory variable would be inappropriate since it would take no account of a key element of DNO performance, i.e. the ability to design optimal networks that where appropriate and make use of fewer assets.

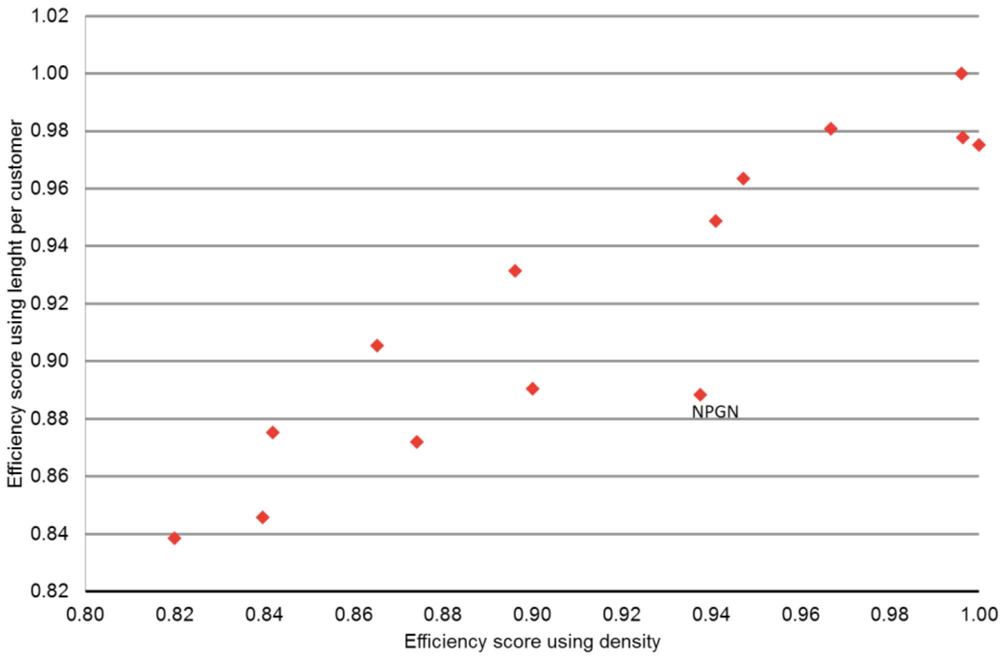
However, it is worth noting that in some respects the choice between an exogenous measure of density and a measure derived from network length, is not particularly significant. Below we show the efficiency scores and ranks obtained under both approaches for our two preferred specifications.

Table 5. Efficiency scores and rankings; Specification 1

	Base Case (density)		Network length	
	Score	Rank	Score	Rank
WMID	0.840	13	0.846	13
EMID	0.947	5	0.963	5
ENWL	0.900	8	0.890	9
NPgN	0.938	7	0.888	10
NPgY	1.000	1	0.975	4
SWales	0.996	2	0.978	3
SWest	0.967	4	0.981	2
LPN	0.896	9	0.931	7
SPN	0.874	10	0.872	12
EPN	0.842	12	0.875	11
SPD	0.941	6	0.949	6
SPMW	0.820	14	0.839	14
SSEH	0.865	11	0.905	8
SSES	0.996	3	1.000	1

