

Parametric and Non-Parametric Tests for Scale  
Economies in a Regulated Industry:  
The Case of Cable Television

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**PARAMETRIC AND NON-PARAMETRIC TESTS FOR SCALE ECONOMIES  
IN A REGULATED INDUSTRY: THE CASE OF CABLE TELEVISION<sup>1</sup>**

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**ABSTRACT**

We examine a situation where parametric and non-parametric approaches to the study of production and optimal scale can be used as complements, rather than substitutes. We illustrate this concept with data from the cable television industry in an evaluation of the timeliness of deregulation. Although we begin with a large sample offering adequate degrees of freedom for parametric estimation, important regulatory policy issues and the structure of the industry lead us to consider parameter estimation over sub-samples. Some sub-samples are small enough that parametric models cannot guarantee reliable estimates. To deal with this problem, we estimate production parameters non-parametrically using various forms of data envelopment analysis (DEA). Since it is not statistical in nature, the use of DEA is not constrained by degrees of freedom. Not only do the non-parametric estimates shed light on important characteristics of the industry sub-samples when considered in isolation, we also find that on aggregate they agree with parametric estimates when these can be computed.

## I. INTRODUCTION

Since its inception, cable television service provided by the cable television (CATV) industry has been the subject of substantial intervention on the part of regulators in Canada. Among other requirements, the Canadian Radio-television and Telecommunications Commission (CRTC) maintains a system of exclusive Licensed Service Areas (LSAs) for CATV operations. In May 1997, the exclusivity of licensing restrictions was eased slightly by the CRTC. The main issues addressed in this research are whether the provision of basic cable television service within the LSAs was characterized by economies of scale that are large relative to the relevant market such that the enforced monopoly provision of the service was justified and what method is appropriate to use in making this determination.<sup>3</sup> Using annual CATV operating and financial data from 1992 – 1996, we evaluate the efficiency of cable television system operations which are the sole providers of service within their respective LSAs. Parametric tests for returns to scale from translog cost function estimates and frontier non-parametric versions of scale tests are compared. Our results yield further insight into the desirability of retaining the exclusive LSA system as a regulatory instrument within the Canadian cable television industry and into the usefulness of complementary procedures of analysis to address such a policy question.

The next section outlines the regulations of the CRTC that arise under the exclusive licensing system. Sections III and IV develop the translog cost function used in this study and also contain a discussion of the estimation results for this model along with comparisons of our results to earlier findings. Section V presents the methodology and results of non-parametric frontier analysis. Finally, in Section VI, we provide some concluding remarks.

## II. CRTC REGULATIONS

Unlike in the United States, where CATV operators compete for franchises from state or municipal licensors, Canadian CATV operators are licensed by a single federal regulatory authority. The American industry is characterized by a bewildering variety of licence agreements; in contrast, the Canadian situation has three classes of licence arrangement. The regulatory authority examines proposals from applicants to determine which application will be successful and reviews performance under the licence to ensure compliance with licence restrictions. Licences are rarely revoked.

In 1986, a set of rules was established to govern the Canadian cable television industry.<sup>4</sup> These rules continued the earlier practice of requiring operators to apply for exclusive licences to serve consumers located in pre-determined areas.<sup>5</sup> These Licensed Service Areas (LSAs) are then classified by the CRTC based partly on the current subscription level within the LSA and partly on the quality of broadcast reception that is available to the CATV service provider.<sup>6</sup> All types of LSAs and all types of services are subject to the rules on carriage, or signal content.<sup>7</sup> Only basic service in Class 1 and Class 2 LSAs is subject to rate regulation. Table 1 summarizes the application of the regulations.

The rate restrictions (found in Part II of the regulations) do not apply to "Part III licensees". The restrictions in Part III concern only carriage, *i.e.*, Part III licensees are required to carry certain signals, are required to deliver a particular mix of Canadian and non-Canadian services, and are provided with a list of those services which they are allowed to carry, much like other licensees but there is no other explicit economic regulation.

The distinction between Classes 1 and 2 arises in the rate regulations which place more severe restrictions on Class 1 systems than upon Class 2 systems.<sup>8</sup> The pricing regulations fix a ceiling for rate increases, allow rate increases related to the amount of investment in capital for the provision of basic service, and permit increases for those systems which are earning returns on net fixed capital that are below a benchmark set by the CRTC.

The rate regulations are not the direct subject of the analysis in this study. Two components of the rules that determine allowable rate increases deserve further mention, however, since they may impact the cost structure of the CATV firms: the "CAPEX" and the "economic need" provisions, both of which provide some incentive for higher levels of investment than might otherwise have been the case. The capital expenditures that are relevant for the "CAPEX" increase are those which are "for the purchase or capital lease of its head end or distribution system to the extent that these capital costs relate to the reception, processing or distribution of the basic service" and "a licensee may increase its basic monthly fee by an amount not greater than the result obtained by dividing 50 per cent of its capital expenditure by 12 times the number of subscribers to whom it sends a notice" (those from whom the licensee wishes to collect fees). The purpose of this clause is clearly to encourage investment. The economic need clause began as a vaguely worded description of an allowable increase based on a documented justification filed with the Commission which the CRTC could later suspend or disallow. Effectively, this clause allowed the CRTC to re-evaluate the base price for a particular LSA and make a further adjustment if the returns to operating in that area were insufficient. The benchmark rate of return used for this assessment was set at 24%. In 1990, the CRTC decreased the benchmark, for fee increases on the basis of economic need, to 23%.<sup>9</sup> The economic need rule looks like inverted rate of return

regulation where the rate of return is a floor (albeit with some holes) rather than a ceiling, since operations earning less than a 23% return on net fixed assets are eligible for price increases (of up to 10%) while operations earning in excess of 23% are not required to request rate decreases.

These two components of rate regulation appear to provide incentives for operators of Class 1 and Class 2 LSAs to invest more heavily in capital assets, relative to operators of Part 3 LSAs. It is likely that the cost structures for Classes 1 and 2 differ from those of Part 3 due to the differing incentives for investment.

The most important feature of the CRTC rules for this study is the exclusive licensing requirement. To investigate the possible need for and impact of this requirement, we turn now to the estimation of the costs of providing cable television service.

### III. TRANSLOGARITHMIC COST FUNCTION FOR CATV

The first approach to gauging the minimum efficient scale of operations involves estimating the parameters of a cost function. The equations for a translogarithmic cost function are applied to data from the sample of CATV operations for 1992 – 1996.

For this cost function to reflect the relevant features of the production decisions of the CATV operators, a number of assumptions must be satisfied. Most importantly, we assume that CATV firms are choosing a mix of inputs to minimize the costs of producing the output level demanded for a given output price. This assumption is critical since CATV firms operate as monopolies in their respective LSAs. In the absence of CRTC rate regulation, exclusive licensing would mean that CATV prices would be constrained only by competition from alternate real-time video signal providers. Since small (Part 3) LSAs are not rate-regulated, the cost-minimization problem assumed here may not correspond to the profit-maximization problem of the firm, with

the result that estimates are subject to simultaneity bias. Further, we assume that although technology over the sample period is fixed, the sample period of one year is long enough to capture long run decisions. If these conditions on technology and conduct are met, we can approximate a cost function that corresponds to a production function under standard duality assumptions.

A second order logarithmic approximation to an arbitrary twice-differentiable cost function, the translog cost function, is given by:

$$\log C = \log \beta_0 + \sum_i \beta_i \log X_i + \frac{1}{2} \sum_i \sum_j \beta_{ij} \log X_i \log X_j + \nu \quad (1)$$

where  $i, j = k, l, m, q_1, q_2, h, d$ .  $P_K$  is the price of capital,  $P_L$  is the price of labour,  $P_M$  is the price of "materials",  $Q_1$  is the number of direct subscribers,  $Q_2$  is the number of indirect subscribers,  $H$  is the number of channels provided in the basic tier,  $D$  is a measure of subscriber density, and  $\nu$  is the residual error term.<sup>10</sup> Variables, e.g.,  $Z$ , are centred around sample means,  $\bar{Z}$ , to avoid arbitrary scaling problems.<sup>11</sup> The estimated function is:

$$\log \tilde{C} = a_0 + \sum_i a_i \log \tilde{X}_i + \frac{1}{2} \sum_i \sum_j a_{ij} \log \tilde{X}_i \log \tilde{X}_j, \text{ where } \tilde{C} = \frac{C}{\bar{C}}, \text{ and } \tilde{X}_i = \frac{X_i}{\bar{X}_i}. \quad (2)$$

Restrictions applied to this function in this study include symmetry, "adding-up" constraints, and linear homogeneity in prices.<sup>12</sup> Shephard's lemma provides cost share equations:

$$S_i = a_i + \sum_j a_{ij} \log \tilde{X}_j = b_i + \sum_j b_{ij} \log \tilde{X}_j, \quad i = k, l, m. \quad (3)$$

where  $S_K$ ,  $S_L$ , and  $S_M$  are the cost shares of capital, labour, and "materials", respectively.<sup>13</sup> The cost share equations are estimated simultaneously with the cost equation to improve the efficiency of the estimates of cost function parameters. With the exception of  $S_K$ ,  $S_L$ , and  $S_M$ , all variables are centred around their respective sample means.

