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The Comparative Efficiency of BT in 2003

A Report for Ofcom

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1. Introduction

This report has been commissioned by Ofcom to estimate the comparative efficiency of BT's fixed line network in 2003. The report compares BT's costs to those of a sample of 67 US Local Exchange Carriers, using econometric and mathematical methods to take account of differences in size and the operating environment.

1.1. Report structure

The remainder of this report is structured as follows:

- Section 2 looks at the theory behind comparative efficiency measurement and the methodology which NERA has used in this study;
- Section 3 describes the data that has been collected and how this has been processed;
- Section 4 outlines the results NERA has obtained, and
- Section 5 concludes.

2. Comparative Efficiency Measurement

2.1. Introduction

The efficiency of a company can be defined as the extent to which it is able to minimise its costs for producing a given set and volume of outputs, taking into account the environment in which it operates (including demographic and geographical circumstances). A perfectly efficient company is one which has the lowest costs possible given the outputs that it produces and the environment in which it operates.

There are a variety of statistical and mathematical programming techniques that can be used to assess the comparative efficiency of different companies. In considering the most appropriate approach to take, it is important to examine the relative merits and drawbacks of the alternative techniques that could be used. This section looks at the most frequently used techniques and examines their main advantages and disadvantages when used in comparative efficiency assessments.

Statistical techniques use regression analysis to estimate a model, based on past data for different companies, that relates costs to different types of output (such as exchange lines, call minutes, leased lines and so on) and environmental factors (population density and dispersion, network size, relative number of business and residential lines, factor input prices and so on).

2.2. Functional Form of Regression Model

The first step in the estimation of a regression model is to consider the functional form of the equation relating the level of costs to the factors that determine costs. For this study, both the Cobb-Douglas and translog functional forms were considered. The Cobb-Douglas functional form is much less flexible than its translog counterpart, which allows the functional form of the regression equation to be influenced by the data to a far greater extent. However, to achieve this greater flexibility, the translog specification includes many more explanatory variables in the model (made up of the squared and cross-product terms of each explanatory variable included in the model) and therefore requires a far larger number of observations in order to derive a statistically significant relationship.

As part of NERA's initial investigations, the availability of data that would enable the translog functional form to be used was investigated, and it was found that, despite the expanded dataset used in this study, the number of observations was too small to accommodate the large number of variables included in the regression¹. Consequently, a Cobb-Douglas (log-log) specification was chosen. The equation below is an example of the Cobb-Douglas specification:

$$\log(C) = a + b_1 \log(L) + b_2 \log(P) + \dots$$

¹ When estimating a translog function it is necessary to estimate simultaneously the demand functions for the inputs to the cost function (labour, capital and other inputs), and the total cost function itself. Investigation into the availability of data for the estimation of the input demand functions indicated that, particularly when looking at other costs, it would not be possible to obtain LEC specific data of sufficient reliability to allow the estimation of these functions.

In this regression, C is a measure of cost, and L and P are explanatory variables, such as the number of switched lines, or population density.

Some of the advantages of using a cost function with this functional form are that:

- Firstly, it allows for non-constant returns to scale;
- Secondly, it limits the impact of heteroscedasticity; and
- Thirdly, a log-log transformation of the Cobb-Douglas functional form results in an equation that is linear in explanatory variables (which is a requirement of regression analysis) and which can be easily interpreted (the coefficient on an explanatory variable indicates the percentage change in total cost that would result from a 1% increase in the explanatory variable, all other variables remaining constant).

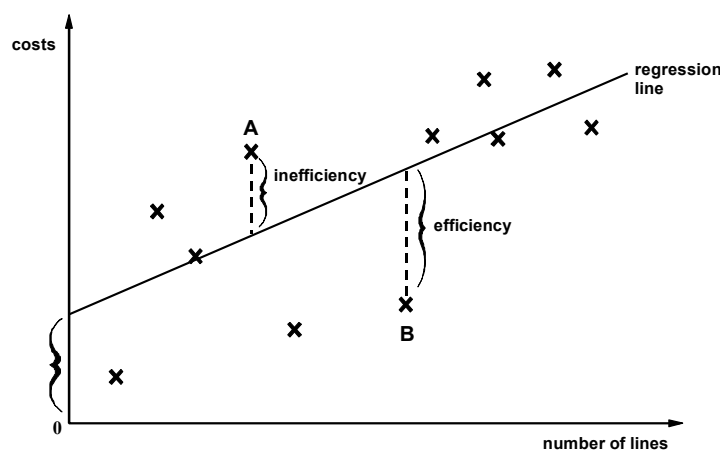
The estimation of the relationship between costs, outputs and environmental factors, based on the use of the Cobb-Douglas functional form, is described in the subsequent paragraphs.

2.3. Ordinary Least Squares (OLS) Regression Analysis

Ordinary Least Squares analysis is one of a variety of techniques which fall under the heading of regression analysis. It involves the identification of the statistical relationship between different variables. In the case of this study, therefore, the objective is to derive the relationship between total cost and a variety of exogenous cost drivers such as the number of lines, the number of call minutes, the dispersion of population etc.

OLS regression analysis can be best understood through the use of a simple example. If the cost of building and operating a network (C) depended only on the number of exchange lines provided (L), then each operator's level of costs and number of customer lines could be plotted on a graph, as in Figure 2.1 below, where each point represents a different operator.

Figure 2.1
Ordinary Least Squares Regression Analysis



Ordinary least squares regression analysis fits a line of “best fit” to these points, such that the line minimises the sum of the squared vertical distances of the observed company costs

(represented by crosses) from the line, hence the technique's formal name, ordinary least squares.

The line of best fit can be written in equation form as:

$$C_i = a + bL_i + u_i$$

where i represents the observations for the different operators, a is the fixed cost involved in providing a network regardless of the number of exchange lines, b is the cost of providing each additional line (the marginal cost), and u is the regression residual (the difference between actual costs and those "predicted" by the line of best fit).

If there are many companies in the sample, it is very unlikely that they would all lie on the best-fit line, but rather some would be above and others below. The best-fit line therefore represents the costs that a company of 'average' efficiency would be expected to incur at each volume of exchange lines. Those companies with an observation above the line (for example, company A in Figure 2.1) have costs above those of a company of average efficiency with the same number of lines. Such companies are, in this relative sense, inefficient. Conversely, those companies that lie below the regression line (for example, company B) may be viewed as being relatively efficient (above average efficiency).

In practice, rather than plotting all the companies' observations on a graph, a computer program is used to estimate the regression coefficients (a and b) using the data on all the companies in the sample. Individual companies are then judged by substituting their actual output numbers into the equation to give a predicted level of costs, Z , as if the company were of average efficiency. If the company's actual cost level were larger than Z , then it would lie above the regression line and, therefore would be deemed inefficient (compared to "average performance"). Likewise, if its predicted costs were to exceed its actual costs, it would be judged to be efficient compared to "average performance".

The difference between a company's actual costs and its predicted costs is termed the residual. A positive residual therefore indicates inefficiency relative to the sample "average", and a negative residual indicates efficiency relative to the sample "average".

Most cost functions are likely to have more than one cost driver. So for example, the cost function for a telecommunications operator will in reality have additional cost drivers as well as the number of exchange lines. OLS regression analysis deals with this through the use of multivariate regressions, which take the general form:

$$C_i = a + b_1L_i + b_2P_i + b_3Q_i + \dots + u_i$$

As before, a represents the level of fixed costs, b_1 measures the marginal cost of explanatory factor L , and u is the regression residual. But in addition, b_2 and b_3 now measure the marginal cost of the new explanatory factors P and Q respectively (assuming in each case that the other two explanatory factors are held constant).

2.3.1. Multi-year least squares regression analysis

The analysis described above uses data for a single year to assess how efficient one firm is compared to others. However, depending upon the number of firms for which data is available, such analysis has limitations with regards to accuracy and robustness. If, for example, a number of firms have low costs for spurious reasons (such as misreporting of accounting data in a particular year) this could skew the model significantly, making other firms look less efficient than they actually are. Also, the number of observations is limited to the number of companies for whom the required data are available.

Where a number of years of data are available, it is possible to create a data panel (or “pool”), which includes data for different companies over a number of years. This helps overcome problems associated with a limited number of observations, and reduces or eliminates the impact of peculiarities in the data, as these tend to “average out”. The use of a panel dataset should therefore lead to a more robust and stable model.

However, including more than one year’s worth of data from any firm can lead to problems due to the existence of heterogeneity both within observations across time and between the different observations in the panel. This can lead to difficulties in obtaining efficient and unbiased estimates of the regression coefficients. In addition, panel data can also lead to problems of autocorrelation, if the within-observation heterogeneity is low (if the figures for each year for an observation do not differ by a large amount).

Ordinary Least Squares analysis is neither able to control for the heterogeneity both within and between observations, nor for the autocorrelation problems that can arise with panel data, and hence it is not an appropriate technique to use with this type of data. In its place a two-step Generalised Least Squares (GLS) approach can be used, which takes account of the repeat observations for each firm.

The model estimated using data for a number of years is similar to that used in single-year analysis, but has an additional term measuring the time trend. This variable, which effectively allows the constant term to change over time, takes account of technological progress, inflation, or other such items that cause changes in the costs of all companies over time. The regression equation in this case is:

$$C_{i,t} = a + b_1 L_{i,t} + b_2 P_{i,t} + b_3 Q_{i,t} + \dots + T + u_{i,t}$$

where T is the time trend, and $L_{i,t}$ is the value of variable L for company i in time period t , and so on. Finally, $u_{i,t}$ is the regression residual which indicates the gap between actual and predicted (average) efficiency for each company in each time period.

It is possible to run panel data analysis with an “unbalanced panel”; that is, a dataset that does not contain an observation for each company in every year in the panel. If, for example, the panel covers eight years, it is possible to include firms in the panel, which are missing data for some of those years (for example a firm which has data for only 5 of the 8 years), without the model being adversely affected.

2.4. Stochastic Frontier Analysis (SFA)

A significant drawback of both OLS and GLS regression analysis is that they both implicitly assume that the whole of the residual that is obtained for any company in any period of time can be attributed to relative inefficiency (or efficiency). However, it is possible, if not probable, that the residuals from such an analysis will include unexplained cost differences that are the result of data errors and other factors affecting costs that have not been picked up in the regression equation. Stochastic Frontier Analysis (SFA) builds on the methodologies outlined above and aims to address this shortcoming.

There is an extensive academic literature on efficiency measurement using SFA, and this technique is increasingly being used by utility regulators to measure inefficiency. It is based on regression analysis, but has two distinctive features:

- In contrast to OLS and GLS regression analysis, SFA models incorporate the possibility that some of the model residual may result from errors in measurement of costs or the omission of explanatory variables, as opposed to the existence of genuine inefficiencies. This decomposition of residuals between ‘error’ and ‘genuine inefficiency’, which is based on assumptions made about the distributions of the ‘error’ and ‘genuine inefficiency’ terms, is intended to provide a more accurate reflection of the true level of inefficiency.
- Secondly, the regression for SFA looks not at the average firm, but at the theoretically most efficient one.

In the case of data for just one year SFA estimates the equation:

$$C_i = a + b_1 L_i + \dots + v_i + u_i$$

where ‘...’ indicates the other variables included in the model.

The residual in a stochastic frontier model is assumed to have two components: the u_i component, which represents the genuine inefficiency; and the v_i component, which represents the genuine error. In econometrics literature, u_i is often referred to as the inefficiency term and v_i is often referred to as the random error.

In order to be able to decompose the residual into inefficiency and random error it is necessary to make assumptions about the distributions of its two components. For single year SFA models, the inefficiency term is assumed to follow a non-negative distribution (such as the half-normal or truncated normal distributions), whilst the genuine error term is assumed to follow a symmetric distribution. By making these assumptions the technique is able to decompose the residual by fitting the assumed non-negative distribution to the residuals to identify the proportion of the residuals that can be explained by this distribution.

Having to make such assumptions is a key disadvantage of single year SFA, as the appropriateness of these assumptions cannot accurately be measured.

SFA is described in greater detail in Appendix A below.

2.4.1. Multi-year stochastic frontier analysis

SFA can also be applied to panel data. This involves estimating a regression equation of the following form:

$$C_{i,t} = a + b_1 L_{i,t} + b_2 P_{i,t} + b_3 Q_{i,t} + \dots + T + v_{i,t} + u_{i,t}$$

where T is a time trend variable that identifies the change over time in the regression constant, i represents an individual company observation and t represents the time period. Note that with this specification, residuals can be different for each firm and for each year. Once again, in a multi-year setting, SFA decomposes the residual between inefficiency and error by making assumptions about the statistical distributions of these two components of the residual.

The advantages of using panel data over simple cross-sectional data (single year data) is that, with cross-sectional data in SFA analysis, strong assumptions are required about the statistical distribution of the inefficiency component of the regression residuals and, in many practical cases when cross-sectional data are used, insufficient data are available to support these assumptions. There is often little evidence to suggest which statistical distribution is appropriate in constructing a model, and in many cases, more than one distribution may be deemed to ‘fit’ the data. The use of panel data, in contrast, allows for these distributional assumptions to be relaxed. By observing each firm more than once, inefficiency can be estimated more precisely as firm data is embedded in a larger sample of observations. Specifically, with panel data, it is possible to construct estimates of the efficiency level of each firm that are consistent as the number of time-series observations per firm (t) increases.

In early SFA panel data studies, however, the benefits described above came at the expense of another strong assumption, namely that relative firm efficiency does not vary over time (that is, $u_{i,t} = u_i$). This may not be a realistic assumption, especially in long panels. Recent studies on this issue, however, have shown that this assumption of time-invariance can be tested, and can also be relaxed, without losing the other advantages of panel data.

Reflecting these points, NERA has applied two different possible parameterisations of the inefficiency term u to the SFA panel.

- A time-invariant model where the inefficiency term is assumed to be constant over time within the panel; and
- A parameterisation of time effects (time-varying decay model) where the inefficiency term is modelled as a random variable multiplied by a specific function of time:

$$u_{i,t} = \varepsilon_{i,t} \cdot e^{\eta(t-T)}$$

where T corresponds to the last time period in each panel and η is the decay parameter to be estimated.

2.5. Assessing the Regression Model

Before drawing conclusions about relative efficiency, it is essential to verify that the regression equation is theoretically and statistically valid and that it represents the best possible model, if there is more than one possibility. The types of questions likely to be raised in this context are:

- How well does the cost model fit the observations (is there a large proportion of cost variation that is left unexplained by the variation in the chosen explanatory factors)? Under Ordinary Least Squares analysis this is measured by the coefficient of determination R^2 (or a variation on it).
- Are the coefficients sensible? For example, does the model predict that costs will rise (rather than fall) as the number of exchange lines increases, as intuition and experience would suggest? Care must be taken here to consider the possible impact of multicollinearity, which may make some coefficients appear unintuitive when they in fact are closely related to other variables.
- Are the coefficients statistically significant? In other words, can we be confident that the relationship described is a statistically valid one?