Source: Frontier Economics

Figure 13. Scatter of efficiency scores; Specification 1



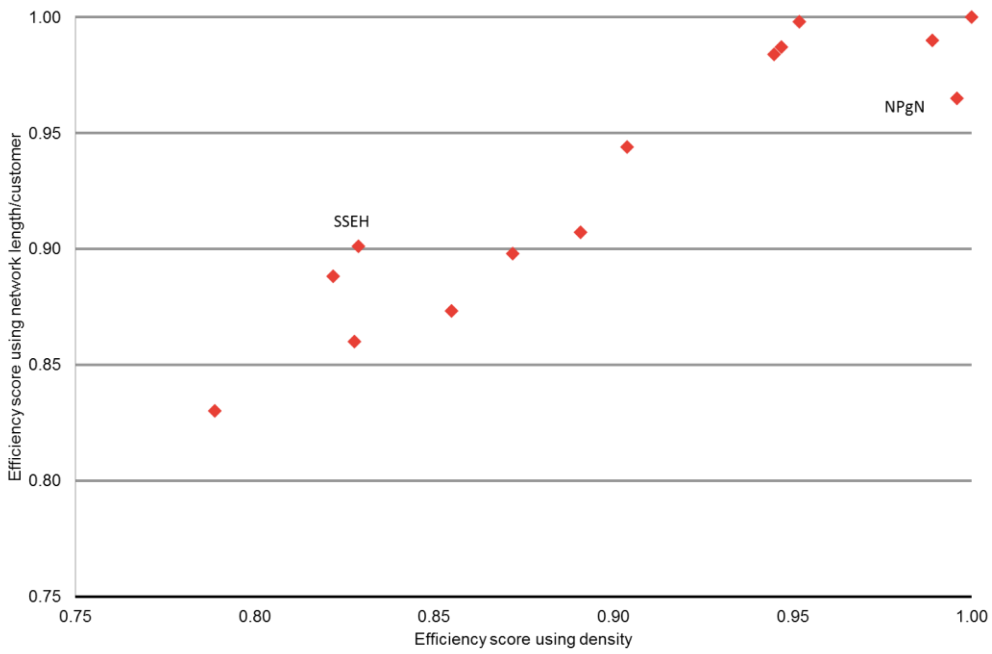
Source: Frontier Economics

Table 6. Efficiency scores and rankings; Specification 2

	Base Case (density)		Network length	
	Score	Rank	Score	Rank
WMID	0.828	12	0.860	13
EMID	0.952	4	0.998	2
ENWL	0.891	8	0.907	8
NPgN	0.996	2	0.965	6
NPgY	0.989	3	0.990	3
SWales	1.000	1	1.000	1
SWest	0.904	7	0.944	7
LPN	0.872	9	0.898	10
SPN	0.855	10	0.873	12
EPN	0.822	13	0.888	11
SPD	0.945	6	0.984	5
SPMW	0.789	14	0.830	14
SSEH	0.829	11	0.901	9
SSES	0.947	5	0.987	4

Source: Frontier Economics

Figure 14. Scatter of efficiency scores; Specification 2



Source: Frontier Economics

As we might expect, we see reasonable correspondence between the efficiency scores on different measures. We also note that the spread of efficiency scores is reduced when using the network length based measure. One interpretation of this is that using the network length based measure "forgives" DNOs in cases where they have chosen network designs that involve the use of a sub optimally high volume of assets. As we have highlighted, we do not regard this as appropriate in a long run assessment model of this kind.

4.5.2 MEAV per customer as a cost driver

In this section we provide analogous results to those presented above when MEAV per customer is included as a potential cost driver.

We show in **Table 7** below the econometric results of our core model specifications when MEAV per customer is employed to substitute density as a cost driver. Since data on MEAV is only available for a single regulatory year (2010-2011), we have assumed it to be constant over the sample period.

Table 7. Relationship between MEAV per customer and density

	Specification 1 (Regional wages, SIC35)		Specification 2 (National wages, SIC35)	
	Base Case (density)	MEAV	Base Case (density)	MEAV
Customer	0.469***	0.626***	0.585***	0.723***
Peak	0.351***	0.258*	0.239*	0.169
Density	-0.078***		-0.056*	
MEAV per customer		0.699***		0.594**
Wages	0.326***	0.296***	0.542***	0.527
Capital price (BEAMA)	0.674	0.704	0.458	0.473
Constant	-8.21***	-6.19***	-8.64***	-6.70***
R^2 [15]	0.8866***	0.8841***	0.8751***	0.8826***

The table reports the estimated coefficient for each variable and the confidence intervals using a 95% probability.[16]

*** Significant at 1% ** Significant at 5% *Significant at 10%

Source: Frontier Economics

As with network length per customer, we observe that MEAV per customer does not significantly change the size of the other core cost driver coefficients. R^2 values do not indicate a greater explanatory power when MEAV per customer is included instead of density across both specifications.