The system of equations, (2) and (3), is estimated using three-stage least squares.<sup>14</sup> The sample from each year of the sample period (1992 - 1996) forms one cross-section of CATV

operations. Data from one cross-section is not pooled with information from earlier years to avoid the complications from (mis)specifying technological change that occurs between years of the sample period. Since the effects of technological change are not treated explicitly by the use of these single-year estimations, the method allows estimation and hypothesis testing without jointly testing the specification of the technological input function. To estimate the system, it is necessary to drop one of the cost share equations to avoid singularity. The parameters from the dropped equation (for  $S_M$  in this case) can be recovered by imposing homogeneity of degree one on the system.<sup>15</sup>

The data for this study, unless otherwise noted, are drawn from the CRTC database constructed from annual returns from each LSA submitted by the CATV firms. Taking the 1996 cross-section as an example, after the removal of observations with missing information or other measurement problems, the number of remaining LSAs is 517 when estimating the model with only one output; however, missing channel information results in a sample size for other estimations of 358. Note that the number of firms does not map directly to the number of LSAs. Within the 1996 sample, 79 corporations operate in one LSA with an average subscription base of 8000 direct subscribers and 440 indirect subscribers. However, 42 corporations serve an average of 6 LSAs which have mean basic subscription levels of 10,600 direct and 670 indirect subscribers. The mean channel depth for both single and multi-LSA operations is 23 channels. There are a few corporations which operate in a relatively large number of LSAs, the largest among these serving several dozen areas.<sup>16</sup> The smallest LSA in the sample typically contains just under one hundred subscribers while the largest contains just under one million. Detailed

definitions and derivations of the variables for estimation, and some descriptive statistics, are provided in Appendix A.

#### IV. RESULTS FROM PARAMETRIC ESTIMATION

Three trials of the translog model were conducted to investigate the value of expanding the output set. The first trial was based on a single output measure, similar to earlier studies of this type.<sup>17</sup> The second separates the single output measure into two components: direct and indirect subscribers. The third trial includes channel depth in the measure of output.

For the first trial, to examine the issue of scale we calculate  $Q^*$ , the output at which average total costs are at a minimum, which solves (both in terms of the estimated parameters for the mean-centred variables and of the untransformed variables):

$$\frac{\partial \log \tilde{C}(\tilde{Q})}{\partial \log \tilde{Q}} = 1 = a_q + a_{qq} \log \tilde{Q}^* + \sum_j a_{jq} \log \tilde{X}_j = b_q + b_{qq} \log Q^* + \sum_j b_{jq} \log X_j, \quad (4)$$

The solution yields:

$$Q^* = \bar{Q} \exp\left(\frac{1 - a_q - a_{kq} \log \tilde{P}_K - a_{lq} \log \tilde{P}_L - a_{mq} \log \tilde{P}_M - a_{dq} \log \tilde{D}}{a_{qq}}\right). \quad (5)$$

In the tables below, estimates of  $Q^*$  are provided which are mean values calculated over the various samples. Values for  $Q^*$  at sample mean values for  $X_j$  are provided under the label  $Q_{min}$ . However, an average value for  $Q^*$ , estimated for each observation, over the sample is often preferable to a value calculated at sample means,  $Q_{min}$ , for two reasons. Averaging individual variables will not necessarily yield a set of figures that represent the characteristics of an average LSA, although this observation is true for all multi-dimensional models and does not generally represent a serious impediment to analysis. More importantly, given that estimates of output level for minimum average cost are notoriously unstable and sensitive to the adding or dropping of a few observations, since a small change in the value of  $a_{qq}$  is transferred exponentially to a change

in  $Q_{min}$ , instability is reduced by averaging over the same sample that generated the initial coefficients, making mean  $Q^*$  a more stable estimate than  $Q_{min}$ . At sample mean values for  $X_j$ :

$$\tilde{X}_j = \frac{X_j}{\bar{X}_j} = 1 \Rightarrow \log \tilde{X}_j = 0 \Rightarrow 1 = a_q + a_{qq} \log\left(\frac{Q^*}{\bar{Q}}\right) \Rightarrow Q^* = \bar{Q} \exp\left(\frac{1 - a_q}{a_{qq}}\right). \quad (6)$$

and so an estimate of  $Q^*$  requires  $a_{qq} > 0$ , which is also the second order condition for the minimization,  $\beta_{qq} > 0$ . If  $1 - a_q = 0$  then the estimate for  $Q^*$  is not different from the mean output level, but this condition corresponds to a condition of constant returns to scale and so  $Q^*$  is no longer a reliable estimate of the minimum efficient scale (MES). The results of both methods of estimating  $Q^*$  – mean  $Q^*$  and  $Q_{min}$  – are provided since the values of mean  $Q^*$  are not as amenable to standard hypothesis testing while the procedure that generates  $Q_{min}$  allows for testing more readily. Where stable estimates of both of these values can be obtained, the pattern and general size of the estimates is roughly similar. However, as noted above, estimates of MES are often unstable and, hence, need to be considered in conjunction with an estimate of cost-output elasticity.

For a single output model, the estimate of the cost-output elasticity, evaluated at mean values for the sample variables, is simply  $a_q$ . The inverse of this value is  $\mu = 1/a_q$ , the ratio of average total cost to marginal cost. The hypothesis of constant returns to scale (CRS) can be tested by evaluating  $1/a_q - 1$ .

Tables 3 and 4 present the estimation results for the single output trial. Generally, the estimates are unstable, especially where the sample size falls below 150 LSAs. The most prominent feature is the suggestion of increasing returns to scale: mean  $Q^*$  and  $Q_{min}$  estimates are larger than sample mean values and  $\mu > 1$  (see Table 5). Results for the whole sample suggest that there are some unexploited economies due to small market size. Fully 98% of the LSAs are

"too small" for the operators to achieve the estimated MES of almost 300,000 subscribers (see Table 6).

In estimating cost functions in a regulated environment, it is important to remain aware of the differential impact of these regulations on the various sizes of operations. The sample was split based on number of subscribers (Groups A, B, and C, divided at 2000 and at 6000 subscribers) corresponding roughly to the CRTC's class system (Class 1, Class 2 and Part 3). These subsamples do not always yield satisfactory results, especially when the subsample contains a small number of divergent (high variance) observations. For example, the results for Group C are contradictory: pronounced returns to scale, ranging from  $\mu = 3.35$  in 1992 to  $\mu = 4.92$  in 1994, but MES estimates of less than one hundred subscribers. Results for the mid-range sample, Group B, suggest that operations of this size are characterized by dramatic returns to scale,  $\mu$  ranges as high as 11.9 (1994), but the inability to reject a hypothesis of failure of the second order condition suggests that producing the mean output level might be sufficient to achieve MES. However, both of these contradictory results are seriously weakened by the small sample sizes. Finally, the estimate for MES from the Group A subsample fall from about one million to about 300,000 from 1992 to 1996, and values for returns to scale in the neighbourhood of 1.2 suggest that large operations are facing increasing returns to scale. This result is in sharp contrast to earlier studies which discovered that larger operations could reach regions of cost functions characterized by constant returns to scale. See Tables in Appendix B for estimates of  $Q^*$ ,  $Q_{min}$ , and  $\mu$  for 1985 - 1991.

The source of these results does not lie in a failure to account for changes in subscription composition over the 1990's. The proportion of subscriptions accounted for by indirect subscribers is not substantially different across class sizes (Group A: 7%; Group C: 9%).

The next step is to expand to a multi-output model by separating direct and indirect subscribers and considering an additional dimension of output: channel depth. Accounting for variations in this component of service further illuminates the upward bias in returns to scale delivered by a single output approach, but at the cost of additional parameterization and the need, statistically, for larger samples.

The value of including the parameters for channel depth is established by the results of Wald tests for the hypothesis that a given set parameters is jointly zero. For example, in 1996, for the channel parameters, the  $\chi^2(7)$  test statistic is 15.99 (with a p-value of 0.025). The hypothesis that the parameters are not significantly different from zero can be rejected.

In addition to the three groups discussed above, the sample has been further subdivided into smaller size categories (see Tables 7 and 8). These divisions correspond to the subsamples used in the data envelopment analysis discussed below. Tables 9-17 contain the results for the three output trial of the translog cost function.

Estimates of MES for  $Q_2$  (Tables 14 and 15) are wildly unstable ranging from near zero to very large levels (*e.g.*,  $2.75 \times 10^{30}$ ). Adding inframarginal indirect subscribers (intensive output expansion) is likely to be accomplished at roughly constant returns to scale and so the unstable estimates would be an artifact of the software program which is seeking a minimum along a function with little or no curvature. Serving an additional set of indirect subscribers (extensive

output expansion), however, is likely to involve substantial increasing returns to scale. The degree to which intensive effects dominate extensive effects, producing unstable estimates, is determined by specific but unobserved characteristics of the LSA. Removing this instability from the measure of output yields more consistent results for direct subscriptions.

Estimation of the cost function over all LSAs provides an estimate of  $Q_1^*$  which falls, during the years 1992 to 1996, from around 35,000 to about 9300 direct subscribers (see Tables 10 and 11). The inverse of the cost-output elasticity, or  $\mu_1$ , for direct subscribers at the mean output level (of roughly 17,000 direct subscribers for this sample) falls from 1.07 to 0.97. After 1993,  $\mu_1$  is not significantly different from one, suggesting that costs in average LSAs are characterized by constant returns to scale in direct subscribers (see Table 12).