Even if the model appears to be satisfactory, there are several potential sources of inaccuracy. These concern:

- Inaccuracies of functional form; it is unlikely that in practice the model's functional form is known exactly in advance. For example, are costs linearly related to the number of lines or is the functional form more complex? Would logarithmic transformation of explanatory factors give a better fit?
- The omission of relevant variables. The accuracy of regression analysis in measuring relative efficiency depends to a large extent on the degree to which all relevant explanatory factors have been included. If, for example, hilly countryside had a significant adverse effect on costs but was ignored in the regression study, then those companies serving hilly terrain might appear to have unduly high costs simply because of their location rather than because of inefficiency; and
- A lack of independence among the cost drivers. For meaningful results, there need to be many more independent observations than the number of cost-driver coefficients being estimated (in econometric terms, there need to be many degrees of freedom).

In some cases these inaccuracies can be tested for, and wherever this is possible, NERA has completed such tests. However, it is not always possible to eliminate all such problems. Consequently the results of analysis using a mathematical programming rather than regression analysis techniques are also often considered. One such mathematical programming technique is data envelopment analysis (DEA).

2.6. Data Envelopment Analysis (DEA)

DEA can be used as an alternative to regression-based techniques. It does not involve statistical estimation, but instead makes use of mathematical programming methods, without

the need to rely on a precise parametric cost function. This, in fact, is its main advantage as it allows a complex non-linear (concave or convex) relationship to exist between outputs and costs, whereas regression analysis usually restricts such relationships to be either linear, or to have fairly simple non-linear forms.

DEA operates by searching for a 'least cost peer group' of comparator companies for each individual target company. The 'peer group' is defined such that a linear combination of these companies can be shown to have at least as great an output and no more favourable operating conditions than the target company (with output and environmental variables measured in the same way as in regression analysis). If such a 'peer group' exists, and the linear combination of their costs is lower than that of the target company, this cost difference is assumed to be attributable to inefficiency on the part of the target company.

It should be noted that since it is a mathematical technique, DEA offers no statistical framework for modelling the performance of firms outside the sample, and cannot offer predictions on the effect of changes in any particular firm's costs or outputs. Furthermore, DEA is unable to assess the relevance or significance of variables, and it is therefore necessary to make assumptions based on other analysis over which variables to use.

This analytical technique is discussed in greater detail in Appendix B below (the discussion includes further detail concerning its use and its potential disadvantages).

2.7. Summary

In this section we have discussed some of the different techniques that can be used to measure comparative efficiency and have highlighted some of the main strengths and weaknesses of these techniques. Given the shortcomings of ordinary and generalised least squares regressions in predicting efficiency, NERA considers it appropriate to examine in the first instance stochastic frontier analysis (SFA), and more specifically SFA run over a number of years. In addition, data envelopment analysis has the potential to provide a useful estimate from a non-statistical point of view. The results of these different techniques can then be reviewed in the light of their relative strengths and weaknesses in order to provide a more informed view of comparative efficiency. Additionally, if the different techniques provide a common picture as to the relative efficiency of an individual firm, greater weight can be placed upon the overall efficiency result.

This common picture can be either in terms of the actual efficiency results or in the rankings of the firms under the different techniques. It is possible, if not likely, that different techniques will produce different efficiency results, as they are based on different underlying assumptions; however if there are similarities between the rankings of firms under the various techniques, this indicates that one can be confident in the relative position of the firm within the sample. It then remains to decide which efficiency result is most appropriate given the purpose for which it is to be used.

3. Data Collection and Processing

This section of the report describes the data used in NERA's study. It looks firstly at the data supplied by BT to NERA, and outlines any required adjustments to or processing of this data. Secondly, it describes the data collected from the US ARMIS database, and the methodology followed to ensure that this data was consistent with the data for BT.

3.1. Data supplied by BT

BT have supplied data on operating costs, depreciation, capital employed, the cost of capital, and volume of outputs (switched and leased lines, and minutes) for their network services. In addition information was provided on the structure of their network. This data covers the years 2001/02 to 2003/04.

3.1.1. Costs

BT's cost data was provided on a current cost accounting (CCA) basis. The data supplied covers only the network side of BT's operations – that is, excluding costs associated with retail. Adjustments have been made to BT's costs to take account of differences in measurement and accounting practices between the UK and US.

NERA has worked closely with BT to ensure that the costs supplied are comparable. In order to ensure that a like-for-like comparison is made between BT and the US LECs, it is necessary to remove any costs that BT incurs in respect of activities or services that are not undertaken by the LECs. In previous studies, it was necessary to remove BT's international network costs, since the US LECs do not have international networks and hence no such costs are included in their reported figures. However, the cost figures supplied by BT for this study do not include the international network, as for the period covered by this report, international network costs were reported separately as part of the operations of Concert and CNS. Therefore, such an adjustment was not necessary.

Adjustments that have been made are as follows:

- The US LECs do not include in their costs payments to other mobile operators (as there are none), or payments to other fixed operators for international calls. Therefore, similar outpayments have been removed from BT's costs.
- Emergency or "911" costs were removed from the US LEC and BT cost datasets because in the US, while the routing of 911 calls to the public safety answering point (PSAP) is under the control of the local telephone company, the processing of the call at the PSAP is controlled by a myriad of different entities. As a result, the US LECs do not incur the full set of costs for such services and the efficiency of provision is outside their control.

- Data network costs were excluded from BT's cost base, as NERA believes that such costs are excluded from the cost base of the US LECs².

In addition to these adjustments, it is necessary to make allowance for differences between UK GAAP and US GAAP. Under FCC guidelines, LECs submit their accounting figures in accordance with US GAAP (generally accepted accounting principles). In contrast BT's figures are prepared using UK GAAP. There are differences between the two sets of principles in the treatment of pension costs (including incremental pensions associated with redundancies), interest costs associated with major construction projects, the sale and leaseback of properties, the impairment of assets and employee share plans. These give rise to differences in operating costs and capital employed.

In its annual reports, BT gives figures for the impact of applying US GAAP rather than UK GAAP for each of the items listed above. Using this information, we have adjusted the costs of BT's relevant network activities to reflect the differences between UK and US GAAP. The methods used to complete these adjustments are set out below:

- To calculate the pension cost adjustment relating to BT's relevant network activities, the total pension cost adjustment for BT Group was multiplied by BT relevant network activities' share of total BT Group staff and other operating expenses (that is, operating costs excluding depreciation).
- In the previous BT efficiency study that NERA carried out for Ofcom, none of the capitalised interest adjustment was allocated to BT Network, due to concerns that it primarily included the capitalisation of interest relating to the funding of 3G licences. However, since the separate flotation of O₂, wireless network costs are no longer included in BT's financial reports. Therefore, the capitalised interest adjustments have been apportioned to the relevant BT network activities using the proportion of BT Group's current cost capital employed accounted for by the relevant network activities.
- To restate the sale and leaseback of properties under the requirements of US GAAP it is necessary to reverse the gain on the disposal of the fixed assets and the rental charge BT paid under the leaseback, and to replace the rental charge with a finance lease interest charge and a depreciation charge. These adjustments were allocated to relevant BT network activities in proportion to the latter's share of BT Group's current cost capital employed.
- To calculate the share of the impairment of assets adjustment that should be allocated to the relevant BT network activities the proportion of the total current cost asset base of BT Group which is accounted for by the relevant BT network activities was used.
- The adjustment for employee share plans was allocated to relevant BT network activities in line with the latter's share of BT Group's staff and other non-capital operating costs.

² The FCC has indicated that, whilst it does not expect such costs to be included in the data reported for the US LECs, it cannot confirm with complete certainty that they are not included. To the extent that they are, this will operate in BT's favour. We have included in our regressions a sensitivity test of what happens if the costs of data networks are included in BT's cost base.

In total, the conversion of BT's relevant network costs to US GAAP resulted in a 1.3% decrease in BT's costs in the financial year 2003/04.

3.1.1.1. Adjustments made to duct assets

Finally, there are two potential issues with how BT's asset base for cable and duct has been calculated. BT's CCA accounting statements, which are prepared on a current replacement cost basis, effectively remove the impact on the asset base of "double digging" where the same trench may have been dug up and re-installed several times as a result of repairs and the addition of new cables. In contrast, the current cost asset valuations for the US LECs, which have been derived by indexing historic cost book values, will still include the impact of double digging. BT have supplied an estimate of the size of the impact of double digging, and, to ensure comparability with the US LECs, the gross replacement cost of BT's duct assets has been increased by this amount.

In addition, the calculation of net replacement cost for BT's asset base differs from that of the US LECs. For each of the US LECs, GRC has been converted to NRC using the NBV/GBV ratio. However, for BT, the NRC is calculated directly (and therefore is effectively converted using the NRC/GRC ratio).

For most asset types, these two calculation methods produce similar results³. However, in the case of duct, assets tend to have a long accounting life, and moreover tend to be older than the average age that this asset life would imply. The long asset life means that the conversion to current costs using asset price indices will have a very large impact on the 'gross value' of the oldest assets, although the impact on 'net value' will be minimal (since for the oldest assets, the majority of the value will have been written off). Therefore, the NRC/GRC ratio will be lower than the NBV/GBV ratio.

Ideally, we would have calculated the NRC of the US LECs using the NRC/GRC ratio. However, this data is not available, and therefore we had to make an adjustment to BT's calculated NRC. BT supplied NERA with both the NRC/GRC and NBV/GBV ratios of duct, which enabled us to make the necessary adjustment.

3.1.1.2. Currency conversion

To achieve comparability between the data for BT and the US LECs it is necessary to express the data in a common currency either by converting the US LECs data into pounds sterling or the BT data into US dollars. As this conversion involves the use of a single exchange rate in each year for all firms in one country, the efficiency comparison is not affected by whether the US LEC data is converted into pounds sterling or BT's data is converted into US dollars. However, as the conversion of BT data into US dollars involves converting the data of only one firm whilst converting the data of the US LECs into pounds sterling involves converting the data of up to 67 firms in every year covered by this study (from 1996 to 2003), the conversion of BT rather than the US LECs reduces processing time and minimises the risk of

³ This has been confirmed by Ofcom from other studies.

any inadvertent data processing errors. Therefore the data for BT was converted from pounds sterling into US dollars.

In general, it would not be appropriate to use actual market exchange rates in this conversion, since actual market exchange rates can be subject to considerable volatility and typically reflect other influences in addition to differences in price levels between countries (and, therefore, do not reflect the comparative costs of labour and material purchases made by telecommunications operators). Exchange rates based on PPP (purchasing power parities), on the other hand, eliminate the impact of differences in price levels between countries. It might be argued that, for goods that can be purchased in international markets, actual market exchange rates would be appropriate. However, even in this case, when exchange rates are fluctuating the prices of goods rarely fluctuate to the same extent and hence the use of actual rates could give a misleading indication of the actual costs

In our analysis we have used PPP exchange rates for all operating expenses and asset categories. The PPP data used in this study has been obtained from the OECD publication “Purchasing Power Parities and Real Expenditures” and the IFS Yearbook.

The OECD publication provides data only for the PPP of GDP in recent years. A previous publication, last published in 1993, calculated PPPs for specific asset categories (for example, non-residential buildings, electrical equipment, non-electrical equipment, transport equipment and civil engineering works). However, this has not been updated for the relevant asset categories. Also, the PPP for GDP is generally considered to be more statistically reliable as it is based on a significant number of different data points, whilst the PPPs for specific asset categories, even when they are available, are based on a relatively small number of data points for each category.

Therefore, NERA has used the GDP PPP exchange rate for each year to convert BT’s costs into US\$⁴.

3.1.2. Output

BT have supplied data on:

- the number of switched lines (both business and residential);
- the number of 64kbps-equivalent leased lines provided; and
- the number of call minutes by service, with associated routing factors for main and local switches.

For switched lines, NERA compared the supplied numbers to those shown in Ofcom’s publication “The Communications Market 2004”. In all cases, the numbers shown by Ofcom

⁴ NERA estimates that around 50% of BT’s asset base is comprised of assets that could be traded on international markets. Therefore, we have carried out a sensitivity on our results to find the impact of converting 50% of BT’s asset base using a smoothed (5-year) market exchange rate.

were significantly lower than those supplied by BT. This difference was greatest in the case of business lines. BT have explained that this difference is due to the exclusion from Ofcom's report of Centrex and VPN lines, private payphones, Concert (or CNS) and service provider lines, and PSTN and ISDN "stops"⁵. For comparability with the US LECs, it is necessary to include these lines.

3.1.3. Network and environmental variables

BT have provided data on how their network is constructed, including the length of cable sheath, number of central and remote switches, length of duct, the proportion of the network which is fibred.

BT also supplied data on the average wage of BT's employees, while Ofcom provided us with a range of estimates for the cost of capital figure for BT that the latter has accepted for use in this study.

In addition to these variables, a number of pure environmental variables have been compiled by NERA that are likely to provide a partial explanation of differences in costs. These include the population density of the UK and the percentage of the population living in metropolitan areas (defined as areas of above 100,000 population).

3.1.4. Comparison to data from previous study

NERA has also looked at how the data supplied for this study differ from the data supplied to us as part of the previous study (published in May 2004).

Comparison of these datasets raises two main points.

- The switched line volumes supplied by BT for the previous study were significantly lower than those supplied for this study and the differences are greater than would be expected given actual market growth and changes in market shares. As described above, NERA has worked with BT to understand why the line numbers supplied for this study are higher than those published in other sources. This work has indicated that the line numbers provided by BT in the last study were understated, as certain categories of line were not included.
- The leased lines volume supplied by BT for this study is significantly higher than that provided for the previous study. While we would expect to see a substantial increase in the number of 64kbps-equivalent leased line circuits, the increase was much larger than could be seen for any of the US LECs. There is no reliable published data for market size and market shares in the case of UK leased lines. We therefore asked BT to explain the difference in numbers. This resulted in the discovery that, in the data provided for the previous study, BT did not take account of 622Mbps lines, and therefore understated the number of leased line 64kbps channels by a significant amount.

⁵ The term "stops" refers to lines which are operational but where service is temporarily not usable.

3.2. US LEC Data

The raw data used for calculating the total costs of the US LECs is drawn from the ARMIS database, which is compiled by the Federal Communications Commission (FCC). This database can be accessed at <http://www.fcc.gov/wcb/armis/>. For each of the years examined in this study, this database provides extensive information on costs, outputs and network variables for around 70 US LECs. A less complete dataset is available for a larger number of companies.

This dataset is derived from a different source to that used in previous efficiency studies carried out by NERA. The ARMIS dataset is more comprehensive than the SOCC tables which have previously been used. The SOCC tables are derived from the ARMIS database, but aggregate a number of state operators to the RBOC level (most noticeably, Bellsouth and Qwest). In addition, the ARMIS database is more up-to-date, with revisions being entered into this database but not the SOCC tables.

3.2.1. Costs

Costs for the US LECs comprise three elements:

- operating costs;
- depreciation; and
- the cost of capital.