Below we present the efficiency scores and rankings under the two specifications, regional and national wages, that emerged from the analysis summarised above.

15 See footnote 3.

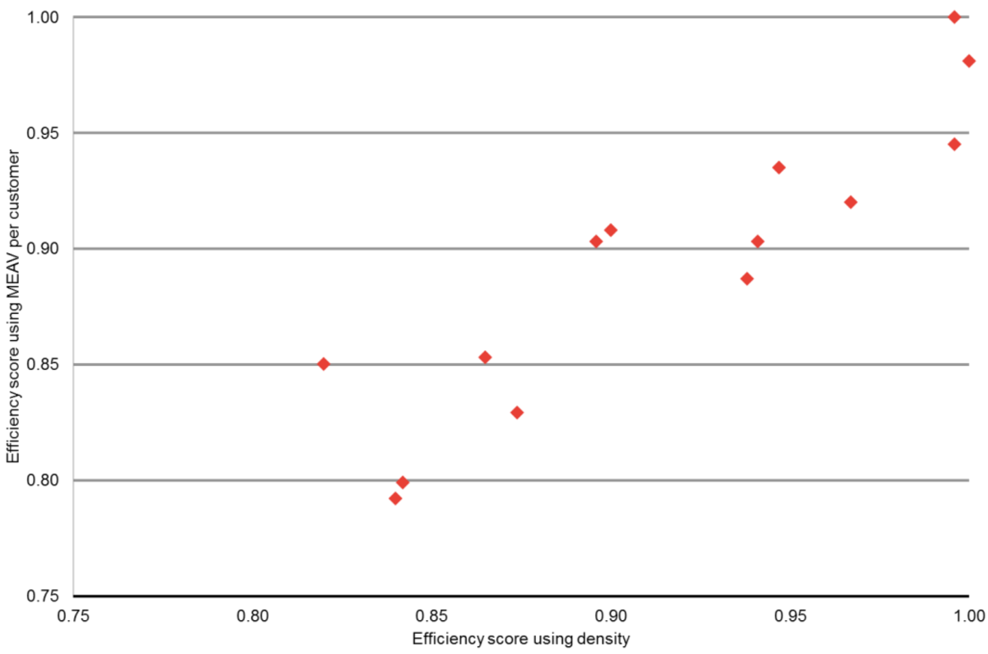
16 See footnote 4

Table 8. Efficiency scores and rankings; Specification 1

	Base Case (density)		MEAV	
	Score	Rank	Score	Rank
WMID	0.840	13	0.792	14
EMID	0.947	5	0.935	4
ENWL	0.900	8	0.908	6
NPGN	0.938	7	0.887	9
NPGY	1.000	1	0.981	2
SWales	0.996	2	0.945	3
SWest	0.967	4	0.920	5
LPN	0.896	9	0.903	8
SPN	0.874	10	0.829	12
EPN	0.842	12	0.799	13
SPD	0.941	6	0.903	7
SPMW	0.820	14	0.850	11
SSEH	0.865	11	0.853	10
SSES	0.996	3	1.000	1