Turning to the estimates for subsamples, in Tables 10 - 12, consider first the division into the groups corresponding to the classes created by the CRTC. With the gradual "deregulation" of smaller systems that occurred over the 1990s, Class 2 was depopulated by the CRTC. However, we can still obtain meaningful inferences about the cost functions of CATV operations in LSAs of this size since the Group B category retains over one hundred LSAs. Note that, as expected, the average number of subscribers for the Group A LSAs (40,000 direct and 4800 indirect subscribers) is higher than the mean for the Part 3 LSAs (930 direct and 100 indirect). However, the estimates for  $Q_1$  for some years are reversed: for Group A, the rate-regulated LSAs, the estimate is on the order of 10,000 direct subscribers, and for Group C it is as high as around one million, although the Group C subsample yields unstable estimates of  $Q_1^*$  (from 370 to one million direct subscribers).

Our results demonstrate the value of alternative approaches to estimating the minimum efficient scale and the importance of considering  $\mu_1$ . The observation that estimates of MES from parametric models are generally unstable is confirmed with this data – consider the results for the mid-sized and small operations, Groups B and C. Results for larger systems, Group A, are consistent internally and with Class 1 results: an MES of roughly 7000 direct subscribers and, given that mean subscription levels for these subsamples are at least 20,000, if not 40,000; and an estimate for  $\mu_1$  that suggests constant returns (Class 1) or slight diseconomies of scale (Group A), *i.e.*, that economies of scale are exhausted at these mean values. The corresponding estimate for 1991 is roughly 22,000 subscribers (although this figure may be biased upward since it includes indirect subscribers), down from a peak of almost 40,000 in 1989.

For the eight subsamples, no clear picture emerges from the estimates of MES or  $\mu$  for direct subscribers (see Tables 10 – 12). The samples are generally too small to permit adequate estimation: the numbers of observations in Groups 1 and 2 in particular leave insufficient degrees of freedom. Nonetheless, the estimates of  $\gamma$ , the fraction of LSAs that are too small to permit operators from fully capturing economies of scale, lend support to the assertions that the MES is in the neighbourhood of the size ranges of Groups 4 and 5, or somewhere between 5000 and 10,000 subscribers (see Table 17).

The primary conclusion that can be drawn from these results is that the MES for CATV operations is, by 1996, substantially smaller than it was ten years earlier. This represents a continuation of the trend observed in the years immediately following the implementation of the *1986 Cable Television Regulations* in which the costs of service in greater numbers of LSAs

exhibit constant returns to scale and the scale of operations is larger than the smallest level necessary to achieve minimum average cost (see Figure 1).

However, there remains a fundamental problem in drawing inferences about changes in the cost function within the CATV industry from the parametric results. There are some questions which can only be fully addressed by examining finer subsamples of LSAs, such as investigating the possibility that the different cost conditions which prevail in different size classes generate "lumpy" cost schedules. Unfortunately, the translog model is not a useful tool for this purpose. Breaking a larger sample into small groups or, equivalently, removing the restriction that the cost curves are the same across ranges of output levels, presents estimation problems for the heavily parameterized translog model. In addition, the consideration of more dimensions of the output further stresses the statistical performance of the model. To resolve these problems, we turned to a non-parametric procedure.

#### **V. NON-PARAMETRIC FRONTIER ANALYSIS AND RETURNS TO SCALE**

Under exclusive licensing, CATV firms operate as monopolies in their respective LSAs. The nature of monopolistic behaviour, and the firm-level changes that are associated with this conduct, brings into question many of the standard assumptions necessary to perform empirical analyses of producer behaviour.<sup>18</sup> More formally, ambiguity arises as to the exact nature of the producer optimization problem for firms operating in the Canadian cable television industry.

To help verify the assumptions made in the parametric analysis of producer behaviour, we examine the robustness of the parametric results by implementing a non-parametric methodology which does not impose stringent firm-level assumptions. This method also produces measures of economies of scale, which is of particular policy interest given the spatial monopoly nature of

cable television provision. Specifically, we construct measures of scale economies from non-parametric frontier efficiency estimators.

Another benefit of this comparative analysis is the following: if results of this exercise can be mapped onto the parametric results, then the policy recommendations obtained from the parametric estimates with respect to the organization and provision of cable television service are strengthened. In this regard, we can also verify that the parametric model used earlier is a reasonable representation of technology in the cable television industry. If the scale results from the non-parametric analysis were dissimilar, this lack of agreement would cast doubt on the ability of the parametric model to fully capture the structure of production in this industry.

### **1. Non-parametric frontier analysis: Data Envelopment Analysis**

The technical efficiency measures used in this analysis are computed by an input- and output-oriented data envelopment analysis (DEA).<sup>19</sup> DEA is a non-statistical radial efficiency measurement technique that uses a specially configured linear program to compute how efficiently firms transform inputs into outputs relative to the other firms in the sample. DEA solves for a "best practice" production frontier relative to which the technical efficiency of each firm in the sample is calculated. DEA is classified as a non-parametric methodology because minimal assumptions about distributions of variables and functional forms for the production correspondence (aside from piecewise linearity of the efficient set) are necessary to perform the analysis.

The measures of technical efficiency used here are radial measures<sup>20</sup> and are also known as Debreu-Farrell measures.<sup>21</sup> The input-oriented efficiency score (bounded by 0 and 1) is a measure representing the level by which actual input level could be decreased in order for the firm

to achieve a best practice level. An efficiency score of one means that a firm is ranked as efficient and hence, also lies on the frontier. Conversely, output-oriented DEA measures yield efficiency scores bounded below by 1; a score of 1 for a firm in this case also means that it is efficient. Scores greater than 1 represent inefficient firms.

Input-oriented DEA generates a measure of how much a firm's inputs could be proportionately "shrunk" in order to be classified as transforming inputs into outputs as efficiently as the best firms in the sample. In fact, this mechanism for computing efficiency can be translated into a linear program. The linear program describing the most general form of input-oriented radial DEA is written as follows:

$$\begin{aligned}
 & \min_{\lambda, z} \lambda \\
 & \text{s. t. } y_{jm} \leq \sum_{j=1}^J z_j y_{jm}, \quad m = 1, \dots, M \\
 & \quad \sum_{j=1}^J z_j x_{jn} \leq \lambda x_{jn}, \quad n = 1, \dots, N \\
 & \quad z_j \geq 0, \quad j = 1, \dots, J
 \end{aligned} \tag{6}$$

for  $j=1, \dots, J$  (number of firms),  $m=1, \dots, M$  (number of outputs),  $n=1, \dots, N$  (number of inputs).

Data envelopment analysis requires the solution to  $J$  linear programs, one for each datum (or firm) in the sample.  $Z$  is called the intensity factor in this linear program; its inclusion makes possible construction of the linear piecewise boundary segments of the solution technology set (Fare *et al.*, 1994). The variable  $\lambda$  in the objective function is a contraction factor, for each input in this case. Thus  $\lambda x$  (as in the second constraint in Equation (6)) is often referred to as a

projected point, a point falling, by definition, on the boundary of the technology set. In the radial forms of DEA as used in this paper, all projected points in input/output space for those firms classified as inefficient lie along a ray from the origin through the data point.

## 2. Measures of scale in DEA

Along with the measurement of technical efficiency, the linear programs used in non-parametric frontier efficiency measurement can be used to address other questions about the nature of production and organization. This includes the flexibility to impose varying levels of returns to scale. The linear programs can be configured to account for variable returns to scale (VRS) or constant returns to scale (CRS).

Graphically, the point where the linear program solution hyperplane passes relative to the origin in input/output space is a measure of returns to scale for the firm. The VRS specification implies that the hyperplane or frontier defined by the data is able to pass anywhere relative to the origin (see Figure 2). VRS also implies that when the efficient frontier is constructed each firm is "compared "(as per technical efficiency) only to those firms of similar size. To account for VRS mathematically, the input-oriented linear program of equation (6) includes a convexity constraint on the multiplier,  $Z$ , of the form (Fare *et al.*, 1994):

$$\sum_{j=1}^J z_j = 1 \tag{7}$$

Conversely, the CRS specification modifies the envelopment hyperplane such that it intersects the origin in input/output space. There is no convexity constraint in the CRS linear program, and it is written simply as equation (6). Intuitively, the imposition of CRS means that

when efficiency is computed, the set of firms that can make up the efficient frontier includes all firms in the sample.

From Figure 2, note how each scale assumption envelopes the data more or less "tightly" in the manner described above. The drawback of the CRS specification is that what is identified by the linear program as inefficiency might be more readily attributable to size or scale differences between firms in the sample. Fortunately, we can exploit this property of non-parametric efficiency estimators and compute (approximate) measures of scale efficiency.

For completeness, both input- and output-oriented versions of the VRS and CRS models are calculated<sup>22</sup> to ensure that the scale results we find are not biased by choice of orientation in the linear program. The specifications of the non-parametric efficiency estimator mean that unlike when computing a parametric specification of technology, the choice of returns to scale is left to the researcher. This is why many non-parametric efficiency studies utilize a priori information about the nature of the industry under analysis to help in the choice of specification.<sup>23</sup> When such knowledge is not available or needs to be tested rather than imposed, it is possible to compute all three types of DEA linear program and use these results to find a non-parametric measure of returns to scale. Necessarily, this measure is not as precise as a parametric measure,<sup>24</sup> but for our purposes it will be used only to examine the overall validity of the parametric scale economy results.