3.2.1.1. US LEC asset data

As the asset book values reported for the US LECs are all on a historical cost accounting (HCA) basis, each operator's reported asset values are influenced by the point in time at which the assets were purchased. Due to changes in asset prices over time, operators with relatively older asset bases will report different Gross Book Values (GBVs) to those with relatively newer asset bases, for comparable assets. This difference impacts on the depreciation and cost of capital of operators. Hence, it was necessary to adjust the reported asset values to express the book values reported by all operators on a comparable basis. To do this, the assets bases of the US LECs were converted from historic to current costs. The derived costs from this process were compared to BT's costs as derived under current cost accounting (CCA).

The process by which this adjustment was completed was as follows:

- Firstly the average age of the assets of each US LEC was estimated for each of the following asset categories: poles, cable, duct, switches, transmission equipment, radio transmission, payphones, buildings, accommodation plant, computing equipment, and vehicles. The actual age of assets is not reported by the US LECs, so it is necessary to estimate the average age for each asset category using the following formula:

$$\text{Average Age} = \text{Asset Life} \times \left(1 - \frac{\text{Net Book Value}}{\text{Gross Book Value}} \right)$$

- Secondly, data on US price indices for each of these asset categories was collected from the US Statistical Abstract. These price indices allowed the identification of the change in asset prices between the point-in-time (on average) that each US LEC purchased its assets and the present day. For example, the price index for Telephone Switching and Switchboard Equipment was 105 in 1992 and 111 in 2003. This indicated that the price of this asset had increased by 5.7% between 1992 and 2003.
- Thirdly, the GBV of the assets of each US LEC, for each asset category, was adjusted for the asset price changes that occurred between the average point in time at which the assets were purchased (which is determined by their average age) and the year for which the data was presented (1996, 1997, and so on). For 2003, this adjustment can be represented by the following equation:

$$GRC_{Cable2003} = GBV_{Cable2003} \times \left(\frac{Cable\ Price_{2003}}{Cable\ Price_{2003 - Average\ Age}} \right)$$

An alternative approach to the adjustment suggested above would be to use BT's CCA/HCA ratio as a proxy for the CCA/HCA ratios for the US LECs. Our principal reason for not using this alternative approach in this study is that the average age of the assets belonging to BT could well differ (possibly to a significant extent) from the average age of the assets belonging to the different US LECs, and so constraining the LECs to have the same CCA/HCA ratio as BT may introduce errors into the analysis.

Furthermore, by using actual US data we allow the average age of assets, and therefore the CCA/HCA ratio, to change for each operator from year to year. When considering a dataset spanning eight years, this will be more accurate than assuming a fixed age of assets over all years.

3.2.1.2. US LEC depreciation costs

To calculate the depreciation costs of the US LECs, it is necessary to use appropriate asset lives. In the previous efficiency study, NERA used BT's depreciation rates for this purpose because information on depreciation for the US LECs was not available on an asset by asset basis in the database used. Therefore, conversion of depreciation to current cost accounting would have been impossible.

The problem with this approach is that there may be an inconsistency if BT's depreciation rates are applied to US LECs' gross asset values, which have been converted to a current cost basis using US LEC average asset age data. Furthermore, Ofcom has previously raised concerns over the fact that BT says it has a procedure whereby assets are removed from their GRC asset base when they are fully depreciated, even if they continue to be used. Compared to the situation where this procedure is not applied, this has the effect of raising BT's effective depreciation rates and NRC/GRC ratios. It is not clear that the LECs adopt the same procedure. If they do not, applying BT's effective depreciation rate to US LEC GRCs would overstate the LECs' depreciation.

In addition, Ofcom recognises that there may be a large difference between the actual effective depreciation rate of an asset and its stated depreciation rate, both in the UK and the

US. In previous studies, NERA has calculated the depreciation for US LECs by using BT's stated depreciation rates. However, this will not necessarily lead to a directly comparable depreciation figure for the US LECs, since BT's actual depreciation itself may not follow these assumptions. This is especially true where there are assets which have been bought under a different depreciation regime. It is preferable, therefore, to look at the actual depreciation written down by each US operator in each year⁶.

Therefore, given that the relevant data is now available from the ARMIS dataset, NERA has used the actual effective depreciation rates for US LECs when estimating their depreciation costs. The effective depreciation rate is calculated by comparing the actual depreciation reported by each company in each year to the GBV of that company in that year.

This approach has a further benefit. In previous studies, a single depreciation calculation was used for all US LECs for all years. When using a dataset spanning eight years, this assumption is unlikely to hold true, since the effective depreciation rate will be influenced by the proportion of capital which is fully written down. Furthermore, this approach allows for the fact that older assets may have been depreciated at a higher or lower rate than currently exists.

Therefore, using actual and year-specific depreciation calculation assumptions should ensure that the dataset is more robust.

3.2.1.3. US LECs cost of capital

It is also necessary to assess the cost of capital for the US LECs. To do this, the net replacement cost for each asset type is multiplied by the weighted average cost of capital (WACC).

There are two possible approaches that can be followed. Firstly, the cost of capital could be calculated using a constant WACC for all firms over all years. The justification for such an approach relies on the view that one would expect the long run cost of capital for each company to be relatively stable and that, for the common set of network activities that are the subject of this study, one might not expect there to be much variation between the cost of capital for different companies.

However, the assumption that each firm faces the same cost of capital in each year is unlikely to be borne out in practice. The cost of capital is likely to vary with the risk rating and gearing of the firm (given different tax regimes). Therefore, an alternative approach would be to use the actual cost of capital faced by each firm in the year it made investments.

There are two main issues with this latter methodology. Firstly, the WACC used by each company when making decisions is not publicly available information, and it is therefore necessary to calculate it from available data. Calculation of WACC is subject to a large number of assumptions and reliance on independent data sources. To calculate robust

⁶ Although the depreciation written down each year is influenced by accounting practises rather than actual economic usage, it is not possible to measure the latter for either the US LECs or BT. Where accounting lives differ from economic lives, therefore, there may be a slight inaccuracy in our calculation of the actual depreciation of a firm's assets. However, this difference is likely to be not material.

estimates of WACC, it would be necessary to carry out detailed analysis of the markets in which these companies operate. This would be a very large exercise, which lies outside the scope of this study.

The second main issue is that capital investment decisions are not made in a single year, but are made over time. Therefore, measuring the cost of capital for each year does not provide an accurate representation of the environment in which firms' capital expenditure decisions have been made. Unlike depreciation, which is calculated and known at the time of investment, the cost of capital can change exogenously and therefore any inefficiency in terms of NRC multiplied by the current cost of capital could be considered as being outside the control of a firm. It would therefore be more meaningful to look at a long-term cost of capital, which does not vary over time.

Calculation of such a long-term cost of capital is, again, a large exercise which would not be feasible within the scope of this study. Therefore, NERA has estimated a cost of capital for each firm from published data for the past eight years (where such data was available), and has taken an average of these figures to find an estimate of the cost of capital faced by each firm. This figure is only an approximation of the relevant long-term cost of capital, but is sufficient to allow us to investigate the effect of applying differing costs of capital to different firms.

Given the arguments above, NERA has estimated capital costs using two measures of the cost of capital for each firm:

- A cost of capital which is broadly consistent with the cost of capital figure Ofcom is considering for use in its price cap model, which is the same for all companies in all years; and
- A constant cost of capital for each company, formulated as an average of individual year costs of capital, which have been calculated by NERA from published data⁷. This will give a reasonable indication of how we would expect costs of capital to vary between companies.

These cost of capital percentages have been applied to the net replacement cost (NRC) to find the cost of capital for each company under these two approaches. The NRC is calculated, as described in Section 3.1.1, by multiplying the GRC by the NBV/GBV ratio.

3.2.1.4. Other adjustments to costs

A number of other adjustments have been made to the US costs:

- The US LECs separately report Telecommunications Plant Under Construction (TPUC), without identifying the component assets. Therefore, it is not possible to identify to which asset categories this construction relates. However, this is only a very small element in the overall asset base of the US LECs. In 2003, for example, TPUC accounted

⁷ In particular, data on the equity and debt financing of firms was taken from Bloomberg, and information on the market's equity risk premium was taken from Ibbotson.

for, on average, only around 2% of the total Telecommunications Plant asset base. Therefore, since there is no information available concerning exactly what assets are included in this account, we allocate these assets to the GRC of each asset category based on the assumption that it is exclusively replacement investment (we allocate plant under construction to the various asset groupings in proportion to the relative level of depreciation in each).

- Total depreciation and amortization expenses on a historical cost basis were removed from the US LEC operating costs, since these have been recalculated on a CCA basis (as described above).
- The US LECs consider bad debts to be a reduction in revenue. However, BT includes bad debt in its operating expenses. Therefore, bad debts have been included in the calculation of the US LECs' operating costs.
- The data for the US LECs covers both network and retail activities. However, this study only looks at the network operations of BT. Therefore, it is necessary to remove those costs of the US LECs that are related to retail operations. To do this, all cost categories for the US LECs were first categorised as either:
 - directly attributable to the running of the network;
 - directly attributable to retail activities; or
 - indirectly attributable to both.

Setting aside indirect costs, the proportions of each company's total direct costs (retail and network) that were attributable to each of 'network' and 'retail' were estimated. Following this, indirect costs were allocated between 'network' and 'retail' according to these proportions, for each company. This allows the total cost of network operations (direct plus indirect) to be derived.

3.2.2. Outputs

As for BT, output data for the US LECs comprises the numbers of switched lines, leased lines (including special access lines), and switch minutes.

3.2.2.1. Line numbers

US LECs operate three types of access line:

- switched lines;
- leased (private) circuits; and
- special access lines.

While the numbers of switched and special access lines are reported in the ARMIS database for every year in our sample, the number of leased circuits has only been reported since 2002. Therefore, we have calculated the number of leased lines using the leased line revenues reported to the ARMIS cost database. These revenues have been divided by the average price of a 64kbps-equivalent leased line, as reported by the OECD⁸, to give an estimate for the number of 64kbps-equivalent leased lines operated by each LEC.

For purposes of comparability with BT, it is necessary to aggregate leased circuits and special access lines into one variable. To do this, NERA has adopted the methodology used in previous studies. Rather than assuming an equal weight for both types of line, we consider the components of each type of line. A leased line has two customer ends and generally a main link, while a special access line has only one customer end (special access lines connect with an inter-exchange carrier point of presence) and generally has a main link and an interconnecting circuit at the inter-exchange carrier point of presence. Therefore, we place a weight of 2 on leased lines, and a weight of 1.5 (more than a pure switched line but less than a leased line) on special access lines⁹.

3.2.2.2. Switch minutes

From the ARMIS dataset, information is available for the number of local, intra-LATA and inter-LATA calls (both incoming and outgoing), as well as the number of outgoing minutes for inter-LATA calls. The latter two figures allow us to calculate the average duration of an inter-LATA call. This average duration has been applied to local calls and intra-LATA calls to calculate the number of minutes for each category.

This methodology assumes that the average duration is constant over all types of call. This is unlikely to be the case; one would expect to see a higher call duration for local calls (which are much cheaper, if not free, in the US) and for intra-LATA calls. We would expect, therefore, that this assumption will tend to underestimate the volume of US LEC call minutes and hence tend to make BT look more efficient than it actually is.

3.2.2.2.1. *Unsuccessful local calls*

In December 1999, the FCC revised its definition of what should be included by the LECs in their submissions concerning the number of local calls made using their networks. This revision introduced an explicit instruction to LECs to include the number of unanswered calls in their measurement of the total number of local calls made, whereas previously there had been no such explicit request for data on unanswered calls.

This raises the question as to what the local call data used for years prior to 1999 represents. Comments from the FCC indicated that some LECs already included unanswered calls when submitting local call numbers whereas others did not. However, they had no indication as to what proportion of companies included unanswered calls.

⁸ OECD Communications Outlook 2004, OECD

⁹ We have run a sensitivity on this assumption, and the results of this are found in Section 4.7.5.

If the LECs had not included unanswered calls in the local call numbers prior to 1999 we would expect to see a sharp increase in the number of local calls in 1999 compared to earlier years. However this does not appear to be the case for any LEC in 1999. Therefore simple inspection of local call numbers suggests that the LECs were already including unanswered calls in their local call numbers. To allow for this we have reduced all local call minutes by 30%¹⁰ for all years in order to provide estimates of the number of completed local calls for each of the LECs.

3.2.2.2.2. Conversion to switch minutes

To convert these call minutes to switch minutes, NERA has used routing factors estimated from the Hatfield model in the US, and from other analysis. The routing factors used are shown in Table 3.1.

Table 3.1
US LEC routing factors

	Local switch routing factor	Main switch routing factor
Local calls	1.54	0.02
Intra-LATA calls	2	0.2
Inter-LATA calls	1	0.3

Source: Hatfield Model and NERA analysis

For the local switch, we estimate that 46% of local calls are “own exchange” (based on an input to the Hatfield model), whilst the remainder use two switching stages. This would imply a local call switching factor of 1.54. Meanwhile, intra-LATA calls pass through two local switches (one at each end of the call), whilst, for inter-LATA calls (where we consider incoming and outgoing calls separately), only one local switch is involved per end.

For the main switch, the Hatfield model states that 98% of local inter-office traffic is directly routed between originating and terminating end offices as opposed to being routed via a tandem switch. This yields a routing factor for local calls passing through tandem switches of 0.02. For long distance calls, however, the situation in the US is more complex. It can be assumed that all long distance calls using LEC switches pass through two local switches – one at each end of the call. However, beyond this, routing is different for intra-LATA and inter-LATA calls.

In the case of intra-LATA toll calls, around 80% are assumed to be routed directly to the terminating local switch, whilst the remaining 20% are assumed to transit through a tandem switch – thus giving a routing factor of 0.2. Inter-LATA calls, on the other hand, are assumed to be routed from the LEC local switch directly to a long distance carrier point of presence in 70% of cases (based on information obtained from Bellcore), whilst in the remainder of cases they will transit through an additional tandem switch on route. At the far end of the long distance operator’s network the call will exit at another point of presence

¹⁰ This is based on the typical proportion of unanswered calls drawn from the Hatfield model in the US, and is consistent with NERA’s experience of the proportion of calls that are unanswered calls in a variety of European countries.

(again usually at a long distance operator switch but sometimes at another location), and be delivered through the destination LEC's network in roughly the same manner as that in which it was originated. This would suggest that each end of an inter-LATA call passes through an average of 0.3 tandem switches within the LEC network.

3.2.2.2.3. *Dialled Equipment Minutes*

In previous efficiency studies, BT has provided NERA with information from the National Exchange Carriers Association (NECA) in the US, which outlines periodic studies of calling patterns. One such study concerns the use of dialled equipment minutes, which are measured at local switches as calls enter and leave the system. In these studies, dialled equipment minutes are measured for a limited sample period and then inflated to give annual-equivalent figures.

