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## Natural or Unnatural Monopolies in UK Telecommunications?

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ABSTRACT

This paper analyses whether scale economies exists in the UK telecommunications industry. The approach employed differs from other UK studies in that panel data for a range of companies is used. This increases the number of observations and thus allows potentially for more robust tests for global subadditivity of the cost function. The main findings from the study reveal that although the results need to be treated with some caution allowing/encouraging infrastructure competition in the local loop may result in substantial cost savings.



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## 1. Introduction

The UK has historically pursued a policy of infrastructure or local loop competition in the telecommunications market with the aim of delivering dynamic competition, the key focus of which is innovation. Recently, however, Directives from Europe have been issued which could be argued discourages competition in the local loop. The Commission's starting point appears to be that the local loop is a natural monopoly and so competition in the local loop harms efficiency by duplicating fixed costs resulting in a reduced exploitation of economies of scale and scope. This belief has to be scrutinised in some detail, as it is fundamental to the question of whether regulation or competition should prevail for the provision of telecommunications networks. And to-date, this has not been adequately analysed for the UK.

Using panel data for UK infrastructure providers and techniques previously not used in the UK literature, we try to examine the extent to which the overall cost function of the U.K. telecommunications industry is subadditive and examine whether joint production or economies of scale and scope characterise the industry. The main finding from the study reveals that despite qualifications as to the reliability of the estimated cost function, which may make us cautious in any inference, allowing/encouraging infrastructure competition in the local loop may result in cost savings.

The remainder of the paper is structured as follows: Section 2 provides a brief outline of the main studies investigating scale and scope economies in telecommunications. Section 3 describes the cost modelling methodology adopted in this paper. Section 4 is dedicated to data discussion pertaining to the above analysis. Section 5 then presents the estimation results of the cost function of the UK telecommunications sector. Section 6 focuses on our subadditivity tests and presents the results emanating from these tests. Finally, Section 7 concludes the paper.

## 2. Previous Related Research

The question of whether a telecommunications system and specifically the local loop of the system is a natural monopoly has been studied extensively. Most of the studies, in the literature have however been based on time-series data of the main incumbent operator. Furthermore, most of them have focused, due to the availability of data, on just the U.S. or Canadian telecommunications sector.

The earlier studies (see Dobell, Taylor, Waverman, Lin and Copeland - 1972, Vinod –1972, and Sudit – 1973) involved estimation of single output functions. And for the most part, the reported results were generally consistent and suggested significant economies of scale. Fuss and Waverman (1981) recognised however that cost or production functions based on an aggregate measure of output are valid only under highly restrictive assumptions. Given this, they developed a multiple output, multiple input model from which they derived a translog cost function. Using Bell Canada data from 1952 to 1975, the authors rejected the hypothesis of an aggregate measure of output i.e. separability of the transformation function, and found weak evidence of cost complementarity between local and toll services and between the toll service and the private line. The derived estimates of scale elasticity appeared, however, to be ambiguous as they rose from less than one in the early years to greater than one in the later years. Fuss and Waverman (1981) therefore commented that there was no strong evidence to support subadditivity. They added, however, that perhaps this was the case because their test was not suitable or reliable as it involved the extrapolation of the cost function far outside the sample in order to calculate stand-alone costs for local, toll and private line services.

In a similar way to the above, Evans and Heckman (1983, 1984, 1986) rejected the single-output specification of the cost function. Instead, they estimated a multiproduct cost function using data developed by Christensen, Cummings and Schoech (1983) and output data generated by dividing output revenues by the average price of local and toll services. Using time-series data for 1947 – 77, they applied a local test of subadditivity, which constrained the output region to that of the available data. The result of this was that they rejected the natural monopoly hypothesis for local and long distance calls for the period 1958 – 77. Charnes, Cooper and Sueyoshi (1988), however, supposedly using the same data as Evans and Heckman (1983, 1984, 1986) modified their test and utilised goal programming or constrained regression analysis. The result of this was that their approach yielded the opposite result to the Evans and Heckman model. In response, Evans and Heckman (1988) argued that there was no basis for comparison between their approach and the Charnes et al. (1988) approach as the functional form as well as the data were not identical for the two models. Additionally, they argued that if the same data and functional forms had been used, the results would have been similar to their study and thus the inference about the natural monopoly hypothesis would have been unchanged.

In 1990, Röller further modified the Evans and Heckman (1983) subadditivity test by constraining the cost function to satisfy a property termed "properness" in order to ensure a well behaved and economically plausible cost function. According to Röller (1990a, b), a proper cost function is defined as being nonnegative and linearly homogeneous, concave and non-decreasing in input prices as well as having positive marginal cost schedules. This last property is argued by Röller to be the most important as it ensures that 'degenerate' translog cost behaviour is not too excessive. Using this concept of 'properness' in conjunction with the Christensen et al. (1983) data used by Evans and

Heckman, Röller estimated a CES-Quadratic cost function and found that the Evans and Heckman (1983, 1984, 1986) results were reversed and that the pre-divestiture Bell data was actually fully consistent with a natural monopoly[1].

In the same year as Röller's study, Hunt & Lynk (1990) in the U.K. carried out time-series analysis for the pre-privatisation period of BT. Their modelling methodology, however, differed substantially from previous analysis of the telecommunications industry in that the data extracted from the Post Office was recognised as being strongly time trended. As a consequence, cointegration and error-correction model techniques were used to derive a long run cost function. An examination of this revealed a long-run elasticity of cost with respect to both outputs of between 0.6 and 0.7 and a long-run multi-product scale economy estimate of between 1.5 and 1.8. They thus concluded that for the period 1951 – 81, telecommunications production in the inland and international areas was characterised by cost complementarities and that the cost function was locally subadditive since the industry appeared to be characterised by both economies of scale and economies of scope. They did not, however, explicitly test for the subadditivity of the cost function. Therefore, their results must be interpretated with caution[2].

1. Fuss and Waverman (2002) argue however that Röller's model biases the subadditivity test towards acceptance of natural monopoly via its assumptions. In particular, Röller's cost function model "assumes that a stand-alone producer of toll services has the *identical* dollar amount of fixed costs as a firm that produces both toll and local services. Also Röller's model assumes that any cost complementarity savings associated with the interconnected nature of toll and local service facilities is lost with respect to the competitor's provision of toll." Conducting some analysis on the Röller model, the authors found that the "fixed cost requirement is not very stringent" and hence they concluded that "the Röller model does not provide evidence against competitive entry."

2. Furthermore, it should be noted that the local nature of their test means that it could never confirm the natural monopoly hypothesis, only reject it. No real inference can therefore be made from their results as to whether or not a natural monopoly characterises BT.

Whilst the studies above using various statistical regression techniques have all contributed to the literature analysing whether telecommunications is a natural monopoly, the empirical results have not been consistent and the analysis conducted is subject to several important limitations. A major problem with previous studies has been the fact that most have relied on single company aggregate time-series data, for the most part using only 30 yearly observations on costs, output, input prices and technological change. It is therefore probable that most of the results obtained, will suffer from a lack of sufficient degrees of freedom and from data that is highly time trended. A further problem with previous studies is that the choice of data for the output variables has usually relied on output revenues. The fact that most costs incurred and revenues received by the various entities that provide telecommunications services are determined by the "separation and settlement" process means that there is much scope for the correspondence between reported costs and revenues and economic costs and revenues for the individual entities/business operations to be disjointed thus leading to inaccurate output measures[3].