To usefully examine the nature of economies of scale with non-parametric frontier estimators, large sample results of different size classes of firms must be analyzed. Here, we simply count the number of individual firms that are revealed by DEA as scale efficient within

a particular size category. The criteria used to measure input-oriented scale efficiency and output-oriented scale efficiency are the following:<sup>25</sup>

(1) *Input-oriented Decision Rule*: Define input scale efficiency, or ISE, by

$ISE = \text{CRS Score} / \text{VRS Score}$ ; then, if  $ISE = 1$ , the activity is scale efficient.

The activity is scale inefficient if  $\text{CRS} / \text{VRS} < 1$ .

(2) *Output-oriented Decision Rule*: Define output scale efficiency, OSE, by

$OSE = \text{CRS Score} / \text{VRS Score}$ ; then, if  $OSE = 1$ , the activity is scale efficient.

If the activity is scale inefficient, then  $\text{CRS} / \text{VRS} > 1$ .

For both decision rules, any other permutation of results is inconclusive regarding the direction of scale economies.

In sum, the number of firms which are scale efficient in a given size range (defined in terms of the chosen output measure) gives an indication of the most efficient size of firm. Additionally, the presence (or lack) of monotonicity in the scale results (with increasing size of operation) is indicative of effects on optimal producer behavior induced by exogenous factors. This latter point will be especially relevant if the non-parametric scale results appear to be clearly influenced by economic regulations related to firm size.

### **3. Non-parametric scale results**

In an effort to keep the non-parametric analysis comparable with the parametric work, we concentrated on choosing the smallest set of inputs and outputs that best capture the structure of production in the industry. The outputs we use are the number of direct and indirect subscribers to cable television services in a given LSA and the number of channels available in an LSA. The channel variable captures service quality differences among the LSAs, an important point when

considering the monopoly nature of cable television in Canada. The inputs we use are labor (number of employees), and capital investment is proxied by the number of kilometres of laid cable available to the firm. While not a complete representation of the capital necessary to operate a cable television system, this last measure has been effectively used as a proxy for capital in previous studies of Canadian cable television.<sup>26</sup>

Table 18 illustrates some general characteristics of the cable television industry, as given by the last year of data (1996). Size class is defined by  $Q_{total}$ , where  $Q_{total}$  = total number of cable subscribers. For comparative purposes, the size classes chosen here correspond closely to those used by the CRTC to set rates and regulatory rules. Since degrees of freedom are not a problem with DEA studies in general, breaking the sample into smaller groups allows us to more precisely identify scale efficient levels of cable provision.

The merit of using a large number of groupings in this type of study is particularly evident when considering firms with  $Q_{total}$  falling between 4000 and 6000 subscribers. The mean number of cable kilometers used in these firms is below that of the next smallest size class in the sample, implying that firms in this size class are likely to operate in more densely populated areas. Grouping this class in the same comparison set as those firms in the next smallest size class would cloud the efficiency and scale results for all firms possessing between 2000 and 6000 subscribers.

Tables 19-23 present the complete results from the four DEA specifications considered. We find that qualitative differences between the input and output oriented results are minimal. The key results from the tables can be found in the columns labeled "% ISE" (percent input scale efficient) and "% OSE" (percent output scale efficient). These categories are the percentage of

firms in a given size class that are scale efficient according to the input/output scale efficiency rules described in the previous section.

All results are aggregated in Figures 3 and 4, which illustrate the input and output oriented results respectively. These figures show that trends of greater or lesser scale efficiency in a size class are consistent across specification and time. Of particular note are the scale results for the 4,000 - 6,000 and 14,000 - 30,000 subscriber classes. They contain relatively more scale efficient firms than any other size class. Why is this so?

As in the parametric analysis section, we find two ranges of efficient scale in this industry. We believe this is due to the regulation of Canadian cable television markets. The first scale efficient output level is the "free-standing" scale of output (14,000 - 30,000 subscribers), which exists for those firms with markets large enough to fall clearly into Class 1 regulations. We refer to this as the "free-standing" level of output because it very likely approximates the efficient scale that would exist if there were no regulations. Since the scale efficient output levels fall well short of the largest size classes in our sample, and all firms are treated equally by regulation above 6,000 subscribers, if there were scale economies in this industry at extremely large output levels, these would have been revealed by our analysis.

More importantly, the second point of efficient scale at 4,000-6,000 subscribers falls at the cusp of substantial regulatory changes for a CATV operator (further growth moves the operation into the rate-regulated Class 1 category). This unusual finding is a strong indication that the CRTC regulations have directly affected industry cost structure.

Furthermore, our consistent findings of scale efficiency among smaller firms hints at the changes which will be necessary to ensure continued provision of cable television as an

inexpensive and easily-obtained consumer good. Many smaller firms are new and use small numbers of satellite dishes, sometimes nothing more than a personal dish connected to various neighbours in the local area. This type of operation has relatively low sunk costs, combined with minimal fixed costs and even smaller variable costs; certainly all the characteristics of a technology which encourages contestability. Contrast this with the head-end technology of the larger firms which offers little encouragement to entry at the margin with its higher capital costs, and more importantly, the potentially higher variable costs if more labor is needed to operate older, analog video mixing and sound systems. What is clear is that the regulatory framework in place during the 1980's and 90's had become outdated by 1995 or 1996 and needed to be removed or adjusted to accommodate the rapid changes occurring in the technology of cable television provision.

#### **VI. CONCLUDING REMARKS**

The evidence presented via the non-parametric results indicates that the CRTC regulations and their relationship to firm size induce some level of suboptimal organization in this industry. The lack of monotonicity of the non-parametric scale measures is highly suggestive of the distortionary effects which regulation had on the cable television industry in Canada. Firms operating at those intermediate output levels just large enough to be subject to extensive regulation contain lower percentages of scale efficient firms. Contrasting this fact with the scale results for the firms operating just below the regulatory cut-off level of output hints that the regulatory rules induced strategic behaviour in the industry in the avoidance of the effects of Class 1 regulation

The non-parametric findings buttress the parametric evidence against the natural monopoly argument that would justify continuation of the mandated monopolization of cable television

service in each LSA by a CATV operator. Our results suggest that there are no longer economies of scale that are large relative to most of the relevant markets. To what extent this result has been influenced by the regulations themselves is not clear.

Estimates from both procedures imply that small systems, in the five- to ten- thousand subscriber range, could achieve scale efficiency if left unregulated. We also find that there are two local minima for average cost (at roughly 5000 and 25,000 subscribers), each occurring in a separate regulatory domain. Without the modality introduced by intervention, we might expect to see a smoother expansion path in this industry.

This evidence also supports the movement to deregulate. Market growth, combined with recent changes in the CRTC's rules, has reduced the coverage of rate regulation. The Class 2 category has been depopulated; some have grown into Class 1 LSAs, others have been deregulated to Part 3 status (see Table 1). Our research indicates that many Class 1 LSAs are large enough to support some easing of rate regulation if barriers to entry are removed. But it is the small Part 3 LSAs that are not rate-regulated. The CRTC retained exclusive licensing while deregulating from the bottom of the size distribution of LSAs. A regulatory strategy that would be more consistent with our findings begins with the removal of entry restrictions for the larger LSAs. With entry, rate regulation could also be discontinued.<sup>27</sup> Given the reluctance of the CRTC to rate-regulate small areas, and the arguments in favour of deregulation in large areas, it seems more appropriate to suggest that the CRTC dispense with rate-regulation and exclusive licensing altogether.<sup>28</sup>

In May of 1997, the Commission indicated that it was willing to entertain applications from other entities, such as telephone companies, for cable television licences.<sup>29</sup> This

development seems promising: with the growth in competition from other real-time video signal providers, monopolistic conduct within the industry seems less likely to occur and less likely to be harmful if it does take place. Further, in January of 1998, the CRTC issued a new set of regulations for CATV.<sup>30</sup> The most salient change is in the rate regulation of larger LSAs: where the efforts of an entrant reduce the subscription level of the incumbent operator by 5% or more, the incumbent's obligation to adhere to the Class 1 rate regulations is removed. This raises the question, for future research, whether this criterion for deregulation is the best that could be chosen, since it introduces some new, and unusual, incentive effects. However, the removal of entry restrictions, followed by the easing of rate regulation, seems timely. This development in regulation is supported by our results - parametric and non-parametric - although it remains to be seen whether the Canadian experiment in the deregulation of CATV in the late 1990s is any more successful than the American experiment of the early 1990s.<sup>31</sup>

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Table 1  
The CRTC Class System

Class label	Subscribers		Head End Location within Grade B contour	Restrictions
"Class 1"	over 6000	AND	of more than 2 broadcast stations	Part II: carriage and basic rates
"Class 2"	under 6000 over 2000 <sup>a</sup>	AND	of more than 2 broadcast stations	Part II: carriage and basic rates
"Part 3"	under 2000 <sup>a</sup> under 6000 <sup>b</sup>	OR	of 2 or fewer broadcast stations	Part III: carriage

Notes: a = as of 1991  
b = as of 1994

*Parametric Results, Unified Output Measure*

Table 2  
 $\bar{Q}$  (sample mean)

	1992	1993	1994	1995	1996
ALL LSAs	39,000 n = 523	40,200 n = 543	43,400 n = 564	34,800 n = 566	37,100 n = 517
Group A	117,000 n = 160	121,000 n = 163	132,000 n = 168	102,000 n = 172	105,000 n = 166
Group B	8820 n = 136	11,300 n = 147	12,900 n = 150	10,900 n = 148	9540 n = 145
Group C	1910 n = 227	1950 n = 233	1790 n = 246	1910 n = 246	1900 n = 206

Samples are separated by number of subscribers (mixed total) given by:

$$X = Q_1 + Q_2 = \text{number of direct subscribers} + \text{number of indirect subscribers}$$

For Group A:  $X < 6000$ ; Group B:  $6000 > X > 2000$ ; and Group C:  $2000 > X$ . The measure of output,  $Q$ , is the number of equivalent total subscribers as described in Appendix A.