While dialled equipment minutes could give a reasonable alternative measure of local switch minutes, there are a number of issues with the NECA dataset. Firstly, the data is presented on a highly disaggregated level. NERA has previously worked with BT to ascertain which data would need to be aggregated to find a robust number for total switch minutes, but it has not been possible to derive a definitive calculation due to a lack of information. Secondly, dialled equipment minutes only apply to the local switch, and it would be necessary to make further assumptions over the number of main switch minutes for each operator¹¹. Finally, the manner in which these yearly figures are calculated may be heavily biased depending on the timing of the sample period.

Therefore, NERA does not believe that switch minutes calculated in this way would be a reasonable substitute for the methodology using routing factors set out in Section 3.2.2.2.2.

3.2.2.2.4. *Composite switch minutes variable*

Multicollinearity presents a particular problem in the case of local and main switch minutes, where the correlation between the variables is so strong that it is impossible to identify the separate cost impact of an additional local switch minute as opposed to a main switch minute. However, it is possible to construct a composite switch minute variable using external data (particularly from network costing studies). Relevant data is shown in the table below.

¹¹ BT has previously identified an FCC report into tandem switch minutes of use for US LECs, which could be used to calculate the number of switch minutes. However, there are a number of companies which were not represented in this report, and others for which the submitted data was zero.

Table 3.2
Relative costs of local and main switching

	Source	Local switch	Main switch	main/local
US (LRIC)	FCC	0.2 – 0.4 cents	0.15 cents	0.38 – 0.75
BT (LRIC)	BT ¹²	0.114 – 0.116 pence	0.044 – 0.064 pence	0.39 – 0.55
Average of midpoints				0.5

Source: as shown

This data indicates some variation in the relative costs of local and main switches in the networks of different operators. However, for the purposes of this analysis it is necessary to determine the appropriate weight for the “output” of a main switch minute relative to a local switch minute, rather than the relative company-specific cost. This is because the fact that the cost of main switches in the BT network may differ from those in other networks is part of the cost efficiency we are trying to measure. If we constructed our output measure using different cost factors for each company, we would remove any cost inefficiency difference.

This suggests that we should use the same relative weight for the output of local and main switch minutes for all operators. The relative weight we have chosen is based on the midpoint cost ratio for local and main switch minutes for all operators. The data in Table 3.2 suggests a figure of around 0.5 for this ratio. Therefore, a new variable has been calculated to reflect traffic volumes as follows:

$$\text{standard switch minutes} = (\text{local switch minutes}) + 0.5 \times (\text{main switch minutes})$$

3.2.2.2.5. Adjusting for Differences in Calling Rates

When modelling the efficiency of BT, there will be concerns that calling rates per line will be significantly different between the UK and the US. The output data collected for this study suggest that calling rates per line (minutes per line) in the US are approximately 1.5 times greater than in the UK.

This difference is captured implicitly though the basic formulation of the regression model.

$$\ln(\text{cost}) = a + b_1 \ln(\text{lines}) + b_2 \ln(\text{minutes}) + \dots + u$$

This could be made more explicit by using the compound variable “minutes per line”, calculated by $\frac{\text{minutes}}{\text{lines}}$, instead of simply “minutes”, as an explanatory variable in the model.

However, since the model is constructed using a double-log specification, the only impact this will have is to impose some constraints on the model coefficients, as follows:

¹² From NERA analysis of data in “Current Cost Financial Statements for the Businesses and Activities 2004 and Restated 2003 Current Cost Financial Statements”, BT, 2004 and “Current Cost Financial Statements for the Businesses and Activities 2003 and Restated 2002 Current Cost Financial Statements”, BT, 2003.

$$\ln(cost) = a + (b_1 + b_2) \ln(lines) + b_2 \ln\left(\frac{minutes}{lines}\right) + \dots + u$$

The value of u , the residual error, would not change. Since it is this residual which reflects the comparative efficiency of the various companies, forcing the model to explicitly consider differences in calling rates would have no effect on the results, and would only serve to impose constraints on the coefficients in the model.

3.2.3. Network and environmental data

Data for the US LECs has been collected to match that provided by BT. This includes:

- Sheath length in the network (split into aerial and non-aerial);
- Central office and remote switches;
- Duct route length;
- The proportion of the network which uses optical fibre;
- The proportion of business lines to residential lines; and
- The average wage of employees.

In addition, a number of environmental variables have been derived including the population density and proportion of the population living in metropolitan areas.

In previous studies, population density has been found to be an insignificant driver of costs. This has been, in part, due to the difficulty of measuring the population density relating to an operator that spans a number of states, such as Bellsouth or Qwest. However, because we are now using the new more disaggregated source of US LEC data, we are more accurately able to map population density data to the US LECs¹³.

3.2.3.1. Regional dummy variables

In previous studies, NERA attempted to account for the impact of higher wages in the North East of the United States by including a dummy variable for those companies operating in this area. Due to the previously aggregated nature of the companies, a pure average staff cost variable was not considered to be sufficient for this purpose.

¹³ We are able to apply a state-wide population density to each company relating to the individual state that it operates in. However, we are aware that some companies do not operate over a whole state, and as such the population density applied to these companies may be slightly inaccurate. Given the lack of availability of more disaggregated data, NERA believes that the state-level population distribution provides a good proxy as to the general operating environment across a state, and therefore of any operators within that state. If there are inaccuracies in this mapping, NERA would expect the significance of our population density variable in any specification to fall.

However, because we have been able to use ARMIS data for this study, it has been possible to derive disaggregated data on a state basis. This has allowed us to consider more accurately the effect of average staff costs, and we have found it not to be a significant cause of cost variations between companies¹⁴. Therefore, we have not included a North East dummy.

Similarly, in previous studies BT argued that a dummy should be included covering the Midwest region of the US. BT claims that companies operating in this region, (particularly those formerly part of the Ameritech group) have reacted adversely to the change in the general US regulatory environment (that is, the move away from rate of return regulation) since 1994. In particular, BT believes that these LECs have:

- reduced their capital bases by lowering annual capital expenditure;
- increased profitability by cutting their number of employees and simultaneously increasing productivity and reducing expenditures;
- increasing profitability by stimulating revenue (more features and lines sold) with little increase in their asset base; and
- reduced costs and increased profits by reducing service quality.

Dealing with the first point, it is a well known result that rate of return regulation provides incentives that can lead to overinvestment and an inefficiently high capital to labour ratio¹⁵. Given a move to price cap regulation, such as has occurred in the US since the 1990s, one might therefore expect there to be a reduction in the rate of investment as firms strive to return to efficient capital to labour ratios. Rather than being an adverse development this would be a manifestation of the efficiency inducing properties of price cap regulation.

As regards the second and third points above, these would appear again to reflect the beneficial effect on efficiency of price cap regulation, to which BT itself is also subject.

Finally, in relation to the fourth point above, while some of these companies have a relatively high number of customer complaints (reflecting the quality of service, as reported by the FCC), the data concerned are far from complete and it is unclear whether there are differences between companies in terms of the way that complaints are reported and defined or in the way that the data are collected.

NERA has carried out an analysis into the relative efficiency of these LECs, to see whether it has in fact significantly improved since 1994. To do this we compared the position of these companies in a study undertaken for Ofcom in 1995 with that in the current study. There are a number of difficulties in comparing the numbers obtained in NERA's 1995 report¹⁶ with the results outlined in this study. These difficulties include a differing methodology used to calculate efficiency, and a different set of companies. However, we can obtain a rough idea

¹⁴ The implication is that wage rates affect productivity and vice versa.

¹⁵ Averch H and Johnson LL (1962) "Behaviour of the Firm under Regulatory Constraint", American Economic Review 52, pp1052-69

¹⁶ "The Efficiency of BT", NERA, September 1995

of whether the relative efficiency of these companies has improved by looking at the relative rankings of companies between studies.

For total costs, the companies' rankings are as shown in Table 3.3:

Table 3.3
Rankings of Ameritech companies

Company	Rank in 1995 study (out of 30 firms)	Rank in current study (out of 68 firms)
Illinois Bell	3	22
Indiana Bell	7	5
Michigan Bell	13	7
Ohio Bell	8	20
Wisconsin Bell	4	9

Source: NERA analysis

This table shows that there has not been a uniform improvement in the relative efficiency of these firms compared to the sample as a whole over the period since rate of return regulation was abandoned. The group of five companies is in the top half of the sample in both studies, but the relative positions of the companies vary.

As stated in the second point above, BT have also argued previously that companies in the Midwest, particularly those formerly part of Ameritech, have cut back the number of employees in order to increase profitability and reduce costs. Analysis of employee numbers shows no such trend. For each of the five companies, there was only a small decrease in employee numbers up until 1999, after which employee numbers have increased. This is no different to the pattern exhibited by the rest of the LECs.

We have therefore found that there is no evidence that can conclusively prove BT's assertions. The relative efficiencies of the companies in question have not all significantly improved over the years that NERA has been carrying out studies of BT's comparative efficiency. Furthermore, there is also no evidence that the numbers of employees for these firms shows a decline compared to those of other firms. Finally, data on quality of service is not adequate to draw firm conclusions.

Therefore, in this study NERA has not used regional dummy variables within our specification.

3.2.4. Other data issues

3.2.4.1. Structural breaks

Statistical analysis of the data collected for US companies has indicated that there is a structural break in the cost data between the years 1998 and 1999. A structural break occurs when there is a step change in the level of costs or other variables.

There are a number of possible explanations for this break. For example, from analysis of NERA's dataset, there was a sharp decrease in cable and wire prices between 1998 and 1999¹⁷ which led to a parallel fall in the US LECs' CCA asset values for cable.

To deal with this structural break, NERA considered two possible options. Firstly, it is possible to run the model only considering years since 1999. However, this reduces significantly the number of observations, and will not produce such a robust model. In particular, for variables which do not experience a structural break, we would be losing a lot of explanatory power.

Secondly, we could introduce a dummy variable to measure the effect of the break between 1998 and 1999, as well as a number of interaction terms to allow the impact of output variables to change between period up to 1998 and the period from 1999 onwards. By including these interaction terms, we will allow the model to fit closely to a model run over only the last five years, while using to use the full dataset to produce the cost model. As a result, this model should be more robust. In our view, this is the better of the two options. We have therefore incorporated a dummy variable and interaction terms into the cost model.

NERA has run a sensitivity on using the reduced sample outlined above. The results of this sensitivity are outlined in Section 4.7.7.

3.2.4.2. Excluded companies

A number of US companies which report to the ARMIS database are excluded from our analysis. These are:

- Puerto Rico Telephone Company and Verizon Hawaii, which both operate on small islands, and as such would be likely to face substantially different cost structures from the remainder of the sample. Initial attempts to take account of these differences through the use of a dummy variable proved to be insufficient, and so both companies were removed from the sample.
- Verizon Washington DC, which was excluded from all datasets because, as in previous comparative efficiency studies, it was identified as a potential outlier since its cable sheath length per line variable was significantly lower than those of the other companies in the dataset, and its ratio of business lines to residential lines was significantly higher. This is due to its restricted, highly urban area of operation, which makes it an unsuitable comparator for BT.
- A number of small Contel companies, which provide cost data separately from a sister company in the same area. For example, Verizon North Contel Indiana provides cost data separately from Verizon North Indiana. However, output and environmental data for these companies is not available on a disaggregated basis. NERA has been advised by the FCC that operations within these Contel companies are mainly governed by the larger companies in each state, and it is therefore reasonable to consider Verizon North's operations in Indiana as a whole.

¹⁷ As taken from the US Statistical Abstract's PPI data.

4. Results

In this section the results of the comparative efficiency assessment are set out and discussed.

Firstly, we look at the final model specification derived for analysis of BT's costs, and examine the definition of costs used. Secondly, we set out our results obtained from using this model.

4.1. Model specification

As described in Section 3, NERA has collected a number of potential cost driver variables for each operator. Our analysis using a Cobb-Douglas log-log model, as discussed in Section 2.2, results in a specification of the following form:

$$\ln(\text{total cost}) = \alpha + \beta_1 \text{outputs} + \beta_2 \text{environmental} + \beta_3 \text{time} \\ + \beta_4 \text{dummy}_{1996-1998} + \beta_5 \text{outputs}_{1996-1998} + \beta_6 \text{time}_{1996-1998}$$

In this equation, the output variables include switched lines, leased lines, and switch minutes. Environmental variables include factors such as the population density, the cable sheath used in the network, the ratio of national call minutes to other call types, and the ratio of business lines to residential lines. Finally, $X_{1996-1998}$ indicates a variable X which is only non-zero for observations before 1999. These last terms are designed to capture the structural break identified in the data, as described in Section 3.2.4.1.

When running this regression model, we do not include BT as an observation. Since BT is one of the largest companies in the sample, it would have a tendency to skew the equation by “pulling” the regression line towards itself. This would have the effect of reducing BT's observed efficiency or inefficiency, and worsening the fit of the model. By removing BT from the sample, we ensure that the regression is not biased in this way, and we may then use the estimated equation to predict BT's costs outside of the model.

The final specification of the model was found using a general-to-specific methodology. Under this methodology, a general specification is formed using all available variables which may be considered potential drivers of costs. These variables are then reduced using a step-by-step process to identify those variables which are empirically (rather than just theoretically) significant explanatory variables and to reject those that were not. Decisions on the step-by-step exclusion of variables were made based generally on the basis of statistical significance¹⁸.

Our final specification takes the form:

¹⁸ The significance of variables was tested using both the t statistics for the variable in the estimated regression and by testing that excluding the variable from the regression did not significantly alter the model fit (as measured by the log likelihood function).

$$\begin{aligned}
\ln(\text{totalcost}) = & \alpha \\
& + \beta_1 \ln(\text{switchedlines}) \\
& + \beta_2 \ln(\text{leasedlines}) \\
& + \beta_3 \ln(\text{switchminutes}) \\
& + \beta_4 \ln(\text{totalsheath}) \\
& + \beta_5 \ln(\text{populationdensity}) \\
& + \beta_6 \ln(\text{businessresidentialratio}_{2003}) \\
& + \beta_7 \text{time} \\
& + \gamma_1 \ln(\text{switchedlines})_{1996-1998} \\
& + \gamma_2 \ln(\text{leasedlines})_{1996-1998} \\
& + \gamma_3 \ln(\text{switchminutes})_{1996-1998} \\
& + \gamma_4 \ln(\text{totalsheath})_{1996-1998} \\
& + \gamma_7 \text{time}_{1996-1998}
\end{aligned}$$

This specification allows for the structural break discussed in Section 3.2.4.1. By interacting variables with the first time period, we are able to see more clearly how the model would predict costs going forwards. Tests have shown that the pure “switch” variable $\text{dummy}_{1996-1998}$ (which was included in the general specification on the previous page), which is set at 1 in 1996, 1997 and 1998 and at 0 in all other years, is insignificant. Furthermore, interaction terms on population density and on the business to residential ratio were deemed insignificant. These variables are therefore not included in our specification.

The functional form of the model outlined above allows us to interpret the coefficients on each variable as an elasticity. Therefore, if we see a 1% increase in switched lines, we would see a β_1 % increase in costs.

This also allows us to consider how costs are varying over time. The time variable above is set at 1 in 1996, and increases by one each year. Therefore, the value of β_7 will give the percentage increase or decrease in costs over time¹⁹.