To resolve a lot of the problems/limitations outlined above, Shin and Ying (1992) examined, therefore, the subadditivity of local exchange carriers (LECs) in the U.S. by using data consisting of a pooled cross-sectional sample of 58 LECs from 1976 to 1983. The result of this was that the small sample size problem that characterised previous studies was no longer an issue here and in

3. In the U.S. and to a lesser extent in the U.K., the separation and settlement process involves periodic negotiations between the incumbent operator and the Regulator. These negotiations assign the costs of operating the network and the revenues earned, to the various business/network operations of the incumbent company using specific formulas. Given the negotiation process involved, it can therefore be argued that the assignment formulas are determined more by a political/regulatory process rather than an economic process. As a consequence, there is much scope for the correspondence between reported costs and revenues and economic costs and revenues for the individual entities to be disjointed.

fact using this data meant that there were sufficient degrees of freedom available to obtain more precise estimates. Shin and Ying (1992) also tried to overcome the measurement error in the output variables by using access numbers and the number of calls reported by firms. The impact of this on their study was that their range of values for the outputs had much higher variance than Evans and Heckman's and hence meant that the local test proposed by Evans and Heckman (as discussed in Section 4.6) was not critical. Estimating a translog cost function using the additional observations and the better data described above, Shin and Ying found that the LECs did not have a subadditive cost function. These results were further confirmed and enhanced when the authors imposed Röller's (1990a, b) concept of 'properness' on the cost function. They hence concluded that breaking up the existing LECs or allowing local exchange competition may result in substantial cost savings.

Although Shin and Ying's methodology offers many important advantages, it does, however, assume that all firms – both hypothetical and actual – will use the same technology. In reality, a range of substitute transmission and local telecommunications systems has emerged. The natural monopoly test should consequently comprise all of these networks as well. A natural monopoly in the telecommunications network will only therefore exist if subadditivity prevails for the terrestrial, the satellite and mobile networks, and any combination of these systems.

Taking the above considerations into account, this paper will therefore further contribute to the literature in this area by firstly extending the natural monopoly analysis in the U.K. to the post-privatisation and post-duopoly period. The analysis contained here utilises unbalanced panel data (instead of time-series data) from the U.K. telecommunications sector for 29 (local) infrastructure providers for the period 1990 to 1997. This ensures that sufficient degrees of freedom are present in the study. The investigation also uses, as Shin and Ying (1992) did in their paper, access line numbers and the number of call minutes reported by firms as output variables. In contrast, however, to the Shin and Ying study, this paper focuses on not only same technology firms but also on substitute telecommunications systems (15 fixed link operators, 11 cable operators and 3 mobile systems[4]). The scope and form of the techniques used in this analysis forms the basis of discussion of the following sections.

## 3. Econometric Estimation Of The Cost Function

To determine the appropriate structure of the U.K. telecommunications industry, we adopt a dual approach and estimate a multiproduct cost function. Using a comprehensive cost function representation of the form:

$$C = C(w, y, a, t) \quad (1)$$

where $C$ represents long-run total costs, $w$ is a vector of factor prices, $y$ is a vector of outputs, $a$ is a vector of operating characteristics and $t$ is a technological change indicator. We assume that this cost function is twice-differentiable and can be approximated by a second-order Taylor series expansion.

Although there are many possible choices for the functional form, we adopt the translog cost function. It places no *a priori* restrictions on substitution possibilities among the factors of productions. Equally important, it allows

4. In the U.K. there are four mobile systems: O2 (formerly known as Cellnet), Vodafone, T-Mobile (formerly known as One2One) and Orange. For the period of analysis (1990 – 1997), O2 was part of BT and separated accounts were not produced for this system so just 3 mobile systems were explicitly modelled.

scale economies to vary with the level of output. This feature is essential to enable the unit cost curve to attain the classical ∪ shape. The function is written as (2):

$$\begin{aligned}\ln C = {} & \alpha_0 + \textstyle\sum_i \alpha_i \ln w_i + \sum_k \beta_k \ln y_k + \sum_m \sigma_m \ln a_m + \varphi_i t \\ & + \tfrac{1}{2} \textstyle\sum_{ij} \alpha_{ij} \ln w_i \ln w_j + \tfrac{1}{2} \sum_{kl} \beta_{kl} \ln y_k \ln y_l + \tfrac{1}{2} \sum_{mn} \sigma_{mn} \ln a_m \ln a_n \\ & + \tfrac{1}{2} \varphi_{tt} t^2 + \textstyle\sum_{ik} \tau_{ik} \ln w_i \ln y_k + \sum_{im} \tau_{im} \ln w_i \ln a_m + \sum_{km} \tau_{km} \ln y_k \ln a_m \\ & + \textstyle\sum_i \varphi_{ti} t . \ln w_i + \sum_k \varphi_{tk} t . \ln y_k + \sum_m \varphi_{tm} t . \ln a_m + \varepsilon \end{aligned} \qquad (2)$$

where $\varepsilon$ is a disturbance term comprising two components, a remainder term $r$ and a random measurement error term $\delta$. All variables utilised in the estimation process except $t$ are deviations from their sample mean[5].

Following the steps as outlined by Berndt (1991), logarithmically differentiating (2) with respect to the input prices and then employing Shephard's Lemma, one obtains cost share equations of the form:

$$\begin{aligned}\frac{\partial \ln C}{\partial \ln w_i} = \frac{w_i}{C}\frac{\partial C}{\partial w_i} = \frac{w_i X_i}{C} = S_i = {} & \alpha_i + \textstyle\sum_j \alpha_{ij} \ln w_j + \sum_k \tau_{ik} \ln y_k + \sum_m \tau_{ik} \ln a_m \\ & + \phi_{ti} t + \varepsilon_i \end{aligned} \qquad (3)$$

where $\varepsilon_i$ is the disturbance term for the *i*th factor share equation. It has two components, a remainder term $r_i = \partial r / \partial w_i$ and white noise $\delta_i$.

For the cost function to be well behaved, costs must be increasing in output and factor prices and it must be homogeneous of degree 1 in factor prices, given $y$. Imposing symmetry and homogeneity via parameter constraints, the cost

5. The variables are deviations from their sample mean after taking logs. Thus, evaluated at the sample mean, second-order parameter estimates would drop out for these variables, and the first-order coefficients would approximately equal elasticities at the sample mean.

function (2) and the factor share equations (3) are jointly estimated using 'seemingly unrelated regression' methods proposed by Zellner (1962).

Since the factor shares always sum to unity, to efficiently estimate the above system of equations, one factor share equation can be removed and the price variables in the remaining share equations can be expressed as price relatives with the denominator being the price of the factor whose share equation has been removed. The parameters of the deleted equation can then be derived through the use of the homogeneity restrictions.

Economies of scale are defined in terms of the relative increase in outputs resulting from a proportional increase in all inputs. Hanoch (1975) has, however, pointed out that it is more appropriate to represent scale economies by the relationship between total cost and output along the expansion path, where input prices are constant and costs are minimised at every level of output. A natural way of expressing scale elasticity - here, called SCE as per Christensen and Greene (1976) - is therefore the inverse of the proportional increase in cost resulting from a small proportional increase in the level of output or the inverse of the elasticity of total cost with respect to output. More specifically:

$$SCE = 1/\varepsilon_{CY} \text{ where } \varepsilon_{\mathrm{CY}} = \sum \frac{\partial \ln C}{\partial \ln y} \qquad (4)$$

This results in an SCE greater than one implying increasing returns to scale whilst a SCE less than one suggests scale diseconomies. Furthermore, SCE has a natural interpretation in percentage terms.

## 4. Data

As discussed in Section 1, the aim of this paper is to investigate whether the post-duopoly cost structure characterising U.K. telecommunications is consistent with a natural monopoly hypothesis. In carrying out this analysis, we should be able to make a more informed judgement as to whether regulation in the form of open network provision with monopoly local networks or competition in the form of infrastructure competition should prevail for the provision of telecommunications networks. Given that the U.K. policy of encouraging competing networks in the industry has been in place since 1990/91 – the Duopoly Review - the dataset used in the current analysis consists of an unbalanced panel of (local) infrastructure providers for the period 1990 to 1997. This should therefore allow us not only to analyse the post-duopoly cost structure of U.K. telecommunications but also to consider the U.K. model of telecommunications.

Annual company accounts were collected for the financial years 1989/90 – 1997/98, for all the U.K. fixed-link public telecommunications operators (PTOs), cable and mobile operators, essentially all operators who had local loop infrastructure[6]. Table 4.1 provides a data summary for the years 1990 and 1997. It should be observed that the size of the firms varies considerably. Consequently, substantial robustness checks have been conducted on the use of the data in the estimation process to ensure that the firms analysed in this study can be grouped together legitimately for the purposes of analysing the UK industry. A discussion of these checks is provided in the next Section.