Table 3  
 $Q_{min}$ , level of output for minimum average cost

	1992	1993	1994	1995	1996
ALL LSAs	$1.23 \times 10^6$ ( $1.49 \times 10^6$ )	$1.47 \times 10^6$ ( $1.98 \times 10^6$ )	$1.52 \times 10^7$ ( $3.38 \times 10^7$ )	380,000 (316,000)	285,000 (248,000)
Group A	$1.32 \times 10^6$ ( $1.46 \times 10^6$ )	$3.39 \times 10^6$ ( $5.91 \times 10^6$ )	$2.09 \times 10^6$ ( $2.63 \times 10^6$ )	921,000 ( $1.08 \times 10^6$ )	452,000 (338,000)
Group B	$1.66 \times 10^{19}$ ( $3.18 \times 10^{21}$ )	a	a	$3.20 \times 10^{8b}$ ( $2.90 \times 10^9$ )	$3.48 \times 10^{12b}$ ( $2.12 \times 10^{14}$ )
Group C	41.7 <sup>b</sup> (22.0)	66.0* <sup>b</sup> (26.6)	87.1** <sup>b</sup> (28.9)	78.5** <sup>b</sup> (27.3)	60.1* (29.9)

a = no estimate available

b =  $Q_{min}$  test fails

Table 4  
mean  $Q^*$ , level of output for minimum average cost

	1992	1993	1994	1995	1996
ALL LSAs	$1.15 \times 10^6$ (533,000)	$1.37 \times 10^6$ (683,000)	$2.02 \times 10^7$ ( $6.03 \times 10^7$ )	353,000 (160,000)	270,000 (96,800)
Group A	$1.63 \times 10^6$ ( $2.11 \times 10^6$ )	$6.31 \times 10^6$ ( $1.31 \times 10^7$ )	$3.03 \times 10^6$ ( $4.97 \times 10^6$ )	$1.27 \times 10^6$ ( $2.02 \times 10^6$ )	442,000 (219,000)
Group B	$4.57 \times 10^{18}$ ( $9.58 \times 10^{19}$ )	a	a	$3.67 \times 10^{8b}$ ( $1.44 \times 10^8$ )	$3.45 \times 10^{12b}$ ( $1.37 \times 10^{12}$ )
Group C	41.7 <sup>b</sup> (3.10)	65.3 <sup>b</sup> (10.7)	89.9 <sup>b</sup> (5.84)	79.4 <sup>b</sup> (1.64)	59.7 (8.38)

a = no estimate available

b = Qmintest fails

Table 5  
Returns to scale,  $\mu$ , inverse of cost-output elasticity

	1992	1993	1994	1995	1996
ALL LSAs	1.25** (0.509)	1.28** (0.0602)	1.35** (0.0579)	1.19** (0.0432)	1.17** (0.0482)
Group A	1.48** (0.125)	1.63** (0.163)	1.53** (0.122)	1.36** (0.100)	1.26** (0.0818)
Group B	7.38* (2.99)	11.2 (5.82)	11.9* (5.60)	9.60* (4.18)	11.3 <sup>c</sup> (7.68)
Group C	3.35** (0.438)	4.26** (0.794)	4.92** (1.15)	4.30** (0.760)	4.42** (1.05)

standard errors in parentheses

\*\* = significantly different from zero, 99% level

\* = significantly different from zero, 95% level

c = CRS not rejected,  $\mu$  not significantly different from 1, 95% level.

Table 6  
 $\gamma$  (percent of LSAs that are "too small")

	1992	1993	1994	1995	1996
ALL LSAs	99.6%	99.6%	100%	98.6%	98%
Group A	96.9%	97.5%	97.0%	94.8%	95%
Group B	100%	a	a	100% <sup>b</sup>	100% <sup>b</sup>
Group C	0% <sup>b</sup>	0.43% <sup>b</sup>	0.81% <sup>b</sup>	0.41% <sup>b</sup>	1%

*Parametric Results, Three Outputs*

$Q_1$  = number of direct subscribers;  $Q_2$  = number of indirect subscribers;  $H$  = channels

Table 7  
 Group definitions

Sample	Number of subscribers ( $Q_1 + Q_2$ )	
	Minimum	Maximum
Group A	6000	
Group B	2000	6000
Group C	1	2000
Group 1	80000	
Group 2	30000	80000
Group 3	14000	30000
Group 4	6000	14000
Group 5	4000	6000
Group 6	2000	4000
Group 7	1000	2000
Group 8	1	1000

Table 8  
Sample sizes

	1992	1993	1994	1995	1996
ALL LSAs	n = 343	n = 360	n = 381	n = 376	n = 358
Group A	n = 131	n = 133	n = 142	n = 146	n = 140
Group B	n = 106	n = 116	n = 125	n = 123	n = 124
Group C	n = 106	n = 111	n = 114	n = 107	n = 94
Group 1	n = 18	n = 17	n = 19	n = 17	n = 19
Group 2	n = 25	n = 29	n = 28	n = 31	n = 30
Group 3	n = 38	n = 36	n = 40	n = 42	n = 40
Group 4	n = 50	n = 51	n = 55	n = 56	n = 51
Group 5	n = 40	n = 47	n = 46	n = 48	n = 52
Group 6	n = 66	n = 69	n = 79	n = 75	n = 72
Group 7	n = 51	n = 50	n = 51	n = 47	n = 43
Group 8	n = 55	n = 61	n = 63	n = 60	n = 51

Table 9

 $\bar{Q}_1$  (sample mean number of direct subscribers)

	1992	1993	1994	1995	1996
ALL LSAs	16800	16100	16100	16700	18100
Group A	40400	400000	39600	39600	42500
Group B	3380	3400	3330	3350	3440
Group C	933	905	909	938	956
Group 1	168000	173000	167000	183000	177000
Group 2	44900	44200	44200	46600	46100
Group 3	18500	18100	18200	18200	18800
Group 4	8860	8690	8670	8430	9020
Group 5	4510	4500	4530	4420	4500
Group 6	2690	2650	2620	2660	2680
Group 7	1380	1360	1340	1420	1440
Group 8	518	530	563	562	548

Table 10  
 $Q_{\min}$ , number of direct subscribers for minimum average cost

	1992	1993	1994	1995	1996
ALL LSAs	38,300* (18,200)	27,900* (11,700)	26,700* (10,710)	14,100** (5190)	9350 (5300)
Group A (6K+)	13,300 <sup>b</sup> (8760)	21,100** (7320)	47,000 <sup>b</sup> (226,000)	7140 <sup>b</sup> (4770)	6730 <sup>b</sup> (4810)
Group B (2K-6K)	12,200 <sup>b</sup> (4020)	13,800** <sup>b</sup> (2200)	14,400 <sup>b</sup> (10,100)	15,400* <sup>b</sup> (7190)	53,100 <sup>b</sup> (281,000)
Group C (0-2K)	1,140,000 <sup>b</sup> (9,640,000)	46,700 <sup>b</sup> (36,400)	910 <sup>b</sup> (4620)	4380 <sup>b</sup> (6780)	529,000 <sup>b</sup> (1.92 x 10 <sup>7</sup> )
Group 1 (80K+)	24,700** <sup>b</sup> (821)	14,800** <sup>b</sup> (370)	18,400** (4010)	17,900** (471)	31,700 <sup>b</sup> (32,100)
Group 2 (30K-80K)	19,700** <sup>b</sup> (2020)	18,500** <sup>b</sup> (959)	24,100** (6670)	13,400** <sup>b</sup> (2470)	41,100 <sup>b</sup> (76,300)
Group 3 (14K-30K)	6,770 <sup>b</sup> (34,200)	16,200** <sup>b</sup> (3153)	18,400** <sup>b</sup> (3120)	16,000** (729)	21,300 <sup>b</sup> (12,200)
Group 4 (6K-14K)	12,000* <sup>b</sup> (5750)	18,900** <sup>b</sup> (5910)	12,900** <sup>b</sup> (3480)	12,600* <sup>b</sup> (6320)	15,700 <sup>b</sup> (8300)
Group 5 (4K-6K)	15,500** <sup>b</sup> (1110)	14,300** <sup>b</sup> (1260)	20,200 <sup>b</sup> (13,700)	15,600** <sup>b</sup> (1280)	8120 <sup>b</sup> (45,100)
Group 6 (2K-4K)	17,000** <sup>b</sup> (5130)	16,700** <sup>b</sup> (3020)	10,400 <sup>b</sup> (14,800)	31,700 <sup>b</sup> (416,000)	70,500 <sup>b</sup> (817,000)
Group 7 (1K-2K)	17,000** <sup>b</sup> (1740)	16,300** <sup>b</sup> (2330)	13,700* <sup>b</sup> (5620)	12,700 <sup>b</sup> (10,400)	22,000 <sup>b</sup> (13,400)
Group 8 (0-1K)	137,000 <sup>b</sup> (702,000)	29,800 <sup>b</sup> (26,100)	6750 <sup>b</sup> (53,600)	51,500 <sup>b</sup> (283,000)	12,200 <sup>b</sup> (6320)

standard errors in parentheses

<sup>b</sup> = hypothesis that second order condition for minimization fails cannot be rejected at 95% level