Finally, the interaction terms allow the relationship between explanatory variables and costs to differ between the first three years of our sample and the last three years. To find the relationship applicable before 1999, the appropriate elasticity will be $\beta_i + \gamma_i$.

4.2. Definition of Costs

In previous efficiency studies carried out for Ofcom (and Oftel), NERA has only looked at the total costs of operators, where total costs are defined as operating costs plus capital costs²⁰.

¹⁹ All costs are measured in nominal terms, so in order to find the change in real costs over time we will need to take account of the rate of inflation. In the US, over the period studied, the average inflation rate has been 2.50%. Therefore, the change in real costs over time can be estimated by the change in nominal costs minus 2.50%.

The use of total costs as our dependent cost variable here is due to the theoretical trade-off between operating costs and capital costs. It is possible that an operator is able to reduce its capital costs by continuing to use equipment older than its stated asset life. By doing this, both the depreciation charged and the cost of capital will fall, since the asset will not have depreciation charged to it and the net replacement cost of this asset will be zero (therefore not incurring any cost of capital). However, it is likely that the use of this older asset will incur higher operating costs, due to greater need for maintenance.

Furthermore, this theoretical trade-off will influence current and future investment decisions. If the trade-off does exist, then decisions will be affected regarding the quality and type of equipment used (since assets of a higher quality may require lower maintenance towards the end of their life), the timings of movements to new technologies, and the depreciation rate used for each asset.

The extent to which this trade-off exists, and how quickly it may come into effect, is open to debate. While operators can make decisions over new investments and retirements, they are not able to accelerate the increase in age of their asset base. Therefore, there will only be a marginal decision made in each year, which means that the trade-off may only happen over a long period of time.

Finally, it is useful to also consider BT's efficiency in terms of operating costs plus depreciation. This method of cost measurement has the advantage of avoiding the issues surrounding the valuation of cost of capital set out in Section 3.2.1.3.

4.3. Comparisons with Previous Studies

Initial analysis of total cost efficiency implies that BT has improved its relative efficiency since the last study carried out by NERA (which covered 2001). However, in addition to the change in its relative efficiency, there are a number of other reasons why our estimate of BT's relative efficiency has changed:

- We have been able to obtain data at a more disaggregated level for the US LECs, which has meant that the number of companies in our sample has increased. Furthermore, we have been better able to capture the influence of factors such as population density on efficiency (because the coverage areas of the companies and the population statistics now coincide);
- Our methodology of calculating the depreciation of the LECs has changed, allowing us to more accurately model the decisions made by these companies in respect to capital expenditure;
- For this study, Ofcom and BT have provided NERA with information to enable us to take account of the impact of "double digging" and of the difference in NBV/GBV and NRC/GRC ratios when calculating the capital costs relating to duct (see Section 3.1.1.1);

²⁰ Where capital costs are depreciation plus the cost of capital.

- As previously explained in Section 3.1.4, we have discovered that, for the last study, BT provided incorrect data on its line numbers (in that it failed to take into account of 622 Mbps leased lines and understated its business switched lines); and
- BT has increased its efficiency in the two years since 2001/02.

4.4. Results for Total Costs

As discussed in Section 3.2.1.3, two models have been calculated to look at the total costs of BT. This section sets out the results from these two models:

- The first model uses a constant cost of capital across all firms. The cost of capital is set to 12%, which is a cost of capital broadly consistent with the cost of capital figure Ofcom is considering for use in its price cap model²¹; and
- The second model uses an estimated long-run cost of capital for each firm that is constant over time.

4.4.1. Using a constant cost of capital

For total costs, calculated by using a constant cost of capital over all firms of 12%, our estimated equation has the coefficients set out in Table 4.1. As stated in Section 4.1, when running this regression BT is not included as an observation. This is to ensure that BT does not have an impact on the final results.

²¹ Sensitivities have been run on this assumption by setting the cost of capital at 11% and 13%. The results for these models can be found in Section 4.7.

Table 4.1
Multi-Year SFA analysis of total costs at 12% cost of capital

	Coefficient	Standard error	T-statistic	Significance ²²
Log of switched lines	0.577	0.05	11.54	0.00
Log of leased lines	0.028	0.01	3.18	0.00
Log of switch minutes	-0.018	0.01	-1.50	0.13
Log of total sheath	0.398	0.04	9.24	0.00
Log of population density	0.057	0.02	2.54	0.01
Log of business line per residential (2003)	0.385	0.13	2.95	0.00
time	0.011	0.00	3.18	0.00
Log of switched lines (1996-1998)	-0.048	0.02	-3.16	0.00
Log of leased lines (1996-1998)	-0.042	0.01	-5.52	0.00
Log of switch minutes (1996-1998)	0.045	0.01	7.15	0.00
Log of total sheath (1996-1998)	0.025	0.01	2.10	0.04
time (1996-1998)	-0.023	0.01	-4.07	0.00
Constant	0.506	0.34	1.48	0.14
Log likelihood	706.22			

Source: NERA analysis

Several interesting points are raised by this regression. Firstly, we can see how total costs have changed over time by looking at the time variable. The coefficient on this variable is 0.011, which implies that there is an annual 1.1% growth in total costs in nominal terms over the past five years²³. If inflation is taken into account, this implies an annual 1.4% fall in real costs since 1999.

Other interesting points relate to the significance of switched lines, leased lines and switch minutes. Switched lines have been a strong cost driver over the whole period, although they have a slightly stronger influence after 1999. Since 1999, leased lines have become a more significant cost driver. The reverse is true for switch minutes, which were only significant in the first three years of our model. In more recent periods, variations in the volume of switch minutes appear to have had much less of an impact on costs.

From examining the general trends for these outputs, NERA has found that there was a significant change in the growth rate of leased lines after 1998. In addition, the number of switch minutes has been declining since this year. This would accord with a general understanding of the communications market, where the demand for (and supply of) leased

²² A significant variable has a statistic less than or equal to 0.05.

²³ Prior to 1999, there was an overall annual fall in nominal costs of 1.3%.

lines was increasing rapidly over the last part of this period, and was therefore becoming more a more important part of the US LECs' cost bases.

While switch minutes is insignificant in the later period of our study, it appears to have an unintuitive negative coefficient. This would appear to imply that as the number of switch minutes falls, costs rise, contrary to expectations. This is likely to be a result of multicollinearity. We would expect that the number of switch minutes would be highly correlated with the number of switched lines – that is, we would expect the number of minutes per line to remain approximately constant as the number of lines increased or fell.

In effect, this means that part of the impact of increasing switch minutes is carried in the coefficient on switch lines. Since, by its nature, our data does not measure the impact of increasing minutes without changes in lines, the regression must attempt to disaggregate the effect of increases on both minutes and lines together. Where variables are so strongly tied (as in this case), this disaggregation can be very difficult, since the coefficients on different variables will reflect changes in other variables as well as changes in their own variable. Therefore, we must consider an overall increase in outputs if we are to draw a reasonably accurate conclusion over how to interpret this model.

We apply the coefficients of this model to our full dataset, including BT, to find the estimated efficiency of each firm. Doing this, we find efficiencies as set out in Table 4.2.

Table 4.2
Efficiency scores for total costs with cost of capital at 12%

Company	Residual	Compared to top firm	Compared to decile	Compared to midpoint
1 Verizon NO-Illinois	0.03	0.00	-0.19	-0.36
2 Verizon SO-Illinois	0.13	0.10	-0.10	-0.30
3 Verizon NO-Ohio	0.15	0.12	-0.09	-0.29
4 Verizon NO-Wisconsin	0.16	0.14	-0.07	-0.27
5 Indiana Bell	0.21	0.20	-0.03	-0.24
6 Verizon NO-Michigan	0.22	0.20	-0.02	-0.23
7 Michigan Bell	0.24	0.23	0.00	-0.22
8 BT	0.25	0.24	0.01	-0.21
9 Wisconsin Bell	0.30	0.30	0.06	-0.17
10 Verizon NO-Pennsylvania	0.31	0.31	0.07	-0.16
11 Verizon NO-Indiana	0.31	0.31	0.07	-0.16
12 Contel Nevada	0.32	0.33	0.08	-0.15
13 Verizon-Delaware	0.33	0.34	0.09	-0.15
14 Qwest-Idaho South	0.34	0.35	0.10	-0.14
15 Qwest-South Dakota	0.35	0.37	0.11	-0.13
16 BellSouth-Mississippi	0.38	0.42	0.15	-0.10
17 Qwest-Iowa	0.39	0.42	0.16	-0.09
18 Contel Arizona	0.40	0.44	0.17	-0.08
19 Qwest-Montana	0.40	0.44	0.17	-0.08
20 Ohio Bell	0.41	0.46	0.19	-0.07
21 BellSouth-Kentucky	0.41	0.46	0.19	-0.07
22 Illinois Bell	0.43	0.48	0.20	-0.06
23 Qwest-North Dakota	0.45	0.52	0.23	-0.03
24 Verizon-Virginia	0.45	0.52	0.24	-0.03
25 Southwestern - Arkansas	0.45	0.52	0.24	-0.03
26 Verizon NE - Rhode Island	0.46	0.53	0.25	-0.02
27 BellSouth-Alabama	0.46	0.54	0.25	-0.02
28 BellSouth-North Carolina	0.47	0.54	0.25	-0.02
29 Verizon-Maryland	0.47	0.54	0.25	-0.02
30 BellSouth-South Carolina	0.47	0.55	0.26	-0.01
31 BellSouth-Tennessee	0.47	0.55	0.26	-0.01
32 Verizon NW-Idaho	0.48	0.56	0.27	-0.01
33 Southwestern - Kansas	0.48	0.56	0.27	0.00
34 Qwest-Wyoming	0.48	0.56	0.27	0.00
35 Verizon NW-West Coast California	0.48	0.57	0.28	0.00
36 Southwestern - Oklahoma	0.48	0.57	0.28	0.00
37 Qwest-Nebraska	0.49	0.58	0.28	0.01
38 Verizon SO-Virginia	0.49	0.58	0.29	0.01
39 BellSouth-Louisiana	0.50	0.59	0.30	0.02
40 BellSouth-Georgia	0.51	0.60	0.31	0.02
41 Qwest-Minnesota	0.52	0.63	0.33	0.04
42 Verizon NE - Vermont	0.53	0.64	0.34	0.05
43 Nevada Bell	0.53	0.65	0.34	0.05
44 Verizon NE - Maine	0.54	0.66	0.35	0.06
45 Verizon SW-Texas	0.54	0.67	0.36	0.06
46 Verizon-New Jersey	0.56	0.70	0.38	0.09
47 Pacific Bell - California	0.57	0.71	0.39	0.09
48 Verizon-West Virginia	0.59	0.73	0.41	0.11
49 Verizon NE - New Hampshire	0.59	0.75	0.42	0.12
50 BellSouth-Florida	0.61	0.78	0.45	0.14
51 SBC/SNET - Connecticut	0.61	0.79	0.45	0.14
52 Verizon SO-South Carolina	0.62	0.79	0.46	0.14
53 Verizon-Pennsylvania	0.62	0.80	0.46	0.15
54 Verizon NW-Oregon	0.62	0.80	0.47	0.15
55 Southwestern - Missouri	0.63	0.81	0.47	0.16
56 Qwest-New Mexico	0.64	0.83	0.49	0.17
57 Verizon NE - Massachusetts	0.68	0.90	0.55	0.21
58 GTE California	0.68	0.91	0.56	0.22
59 Verizon NW-Washington	0.70	0.94	0.58	0.24
60 Verizon SO-North Carolina	0.70	0.94	0.58	0.24
61 Southwestern - Texas	0.71	0.96	0.59	0.25
62 Qwest-Utah	0.71	0.96	0.60	0.25
63 Qwest-Arizona	0.73	1.01	0.63	0.28
64 Qwest-Washington	0.73	1.01	0.64	0.29
65 Qwest-Colorado	0.75	1.05	0.67	0.31
66 Qwest-Oregon	0.77	1.08	0.69	0.33
67 Verizon Florida	0.77	1.09	0.70	0.33
68 Verizon New York Telephone	1.01	1.66	1.16	0.70

A negative efficiency score indicates efficiency compared to the reference point and a positive result indicates inefficiency. For example, Verizon-Delaware is 9% less efficient than the decile, and 15% more efficient than the midpoint firm.

Results are shown for performance relative to points in the sample. The comparison with these points is shown to ensure that the comparison is against an achievable level of efficiency. By its nature, the SFA technique aims to fit an ‘envelope’ around the most efficient observations. Therefore, if there are any data or estimation problems (for example, unobservable heterogeneity), the technique could produce a frontier that is biased outwards and would make observations appear spuriously efficient.

As the SFA regression estimated here follows the time invariant specification, any spurious observations for an operator in a sub-set of the years in the sample will be controlled for in the time invariant result. Therefore, by comparing efficiency relative to the upper decile of the sample, we can be certain that we are comparing against an achievable level of efficiency.

These results indicate that BT lies just below the top 10% of the sample, and is 1.05% less efficient than the top decile.

4.4.2. Varying cost of capital by firm

As described in Section 3.2.1.3, NERA has estimated a long-run cost of capital for each firm. While these should not be taken as definitive values due to uncertainty over assumptions made during this estimation, we believe these costs of capital are a reasonable approximation of the costs of capital faced by each operator. In particular, the use of an average figure over a number of years will ensure that any variation in assumptions made will have a small effect on the final cost of capital figure used.

Allowing firms to have different costs of capital gives a model as shown in Table 4.3.

Table 4.3
Multi-Year SFA analysis of total costs with varying cost of capital

	Coefficient	Standard error	T-statistic	Significance
Log of switched lines	0.592	0.05	11.54	0.00
Log of leased lines	0.030	0.01	3.27	0.00
Log of switch minutes	-0.019	0.01	-1.49	0.14
Log of total sheath	0.391	0.04	8.73	0.00
Log of population density	0.040	0.02	1.77	0.08
Log of business line per residential (2003)	0.391	0.13	3.00	0.00
time	0.012	0.00	3.22	0.00
Log of switched lines (1996-1998)	-0.053	0.02	-3.33	0.00
Log of leased lines (1996-1998)	-0.041	0.01	-5.17	0.00
Log of switch minutes (1996-1998)	0.047	0.01	7.13	0.00
Log of total sheath (1996-1998)	0.027	0.01	2.12	0.03
time (1996-1998)	-0.024	0.01	-4.09	0.00
Constant	0.363	0.34	1.07	0.28
Log likelihood	686.54			

Source: NERA analysis

From the last column of this table, we can see that a number of variables become more insignificant when we use this measure of the cost of capital. In particular, population density is no longer a significant cost driver.

This model implies that the trend in nominal costs is similar to that found in Table 4.1, at 1.2% per year. From this result we may calculate that real costs are falling by 1.3% a year, *ceteris paribus*.

Applying this model to BT's explanatory variables and comparing the predicted cost to its actual cost gives us the inefficiency calculation shown in Table 4.4.