An important advantage of using this extended dataset is that we now have more observations to circumvent the small sample size problem that has

6. A list of the firms analysed in this paper can be obtained from the author on request.

characterised previous studies i.e. Hunt and Lynk (1990). This enables us to obtain better estimates for BT.

Using the annual accounts, data on capital costs, wages and operating costs were

**Table 4.1**
**Summary Statistics of UK Firm Data For 1990 and 1997**

| | | UK Firm Outputs | | | |
|---|---|---|---|---|---|
| | | Access Lines (Thousands) | Local Call Minutes (Millions) | National & International Call Minutes (Millions) | Ratio[c] |
| 1990[a] | Maximum | 24797 | 57775 | 25438 | 76 |
| | Minimum | 0.0175 | 0.0079 | 0.0010 | 0.5828 |
| | Ratio of Max/Min | 1417152 | 7309728.4 | 24917325.67 | 130 |
| | Mean of All Firms | 1990 | 4622 | 2094 | 12 |
| | Standard Deviation | 6855 | 15974 | 7027 | 20 |
| | Mean of Top 4 Firms | 6448 | 14981 | 6804 | 57 |
| | Number of Others | 9 | 9 | 9 | 9 |
| | Mean of Other Firms | 9 | 18 | 1 | 8 |
| 1997[b] | Maximum | 27553 | 75555 | 40206 | 247 |
| | Minimum | 0.0001 | 0.0010 | 0.0010 | 0.3854 |
| | Ratio of Max/Min | 275530000 | 75555000 | 40206000 | 642 |
| | Mean of All Firms | 1364 | 2955 | 1619 | 18 |
| | Standard Deviation | 5103 | 13978 | 7497 | 52 |
| | Mean of Top 4 Firms | 8759 | 20498 | 11591 | 171 |
| | Number of Others | 25 | 25 | 25 | 25 |
| | Mean of Other Firms | 180 | 149 | 23 | 6 |

[a]In 1990, thirteen infrastructure providers were present in the marketplace - 8 cable operators, 4 fixed link operators and 1 mobile

[b]In 1997, twenty-nine infrastructure providers were present in the marketplace - 11 cable operators, 15 fixed link operators and 3 mobile systems

[c]This is the ratio of access-to-national and international calls

collected. To calculate total cost (TC), expenses for factors excluding capital are given by operating expenses minus depreciation. Capital expenditures were measured by depreciation charges, interest on capital and interest on working capital where for the latter two charges, the same cost of capital was utilised[7].
For the inputs, the price of labour (PL) is compensation per employee. The capital price (PK) is capital expenses divided by the average number of access lines[8]. For the price of other factors (PO), residual expenses are divided by the average number of access lines. The factor shares are the corresponding expenses over total cost (TC).

The output variables are the average number of access lines (A), local calls (LO), other calls – comprising national and international calls (NAIN) and for the cable operators, the number of basic TV subscribers (TV). To take account of the heterogeneous nature of the industry[9], the vector of operating

7. Given that capital in telecommunications does not have constant productivity over its life, the depreciation figures were collected from the individual company annual accounts. To calculate interest on capital (we used the net book value as our proxy for capital) and on working capital (defined as current assets minus liabilities), we utilised the real cost of capital figure used by OFTEL in setting BT's network charge controls.

8. Given data limitations, it is impossible to obtain capital prices. As a consequence, given that capital costs in telecommunications predominantly originate from network costs, which in turn are mainly driven by access line numbers and the usage that customers make of these lines, it appears acceptable to use capital expenses divided by access lines, as a proxy for the price of capital. Nonetheless, as a check, we also estimated the translog cost function (as discussed above) assuming that the price of capital was constant across firms. The impact of this on the results was negligible. A similar check was also conducted on other prices and again there was no significant change in the results.

9. It is reasonable to assume that firms with different systems may have different production technologies. Consequently, in Section 5, we first analyse the estimated cost functions for the separate systems and then via Chow tests, we consider whether it is possible to group the systems together into one function. If we are to do this, however, it is important that the heterogeneous nature of the systems is captured.

characteristics includes customer density (DEN), the percentage of exchanges that are digital for fixed link operators (DE)[10], channel capacity for cable operators (CAP)[11], and for mobile operators, a technology shifter to distinguish between PCN and GSM systems (MO). These latter three characteristics can be viewed as proxies for quality or technology whilst the customer density variable, which is customers or access lines per kilometre squared, indicates the density of service. So for example, rural areas may have lower customer density and so would *ceteris paribus* be more costly to serve.

Technological change for the industry was measured using the Peterson Index of Productivity (see Peterson – 1979, Correa - 2003). The index was calculated for the telecommunications industry on a year-on-year basis for 1990 to 1997 using annual input-output matrices (CSO 1998; HMSO, 1992). The year-on-year changes were

10. In the total cost estimation, a check was carried out to ascertain whether the results would change if the variable DE was included in the function as a percentage rather than as a logarithm. The effect was negligible, so the logarithm approach was maintained.

11. As a proxy for quality for the cable operators, the number of cable channels (CAP) was used. Crandall and Furchgott-Roch (1996) found that more channels encourage greater subscription to basic services and so reduce the overall cost to operators in providing cable TV. The log of the age of the system was also trialled – as an alternative and additional variable to channel capacity. The number of years between the date of initial service and the year of analysis was used as the measure of sytem age. This variable was however not used in the final reported cost equation because its inclusion did not significantly improve the overall fit. Notwithstanding, there were a few significant changes in the coefficients: the interaction term of age and the output variables showed that as the age of the system increases, the cost for access lines and TV subscriptions decreases significantly, the cost for local calls increases significantly and for national calls, it weakly decreases. These results therefore appear to weakly confirm an observation made in the 1970s by Comanor and Mitchell (1971); Park (1972); and Noll, Peck and McGowan (1973) that cable system subscriptions (and access lines) may increase with the age of the system and so reduce the average cost to operators in providing service.

generally positive except for 1992/93 and 1996/97[12].

## 5. Econometric Estimation Results Of The Cost Function

As mentioned, a range of substitute transmission and local telecommunications systems has emerged. In analysing firms with different systems and characteristics, it is reasonable to assume that their production technologies may differ. Consequently, separate cost functions for these systems were estimated (where possible) and residuals were examined by type of infrastructure. The results of this analysis show that the hypothesis of stability cannot be rejected and so it appears reasonable to group the cable and fixed link operators together into one cost function[13 14]. Given the apparent differences in

12. The Peterson Index of Productivity was also calculated for the period 1990/97. This showed that the efficiency effect was positive over the whole period. Consequently, in the cost estimation, as a check, the annual average efficiency effect from the 1990/97 Peterson Index was also used. The results did not change significantly. So the annual year-on-year Peterson indices were maintained in the dataset.

13. There are 80 observations for the cable data and 77 observations for the fixed link operators. Chow predictive tests and analysis of variance tests for the inclusion of both cable and fixed link operators in a single function shows that at the 5% level of significance, the hypothesis of stability cannot be rejected. Additional tests for grouping together the different fixed link operators (i.e. the group comprises regional players – Kingston - and small national carriers e.g. Mercury) was also conducted. The fixed link cost function was estimated with Kingston excluded and a Chow predictive test was then conducted. This showed that Kingston could be included in the sample. A further test was also done for Mercury. Again, this showed that stability could not be rejected and so this player could be included in the sample.

14. For the fixed operators in the combined dataset, TV output was set at 0.00001. As a check, however, we also applied 1% of the average ratio of TV subscriptions to access lines from the cable operator data to the actual number of actual lines supplied by the fixed link operators. Doing this allowed the TV output figure in these firms to vary over time and with the size of the firm. The results did not however change significantly so the constant TV output figure of 0.00001 was maintained for the fixed operators in the sample.