\*\* = significantly different from zero, 99% level

\* = significantly different from zero, 95% level

Table 11  
 mean  $Q_1^*$ , number of direct subscribers for minimum average cost

	1992	1993	1994	1995	1996
ALL LSAs	35,000 (21,500)	34,600 (127,700)	25,900 (29,100)	15,000 (14,200)	a
Group A (6K+)	358,000 <sup>b</sup> (1.45 x 10 <sup>6</sup> )	49,500 (7320)	9.58 x 10 <sup>11</sup> <sup>b</sup> (1.10 x 10 <sup>13</sup> )	49,800 <sup>b</sup> (92,200)	20,800 <sup>b</sup> (17,200)
Group B (2K-6K)	3530 <sup>b</sup> (2490)	3080 <sup>b</sup> (887)	7390 <sup>b</sup> (20,400)	14,500 <sup>b</sup> (29,900)	9.43 x 10 <sup>6</sup> <sup>b</sup> (5.96 x 10 <sup>7</sup> )
Group C (0-2K)	283,000 <sup>b</sup> (766,000)	2670 <sup>b</sup> (1150)	371 <sup>b</sup> (1080)	374 <sup>b</sup> (589)	6.51 x 10 <sup>7</sup> <sup>b</sup> (3.93 x 10 <sup>8</sup> )
Group 1 (80K+)	354,000 <sup>b</sup> (440,000)	161,000 <sup>b</sup> (155,000)	637,000 (1.23 x 10 <sup>6</sup> )	334,000 (566,000)	1.55 x 10 <sup>6</sup> <sup>b</sup> (3.50 x 10 <sup>6</sup> )
Group 2 (30K-80K)	53,400 <sup>b</sup> (11,200)	49,700 <sup>b</sup> (8390)	88,400 (93,200)	36,800 <sup>b</sup> (12,000)	433,000 <sup>b</sup> (712,000)
Group 3 (14K-30K)	6.12 x 10 <sup>6</sup> <sup>b</sup> (2.68 x 10 <sup>7</sup> )	28,300 <sup>b</sup> (25,800)	30,500 <sup>b</sup> (26,800)	17,100 (1770)	45,700 <sup>b</sup> (60,000)
Group 4 (6K-14K)	7450 <sup>b</sup> (3580)	13,000 <sup>b</sup> (9970)	9360 <sup>b</sup> (4540)	9400 <sup>b</sup> (5570)	11,600 <sup>b</sup> (6650)
Group 5 (4K-6K)	4400 <sup>b</sup> (701)	4730 <sup>b</sup> (1640)	5560 <sup>b</sup> (1780)	4650 <sup>b</sup> (1290)	3750 <sup>b</sup> (4050)
Group 6 (2K-4K)	2640 <sup>b</sup> (515)	3040 <sup>b</sup> (1060)	1690 <sup>b</sup> (1380)	1620 <sup>b</sup> (1210)	73,900 <sup>b</sup> (177,000)
Group 7 (1K-2K)	1500 <sup>b</sup> (338)	1380 <sup>b</sup> (182)	1690 <sup>b</sup> (1380)	1620 <sup>b</sup> (1210)	1940 <sup>b</sup> (1150)
Group 8 (0-1K)	14,800 <sup>b</sup> (29,900)	1010 <sup>b</sup> (195)	3.02 x 10 <sup>8</sup> <sup>b</sup> (1.61 x 10 <sup>9</sup> )	27,700 <sup>b</sup> (159,000)	365 <sup>b</sup> (83.2)

standard errors in parentheses, for comparison only

a = no estimate available: sample size too small; or singular derivatives; or  $a_{qiqi}$  too small relative to  $a_{qi}$

b = hypothesis that second order condition for minimization fails cannot be rejected at 95% level

Table 12  
 $\mu_1$  (inverse of cost-output elasticity), direct subscribers

	1992	1993	1994	1995	1996
ALL LSAs	1.07** (0.0326)	1.05** <sup>c</sup> (0.0317)	1.05** <sup>c</sup> (0.0300)	0.988** <sup>c</sup> (0.0260)	0.966** <sup>c</sup> (0.287)
Group A (6K+)	0.988** <sup>c</sup> (0.0327)	1.03** <sup>c</sup> (0.0418)	1.02** <sup>c</sup> (0.0362)	0.952** <sup>c</sup> (0.0262)	0.913** (0.0282)
Group B (2K-6K)	1.12** <sup>c</sup> (0.119)	1.08** <sup>c</sup> (0.103)	1.01** <sup>c</sup> (0.0861)	1.01** <sup>c</sup> (0.0968)	0.896** <sup>c</sup> (0.819)
Group C (0-2K)	1.31** (0.113)	1.37** (0.135)	1.31** (0.126)	1.23** <sup>c</sup> (0.130)	1.08** <sup>c</sup> (0.119)
Group 1 (80K+)	0.734** (0.016)	2.29** <sup>c</sup> (0.858)	1.12** (0.211)	1.08** (0.0344)	0.926** <sup>c</sup> (0.0592)
Group 2 (30K-80K)	0.793** (0.0568)	0.711** (0.0713)	0.710** (0.0629)	0.811** (0.0760)	0.825** (0.0690)
Group 3 (14K-30K)	1.15** <sup>c</sup> (0.134)	1.00** <sup>c</sup> (0.142)	1.14** <sup>c</sup> (0.143)	0.898** (0.0908)	1.06** (0.128)
Group 4 (6K-14K)	1.19** <sup>c</sup> (0.178)	1.12** <sup>c</sup> (0.170)	1.12** <sup>c</sup> (0.142)	1.12** <sup>c</sup> (0.136)	1.05** <sup>c</sup> (0.195)
Group 5 (4K-6K)	2.31 <sup>c</sup> (1.86)	2.76 <sup>c</sup> (2.03)	1.82 (1.31)	1.52 <sup>c</sup> (0.835)	0.727** <sup>c</sup> (0.185)
Group 6 (2K-4K)	0.989** <sup>c</sup> (0.172)	0.963** <sup>c</sup> (0.157)	0.910** <sup>c</sup> (0.114)	0.955** <sup>c</sup> (0.170)	0.796** <sup>c</sup> (0.146)
Group 7 (1K-2K)	1.03** <sup>c</sup> (0.233)	1.02** <sup>c</sup> (0.236)	1.11** <sup>c</sup> (0.243)	1.26* <sup>c</sup> (0.498)	0.821** <sup>c</sup> (0.214)
Group 8 (0-1K)	1.31** <sup>c</sup> (0.215)	1.27** <sup>c</sup> (0.215)	0.973** <sup>c</sup> (0.103)	0.889** <sup>c</sup> (0.132)	0.842** <sup>c</sup> (0.144)

standard errors in parentheses

c = hypothesis of constant returns to scale not rejected:  $\mu_1$  not significantly different from 1, 95% level

\*\* = significantly different from zero, 99% level

\* = significantly different from zero, 95% level

Table 13

 $\bar{Q}_2$  , sample mean number of indirect subscribers

	1992	1993	1994	1995	1996
ALL LSAs	1960	1960	1920	1471	1430
Group A	4780	4890	4780	3470	3320
Group B	325	368	341	291	298
Group C	95.6	102	96	101	97.7
Group 1	24000	26200	24200	18700	15900
Group 2	3950	3750	3850	3030	2840
Group 3	1600	1640	1760	1440	1300
Group 4	685	706	741	609	497
Group 5	375	409	395	357	385
Group 6	295	340	310	248	236
Group 7	122	133	118	145	141
Group 8	71	76.4	78	66	61.1