Table 4.4
Efficiency scores for total costs with varying cost of capital

	Company	Residual	Compared to top firm	Compared to decile	Compared to midpoint
1	Verizon NO-Illinois	0.04	0.00	-0.20	-0.37
2	Verizon NO-Ohio	0.16	0.12	-0.10	-0.30
3	Verizon NO-Wisconsin	0.16	0.13	-0.10	-0.30
4	Verizon SO-Illinois	0.19	0.17	-0.07	-0.27
5	Verizon NO-Michigan	0.22	0.20	-0.04	-0.25
6	Indiana Bell	0.24	0.23	-0.02	-0.23
7	Michigan Bell	0.26	0.25	0.00	-0.22
8	BT	0.30	0.30	0.04	-0.19
9	Verizon NO-Indiana	0.30	0.31	0.04	-0.18
10	Contel Nevada	0.32	0.32	0.05	-0.17
11	Verizon NO-Pennsylvania	0.32	0.32	0.05	-0.17
12	Wisconsin Bell	0.32	0.32	0.06	-0.17
13	Verizon-Delaware	0.35	0.36	0.09	-0.15
14	Qwest-Idaho South	0.37	0.40	0.12	-0.13
15	Qwest-South Dakota	0.38	0.41	0.13	-0.12
16	BellSouth-Mississippi	0.40	0.43	0.14	-0.11
17	Qwest-Montana	0.43	0.48	0.18	-0.08
18	BellSouth-Kentucky	0.43	0.48	0.18	-0.07
19	Verizon NW-Idaho	0.44	0.49	0.19	-0.07
20	Qwest-Iowa	0.44	0.49	0.19	-0.07
21	Verizon-Virginia	0.44	0.50	0.20	-0.06
22	Contel Arizona	0.44	0.50	0.20	-0.06
23	Ohio Bell	0.44	0.50	0.20	-0.06
24	Illinois Bell	0.45	0.51	0.20	-0.06
25	BellSouth-Alabama	0.48	0.55	0.23	-0.03
26	Southwestern - Arkansas	0.48	0.55	0.24	-0.03
27	Verizon-Maryland	0.48	0.56	0.24	-0.03
28	BellSouth-North Carolina	0.48	0.56	0.25	-0.02
29	Qwest-North Dakota	0.49	0.57	0.25	-0.02
30	Southwestern - Kansas	0.49	0.58	0.26	-0.01
31	BellSouth-Tennessee	0.49	0.58	0.26	-0.01
32	BellSouth-South Carolina	0.49	0.58	0.26	-0.01
33	Verizon NE - Rhode Island	0.50	0.59	0.27	-0.01
34	Southwestern - Oklahoma	0.51	0.60	0.27	0.00
35	Qwest-Wyoming	0.51	0.60	0.28	0.00
36	BellSouth-Louisiana	0.51	0.61	0.28	0.00
37	Verizon NW-West Coast California	0.52	0.61	0.29	0.01
38	BellSouth-Georgia	0.52	0.61	0.29	0.01
39	Verizon NE - Maine	0.53	0.63	0.30	0.02
40	Verizon NE - Vermont	0.53	0.63	0.30	0.02
41	Verizon SW-Texas	0.53	0.64	0.31	0.02
42	Qwest-Nebraska	0.53	0.64	0.31	0.02
43	Verizon SO-Virginia	0.53	0.64	0.31	0.03
44	Nevada Bell	0.54	0.65	0.32	0.03
45	Qwest-Minnesota	0.57	0.70	0.36	0.06
46	Verizon-New Jersey	0.58	0.73	0.38	0.08
47	Pacific Bell - California	0.58	0.73	0.38	0.08
48	Verizon NW-Oregon	0.59	0.73	0.38	0.08
49	Verizon-West Virginia	0.59	0.74	0.38	0.08
50	Verizon NE - New Hampshire	0.59	0.74	0.39	0.09
51	Verizon-Pennsylvania	0.62	0.79	0.43	0.12
52	BellSouth-Florida	0.63	0.81	0.44	0.13
53	Southwestern - Missouri	0.65	0.84	0.47	0.15
54	Verizon SO-South Carolina	0.66	0.86	0.48	0.16
55	Verizon NW-Washington	0.67	0.88	0.50	0.18
56	Qwest-New Mexico	0.67	0.89	0.50	0.18
57	GTE California	0.68	0.89	0.51	0.18
58	SBC/SNET - Connecticut	0.68	0.89	0.51	0.18
59	Verizon NE - Massachusetts	0.69	0.92	0.53	0.20
60	Southwestern - Texas	0.71	0.97	0.57	0.23
61	Verizon SO-North Carolina	0.74	1.02	0.61	0.26
62	Qwest-Utah	0.75	1.03	0.62	0.27
63	Verizon Florida	0.77	1.07	0.65	0.30
64	Qwest-Arizona	0.77	1.07	0.65	0.30
65	Qwest-Washington	0.78	1.11	0.68	0.32
66	Qwest-Colorado	0.79	1.12	0.69	0.32
67	Qwest-Oregon	0.81	1.16	0.72	0.35
68	Verizon New York Telephone	1.02	1.66	1.12	0.66

Compared to our analysis where a constant cost of capital is applied over all firms, we find that, although BT's ranking is the same, it is 3.80% less efficient than the decile (compared with 1.05% in the previous case). This is consistent with a general spreading out of the efficiency scores. This effect may be due to this model's slightly lower predictive power, which leads to a larger gap between predicted and actual costs.

4.4.2.1. Cost of capital as an explanatory variable

An alternative way to allow cost of capital to influence the regression is to include a cost of capital variable in the specification when looking at total costs. The variable takes the form of the logarithm of the cost of capital used to calculate capital costs as used in Section 4.4.2, and will vary by firm.

Including this variable in our standard regression, however, implies that it is insignificant. This is most likely due to the low amount of variation across the variable, with most companies observing a similar long-run cost of capital.

4.5. Results for Operating Costs plus Depreciation

When measuring costs in terms of operating costs plus depreciation, we do not have to make assumptions over the level of the cost of capital. This measure of costs looks only at the true costs faced by a firm, and not at the opportunity cost that a cost of capital represents.

However, costs measured in this way do not necessarily reflect a true measure of the costs considered by firms when making decisions. It is likely that a firm will consider not only its depreciation but also its (then) cost of capital when deciding on capital expenditure. By ignoring the cost of capital, we may be underestimating the importance of a firm's asset base on its costs and therefore on its efficiency.

For operating costs plus depreciation, our model gives the following estimated equation:

Table 4.5
Multi-Year SFA analysis of operating costs plus depreciation

	Coefficient	Standard error	T-statistic	Significance
Log of switched lines	0.630	0.05	12.04	0.00
Log of leased lines	0.048	0.01	4.24	0.00
Log of switch minutes	-0.019	0.02	-1.25	0.21
Log of total sheath	0.332	0.05	6.72	0.00
Log of population density	0.058	0.02	2.69	0.01
Log of business line per residential (2003)	0.282	0.12	2.29	0.02
time	0.010	0.00	2.39	0.02
Log of switched lines (1996-1998)	-0.066	0.02	-3.38	0.00
Log of leased lines (1996-1998)	-0.042	0.01	-4.28	0.00
Log of switch minutes (1996-1998)	0.051	0.01	6.30	0.00
Log of total sheath (1996-1998)	0.034	0.02	2.22	0.03
time (1996-1998)	-0.022	0.01	-3.17	0.00
Constant	-0.147	0.32	-0.46	0.65
Log likelihood	587.38			

Source: NERA analysis

This model appears to have largely the same properties as the model derived for total costs with a constant cost of capital. With the exception of switch minutes in the years since 1999, all variables are significant and the coefficients are intuitively correct²⁴.

In addition, the time trend suggested by this model is very similar to that derived in Section 4.4.1. Taking into account inflation, we find a real fall in costs of 1.5% per year.

Again, we may use this model to estimate BT's efficiency. Our results are shown in Table 4.6.

²⁴ Again, to interpret the coefficients on the variables applied to 1996-1998, we must also take into account the coefficients on the variable as a whole. Thus, for leased lines, the coefficient before 1999 was 0.006, and after 1999 it was 0.048.

Table 4.6
Efficiency scores for operating costs plus depreciation

	Company	Score	Compared to top firm	Compared to decile	Compared to midpoint
1	Verizon NO-Illinois	0.04	0.00	-0.21	-0.36
2	Verizon NO-Ohio	0.14	0.10	-0.13	-0.30
3	Verizon NO-Wisconsin	0.16	0.12	-0.11	-0.29
4	Indiana Bell	0.21	0.17	-0.07	-0.25
5	Verizon NO-Michigan	0.22	0.19	-0.06	-0.24
6	Wisconsin Bell	0.26	0.25	-0.01	-0.21
7	Verizon NO-Pennsylvania	0.28	0.26	0.00	-0.19
8	Michigan Bell	0.28	0.27	0.00	-0.19
9	BT	0.28	0.27	0.01	-0.19
10	Verizon NO-Indiana	0.29	0.28	0.01	-0.19
11	Verizon SO-Illinois	0.30	0.28	0.02	-0.18
12	Qwest-Idaho South	0.30	0.29	0.02	-0.18
13	Verizon-Delaware	0.31	0.31	0.03	-0.17
14	Qwest-Iowa	0.36	0.37	0.08	-0.13
15	Contel Nevada	0.38	0.39	0.10	-0.11
16	Ohio Bell	0.38	0.40	0.10	-0.11
17	Qwest-South Dakota	0.38	0.40	0.11	-0.11
18	BellSouth-Mississippi	0.39	0.42	0.12	-0.10
19	Qwest-Montana	0.40	0.42	0.12	-0.10
20	BellSouth-Kentucky	0.40	0.43	0.13	-0.09
21	BellSouth-Alabama	0.42	0.45	0.15	-0.07
22	Illinois Bell	0.42	0.46	0.15	-0.07
23	Verizon NW-Idaho	0.43	0.47	0.16	-0.06
24	BellSouth-Tennessee	0.43	0.48	0.17	-0.06
25	BellSouth-North Carolina	0.44	0.48	0.17	-0.06
26	Verizon-Virginia	0.45	0.49	0.18	-0.05
27	BellSouth-South Carolina	0.45	0.51	0.19	-0.04
28	Verizon-Maryland	0.46	0.51	0.19	-0.04
29	Qwest-North Dakota	0.46	0.51	0.20	-0.04
30	Verizon NE - Rhode Island	0.46	0.52	0.20	-0.03
31	BellSouth-Louisiana	0.48	0.54	0.22	-0.02
32	Qwest-Minnesota	0.48	0.55	0.22	-0.02
33	Verizon NW-West Coast California	0.48	0.55	0.22	-0.01
34	BellSouth-Georgia	0.49	0.56	0.23	-0.01
35	Southwestern - Arkansas	0.50	0.58	0.25	0.01
36	Qwest-Wyoming	0.51	0.59	0.26	0.01
37	Qwest-Nebraska	0.52	0.61	0.27	0.03
38	Verizon-New Jersey	0.52	0.61	0.27	0.03
39	Southwestern - Oklahoma	0.52	0.62	0.28	0.03
40	Nevada Bell	0.53	0.62	0.28	0.03
41	Southwestern - Kansas	0.53	0.62	0.28	0.03
42	Pacific Bell - California	0.53	0.62	0.28	0.03
43	Verizon NW-Oregon	0.54	0.64	0.30	0.04
44	BellSouth-Florida	0.55	0.66	0.31	0.06
45	Contel Arizona	0.56	0.67	0.32	0.07
46	Verizon NE - Vermont	0.57	0.69	0.33	0.07
47	Verizon NE - Maine	0.58	0.71	0.35	0.09
48	Verizon NE - New Hampshire	0.59	0.72	0.36	0.10
49	Verizon SW-Texas	0.59	0.73	0.37	0.10
50	Verizon-Pennsylvania	0.59	0.73	0.37	0.10
51	Verizon NW-Washington	0.59	0.73	0.37	0.10
52	Qwest-New Mexico	0.60	0.74	0.38	0.11
53	Verizon-West Virginia	0.60	0.75	0.38	0.11
54	Southwestern - Missouri	0.61	0.76	0.39	0.12
55	Qwest-Utah	0.63	0.79	0.42	0.14
56	SBC/SNET - Connecticut	0.63	0.79	0.42	0.14
57	Verizon SO-Virginia	0.65	0.84	0.45	0.17
58	Qwest-Washington	0.66	0.85	0.46	0.18
59	GTE California	0.66	0.86	0.47	0.18
60	Verizon NE - Massachusetts	0.68	0.88	0.49	0.20
61	Qwest-Arizona	0.68	0.89	0.49	0.20
62	Verizon Florida	0.69	0.90	0.50	0.21
63	Qwest-Oregon	0.69	0.91	0.51	0.22
64	Southwestern - Texas	0.70	0.93	0.52	0.23
65	Qwest-Colorado	0.71	0.94	0.53	0.24
66	Verizon SO-South Carolina	0.76	1.05	0.62	0.31
67	Verizon SO-North Carolina	0.86	1.25	0.78	0.43
68	Verizon New York Telephone	1.00	1.61	1.06	0.66

Under this definition of costs, BT lies one rank further from the top decile. However, due to a closer fit of the model, BT is only 0.50% less efficient than the firm on the top decile.

4.6. Results for Operating Costs and Capital Costs

To investigate the potential for an operator's efficiency to vary between operating costs and capital costs, Ofcom has asked NERA to apply the specification identified above to operating costs and capital costs separately.

4.6.1. Results for Operating Costs

Looking only at operating costs, we derive a regression model as shown in Table 4.7.

Table 4.7
Multi-Year SFA analysis of operating costs

	Coefficient	Standard error	T-statistic	Significance
Log of switched lines	0.798	0.05	15.28	0.00
Log of leased lines	0.100	0.02	6.09	0.00
Log of switch minutes	0.011	0.02	0.50	0.62
Log of total sheath	0.115	0.04	2.78	0.01
Log of population density	0.037	0.02	2.29	0.02
Log of business line per residential (2003)	0.186	0.11	1.62	0.10
time	0.038	0.01	7.02	0.00
Log of switched lines (1996-1998)	-0.082	0.03	-2.85	0.00
Log of leased lines (1996-1998)	-0.090	0.01	-6.53	0.00
Log of switch minutes (1996-1998)	0.094	0.01	7.98	0.00
Log of total sheath (1996-1998)	0.039	0.02	1.71	0.09
time (1996-1998)	-0.066	0.01	-7.04	0.00
Constant	-2.104	0.34	-6.16	0.00
Log likelihood	416.82			

Source: NERA analysis

This regression appears to be largely significant (although some variables are less significant than in previous regressions), but there are some unintuitive elements which raise concern.

Firstly, the coefficient on switched lines is much higher than seen in other regressions, and the coefficient on total sheath is lower. While this could indicate that operating costs are driven more strongly by the number of switched lines, it is as likely to be evidence of multicollinearity in the model.