Source: Frontier Economics

Figure 15. Scatter of efficiency scores; Specification 1



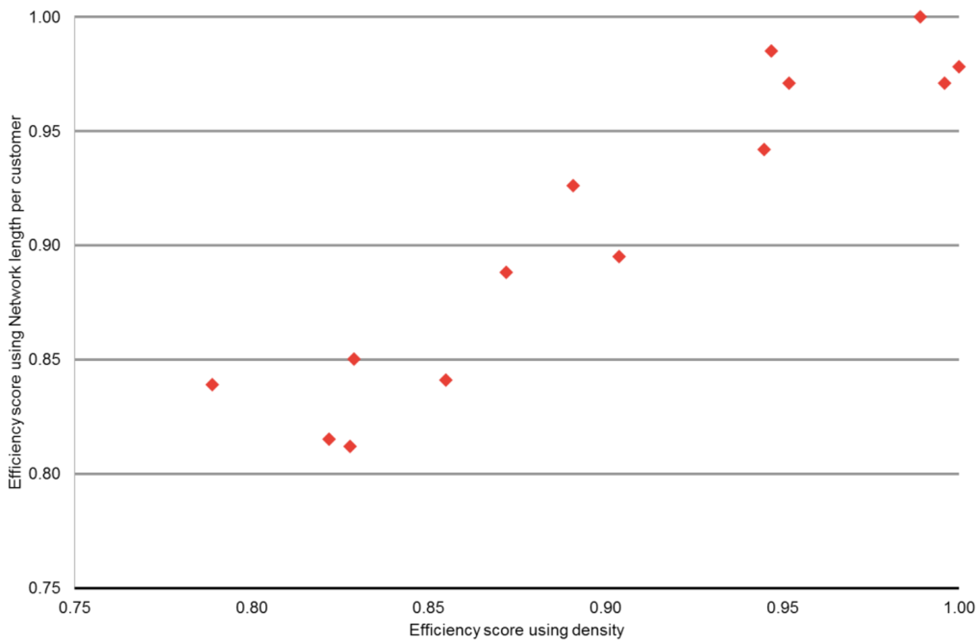
Source: Frontier Economics

Table 9. Efficiency scores and rankings; Specification 2

	Base Case (density)		MEAV	
	Score	Rank	Score	Rank
WMID	0.828	12	0.812	14
EMID	0.952	4	0.971	5
ENWL	0.891	8	0.926	7
NPgN	0.996	2	0.971	4
NPgY	0.989	3	1.000	1
SWales	1.000	1	0.978	3
SWest	0.904	7	0.895	8
LPN	0.872	9	0.888	9
SPN	0.855	10	0.841	11
EPN	0.822	13	0.815	13
SPD	0.945	6	0.942	6
SPMW	0.789	14	0.839	12
SSEH	0.829	11	0.850	10
SSES	0.947	5	0.985	2

Source: Frontier Economics

Figure 16. Scatter of efficiency scores; Specification 2



Source: Frontier Economics

Based on the previous tables and figures we cannot conclude that the spread of efficiency scores depends on whether density or MEAV per customer is used. We are cautious that MEAV values have been constant across the sample period, and so MEAV per customer ratios are decreasing at a rate inversely proportional to customer increases. In such case the individual error terms might be capturing the different rates at which DNOs increase their customer base, and hence might be considered biased. We have not investigated whether this is in fact the case.

As we have highlighted above, we do not regard using MEAV per customer as appropriate in a long run assessment model of this kind

4.6 Conclusion

In our core models, substituting network length by density has a marginal effect on the explanatory power of the model, i.e. we observe that network length per customer shows a slightly better fit with the data.

Nevertheless, we do not recommend including network length (or MEAV) in the total cost function as this prevents us from capturing how efficient DNOs are at designing their networks and provides a strong incentive to, at the margin, adopt more asset intensive operational solutions.

In terms of efficiency rankings, the effects of substituting density by network length or MEAV are marginal for most DNOs.

As a consequence of the analysis reported in this section, in addition to our in principle concerns with including asset related outputs in our totex model, we have concluded that our preferred model specification should not include asset related outputs, but should instead continue to make use of an exogenous measure of density.

5 Accounting for voltage structure

5.1 Phase 1

During Phase 1 we did not take account of differences in the voltage structure of the DNOs. However, we acknowledged in our list of areas for further research that voltage structure is a potential driver of DNOs totex. For example, in other countries, regulators have adopted benchmarking models that take account of voltage structure. Furthermore, we also understand that the Scottish DNOs do not operate at the 132kV level, which raises the question of whether an adjustment should be made to account for this.