Table 14  
 $Q_{2min}$ , number of indirect subscribers for minimum average cost

	1992	1993	1994	1995	1996
ALL LSAs	a	$7.71 \times 10^{29}{}^b$ ( $3.45 \times 10^{31}$ )	$7.09 \times 10^{26}{}^b$ ( $2.17 \times 10^{28}$ )	a	a
Group A (6K+)	$3.65 \times 10^{-21}{}^b$ ( $1.50 \times 10^{-19}$ )	a	a	$5.90 \times 10^{-30}{}^b$ ( $4.17 \times 10^{-28}$ )	$1.12 \times 10^{-31}{}^b$ ( $9.83 \times 10^{-30}$ )
Group B (2K-6K)	$5.62 \times 10^{11}{}^b$ ( $6.08 \times 10^{12}$ )	$7.53 \times 10^{15}{}^b$ ( $1.74 \times 10^{17}$ )	$2.89 \times 10^{12}$ ( $2.60 \times 10^{13}$ )	$1.90 \times 10^{10}$ ( $1.35 \times 10^{11}$ )	$5.92 \times 10^8$ ( $3.06 \times 10^9$ )
Group C (0-2K)	$1.00 \times 10^8{}^b$ ( $2.28 \times 10^7$ )	$2.30 \times 10^{15}{}^b$ ( $4.95 \times 10^{16}$ )	$8.84 \times 10^{10}{}^b$ ( $8.62 \times 10^{11}$ )	a	$1.79 \times 10^{12}{}^b$ ( $3.91 \times 10^{13}$ )
Group 1 (80K+)	614 <sup>b</sup> (15.6)	1980 <sup>b</sup> (42.4)	4160** (433)	$2.63 \times 10^7$ ( $4.84 \times 10^7$ )	3.15 (8.36)
Group 2 (30K-80K)	$8.66 \times 10^8{}^b$ ( $6.62 \times 10^9$ )	0.225 <sup>b</sup> (0.472)	$3.08 \times 10^{21}{}^b$ ( $2.33 \times 10^{23}$ )	266,000 (350,000)	$1.83 \times 10^8$ ( $8.56 \times 10^8$ )
Group 3 (14K-30K)	a	1.35 <sup>b</sup> (4.13)	0.0673 <sup>b</sup> (0.358)	$5.48 \times 10^{-14}$ ( $2.50 \times 10^{-12}$ )	$6.94 \times 10^{-8}{}^b$ ( $1.75 \times 10^{-6}$ )
Group 4 (6K-14K)	$7.06 \times 10^{-21}{}^b$ ( $3.91 \times 10^{-19}$ )	a	$1.82 \times 10^{-15}{}^b$ ( $6.48 \times 10^{-14}$ )	$1.21 \times 10^{-17}{}^b$ ( $5.33 \times 10^{-16}$ )	$1.26 \times 10^{-23}$ ( $1.04 \times 10^{-21}$ )
Group 5 (4K-6K)	a	$8.09 \times 10^{-4}{}^b$ ( $6.51 \times 10^{-3}$ )	$1.01 \times 10^9{}^b$ ( $8.27 \times 10^9$ )	$4.37 \times 10^{-3}{}^b$ (0.0363)	$8.92 \times 10^{-14}{}^b$ ( $8.00 \times 10^{-12}$ )
Group 6 (2K-4K)	$1.25 \times 10^8$ ( $6.50 \times 10^8$ )	$1.21 \times 10^9{}^b$ ( $1.06 \times 10^{10}$ )	$5.37 \times 10^{14}{}^b$ ( $8.48 \times 10^{15}$ )	$4.03 \times 10^8$ ( $2.07 \times 10^9$ )	$1.91 \times 10^8$ ( $1.18 \times 10^9$ )
Group 7 (1K-2K)	$1.59 \times 10^{-10}{}^b$ ( $4.34 \times 10^{-9}$ )	a	$1.35 \times 10^{13}{}^b$ ( $1.95 \times 10^{14}$ )	$1.15 \times 10^{17}{}^b$ ( $7.81 \times 10^{18}$ )	$1.50 \times 10^{-34}{}^b$ ( $5.51 \times 10^{-32}$ )
Group 8 (0-1K)	$1.30 \times 10^{-12}{}^b$ ( $6.80 \times 10^{-11}$ )	$3.19 \times 10^7{}^b$ ( $1.59 \times 10^8$ )	$2.45 \times 10^{10}{}^b$ ( $3.32 \times 10^{11}$ )	$2.41 \times 10^{24}{}^b$ ( $3.78 \times 10^{26}$ )	$7.22 \times 10^6{}^b$ ( $5.06 \times 10^7$ )

standard errors in parentheses

a = no estimate available: sample size too small; or singular derivatives; or  $a_{qiqi}$  too small relative to  $a_{qi}$

b = hypothesis that second order condition for minimization fails cannot be rejected at 95% level

\*\* = significantly different from zero, 99% level

\* = significantly different from zero, 95% level

Table 15  
mean  $Q_2^*$ , number of indirect subscribers for minimum average cost

	1992	1993	1994	1995	1996
ALL LSAs	a	$2.75 \times 10^{30}{}^b$ ( $4.43 \times 10^{30}$ )	$4.40 \times 10^{27}{}^b$ ( $4.54 \times 10^{28}$ )	a	a
Group A (6K+)	$7.74 \times 10^{-18}{}^b$ ( $4.86 \times 10^{-17}$ )	a	a	$2.81 \times 10^{-27}{}^b$ ( $2.33 \times 10^{-26}$ )	$6.94 \times 10^{-31}{}^b$ ( $2.30 \times 10^{-30}$ )
Group B (2K-6K)	$1.07 \times 10^{11}{}^b$ ( $6.16 \times 10^{10}$ )	$3.40 \times 10^{15}{}^b$ ( $6.99 \times 10^{15}$ )	$2.85 \times 10^{12}$ ( $1.33 \times 10^{13}$ )	$1.12 \times 10^{10}$ ( $2.32 \times 10^{10}$ )	$1.89 \times 10^8$ ( $1.54 \times 10^8$ )
Group C (0-2K)	$3.17 \times 10^{-11}{}^b$ ( $8.09 \times 10^{-11}$ )	$1.77 \times 10^{14}{}^b$ ( $2.62 \times 10^{14}$ )	$1.23 \times 10^{10}{}^b$ ( $2.33 \times 10^{10}$ )	a	$4.67 \times 10^{11}{}^b$ ( $1.32 \times 10^{12}$ )
Group 1 (80K+)	10,900 <sup>b</sup> (14,800)	26,700 <sup>b</sup> (26,200)	122,000 <sup>**</sup> (184,000)	$1.32 \times 10^{11}$ ( $4.63 \times 10^{11}$ )	109 (283)
Group 2 (30K-80K)	$2.82 \times 10^9{}^b$ ( $2.32 \times 10^9$ )	0.913 <sup>b</sup> (1.47)	$3.94 \times 10^{26}{}^b$ ( $1.95 \times 10^{27}$ )	674,000 (517,000)	$4.81 \times 10^8$ ( $5.00 \times 10^8$ )
Group 3 (14K-30K)	a	1.73 <sup>b</sup> (2.19)	0.162 <sup>b</sup> (0.303)	$6.08 \times 10^{-11}$ ( $2.62 \times 10^{-10}$ )	$7.75 \times 10^{-8}{}^b$ ( $6.96 \times 10^{-8}$ )
Group 4 (6K-14K)	$2.73 \times 10^{-18}{}^b$ ( $1.88 \times 10^{-17}$ )	a	$5.76 \times 10^{-13}{}^b$ ( $3.45 \times 10^{-12}$ )	$9.51 \times 10^{-15}{}^b$ ( $3.26 \times 10^{-16}$ )	$2.52 \times 10^{-22}$ ( $7.20 \times 10^{-22}$ )
Group 5 (4K-6K)	a	$2.09 \times 10^{-3}{}^b$ ( $5.04 \times 10^{-3}$ )	$8.83 \times 10^8{}^b$ ( $2.88 \times 10^9$ )	0.0104 <sup>b</sup> (0.0505)	$5.41 \times 10^{-13}{}^b$ ( $1.05 \times 10^{-12}$ )
Group 6 (2K-4K)	$2.26 \times 10^7$ ( $8.83 \times 10^6$ )	$3.47 \times 10^8{}^b$ ( $5.22 \times 10^8$ )	$3.87 \times 10^{14}{}^b$ ( $7.17 \times 10^{14}$ )	$2.37 \times 10^8$ ( $3.39 \times 10^8$ )	$9.29 \times 10^7$ ( $1.40 \times 10^8$ )
Group 7 (1K-2K)	$9.59 \times 10^{-10}{}^b$ ( $5.15 \times 10^{-9}$ )	a	$1.04 \times 10^{13}{}^b$ ( $4.51 \times 10^{13}$ )	$6.65 \times 10^{17}{}^b$ ( $2.41 \times 10^{17}$ )	$1.16 \times 10^{-28}{}^b$ ( $7.17 \times 10^{-28}$ )
Group 8 (0-1K)	$2.07 \times 10^{-12}{}^b$ ( $1.00 \times 10^{-11}$ )	$1.82 \times 10^6{}^b$ ( $2.19 \times 10^6$ )	$3.67 \times 10^9{}^b$ ( $6.07 \times 10^9$ )	$1.63 \times 10^{31}{}^b$ ( $1.26 \times 10^{32}$ )	354,000 <sup>b</sup> (138,000)

standard errors in parentheses

a = no estimate available: sample size too small; or singular derivatives; or  $a_{qi}$  too small relative to  $a_{q_i}$

b = hypothesis that second order condition for minimization fails cannot be rejected at 95% level