Secondly, the time trend is very large and positive in the period since 1999, but is large and negative before 1999. Furthermore, the coefficients on the interaction terms (those terms

measuring the variable before 1999) are relatively large compared to the effects we have seen previously. These two concerns are likely to be caused by some multicollinearity between the time trend and interaction terms, and therefore care must be taken when drawing conclusions over the size of these coefficients.

If this model is used to calculate the comparative efficiency of BT, we find that BT is 2.66% less efficient than the decile in terms of operating costs. Combined with the above analysis, it would appear that BT is more efficient in terms of capital costs and less efficient in terms of operating costs.

4.6.2. Results for Capital Costs

If capital costs are calculated using a constant cost of capital of 12%, we find the estimated model shown in Table 4.8.

Table 4.8
Multi-Year SFA analysis of capital costs at 12% cost of capital

	Coefficient	Standard error	T-statistic	Significance
Log of switched lines	0.542	0.06	9.09	0.00
Log of leased lines	-0.015	0.01	-1.42	0.16
Log of switch minutes	-0.032	0.01	-2.24	0.03
Log of total sheath	0.486	0.05	9.54	0.00
Log of population density	0.046	0.03	1.86	0.06
Log of business line per residential (2003)	0.357	0.14	2.48	0.01
time	-0.002	0.00	-0.45	0.65
Log of switched lines (1996-1998)	-0.012	0.02	-0.69	0.49
Log of leased lines (1996-1998)	-0.026	0.01	-2.87	0.00
Log of switch minutes (1996-1998)	0.019	0.01	2.57	0.01
Log of total sheath (1996-1998)	0.008	0.01	0.58	0.56
time (1996-1998)	-0.003	0.01	-0.49	0.62
Constant	0.476	0.38	1.24	0.22
Log likelihood	629.45			

Source: NERA analysis

For comparability, we have used the same specification for all measures of costs. However, the model for capital costs shown above indicates that there are large drawbacks to this approach.

As Table 4.8 shows, a number of variables which were significant in previous models are now insignificant. In addition, some of the coefficients have values which do not accord with intuition or prior expectations. For example, the coefficient on leased lines in this model implies that as the number of leased lines increases, the total cost of an operator decreases.

This impact is most pronounced at the start of the dataset's period, where the total coefficient for leased lines is - 0 .041 (that is, equal to - 0.015 - 0.026). Furthermore, switch minutes also appear to be inversely related to costs, particularly in the period since 1999 (although, as previously explained, this may be due to multicollinearity in our explanatory variables).

Overall this model appears to be a relatively poor specification for capital costs. However, using this model to estimate efficiency will allow us to compare efficiency in operating cost and in capital cost for each company while assuming that the same outputs drive all types of cost. By comparing the efficiency scores for these two types of cost for each firm, we will investigate whether firms tend to have similar efficiency over all types of cost incurred.

4.6.3. Comparison of Rankings

In order to compare these models, we must calculate the efficiency of each firm under the two cost assumptions. However, it is unlikely that we would find these efficiency measures to be directly comparable. Given the issues surrounding the capital costs model described above, we would expect the residual of each firm (that is, the difference between predicted costs and actual costs) to be greater for capital costs, since less of the actual cost is being explained by the explanatory variables in the model. Therefore, we would expect residuals to be more spread out over a greater range, and therefore be non-comparable with the results obtained for operating costs.

Rather than looking at the relative efficiencies, therefore, it is preferable to look at the relative rankings of companies. Table 4.9 details the efficiency rankings for companies for operating costs and for capital costs separately.

Table 4.9
Company rankings for operating and capital costs

Company	Ranking for total costs	Ranking for operating costs	Ranking for capital costs
Verizon NO-Illinois	1	2	1
Verizon SO-Illinois	2	7	3
Verizon NO-Ohio	3	5	2
Verizon NO-Wisconsin	4	8	5
Indiana Bell	5	4	7
Verizon NO-Michigan	6	21	4
Michigan Bell	7	10	9
BT	8	12	6
Wisconsin Bell	9	6	12
Verizon NO-Pennsylvania	10	18	10
Verizon NO-Indiana	11	17	11
Contel Nevada	12	1	18
Verizon-Delaware	13	13	14
Qwest-Idaho South	14	3	19
Qwest-South Dakota	15	37	13
BellSouth-Mississippi	16	23	17
Qwest-Iowa	17	14	20
Contel Arizona	18	67	8
Qwest-Montana	19	20	22
Ohio Bell	20	9	30
BellSouth-Kentucky	21	22	27
Illinois Bell	22	19	25
Qwest-North Dakota	23	47	21
Verizon-Virginia	24	35	28
Southwestern - Arkansas	25	50	23
Verizon NE - Rhode Island	26	39	26
BellSouth-Alabama	27	11	44
BellSouth-North Carolina	28	16	41
Verizon-Maryland	29	25	32
BellSouth-South Carolina	30	31	33
BellSouth-Tennessee	31	15	35
Verizon NW-Idaho	32	27	42
Southwestern - Kansas	33	56	15
Qwest-Wyoming	34	44	37
Verizon NW-West Coast California	35	52	36
Southwestern - Oklahoma	36	55	16
Qwest-Nebraska	37	59	31
Verizon SO-Virginia	38	36	46
BellSouth-Louisiana	39	30	38
BellSouth-Georgia	40	28	47
Qwest-Minnesota	41	29	45
Verizon NE - Vermont	42	61	34
Nevada Bell	43	63	24
Verizon NE - Maine	44	62	29
Verizon SW-Texas	45	54	40
Verizon-New Jersey	46	32	48
Pacific Bell - California	47	24	51
Verizon-West Virginia	48	58	39
Verizon NE - New Hampshire	49	53	49
BellSouth-Florida	50	26	55
SBC/SNET - Connecticut	51	65	43
Verizon SO-South Carolina	52	46	57
Verizon-Pennsylvania	53	38	52
Verizon NW-Oregon	54	45	53
Southwestern - Missouri	55	49	50
Qwest-New Mexico	56	40	56
Verizon NE - Massachusetts	57	64	54
GTE California	58	33	61
Verizon NW-Washington	59	41	63
Verizon SO-North Carolina	60	66	59
Southwestern - Texas	61	57	58
Qwest-Utah	62	34	66
Qwest-Arizona	63	48	60
Qwest-Washington	64	42	64
Qwest-Colorado	65	60	62
Qwest-Oregon	66	51	65
Verizon Florida	67	43	67
Verizon New York Telephone	68	68	68

This table indicates that the rankings for operating costs and capital costs differ. However, generally an operator which is efficient in one cost type is efficient in another; that is, there are few companies for whom the rankings under different methods are markedly different.

Overall, the ranking correlation coefficient between operating costs and capital costs is 0.514. This implies that, while there is not a perfect relationship between the rankings found, we would expect a company efficient in operating costs to be efficient in capital costs. It would be incorrect to conclude that a company efficient in one area will be inefficient in another. Moreover, since operating cost efficiency and capital cost efficiency are closely tied, and since total cost efficiency is a combination of these, we can be confident that an estimate of total cost efficiency is a reasonable approximation of efficiency in operating costs or in capital costs.

4.7. Sensitivities and model robustness

This section describes a number of sensitivity analyses conducted to test the robustness of our model using the total cost methodology. Each of these sensitivities may be compared to a base case as shown in Section 4.4.1, where cost of capital is held at 12% for all firms, and we model total costs.

4.7.1. Use of maximum likelihood ‘GLS’ analysis

As described in Section 2.7, NERA believes that a multi-year stochastic frontier analysis is the best measure of efficiency given the size and scope of our dataset. However, we can also run the same specification using an alternative model to test for the robustness of our results.

Generalised least squares (as described in Section 2.3.1) provides one such alternate model. GLS seeks to estimate an ‘average’ cost function rather than an efficiency frontier, and does not decompose the residual into measurement error and inefficiency as stochastic frontier analysis does. This limitation is shared by a random effects error components model, which is estimated using maximum likelihood iterative techniques in the same way as stochastic frontier analysis. Therefore, to examine the effect of moving to an average cost function and of not decomposing the residual, it is best to use this maximum likelihood method²⁵.

This model results in the equation set out in Table 4.10.

²⁵ Where residuals are assumed normally distributed, a random effects error component model will give an identical regression equation to a generalised least squares model.

Table 4.10
Multi-Year random effects analysis of capital costs at 12% cost of capital

	Coefficient	Standard error	T-statistic	Significance
Log of switched lines	0.577	0.05	11.64	0.00
Log of leased lines	0.028	0.01	3.18	0.00
Log of switch minutes	-0.018	0.01	-1.51	0.13
Log of total sheath	0.399	0.04	9.33	0.00
Log of population density	0.058	0.02	2.60	0.01
Log of business line per residential (2003)	0.379	0.13	2.97	0.00
time	0.011	0.00	3.19	0.00
Log of switched lines (1996-1998)	-0.048	0.02	-3.16	0.00
Log of leased lines (1996-1998)	-0.042	0.01	-5.52	0.00
Log of switch minutes (1996-1998)	0.045	0.01	7.16	0.00
Log of total sheath (1996-1998)	0.025	0.01	2.09	0.04
time (1996-1998)	-0.023	0.01	-4.09	0.00
Constant	0.977	0.33	2.97	0.00
Log likelihood	706.07			

Source: NERA analysis

As this table shows, the coefficients obtained using this model are very similar to those obtained through stochastic frontier methods. Similar conclusions over the time trend can also be drawn.

When applied to BT's data, we obtain an estimated efficiency as shown in Table 4.11.

Table 4.11
SFA and random effects estimates of total cost efficiency

	Compared to top firm	Compared to decile	Compared to average
Total costs using SFA	24.11%	1.05%	-20.74%
Total costs using random effects model	22.17%	0.00%	-22.70%

Source: NERA analysis

We can therefore see that using the random effects model, BT lies on the decile. The reason for this difference in ranking is most likely due to the inability of this model to separate out true inefficiency from random error. This would mean that BT's inefficiency would be understated if the random error component of BT's residual was positive. This affects not only BT's calculated inefficiency, but also that of the LECs.

While the random effects model is less likely to give an accurate picture of BT's efficiency, its similarity to our SFA model in terms of coefficients and significance does imply that our model is relatively robust.

4.7.2. Varying the fixed cost of capital

In Section 4.4.1, we estimated a model where the cost of capital for all firms was set at 12%, a cost of capital which is broadly consistent with the cost of capital figure Ofcom is considering for use in its price cap model.

However, this 12% is a relatively arbitrary assumption, and therefore we test for its impact on BT's efficiency. To this end, we ran models assuming a cost of capital fixed firstly at 11%, and then at 13%.

Table 4.12
Multi-Year SFA analysis of total costs

	Coefficients assuming		
	11% cost of capital	12% cost of capital	13% cost of capital
Log of switched lines	0.581	0.577	0.573
Log of leased lines	0.029	0.028	0.027
Log of switch minutes	-0.019	-0.018	-0.018
Log of total sheath	0.394	0.398	0.401
Log of population density	0.057	0.057	0.058
Log of business line per residential (2003) time	0.377	0.385	0.394
Log of switched lines (1996-1998)	-0.049	-0.048	-0.047
Log of leased lines (1996-1998)	-0.042	-0.042	-0.042
Log of switch minutes (1996-1998)	0.046	0.045	0.045
Log of total sheath (1996-1998) time (1996-1998)	0.026	0.025	0.025
Constant	0.452	0.506	0.560

Source: NERA analysis

The results show that these models are very similar in terms of the coefficients on variables. When we use these models to predict BT's efficiency, we find results as shown in Table 4.13.

Table 4.13
SFA estimates of total cost efficiency at different costs of capital

	Compared to top firm	Compared to decile	Compared to average
Total costs at 11% cost of capital	24.09%	0.83%	-20.91%
Total costs at 12% cost of capital	24.11%	1.05%	-20.74%
Total costs at 13% cost of capital	24.17%	1.29%	-20.51%

Source: NERA analysis

Overall, therefore, the impact of changing the cost of capital assumption for all firms has minimal effect on our model.

4.7.3. Relaxing the assumption of time invariance

In all stochastic frontier models estimated so far, we have assumed that the inefficiency of a company does not vary over time. As discussed in Section 2.4.1, it is possible to relax this assumption.

When predicting our model for total costs using a time varying decay model, we find that the statistic on this decay is insignificant²⁶. This implies that it is valid to assume constant inefficiencies over time.

4.7.4. Changing the exchange rate for capital

NERA has outlined in Section 3.1.1.2 our reasoning for converting BT's costs to US dollars using a GDP purchasing power parity exchange rate. However, for a number of asset types, it is reasonable to expect that costs will be dictated by a market exchange rate, as these assets are bought on an international market.

There exist a number of difficulties in estimating how such an assumption would affect BT's capital costs:

- Firstly, the data provided to NERA does not allow us to estimate what percentage of BT's capital base consists of assets which may be traded in an international market. We are therefore unable to define which assets should be converted using PPP exchange rates and which should be converted using market rates.
- Secondly, the market exchange rate has moved at a rapid rate in recent years. The decline of the US dollar has led to the exchange rate being unfavourable to UK companies when converting costs and prices into dollars. In addition, the speed of the change of exchange rate means that it is very unlikely that the prices offered in pounds sterling and US dollars will be equal – that is, it is likely that the sterling price will be “sticky” and will only decrease slowly over time.

²⁶ The t-ratio on ‘eta’ is 0.44, which lies well outside the 95% confidence interval.

Based on figures discussed with BT, NERA estimates that a maximum of around 50% of BT's asset base could be traded on an international market, and therefore could be converted to dollars using a market exchange rate. Therefore, we have run a sensitivity analysis where 50% of BT's assets are converted to US dollars in this way.

Table 4.14
SFA estimates of total cost efficiency using different exchange rates

	Compared to top firm	Compared to decile	Compared to average
Using GDP PPP rates	24.11%	1.05%	-20.74%
Using market exchange rates for 50% of BT's asset base	23.56%	0.60%	-21.09%

Source: NERA analysis

This represents an extreme case because it is unlikely that prices would follow the market rate precisely, even for goods traded on an international market.

Overall, this currency conversion can be said to have a minimal impact on the estimation of BT's efficiency.

4.7.5. Changing the weighting on special access lines

As described in Section 3.2.2.1, it is necessary for comparability to aggregate the US LECs' leased circuits and special access lines. NERA believes that it is appropriate to weight these two types of lines using the factors 2 and 1.5 respectively, given the equipment used by each type of line. However, it is possible that the costs incurred will not follow this relative weighting. Therefore, we have carried out a sensitivity where the weight of special access lines was altered firstly to 1.25 and secondly to 1.75.

The results of these sensitivities are shown in Table 4.15.

Table 4.15
SFA estimates of total cost efficiency using different line weights

	Compared to top firm	Compared to decile	Compared to average
Special access lines given weighting of 1.25	23.44%	0.61%	-21.08%
Special access lines given weighting of 1.5	24.11%	1.05%	-20.74%
Special access lines given weighting of 1.75	24.66%	1.41%	-20.46%

Source: NERA analysis

Therefore, the choice of weighting for special access lines has relatively little effect on the calculation of BT's comparative efficiency.