5.2 Phase 2 approach

In principle, the voltage at which a DNO decides to transport and deliver its electricity is not an output in itself, but rather a means to an end. However, when it is used in benchmarking, it could be an instrument that captures underlying differences in the type of areas that DNOs are required to serve, like the terrain or population density. For example, differences in the equipment (and hence voltage structures) chosen to serve areas that face different challenges could act as a signal the difficulty of serving the area. However, it is also possible that differences of this nature are already captured by the density variable that is included in the model, which would eliminate the need for a further voltage structure variable.

We also note that differences between DNOs are likely to be more pronounced when those DNOs are small, since these differences in sub-areas don't average out over a relatively large total service area. For example, consider a small DNO that serves only an airport or an industrial zone. To benchmark such a DNO against a more typical DNO, serving primarily domestic customers in urban/suburban regions, it is likely to be necessary to control for demonstrable differences in the underlying DNO's task. These arguments are likely to have played a role in the benchmarking studies undertaken in other countries where in certain cases hundreds of DNOs, many of them small by GB standards, serve markedly different areas and/or types of customers.

In GB, as we have set out in the section on connection density, the network operators, with the exception of SSEH and LPN, have relatively large and homogenous service areas. This suggests that voltage structure might have a limited role in GB.

Nevertheless, we have investigated whether there is evidence to suggest that voltage structure might explain observed differences in totex. We set out the results of our investigation below.

Additionally, as noted above, we understand that the Scottish DNOs do not own or operate any assets at the 132kV voltage level, whereas all of the other DNOs operating in England and Wales do. We have investigated whether there is evidence to suggest that this needs to be controlled for in the totex model.

We have followed a two stage approach.

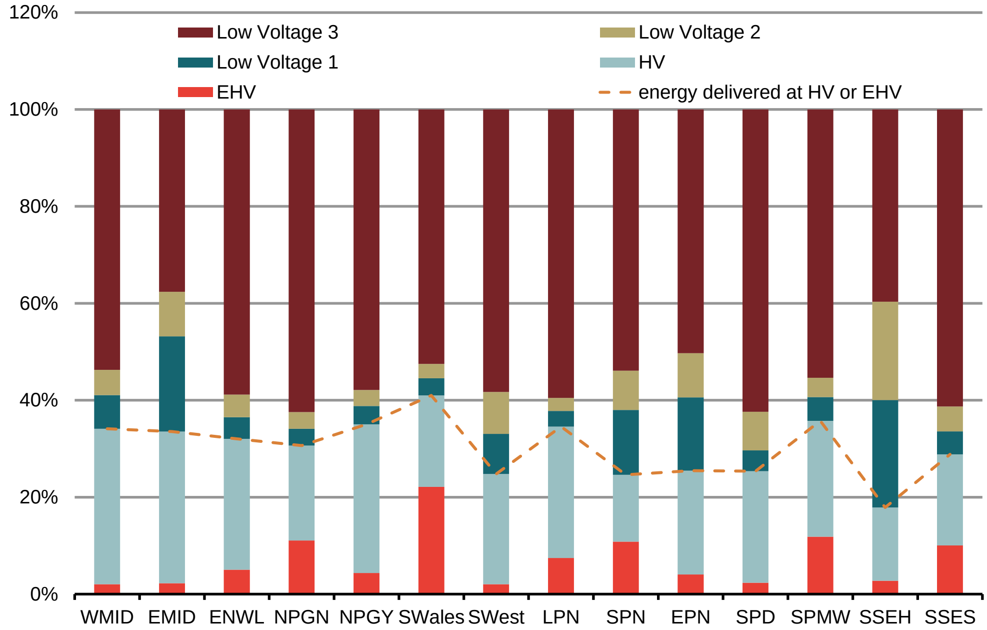
- We test directly whether certain variables that capture voltage structure are significant when added to our preferred specification.
- We also test whether the efficiency estimates derived from our preferred model specifications absent any voltage structure variables are themselves correlated with voltage structure (i.e. whether there is evidence that our estimates of efficiency might be explained by voltage structure).

5.3 Data

We understand that data on the voltage structure of the fourteen DNOs in GB is available for energy delivered, network length and customer numbers, but only for the years 2006 to 2009, which is only a subset of the years in the panel. However, we think it is reasonable to assume that the voltage structure of a network operator does not change rapidly and hence 2009 values were used for subsequent years in our analysis.