    As an additional consideration with regard to the combined dataset, it was thought that the newness of the cable operators in the market (resulting in the early years technologies, this is an interesting result and by increasing the size of the panel in which BT can be embedded, further augments our ability to obtain better estimates for BT. Mobile operators, in contrast, can not be included in this combined function[15]. This conclusion should perhaps not be unexpected especially given the differences in technologies and the regulatory development of this sector[16,17].

Table 5.1 presents the results of the econometric estimation of the combined translog cost function for cable and fixed link operators[18]. Of the 66

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of service in large investments and few customers) might give rise to problems of lumpy investment. To try to take account of this, the age of the system – recommended by Nick Oulton – was included as an extra variable in the estimation process. As discussed above (footnote 11), it was not however included in the final reported cost equation as it did not significantly change the results. As another robustness check, inspection of the data was conducted and certain data points (specifically 8 data points from new start-ups in the first year of service) were removed. The estimation was then repeated. Again, the results did not change significantly, so the full dataset was maintained in the final estimation.

15. For the mobile operators, there are only 18 observations available for the period 1990 to 1997. Thus Chow predictive tests were conducted for the fixed link and mobile operators, and for the cable and mobile operators. The results showed that at the 5% level of significance, the hypothesis of stability was rejected and so the data for mobile could not be grouped with either the fixed link or cable operator data.

16. Although there are considerable differences in technology between mobile systems and fixed and cable systems, new techniques of radio transmission developed for the radio market have potential fixed link applications and public mobile networks already established in the market are well positioned to provide fixed and mobile integrated services. However, other differences have also arisen from the regulatory environment and from the historical treatment of the mobile market as a premium and distinct market from ordinary PSTN rather than as an alternative to fixed and cable telephony. This has meant that the cost structure of the mobile market has not developed as its PSTN equivalent.

17. Details of the separate estimated cost functions for the fixed link and cable operators can be obtained from the author on request.

18. Checks on the estimated translog cost function were conducted to ensure that it conformed to economic theory. As stated above, homogeneity and symmetry were imposed during the estimation and continuity followed from the functional form. Checking for monotonicity and concavity, we found that the estimated

parameters estimated, 15 are significant at the 1% level, 6 more are significant at the 5% level and a further 3 parameters are significant at the 10% level. Furthermore, 60% of the first-order terms for the independent variables in our model are significant at the 10% level.

Although the output variable estimates will be discussed in more detail in Section 6, it is worthwhile noting that the estimated parameters for the second-order output terms are all less than one and of mixed signs. This contrasts significantly with the results derived by Evans and Heckman (1983) and

translog cost function was monotonic with respect to input prices for most years. In the case of concavity, 97 observations (62%) are concave in factor prices. We also checked for negative marginal costs. In this case, only 10% had positive marginal costs for all outputs. Analysing this further, it was found that 51% of local marginal costs, 54% of national and international marginal costs (predominantly in operators using BT for national indirect access), 1% of access marginal costs and 23% of TV marginal costs (mainly in non cable operators) were negative. The negativity in marginal costs was predominantly present therefore for local and national calls. On the basis that subsidisation of local and access costs has been encouraged for political and social reasons and is thus being picked up by the results, checks were thus conducted to ascertain whether total marginal costs for all outputs were positive. In this instance, 99% of the observations had positive marginal costs. A further check was also carried out by estimating an unconstrained total cost function. Again similar results were obtained.

These problems of not meeting regularity conditions for estimated cost functions are common in these exercises. A number of studies (Fuss and Waverman, 2002, Röller 1990a, b) identify problems with the translog function as a flexible approximation. In particular, it has proven difficult for U.S. and Canada to obtain well-behaved multiple-output telecommunications cost function estimates with positive cost elasticities. The main reason being because of the very flexible nature of the translog functional form. As a consequence, positive marginal costs at the mean were imposed on our model (see Jorgenson, 2000; Diewert and Wales, 1987; Fuss and McFadden, 1978; Lau, 1978; Terrell, 1996; Ryan and Wales, 2000; and Salvanes and Tjøtta, 1998). This improved concavity to 84% and marginal costs for local, national and international and access all became positive. The problem with the estimates of this function are however that they result in the total cost equation having an $R^2$ of zero. It appears therefore that the use of this data is not ideal and so caution needs to be observed in any inference. However, given that this is the only data available, one has no choice than to work within the context of this existing data limitation and as an exercise for the UK market, it contributes to the sparse UK literature in this area.

Charnes, Cooper and Sueyoshi (1988) who obtained implausibly large values in the range of 5 to 10. This meant that a 1% increase in an output could cause, according to their results, a very large increase or decrease in output cost elasticity. Comparing our estimates with those obtained by Shin and Ying (1992), suggests that although our results are higher than their estimates, they are nonetheless in the right range. Part of the reason why we would expect our estimates to be different is because we are analysing a sample of firms that covers substitute telecommunications systems such as cable and mobile networks. One could also argue that the underlying production function of the U.K. telecommunications industry is different from the Shin and Ying study of the U.S. as the firms used in their analysis were more comparable.

Generally the signs of the output interaction terms appear to be consistent with industry expectations. In particular, the interaction term for access lines and local call minutes is negative and significant which confirms the telecommunications economic argument that these two services are interdependent. The closeness between these two services, specifically with regard to the network components used, thus means that considerable cost savings may be made in producing these two services in tandem. The interaction term of access lines and TV subscriptions is also negative and significant. This is to be expected given the network architecture of cable operators in producing TV and access. The interaction term of access lines with national and international call minutes is, in contrast, positive and significant, as per industry expectations, indicating that these two services appear not to be characterised by economies of scope. With regard to the other interaction terms: local and national and international, local and TV and TV and national and

**Table 5.1 Translog Cost Function Estimation Results From Combined Fixed And Cable Dataset**

| Equation | Standard Error Of Regression | R-Square |
|---|---|---|
| Total Cost | 0.22096 | 0.997764 |
| Labour Share | 0.16270 | 0.292502 |
| Capital Share | 0.11803 | 0.769395 |

| Parameter | Estimate | | Standard Error | Parameter | Estimate | | Standard Error |
|---|---|---|---|---|---|---|---|
| Intercept | -0.69496 | | 0.88690 | PK.TV | -0.00616 | | 0.00707 |
| PL | 0.24423 | * | 0.04918 | PK.DE | 0.00151 | | 0.00329 |
| PK | 0.33823 | * | 0.03680 | PK.CAP | 0.01380 | **** | 0.01027 |
| A | 0.93327 | * | 0.09814 | PK.DEN | -0.01155 | * | 0.00253 |
| LO | -0.316564 | ** | 0.14574 | PK.T | 0.01380 | *** | 0.00770 |
| NAIN | 0.17876 | *** | 0.09740 | A.LO | -0.04797 | * | 0.00990 |
| TV | 0.09459 | | 0.63541 | A.NAIN | 0.03359 | * | 0.00858 |
| DE | 0.06760 | | 0.05720 | A.TV | -0.08162 | ** | 0.03946 |
| CAP | -0.12969 | | 0.91943 | A.DE | 0.06130 | * | 0.01539 |
| DEN | 0.07666 | ** | 0.02967 | A.CAP | 0.11532 | *** | 0.05813 |
| T | 0.06945 | | 0.33212 | A.DEN | 0.00203 | | 0.00778 |
| 1/2 $PL^2$ | 0.04636 | * | 0.00506 | A.T | -0.00595 | | 0.01921 |
| 1/2 $PK^2$ | 0.12870 | * | 0.00408 | LO.NAIN | 0.00834 | | 1.43649 |
| 1/2 $A^2$ | 0.03970 | ** | 0.01776 | LO.TV | 0.07606 | ** | 0.03765 |
| 1/2 $LO^2$ | 0.02387 | * | 0.00234 | LO.DE | 0.00666 | | 0.01295 |
| 1/2 $NAIN^2$ | -0.028578 | ** | 0.01123 | LO.CAP | -0.11551 | ** | 0.05451 |
| 1/2 $TV^2$ | 0.07219 | ** | 0.02847 | LO.DEN | -0.028792 | * | 0.00562 |
| 1/2 $DE^2$ | 0.05936 | * | 0.01394 | LO.T | 0.08063 | * | 0.02995 |
| 1/2 $CAP^2$ | 0.11282 | | 0.20394 | NAIN.TV | -0.01671 | | 0.03918 |
| 1/2 $DEN^2$ | 0.02924 | * | 0.00498 | NAIN.DE | 0.00898 | | 0.01428 |
| 1/2 $T^2$ | -0.03472 | | 0.07908 | NAIN.CAP | 0.02698 | | 0.05616 |
| PL.PK | -0.018351 | * | 0.00347 | NAIN.DEN | 0.00542 | | 0.00555 |
| PL.A | -0.047823 | * | 0.00606 | NAIN.T | -0.045498 | ** | 0.02023 |
| PL.LO | -0.00429 | | 0.00470 | TV.DE | -0.04842 | | 0.04985 |
| PL.NAIN | 0.01869 | * | 0.00490 | TV.CAP | -0.08914 | | 0.07178 |
| PL.TV | 0.02404 | ** | 0.00958 | TV.DEN | -0.030221 | * | 0.00931 |
| PL.DE | -0.00733 | *** | 0.00422 | TV.T | -0.00224 | | 0.01394 |
| PL.CAP | -0.03782 | * | 0.01415 | DE.CAP | 0.08320 | | 0.07490 |
| PL.DEN | 0.01503 | * | 0.00332 | DE.DEN | -0.066546 | * | 0.00910 |
| PL.T | -0.02695 | * | 0.01022 | DE.T | 0.01224 | ** | 0.00562 |
| PK.A | 0.02125 | * | 0.00435 | CAP.DEN | 0.04049 | * | 0.01299 |
| PK.LO | 0.00449 | | 0.00361 | CAP.T | 0.00579 | | 0.02078 |
| PK.NAIN | -0.01108 | * | 0.00366 | DEN.T | -0.013827 | * | 0.00504 |