4.7.6. Including data network costs

As described in Section 3.1.1, NERA has been told by the FCC that costs relating to data networks should be excluded from the filings of companies to ARMIS. Therefore, we asked BT to separately identify such costs in the data they provided, so that such costs could be removed. However, the FCC cannot confirm with absolute certainty that data networks are excluded from all LEC costs.

To test for the sensitivity of results to the inclusion of data network costs in BT's data, we have run our model with these costs included. The results are shown in Table 4.16.

Table 4.16
SFA estimates of total cost efficiency including data networks

	Compared to top firm	Compared to decile	Compared to average
Excluding data networks from BT costs	24.11%	1.05%	-20.74%
Including data networks in BT costs	28.40%	4.54%	-18.00%

Source: NERA analysis

It can be seen that if data network costs were included in the data for the US LECs, BT's inefficiency compared to the decile would increase by 3.5%.

4.7.7. Testing for use of a reduced sample

As discussed in Section 3.2.4.1, where a structural break exists in our dataset there are two possible remedies. In all models set out so far, we have used interaction terms to allow variables to vary in their influence between the first and second periods in our sample (where the first period covers 1996 to 1998, and the second period from 1999 onwards). This has the advantage of keeping all available information in the model. In particular, this model allows a full dataset to be used when estimating variables which do not appear to vary in significance over the period (such as population density, and the constant term in our regression).

The alternative method would be to discard data from the model which occurs before this break. This would mean reducing our dataset from eight years to five years. When we run our specification over this reduced five-year sample, we find that a number of variables become insignificant which were significant in our previous models, including leased lines and population density. In addition, the coefficients on some other variables become unintuitive.

Since we are comparing two models with different sample sizes, a normal likelihood ratio test will not allow us to analyse whether the assumption of moving from one model to the other is valid. We are able to 'force' a likelihood ratio test by ignoring the differences in sample size, but this does not give a statistically robust result.

When this model is used to predict BT's efficiency, we estimate that BT is more efficient than is suggested by the previous analysis. Our concerns over the structure of this model, however, mean that we would not recommend this measure of BT's efficiency to be used.

4.8. Data Envelopment Analysis

In addition to the stochastic frontier and generalised least squares analysis outlined above, NERA has also attempted to measure BT's efficiency using a mathematical technique, data envelopment analysis (DEA). DEA involves using a mathematical programme, rather than statistical, techniques to assess comparative efficiency. DEA operates by searching for a 'least cost peer group' of comparator companies for BT. The 'peer group' is defined such that a linear combination of these companies can be shown to have at least as great an output and no more favourable operating conditions than BT. If such a 'peer group' exists, and the linear combination of their costs is lower than that of BT, this cost difference is assumed to be attributable to inefficiency on the part of BT.

It should be noted that, since it is a mathematical technique, DEA offers no statistical framework for modelling the performance of firms outside the sample, nor does it allow us to assess the significance of the variables used in the analysis. Therefore, DEA analysis was completed using the same explanatory variables as the regression analysis, as the statistical validity of including these variables in a total costs model has already been established.

Using these variables, DEA is unable to find peers to compare against BT's total costs in the year 2003. It is difficult to draw firm conclusions from this because there are two possible explanations for why DEA cannot find peers for a company:

- Firstly, it could be that the company is 100% efficient.
- The second possibility is that DEA is unable find comparable firms within the sample against which to assess the efficiency of the firm.

Given the conclusions of the regression analysis, it is reasonable to assume that the latter of these is the more likely.

5. Summary of Results and Conclusions

This section outlines the comparative efficiency of BT using the cost equations estimated above. Table 5.1 shows BT's comparative efficiency for total costs using a constant cost of capital of 12% applied to all firms (where 12% is a cost of capital which is broadly consistent with the cost of capital figure Ofcom is considering for use in its price cap model), and using a firm-specific long run cost of capital, and for operating costs plus depreciation.

Table 5.1
Summary of SFA efficiency results

	Compared to top firm	Compared to decile	Compared to average
Total costs with cost of capital at 12%	24.11%	1.05%	-20.74%
Total costs with varying cost of capital	30.23%	3.80%	-18.59%
Operating costs plus depreciation	27.08%	0.50%	-19.04%

Source: NERA analysis

BT's inefficiency would therefore appear to lie in the range from 0.5% to 3.8%.

Our report has discussed the robustness of these results. In particular, as discussed in Section 3.2.1.3 and Section 4.4.2, our model where cost of capital is allowed to vary between firms appears to have a lower predictive power than other regressions. NERA would therefore suggest that lesser weight should be placed on this result.

NERA has also run sensitivities on these results. Our analysis of a random effects model (as discussed in Section 4.7.1) indicates that the estimated equation obtained from stochastic frontier analysis is reasonably robust. In addition, analysis of the effect of changing the assumed constant cost of capital (from 12% to 11% and 13%) indicates that our efficiency estimates for BT are little affected by this assumption.

Finally, our analysis allows us to examine trends in the change of costs over time. For total costs, our analysis produces a fairly consistent trend of around a 1% increase in nominal costs per annum for the latter part of our study period. This translates, given the average US inflation rate over our study period of 2.5%, to a 1.5% decrease in real costs per annum. This represents a slowdown in the rate of change of costs since the first part of the study period, where real costs were observed to fall much more quickly.

Appendix A. Stochastic Frontier Analysis

There is an extensive academic literature on efficiency measurement using Stochastic Frontier Analysis (SFA), and it is increasingly being used by utility regulators as a robust measure of inefficiency. It is based on regression analysis, but with a key distinction. In the context of efficiency comparisons, OLS regression models implicitly assume that the whole of the residual for a particular observation (company) is the result of genuine inefficiency. In contrast, SFA models incorporate the possibility that some component of the model residual may result from errors in measurement of costs or the omission of explanatory variables, as opposed to the existence of genuine inefficiencies. This decomposition of residuals between ‘error’ and ‘genuine inefficiency’ is intended to provide a more accurate reflection of the true level of inefficiency.

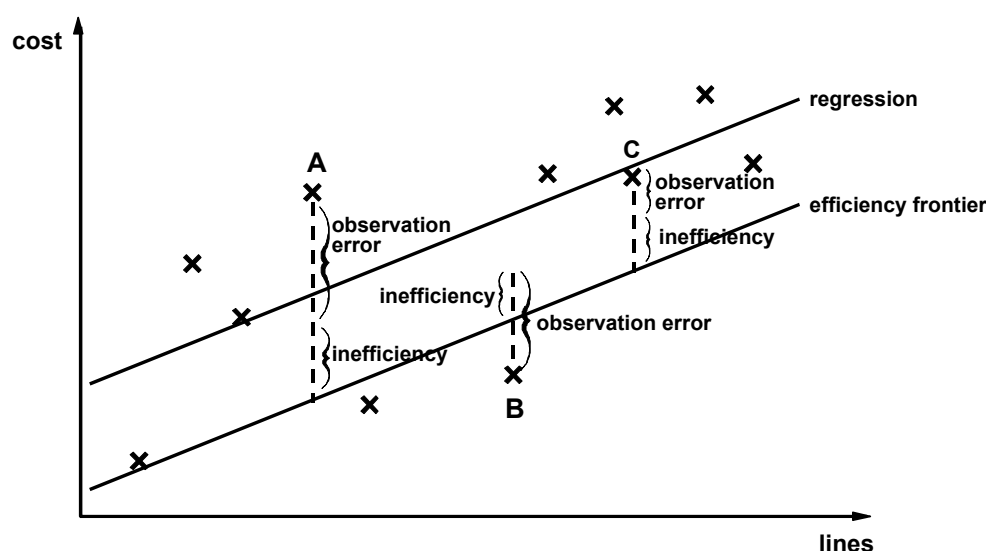
Under the simplest implementation of SFA, an Ordinary Least Squares (OLS) regression is first estimated to capture the sensitivity of costs to differences in operating environments, scale of production or mix of outputs. This model will leave residuals that can be attributed to the two remaining causes of measured cost differences:

- those that are the result of remaining incompatibilities in data that have not been picked up in the preceding adjustments, or even just plain errors in the observed data;
- genuine inefficiencies of the operators compared to best practice, in which we are primarily interested.

It is assumed that remaining data errors and incompatibilities are equally likely to increase or reduce measured costs for any one operator. However, inefficiencies, where they exist, will only increase costs. Therefore, to the extent that there are genuine operator inefficiencies, the distribution of the residuals from the regression model will be skewed in the direction of being positive (actual cost exceeds that estimated by the regression). By measuring the extent of this skew to the distribution (estimated by the third moment of distribution) it is possible to calculate the relative importance of observation errors vs. genuine inefficiencies.

Once the relative importance of the genuine inefficiencies in the residual distribution has been estimated, it is possible to adjust the estimated regression line downward by this amount to form an efficiency frontier. Thus, distances of each observation from the original OLS regression line measure departures of cost from “mean” industry performance, whilst in the new line they measure departures from the efficiency frontier. Figure A.1 provides an illustration of this. We have used the simplified example of just one explanatory variable in the regression model – the number of lines.

Figure A.1
Stochastic Frontier Analysis



Once an efficiency frontier has been estimated, it is still necessary to estimate the efficiency of each company, bearing in mind that the vertical distance of the measured cost of each company from the efficiency frontier will still be composed of two components:

- observation error and data incompatibilities for that particular company;
- genuine inefficiency for that particular company.

Indeed, it will still be possible for a particular company to have a cost below that of the efficiency frontier if the downward bias due to observation error exceeds the company's inefficiency (as is the case for observation B in Figure A.1). However, knowledge of the company's cost relative to the efficiency frontier does provide information on which to base an estimate of the company's inefficiency. For example, if the company's cost is high relative to the efficiency frontier (as in the case of observation A), its inefficiency is also likely to be high, whereas if its cost is low relative to the efficiency frontier, its inefficiency is likely to be low (as in the case of observation C).

It is also possible to estimate the regression line taking account of the distribution of the residuals, using a maximum likelihood estimator. This will produce a more statistically efficient estimate than that given by OLS, and is the technique used in the analysis contained in this report. This method involves analysing a number of statistical distributions, to see if they will fit the distribution of the 'inefficiency' component of the residual error (which, as we have discussed above, is skewed in the direction of being positive). Three different distributions are commonly considered:

- the half normal distribution;
- the negative exponential distribution; and
- the truncated normal distribution.

Essentially, SFA attempts to estimate a maximum likelihood model using each of these statistical distributions. If a distribution is found not to fit the data, the model is abandoned. However, if a distribution fits the data, the model produces estimates of the position of each observation (company) relative to the theoretical efficiency frontier. The model also yields estimates of the average distance of all observations from the efficiency frontier, as well as the proportion of the total residual error which is characterised as ‘inefficiency’ (as opposed to ‘measurement error’).

The main disadvantage of SFA is that strong assumptions are required in order to decompose the regression residuals, and in many practical cases insufficient data is available to support this decomposition. That is, there is often little evidence to suggest which of the above statistical distributions is most appropriate in constructing a model (note that, in many cases, more than one distribution may be deemed to ‘fit’ the data).

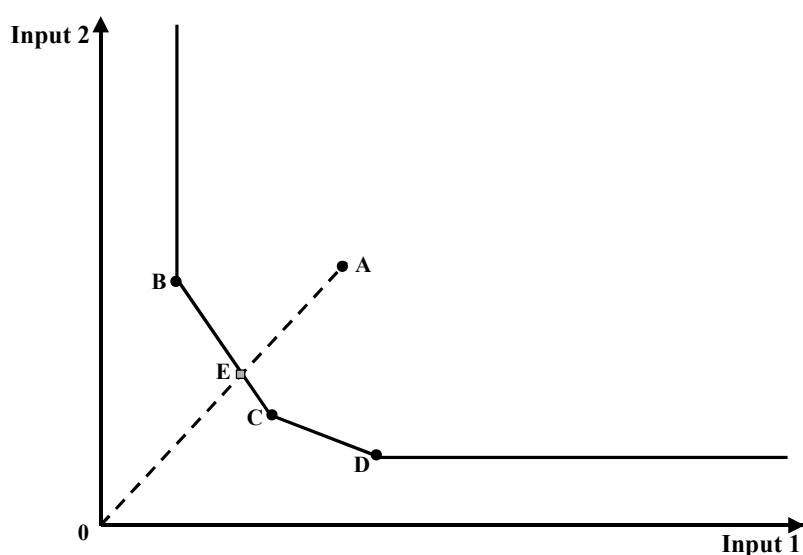
Appendix B. Data Envelopment Analysis

Data Envelopment Analysis (DEA) can be used as an alternative to regression-based techniques. It is not a statistical estimation technique, but rather makes use of mathematical programming methods, without the need to rely on a precise parametric cost function. This, in fact, is its main advantage; it allows a complex non-linear (concave or convex) relationship to exist between outputs and costs, whereas regression usually restricts such relationships to be either linear, or to have fairly simple non-linear forms. One additional important advantage of DEA is that it does not suffer from statistical problems, such as multicollinearity between variables, which may affect OLS, panel data and SFA models.

DEA operates by searching for a ‘least cost peer group’ of comparator companies for each individual target company. The ‘peer group’ is defined such that a linear combination of these companies can be shown to have at least as great an output and no more favourable operating conditions as the target company (with output and environmental variables measured in the same way as in regression analysis). If such a ‘peer group’ exists, and the linear combination of their costs is lower than that of the target company, this cost difference is assumed to be attributable to inefficiency on the part of the target company.

This is explained more clearly with the aid of a diagram. Figure B.1 below shows an example of an input minimisation model. Points A, B, C and D represent different companies, such that company A produces the same amount or less of each (common) output than the other three. Now, DEA assumes that, since B and C are technically feasible positions, point E (a linear combination of the two) is also technically feasible. Point E lies on a radial to A from the origin, and hence is a point using proportionately less of every output than A (a ‘radial contraction’), in order to produce the same (or greater) amount of each output. Therefore, point A is considered to be inefficient. The degree of inefficiency is reflected in the Farrell measure, which is defined as the ratio OE/OA , and companies B and C form a ‘peer group’ for company A.

Figure B.1
DEA: Input Minimisation



It should be noted that DEA has a number of disadvantages:

- it provides no statistical framework to model the possibility of errors in the observations;
- it has a tendency to give observations the ‘benefit of the doubt’. In arriving at an efficiency score for an observation, DEA adopts a weighting structure which emphasises the particular inputs and outputs which show that observation in the best possible light;
- related to the last point, unless restrictive assumptions are imposed (such as constant returns to scale), DEA is unable to assess the efficiency of companies with outputs or environmental variables on the “edges” of the data set. For example, if a company operates in an environment that is more adverse than any other in the sample, DEA will always assume that this company is 100% efficient, regardless of its cost base (since it has no other equivalent comparator). Regression analysis, on the other hand, by assuming a particular functional form for the impact of the environmental variable, is able to estimate the impact that the environmental variable should have on the company’s costs, and calculate the company’s underlying efficiency on this basis.

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