Figure 17 shows the share of energy distributed by the different voltage levels. Although some shares vary, for example the share of energy delivered at EHV (extra high voltage), the general split between high voltage (EHV and HV) and low voltage (the others) is relatively constant (this is indicated by the dotted line in the figure). The only apparent outliers in respect of the share of high voltage energy delivered are SSEH (which has a low proportion of HV) and potentially SWales (which has a relatively high proportion of HV).

Figure 17. Energy distributed by voltage level (based on 2009 data)

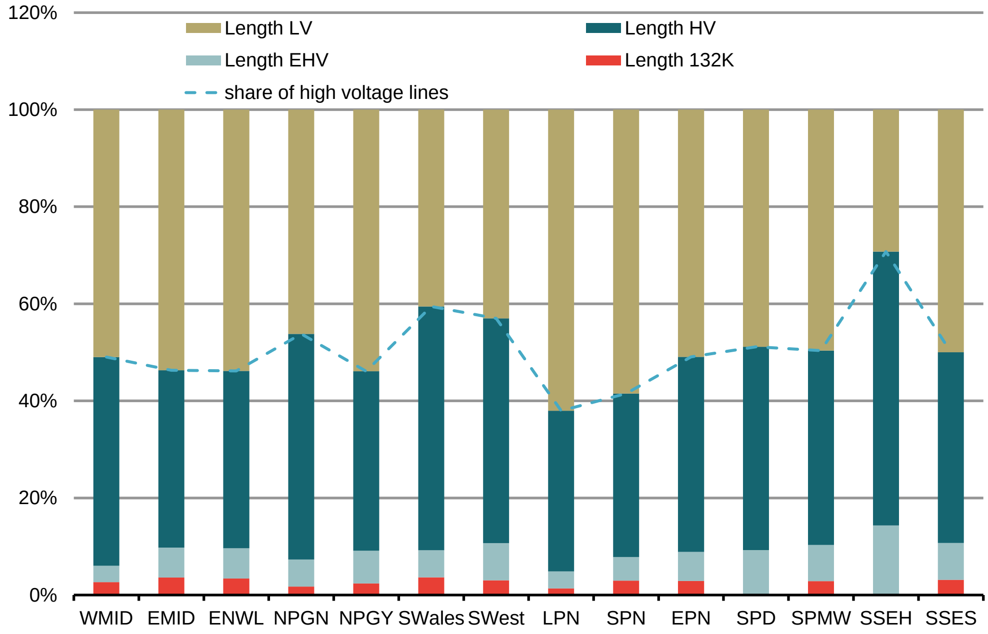


Note: We understand that the split of energy delivered at the 132 kV level is not available.

Source: Frontier Economics using data from UK DNOs/Ofgem

Figure 18 shows the total share of network length at different voltage levels. We observe that the share of high voltage lines is relatively constant across the DNOs, although there are again some outliers, i.e. SSEH (high proportion of HV), and potentially LPN (low proportion of HV). We note that these are the same two outliers identified in our density analysis. We also observe that neither Scottish DNO has any 132kV network length, as previously indicated.

Figure 18. Share of network by voltage (based on 2011 data)



Source: Frontier Economics using data from UK DNOs/Ofgem

We also examined the shares of customers that are connected at different voltage levels. As the share of customers at high voltage levels (again defined as HV+EHV+ 132kV) is only between 0.04% and 0.2%, (equivalently, all DNOs have between 99.80% and 99.96% of their customers connected at the LV level) we do not illustrate the data in a figure as this comparison is uninformative.

5.4 Results

5.4.1 Testing the significance of voltage structure variables

In order to test, whether voltage structure has a significant impact on totex, we tried adding the following variables separately to our two preferred model specifications:

- the share of energy delivered by HV and EHV networks;
- the share of HV, EHV and 132kV lines; and
- a dummy variable for the two Scottish DNOs[17].