* indicates significance at the 1% level, ** indicates significance at the 5% level, *** indicates significance at the 10% level and **** indicates significance at the 20% level.

Definitions: PL=Labour price, PK=Capital Price, A=Access lines, LO=Local calls, NAIN=National & International Calls, TV=TV Subscription Numbers, DE=% Digital Exchanges, CAP=Cable TV Channel Capacity, DEN=Customers Per Kilometre Squared, T=Peterson Index of Productivity

All variables are in natural logs. The period of estimation covers 1990 - 1997 and 26 local infrastructure operators are analysed in the unbalanced panel international, the results appeared to contradict the standard view but most were insignificant'[19].

The input prices estimates or factor shares at the sample mean are all positive and appear to be of appropriate magnitudes. The labour, capital and other input shares are 0.21, 0.356 and 0.433 respectively. The interaction terms with time reveal a tendency for labour shares to decrease and capital input and other shares to increase over time. This pattern of increased capital usage should not be unexpected, given the sample period under analysis. Furthermore, it appears to mirror the results in Correa (2003) which showed that over 1991 to 1996, capital usage increased - perhaps in response to the infrastructure policy in place at the time - and labour usage decreased – because perhaps with increased numbers of firms competing in the market, it was necessary for firms to become more cost-effective (see Haskel and Szymanski, 1993).

Turning now to the percentage of digital exchanges variable (DE) and the cable operator channel capacity variable (CAP), the results are mixed. In the case of the latter variable: cable operator channel capacity, the results show that the first-order term is negative but insignificant. Computing the CAP cost

19. Given the non-positive parameter estimate value for local call minutes, further robustness checks were conducted. In particular, the estimation was re-done excluding the parameters involving local call minutes. Under this scenario, the parameters for national and international call minutes and TV subscriptions now became non-positive but insignificant. Additionally removing the parameters involving national and international call minutes and TV subscriptions meant that the first-order access line term remained positive. Conducting a F-test on these restrictions showed that they could not be rejected. It suggests therefore that there is a strong correlation between the outputs. This is not surprising given the network components used to produce these services. Analysing the estimates from the translog cost function comprising access lines only, shows that 0% of the observations are now concave, 93% are monotonic in input prices and 99% have positive marginal costs. This implies therefore that in this function, flexibility and concavity are working in opposite directions. This is not something new and in fact has been observed by many other economists doing these types of exercises (see footnote 18).

elasticity at sample averages (see Table A.I.1 in Annex I) shows that this remains negative but insignificant. This weakly confirms therefore the argument that as the channel capacity of cable operators increases, costs decline. For the DE variable, the parameter estimate at sample averages is positive (see Table I.1 in Annex I) but insignificant from zero. This suggests therefore that costs are not generally affected by this variable. Digital and electronic technologies offer many advantages. They increase network capability and reduce the cost of capacity and access. Thus as more exchanges are converted, costs should, according to expectations, decline. The results from the combined dataset do not however show this[20].

The customer density variable (DEN) has a small positive and significant first-order term and a small positive and significant squared term[21]. This contradicts the standard concept of economies of density as it implies that more customers/access lines per kilometre squared will actually result in an increase in cost. Reviewing, however the interaction terms with DEN shows that as customer density increases, the price impact of capital decreases – this observation appears to be consistent in the separate cost function estimations as well. The interaction term of DEN with access lines is positive but very small and insignificant[22], whilst the interaction terms of DEN with local call minutes and TV subscriptions are negative and significant. This shows therefore that via the interaction terms, the density argument is weakly supported.

20. The DE cost elasticity for the fixed operators estimation is significantly negative. This implies therefore that cost savings can be enjoyed as exchanges are converted for fixed link operators.

21. Furthermore, computing the DEN cost elasticity (see Table A.I.1) shows that costs increase but by a small amount.

22. For the separate estimations, the interaction term of DEN with access for the fixed link operator cost function is small, positive and significant whilst for the cable operator cost function, it is small, negative and significant.

Finally looking at technological change (T), the first-order coefficient is positive but insignificant. Evaluated at the sample mean, the cost elasticity (see Table A.I.1) of T is negative and significant. This thus confirms the positive productivity growth rate in telecommunications during the period 1991-1996 as shown by Correa (2003).

## 6. Global Subadditivity Of UK Infrastructure Providers

As discussed in Section 1, the determination of whether the set of local loops in the U.K. is a natural monopoly is essentially an empirical question and to date, within the U.K., no study has managed to examine this process in detail[23]. Using the translog cost function estimation results from Section 5, we investigate in this section, the subadditivity of U.K. infrastructure providers' costs.

A useful starting point in the analysis of the U.K. infrastructure providers' costs is the examination of scale elasticities (SCE) as discussed in Section 3 (see Table A.I.2 in Annex I). At the sample mean, the overall fixed and cable industry scale elasticity estimate equals 1.028 or the sum of the output cost elasticities is 0.973. Testing this estimate for constant returns to scale shows that this hypothesis cannot be rejected.

Calculating the specific scale elasticity for BT on an annual basis from the combined fixed link and cable operator dataset shows that BT on average (over the eight-year period) has a SCE of 1.033 which is insignificant from constant returns to scale. This is quite a strong result, especially given the tighter bounds of the test arising from the BT data being embedded in a much richer

23. As discussed in Section 2, the Hunt and Lynk (1990) study estimated a long run cost function and concluded from the estimate of scale economies that BT was locally subadditive. This, however, was not explicitly tested. Therefore, Hunt and Lynk's conclusion from their study must be interpreted with caution.

panel so that more robust estimates are obtained. Comparing the results obtained for BT with the estimates derived by Hunt and Lynk (1990), one can observe differences. In particular, Hunt and Lynk's study seemed to show that BT had very strong scale economies although they did not report any significant tests. This divergence in the results should not be unanticipated as the present study, unlike Hunt and Lynk's, considers a post-duopoly industry that is multi-firm and multi-technology. It appears therefore that the two studies are suggesting different stories with our results on economies of scale for BT suggesting that infrastructure competition may be a reasonable policy. This however need not be true. The fact that the industry being analysed is a multi-output market means that economies of scale are neither necessary nor sufficient for natural monopoly status (see Sharkey, 1982). As a consequence, in order to investigate whether the local loop in the U.K. is a natural monopoly, more thorough subadditivity tests need to be conducted on our sample of firms. In particular, we need to consider whether BT's outputs (comprising access lines, local calls and national and international calls) can be divided more efficiently amongst new firms in the marketplace.

An industry is said to be naturally monopolistic if it is not possible to reduce total costs by dividing monopoly output between more than one firm. More formally, this means that for a firm to be a natural monopoly, its cost function must be strictly and globally subadditive over the relevant range of output. Subadditivity requires that the cost of producing the monopoly output, $q^m$, be strictly less than the costs of any $n$ vector of outputs summing to $q^m$. In general, $n$ is typically limited to the case of two firms, $\alpha$ and $\beta$[24]. Given this, a test of subadditivity involves checking for:

24. The particular two firm configuration is determined by weights. This is discussed further below. These weights designate the way in which industry output is

$$C(q^m) < C(q^\alpha) + C(q^\beta)$$
$$\text{where } q^\alpha + q^\beta = q^m \qquad (5)$$

Evans and Heckman in their 1983 paper proposed a local test for subadditivity. What this meant was that the hypothetical outputs of the two firms were required to be no less than the minimum of the data and had to lie within the sample range of ratios[25]. Given that they used only 30 yearly observations, the requirement to restrict their test was necessary for reasons of practicality. However, because the dataset used in this study is much larger and of a wider range, the test for subadditivity, given by equation (5), where each vector consists of three outputs $(q_1, q_2, q_3)$, where $q_i$ refers to access, local, national and international calls[26], could be considered to be more global like that conducted by Shin and Ying (1992).

To generate the hypothetical output vectors:

divided between the firms. If $C(q^\alpha) + C(q^\beta) > C(q^m)$ for any values of the weights, then monopoly provision of $q^m$ is not cost minimising. This condition is stringent.

25. In particular, this meant that the hypothetical outputs of the two firms had to lie within a sample range of ratios which are equal to $R_L = \text{Min}(Q_{1t}/Q_{2t})$ and $R_U = \text{Max}(Q_{1t}/Q_{2t})$ where $Q_1$ and $Q_2$ are the separate outputs of the firms.

26. The subadditivity test in this paper does not include TV subscriptions because the main focus of this thesis is on telecommunications and not broadcasting issues. However, given the increasing convergence of telecommunications, broadcasting and IT, the inclusion of TV subscriptions would be a useful extension of this exercise.

$$q^{\alpha} = (\pi q_1^m, \varpi q_2^m, \theta q_3^m)$$

and (6)

$$q^{\beta} = ((1-\pi)q_1^m, (1-\varpi)q_2^m, (1-\theta)q_3^m)$$

where the scalars $\pi, \varpi$ and $\theta = (0.1, 0.2, 0.3, .....0.9)$ and $q_1^m$, $q_2^m$ and $q_3^m$ are the monopoly outputs relating to access, local, national and international calls. This results in 729 output vector combinations for each observation. It should be noted that the scalar vector excludes zero and thus means that firms $\alpha$ and $\beta$ do not produce zero outputs where the translog cost function would not be defined[27].

Dividing BT's outputs between two firms in our sample, the costs of the 729 hypothetical vector pairs are compared to the BT cost arising from the provision of those outputs. In computing these divisions, there are many alternative or additional
approaches. In the following analysis, two specific approaches are considered:

(i) apportioning BT's outputs amongst any two firms who have costs and characteristics corresponding to the firms in our sample i.e. fixed and cable operators. This involves a large number of combinations of each and every firm. For example, BT's outputs could be distributed

27. The fact that the two hypothetical firms do not produce zero outputs means that the subadditivity tests conducted here are tests of necessary conditions for natural monopoly. In the words of Evans and Heckman, (1983 pp36) 'Rejection of that hypothesis is informative. Acceptance within a region... is not informative'. All that acceptance demonstrates is that there are inefficient ways in dividing output between more than one firm. Failure to reject the necessary condition for natural monopoly does not imply that the incumbent operator is a natural monopoly. To perform such a test requires extrapolation of the cost function well outside the range of the data used to estimate it.

amongst a fixed link and cable operator or two fixed link operators or two cable operators; and

(ii) dividing BT's outputs amongst two firms who are assumed to have the same costs and operating features as BT.

### *6.1.1. Subadditivity Analysis For (i): Dividing BT Outputs Amongst Fixed and Cable Operators*

Processing the data by year, to avoid memory problems, gives Table 6.1. Since we use an unbalanced data panel, the second column sets out the number of possible two-firm output combinations considered each year. The figures presented in the third and fourth columns of the table show the frequency and percentage of cases where monopoly costs are lower than the sum of the two-firm costs as in equation (5) above. The remaining four columns show the savings from having a monopoly. The savings are computed as:

$$100.([C(q^{\alpha})+C(q^{\beta})]-C(q^{m}))/C(q^{m}) \qquad (7)$$

where positive values indicate subadditivity and negative values indicate superadditivity.

Table 6.1 shows that the general results are similar over the years. Consequently, the detailed discussion of the summary test statistics focuses only on the most recent year in the sample, 1997. Analysing the summary statistics in Table 6.1, one can observe that in 1997, if monopoly outputs were divided between two firms, then in

18% of the possible vector combinations, society could benefit from lower costs[28].

Now if these percentages were derived from the 'true' cost function then particularly since they come from plausible divisions of structure, they would indicate the potential for cost savings. However, since they are obtained from an estimated cost function, the statistical properties of the function must be considered – see footnote 29.

Table 6.1 shows the minimum, maximum and average percentage differences between the monopoly and the two-firm costs, where positive values indicate that the monopoly costs are lower. The minimum percentage difference, in Table 6.1 is negative in all cases. Two firms sharing the monopoly output in 1997 could have possibly lowered costs by a minimum percentage of 4.2% or raised costs by 12% - see discussion about statistical properties of these estimates below.

28. Additional tests were carried out on the robustness of the results obtained here. In particular, subadditivity tests were performed for various scenarios: (i) BT was excluded from the data, (ii) other companies were iteratively left out of the data, and (iii) BT data (using the translog results above) was analysed only. For all scenarios, the minimum percentage difference remained negative. Now because of the statistical properties issue discussed below, it is unclear whether subadditivity or superadditivity prevails. Either way the percentage differences are small so it is probable that the normal benefits from competition: allocative, productive and dynamic will outweigh such small potential efficiency losses. Table 6.2 presents the subadditivity results from examining BT. The results of the other scenarios are not presented in this paper. In addition to the checks above, subadditivity tests were furthermore carried out on the translog cost estimates derived from the dataset where certain data points were removed (to take account of start-up issues) and also on the cost estimates from the fixed link translog cost function. Again the tests seemed to show that the minimum percentage difference remained negative but small. Once more, indicating potential gains from introducing competition into the local loop. Details of the subadditivity tests for the fixed link estimation can be obtained from the author on request.

The seventh column in Table 6.1 shows the average percentage savings from having a monopoly. The results for 1997 show that on average, two firms sharing industry output might raise production costs by 1.08%. This suggests therefore that there are inefficient ways of dividing output and that 'inefficient entry' may occur. Now, it can be argued that specific operators "uneconomically duplicating" network should be prevented, as it is "inefficient" entry into the marketplace. Prevention of "inefficient" entry can only be defended, however, if it can be proved that this is to the detriment of the consumer in the long run. Inefficient companies can only impose a cost on the consumer if they are not allowed to fail when they should. Provided this is allowable, the only loser from an "inefficient" entry is the investor, who should be quite capable of making a judgement on market entry without assistance.

The condition where the minimum percentage difference is negative is therefore stringent in that it implies that there is a potential for cost savings. It should be noted, however, that there is no guarantee that these cost savings or optimal splits will materialise especially given strategic oligopoly behaviour by firms in the marketplace. Furthermore whilst the conventionally calculated standard errors (the last column of Table 6.1) appear to demonstrate that all the percentage differences are strongly different from zero, they are likely to be biased estimates of the true standard errors[29]. In any case the absolute magnitudes are small and so it is probable that the normal benefits from competition i.e. innovation will exceed such small potential losses of efficiency.