[17] Although we have tested this dummy variable approach in order to ensure the most exhaustive review, we would otherwise be cautious about adopting an approach of this kind. In this instance we wish to consider whether we need to control for the absence of 132 kV assets. However, it

The results of this analysis are presented in a series of tables below.

Table 10. Regression results including voltage structure variables; Specification 1

	Base Case	Incl. share of energy delivered at HV	Incl. share of HV lines/cables	Incl. dummy for Scottish DNOs
Customer	0.469***	0.437***	0.438***	0.480***
Peak	0.351***	0.372***	0.352***	0.345***
Density	-0.078***	-0.067**	-0.094**	-0.074***
Wages	0.326***	0.321***	0.328***	0.328***
Share of energy delivered at HV		-0.384		
Share of HV lines/cables			-0.361	
Scottish dummy				0.26
Constant	-8.21***	-8.20***	-7.73***	-8.33***
R^2 [18]	0.8866***	0.8913***	0.8895***	0.8871***

The table reports the estimated coefficient for each variable and the confidence intervals using a 95% probability.[19]

*** Significant at 1% ** Significant at 5% *Significant at 10%

Source: Frontier Economics

would have been possible that the dummy variable might pick up a wide range of other potential factors associated with differences between Scotland and other DNOs. Consequently, had we found a significant result in this test, it would have been necessary to interpret the results with caution.

18 See footnote 3.

19 See footnote 4

Table 11. Regression results including voltage structure variables; Specification 2

	Base Case	Incl. share of energy delivered at HV	Incl. share of HV lines/cables	Incl. dummy for Scottish DNOs
Customer	0.585***	0.545***	0.592***	0.600***
Peak	0.240**	0.270**	0.23	0.23
Density	-0.056**	-0.039	-0.054	-0.051
Wages	0.541***	0.564***	0.54***	0.55***
Share of energy delivered at HV		-0.640		
Share of HV lines/cables			0.043	
Scottish dummy				0.031
Constant	-8.63***	-8.04***	-8.75***	-8.79***
R^2[20]	0.8751	0.8879	0.8759	0.8755

The table reports the estimated coefficient for each variable and the confidence intervals using a 95% probability.[21]

*** Significant at 1% ** Significant at 5% *Significant at 10%

Source: Frontier Economics

As shown in the tables above, we did not find a significant statistical relationship between voltage structure and totex in any of these formulations.

5.4.2 Correlation between efficiency scores and voltage structure

As a further cross check, we have also considered whether voltage structure might explain some proportion of the efficiency scores we estimate from our preferred totex models absent any voltage structure variable. **Table 12** reports the correlation coefficient between our efficiency estimates and the voltage structure variables set out above.

20 See footnote 3.

21 See footnote 4

Table 12. Correlations between condition variables and efficiency scores

	Share of energy delivered at HV	Share of HV lines/cables	Residuals* of specification 1	Residuals* of specification 2
Share of energy delivered at HV	100%			
Share of HV lines/cables	-34%	100%		
Residuals* of specification 1	**-23%**	**-7%**	100%	
Residuals* of specification 2	**-33%**	**-1%**	92%	100%

Source: Frontier Economics

* time invariant residuals

This analysis reveals a low level of correlation, which reinforces the results of our regression analysis.

5.5 Conclusion

We have found no evidence to suggest that it is necessary to take account of voltage structure in the context of the GB totex benchmarking. Consequently, we do not recommend that voltage structure should be controlled for in our preferred model.

This result is probably a consequence of the large scale of operation (by European standards) of the GB companies, which implies that local differences and the effect of single large customers are averaged out. Possible evidence of this averaging out effect is that the split between the share of high and low voltage levels, both in terms of energy delivered and in terms of total line length is relatively constant across DNOs (see **Figure 17** and **Figure 18**). Furthermore, it is also possible that any effect that might be captured through the use of a voltage structure variable is already captured in the model through the inclusion of a density variable.

We have found no evidence to suggest it is necessary to adjust for the lack of 132kV assets in Scotland.

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