The summary results for 1990 to 1996 further support the results from above. At best, in 1995, 91% of the vector combinations produces lower single-firm

29. The standard errors have been calculated using the formula: $\sigma_x / \sqrt{n}$. However, this is only valid if the standard errors are computed from statistically independent cost functions. Given that they have been derived from the same cost function, it means that caution must be observed in any inference.

costs. The minimum percentage difference is constantly negative and on the basis of conventionally calculated standard errors, significantly different from zero. Depending on the extent of the bias in those standard errors the results therefore again suggest that industry and economy gains could potentially be made from introducing competition in the local loop

**Table 6.1 Subadditivity Summary Results By Year For Fixed/Cable Operator Combinations Arising From The Combined Fixed and Cable Cost Function Estimation**

| | | Monopoly Costs Lower Than Two-Firm Costs | | Percentage Savings From Having a Monopoly | | | |
|---|---|---|---|---|---|---|---|
| Year | Possible Cases | N | Percent | Minimum | Maximum | Average | Std. Error |
| 1990 | 56862 | 35,733 | 62.84 | -2.06 | 2.61 | 0.69 | 0.0049 |
| 1991 | 66339 | 48,169 | 72.61 | -1.64 | 9.04 | 1.62 | 0.0102 |
| 1992 | 76545 | 55,407 | 72.38 | -2.00 | 10.00 | 1.41 | 0.0097 |
| 1993 | 152361 | 105,574 | 69.29 | -3.34 | 9.53 | 1.15 | 0.0056 |
| 1994 | 168399 | 129,547 | 76.93 | -4.56 | 10.82 | 1.54 | 0.0060 |
| 1995 | 239841 | 218,634 | 91.16 | -2.42 | 11.34 | 1.62 | 0.0045 |
| 1996 | 258794 | 235,275 | 90.91 | -2.40 | 13.18 | 1.46 | 0.0049 |
| 1997 | 258794 | 212,454 | 82.09 | -4.18 | 11.96 | 1.08 | 0.0047 |

### *6.1.2. Subadditivity Analysis For (i):Dividing BT Outputs Amongst Fixed and Cable Operators With Positive Marginal Costs Imposed*

Checking whether the above results are robust to Röller's (1990) criticism[30], the marginal costs of the three outputs were computed for each hypothetical vector combination. If any of the three marginal costs were negative, then that observation was deleted from the analysis[31,32].

30. Röller (1990) criticised Evan and Heckman's (1983, 1984, 1986, 1988) results because he said that if the test region was constrained to exhibit positive marginal costs, the Evans and Heckman results were reversed so that they did not reject the natural monopoly hypothesis.

31. As discussed above, in Section 5, it has proven difficult for our data to obtain well-behaved multiple-output telecommunications cost function estimates with positive cost elasticities. It is possible therefore that the use of this data is not ideal and so caution needs to be observed in any inference.

32. It is worthwhile noting that access and national and international cost elasticities are generally positive whilst the local marginal costs are predominantly negative.

**Table 6.2 Subadditivity Summary Results With Positive Marginal Costs By Year For Fixed/Cable Operator Combinations Arising From The Combined Fixed and Cable Cost Function Estimation**

| | | Monopoly Costs Lower Than Two-Firm Costs | | Percentage Savings From Having a Monopoly | | | |
|---|---|---|---|---|---|---|---|
| Year | Possible Cases | N | Percent | Minimum | Maximum | Average | Std. Error |
| 1990 | 681 | 631 | 92.66 | -0.32 | 1.72 | 0.93 | 0.0228 |
| 1991 | 927 | 810 | 87.38 | -0.54 | 1.42 | 0.64 | 0.0152 |
| 1992 | 3210 | 2,881 | 89.75 | -0.77 | 1.60 | 0.71 | 0.0089 |
| 1993 | 25089 | 23,965 | 95.52 | -0.93 | 10.61 | 1.34 | 0.0049 |
| 1994 | 17939 | 16,745 | 93.34 | -0.71 | 10.58 | 0.92 | 0.0069 |
| 1995 | 53343 | 52,544 | 98.50 | -0.88 | 2.35 | 1.03 | 0.0025 |
| 1996 | 50540 | 49,156 | 97.26 | -0.77 | 2.42 | 0.91 | 0.0028 |
| 1997 | 34346 | 34,120 | 99.34 | -1.05 | 2.69 | 1.40 | 0.0031 |

Table 6.2 presents the results from this procedure. It shows that imposing positive marginal costs reduces the number of possible configurations by a considerable amount. This should not be too surprising given the difficulties encountered in obtaining cost function estimates with positive cost elasticities.

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This is due to the non-positive parameter estimate value for local call minutes and might be because of the strong correlation between the outputs as shown by robustness checks on the estimation (see footnote 21). For this reason, subadditivity tests were carried out on the estimation comprising access lines only and also on the cost estimation with positive marginal costs imposed. The results in both instances show that the minimum percentage difference is consistently negative. Thus it suggests again that gains may be made by having competition in the local loop.

On the basis that marginal costs may be partly distorted by cross-subsidisation, checks were conducted to ascertain whether total marginal costs for all outputs were positive. In this instance, all observations had positive marginal total costs. Given this, if cross-subsidisation is the reason for these results then Table 6.1 rather than Table 6.2 would be valid. However, because we cannot be entirely sure, we must be cautious in interpreting the data.

In the case of national and international calls, negative marginal costs appear usually only to be present in combinations with Atlantic Telecom. A possible reason for this is because this firm during the sample period generally provided a low level of national and international service. Given this, it is understandable that negative marginal costs have been observed.

The greatest reduction is in 1990 of 98.8% and the least decrease of 77.7% occurs in 1995[33].

Despite this considerable decrease in possible configurations, Table 6.2 shows however that the constraint of positive marginal costs still generally confirms the results of Table 6.1. Although the percentage where a single firm is more cost effective increases, the minimum percentage difference remains consistently negative. Now because of the statistical properties issue discussed previously, it is unclear whether subadditivity or superadditivity prevails. Either way the percentage differences are small so it is probable that the normal benefits from competition: allocative, productive and dynamic will outweigh such small potential efficiency losses. Therefore, incorporating Röller's (1990) criticism in our analysis, serves only to confirm the results of Table 6.1.

### *6.2.1. Subadditivity Analysis For (ii): Dividing BT Outputs Amongst Firms with BT Characteristics*

As discussed previously, subadditivity tests were also conducted just on BT[34] so as to provide a check against the Hunt and Lynk study mentioned previously. Table 6.3 outlines the summary statistics for BT. Even taking account of the fact that these estimates are obtained from the derived cost function, Table 6.3

33. This considerable reduction in the number of possible configurations is worrying – this may in part relate to the accounting procedures of firms in the market. The suggestion that parts of the system have been unduly extrapolated was also examined. In particular, the hypothetical outputs of the two firms were checked to ensure that they lay within the sample range of ratios (as per Evans and Heckman, 1983 – see footnote 25) and that they were no less than the minimum of the data. The results of this comparison show that the data in this study is much larger and of a wider range. Thus the subadditivity tests conducted here could be considered to be more global like the tests conducted by Shin and Ying (1992).

34. As discussed above, robustness checks were conducted on the subadditivity tests. One of those checks analysing BT data (using the translog cost function estimates from Section 5) is presented here. As another check, however, we also analysed the BT data for the translog cost estimates derived from the dataset where certain data points were removed (to take account of start-up issues). The results again showed that the minimum percentage difference is negative.

shows that in 1997, of the 729 possible configurations, 332, or only 46%, result in a single firm being able to produce at a lower cost than two firms.

Analysing the minimum, maximum and average summary statistics reveals that the minimum percentage difference is negative in all cases. Two firms sharing the 1997 BT monopoly output can possibly lower costs by a minimum percentage of 0.3% or raise costs by 0.4%. These differences are small and so it is probable that the normal benefits from competition i.e. innovation will exceed such small potential losses of efficiency. In terms of the average percentage savings from having a monopoly, the results suggest that for 1997, the monopoly saving is small but positive. This differs however for most other years. In particular, the results for 1991 to 1996 seem to show that

**Table 6.3 Subadditivity Summary Results By Year For BT Arising From The Combined Fixed and Cable Cost Function Estimation**

| | Monopoly Costs Lower Than Two-Firm Costs | | Percentage Savings From Having a Monopoly | | | |
|---|---|---|---|---|---|---|
| Year | N | Percent | Minimum | Maximum | Average | Std. Error |
| 1990 | 364 | 49.93 | -0.134 | 0.188 | 0.010 | 0.0019 |
| 1991 | 252 | 34.57 | -0.131 | 0.152 | -0.005 | 0.0017 |
| 1992 | 166 | 22.77 | -0.119 | 0.109 | -0.018 | 0.0014 |
| 1993 | 204 | 27.98 | -0.152 | 0.163 | -0.014 | 0.0019 |
| 1994 | 128 | 17.56 | -0.136 | 0.107 | -0.030 | 0.0015 |
| 1995 | 102 | 13.99 | -0.136 | 0.096 | -0.035 | 0.0014 |
| 1996 | 14 | 1.92 | -0.125 | 0.069 | -0.043 | 0.0012 |
| 1997 | 332 | 45.54 | -0.260 | 0.388 | 0.017 | 0.0039 |

on average small cost savings could have been made by dividing output amongst two firms. This analysis for BT suggests therefore that there might be gains from introducing competition in the local loop.

### *6.2.2. Subadditivity Analysis For (ii): Dividing BT Outputs Amongst Firms With BT Characteristics With Positive Marginal Costs Imposed*

Checks were also conducted on the BT subadditivity tests with respect to Röller's criticism. Table 6.4 presents the results from this analysis. It shows that only in 1995 and 1996 were there data points which exhibited positive marginal costs for all outputs. This means that for the other years, no real inference can be made. This should not be surprising given the discussion in Section 5 regarding the non-positive parameter estimate value for local call minutes. Despite this, however, the results in 1995 and 1996 for BT's costs continue to support the view expressed in the previous paragraph. Conducting further robustness checks, in particular, subadditivity tests on the estimation comprising access lines only and also on the cost estimation with positive marginal costs imposed showed that the minimum percentage difference is consistently negative for BT. Even though the percentage differences remain consistently small, the natural monopoly hypothesis may not be valid.

Table 6.4 Subadditivity Summary Results For BT With Positive Marginal Costs By Year Arising From The Combined Fixed and Cable Cost Function Estimation

| | | Monopoly Costs Lower Than Two-Firm Costs | | Percentage Savings From Having a Monopoly | | | |
|---|---|---|---|---|---|---|---|
| Year | Possible Cases | N | Percent | Minimum | Maximum | Average | Std. Error |
| 1990 | 0 | - | - | - | - | - | - |
| 1991 | 0 | - | - | - | - | - | - |
| 1992 | 0 | - | - | - | - | - | - |
| 1993 | 0 | - | - | - | - | - | - |
| 1994 | 0 | - | - | - | - | - | - |
| 1995 | 44 | 12 | 27.27 | -0.11 | 0.03 | -0.03 | 0.0058 |
| 1996 | 92 | 2 | 2.17 | -0.12 | 0.07 | -0.04 | 0.0040 |
| 1997 | 0 | - | - | - | - | - | - |

## 7. Conclusions

It has been conjectured by many industry economists that the Commission's policy of open network provision and unbundled local loop networks rests on the premise that the local loop is a natural monopoly and therefore competition in the local loop harms efficiency by duplicating fixed costs resulting in a reduced exploitation of economies of scale and scope. Although, the question of whether the telecommunications system is a natural monopoly has been the subject of numerous studies, it has never been fully resolved and the empirical results have not been consistent. Furthermore, studies on the U.K. telecommunications industry have only focused on the pre-privatisation period. There is therefore much scope for additional analysis of this issue within the U.K. market.

Using unbalanced panel data and techniques not previously used in the UK literature, we have, in this paper, focused our analysis on infrastructure providers in the U.K.-comprising fixed link and cable operators - and have tried to examine the extent to which the overall cost function of the U.K. telecommunications industry is subadditive.

By using a model similar to that adopted by Shin and Ying, (1992) the analysis in this paper uses unbalanced panel data instead of time-series data from the U.K. telecommunications sector for 26 (local) infrastructure providers for the period 1990 to 1997. This ensures that more degrees of freedom are present in the exercise compared to other UK research in this area and so more robust estimates may be obtained for BT. In contrast, however, to the Shin and Ying study, this paper focuses on not only same technology firms but also on substitute telecommunications systems.

In analysing firms with different systems and characteristics, it is reasonable to assume that their production technologies may differ. Consequently, separate cost functions for these systems were estimated and residuals were examined by type of infrastructure. Analysis showed that it is reasonable to group the cable and fixed link operators together into one cost function. This is an interesting result and increases the advantages of embedding the BT data in a larger panel.

Estimating a translog cost function for the combined dataset, we found that the overall fixed and cable industry scale elasticity suggested constant returns to scale at the sample mean. Computing the scale elasticity at BT averages also showed that constant returns to scale might characterise the company. Given the tighter bounds of this test i.e. lower standard errors, this is a strong result. The fact that the industry being analysed is a multi-output market means however that economies of scale are neither necessary nor sufficient for natural monopoly status. As a consequence, more thorough subadditivity tests were conducted on our sample of firms.

Conducting subadditivity tests:

(i) apportioning BT's outputs amongst any two firms who have costs and characteristics corresponding to the firms in our sample; and
(ii) dividing BT's outputs amongst two firms who are assumed to have the same costs and operating features as BT.

showed that the estimated minimum percentage difference, although small, are consistently negative. Even if these potential cost savings were not considered to be statistically convincing, at the very least, they suggest that any potential losses are very small and thus would be outweighed by the normal benefits of competition i.e. innovation. Furthermore, deleting vector combinations where marginal cost schedules are negative, did not contradict this conclusion.

Taken at face value, the public policy implications of these results could be significant. Firstly, they appear to support the infrastructure competition policy that has been implemented in the U.K. since 1990. Secondly, they suggest that although specific operators may uneconomically duplicate network costs, this does not appear to have a significant impact on the total industry cost position so industry and economy gains may be made from introducing competition in the local loop. Thus although the result need to be treated cautiously, they do suggest that the local loop in the U.K. may not be a natural monopoly and that allowing/encouraging infrastructure competition in the local loop may result in cost savings.

# ANNEX I
## Additional Analysis For Combined Fixed & Cable Cost Function

The data definitions used in this paper are given in Table A.I.1. Employment, wages and capital data are all derived from company accounts. Wage data is calculated as wage cost divided by employment. Capital was measured by depreciation charges, interest on capital and interest on working capital where for the latter two charges, the same cost of capital was utilised. All data is in current cost terms.

| Table A.I.1 | Data Definitions |
|---|---|
| TC | Total Cost |
| PL | Compensation per employee |
| PK | Capital expenses per access line |
| PO | Residual expenses per access line |
| A | Access lines |
| LO | Local call minutes |
| NAIN | National & International calls |
| TV | Basic TV Subscriptions |
| DEN | Customers/Access Lines per $Km^2$ |
| CAP | Channel Capacity |
| DE | Percentage of Digital Exchanges |

**Table A.I.2**
**Cost Elasticities For The Combined Fixed And Cable Cost Function Estimation**

| | Cost Elasticities | Standard Error | T-Statistic |
|---|---|---|---|
| Scale Elasticity | 1.02878 | 0.623649 | 1.64962 |
| Output Cost Elasticity | 0.972022 | 0.589241 | 1.64962 |
| Capacity Cost Elasticity | -0.12576 | 0.843654 | -0.149067 |
| Digital Cost Elasticity | 0.073915 | 0.053837 | 1.37295 |
| Density Cost Elasticity | 0.05704 | 0.013795 | 4.13492 |
| Productivity Cost Elasticity | -0.06589 | 0.030074 | -2.19095 |

Table A.I.2 outlines the cost elasticities calculated from the results presented in Table 5.1. A discussion of these estimates is provided in Section 5

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