\*\* = significantly different from zero, 99% level

\* = significantly different from zero, 95% level

Table 16  
 $\mu_2$  (inverse of cost-output elasticity), indirect subscribers

	1992	1993	1994	1995	1996
ALL LSAs	24.0 <sup>c</sup> (13.5)	14.2** (5.04)	19.1* (8.25)	837 <sup>c</sup> (16,500)	110 <sup>c</sup> (323)
Group A (6K+)	18.0* (8.03)	13.8* (5.93)	13.0** (4.60)	35.4 <sup>c</sup> (29.1)	-211 <sup>c</sup> (1090)
Group B (2K-6K)	9.85** (3.08)	18.5 <sup>c</sup> (11.8)	13.8** (5.21)	18.2 <sup>c</sup> (10.7)	10.6** (3.80)
Group C (0-2K)	-87.8 <sup>c</sup> (309)	23.3 <sup>c</sup> (22.0)	15.4 <sup>c</sup> (9.49)	26.2 <sup>c</sup> (33.1)	38.5 <sup>c</sup> (85.0)
Group 1 (80K+)	-28.5 <sup>c</sup> (15.1)	0.929** <sup>c</sup> (0.117)	3.86** <sup>c</sup> (1.46)	2.61** (0.117)	16.5 <sup>c</sup> (11.4)
Group 2 (30K-80K)	4.23** (0.678)	91.8 <sup>c</sup> (297)	8.58** (2.79)	5.25** (1.05)	13.5 <sup>c</sup> (5.60)
Group 3 (14K-30K)	101 <sup>c</sup> (543)	23.7 <sup>c</sup> (29.1)	42.3 <sup>c</sup> (95.9)	-9.53** (3.69)	-14.6 <sup>c</sup> (9.76)
Group 4 (6K-14K)	-360 <sup>c</sup> (4230)	60.4 <sup>c</sup> (143)	-44.7 <sup>c</sup> (75.9)	-39.7 <sup>c</sup> (63.9)	-257 <sup>c</sup> (3130)
Group 5 (4K-6K)	15.0 <sup>c</sup> (13.9)	27.6 <sup>c</sup> (40.8)	7.25* (6.25)	-19.2 <sup>c</sup> (29.5)	27.9 <sup>c</sup> (55.8)
Group 6 (2K-4K)	6.99** (1.85)	16.7 <sup>c</sup> (14.0)	21.1 <sup>c</sup> (14.7)	14.9 <sup>c</sup> (8.78)	8.81* (3.73)
Group 7 (1K-2K)	-294 <sup>c</sup> (4940)	40.9 <sup>c</sup> (106)	13.0 <sup>c</sup> (7.49)	9.38 <sup>c</sup> (7.25)	148 <sup>c</sup> (1560)
Group 8 (0-1K)	-19.8 <sup>c</sup> (20.6)	14.2 <sup>c</sup> (10.7)	12.4 <sup>c</sup> (7.86)	12.0 <sup>c</sup> (8.63)	20.9 <sup>c</sup> (36.4)

standard errors in parentheses

c = hypothesis of constant returns to scale not rejected:  $\mu_1$  not significantly different from 1, 95% level

\*\* = significantly different from zero, 99% level

\* = significantly different from zero, 95% level

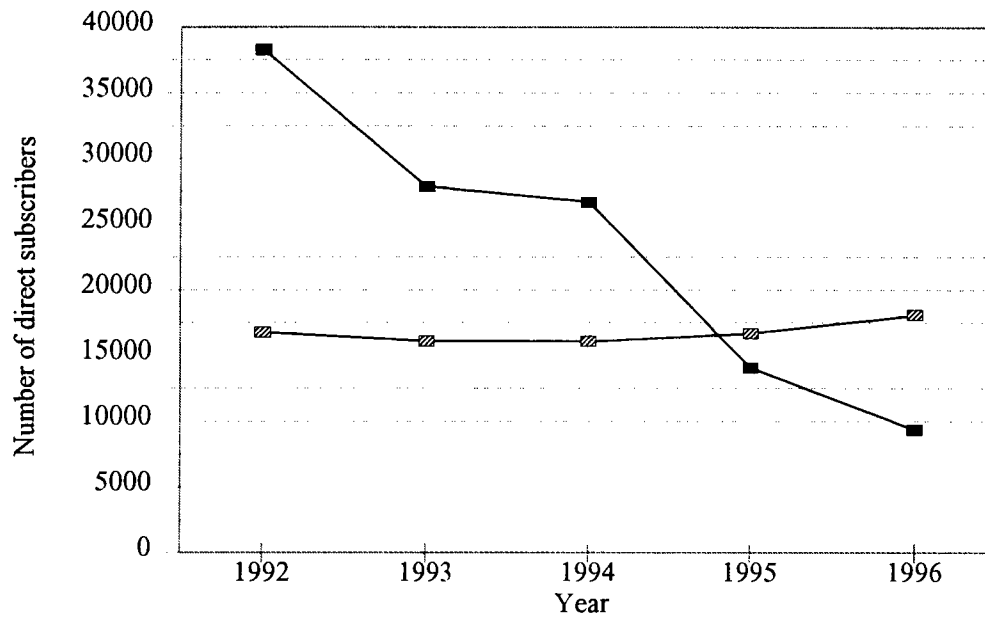
Table 17  
 $\gamma$  (percent of LSAs that are "too small"), direct plus indirect subscribers

	1992	1993	1994	1995	1996
ALL LSAs	88 <sup>R</sup>	100	100	65 <sup>R</sup>	63 <sup>R</sup>
Group A (6K+)	54	71	65 <sup>R</sup>	36	25
Group B (2K-6K)	100	100	100	100	100
Group C (0-2K)	100	100	100	6 <sup>R</sup>	100
Group 1 (80K+)	50	29	63	94	57
Group 2 (30K-80K)	100	34	100	100	100
Group 3 (14K-30K)	39 <sup>R</sup>	36	45	10	58
Group 4 (6K-14K)	18	47 <sup>R</sup>	33	29	45
Group 5 (4K-6K)	3 <sup>R</sup>	9	100	8	13
Group 6 (2K-4K)	100	100	100	100	100
Group 7 (1K-2K)	24	16 <sup>R</sup>	100	100	44
Group 8 (0-1K)	82	100	100	100	100

"too small" means that  $Q_{1min} + Q_{2min} > \text{maximum number of subscribers in LSA}$

R = based on direct subscribers ( $Q_{1min}$ ) only

**Figure 1**  
Direct Subscribers: Number for Minimum ATC and Sample Mean



—■— Direct subs for min ATC      —▨— Sample mean

**Table 18**  
DEA sample characteristics (1996) by size class

		Labour (input)	Cable KM (input)	Direct Subscribers (output)	Indirect Subscribers (output)	# channels (output)
$Q_{total} < 1000$	Mean	1.2781	29.33	534.35	67.777	19.87
N = 54	(S.D.)	(0.9595)	(27.45)	(237.69)	(78.13)	(6.690)
$1000 < Q_{total} < 2000$	Mean	2.23	61.93	1430.3	140.77	22.47
N=44	(S.D.)	(1.56)	(29.69)	(266.1)	(115.18)	(5.20)
$2000 < Q_{total} < 4000$	Mean	3.57	216.94	2666.3	235.06	23.438
N=73	(S.D.)	(2.18)	(895.92)	(545.67)	(291.11)	(6.80)
$4000 < Q_{total} < 6000$	Mean	6.16	184.99	4494.2	384.83	23.547
N=53	(S.D.)	(2.92)	(99.63)	(670.52)	(319.77)	(4.81)
$6000 < Q_{total} < 14000$	Mean	12.59	367.02	9023.1	496.54	23.21
N=51	(S.D.)	(5.92)	(226.04)	(2277.67)	(414.41)	(5.10)
$14000 < Q_{total} < 30000$	Mean	21.11	590.2	18806	1299.8	25.875
N=40	(S.D.)	(9.38)	(223.01)	(4373.9)	(939.02)	(4.49)
$30000 < Q_{total} < 80000$	Mean	53.18	1249.0	46073	2843.5	26.433
N=30	(S.D.)	(21.19)	(517.8)	(13324)	(2157.2)	(4.53)
$Q_{total} > 80000$	Mean	196.63	3158.3	176708	15901	28.63
N=19	(S.D.)	(178.97)	(2331.6)	(48835.4)	(17842)	(5.00)

Table 19

Average DEA scores and scale efficiency measures by size class (1992)

Size Class and Average Scores	Input Orientation			Output Orientation		
	VRS	CRS	% ISE	VRS	CRS	% OSE
$Q_{total} \leq 1000$	0.617	0.521	0.22	1.393	2.358	0.11
$1000 < Q_{total} \leq 2000$	0.721	0.532	0.10	1.169	2.259	0.15
$2000 < Q_{total} \leq 4000$	0.688	0.521	0.07	1.164	2.218	0.07
$4000 < Q_{total} \leq 6000$	0.829	0.734	0.35	1.079	1.486	0.3
$6000 < Q_{total} \leq 14000$	0.562	0.394	0.08	1.255	3.279	0.06
$14000 < Q_{total} \leq 30000$	0.923	0.845	0.26	1.074	1.219	0.29
$30000 < Q_{total} \leq 80000$	0.869	0.784	0.4	1.138	1.356	0.36
$Q_{total} > 80000$	0.875	0.777	0.22	1.089	1.339	0.17

Table 20

Average DEA scores and scale efficiency measures by size class (1993)

Size Class and Average Scores	Input Orientation			Output Orientation		
	VRS	CRS	% ISE	VRS	CRS	% OSE
$Q_{total} \leq 1000$	0.636	0.537	0.26	1.299	2.420	0.20
$1000 < Q_{total} \leq 2000$	0.813	0.700	0.22	1.110	1.664	0.28
$2000 < Q_{total} \leq 4000$	0.663	0.497	0.17	1.172	2.386	0.08
$4000 < Q_{total} \leq 6000$	0.790	0.666	0.23	1.108	1.651	0.15
$6000 < Q_{total} \leq 14000$	0.545	0.394	0.08	1.241	3.324	0.04
$14000 < Q_{total} \leq 30000$	0.913	0.862	0.44	1.067	1.196	0.33
$30000 < Q_{total} \leq 80000$	0.867	0.778	0.27	1.120	1.361	0.27
$Q_{total} > 80000$	0.906	0.786	0.29	1.066	1.332	0.23

Table 21  
Average DEA scores and scale efficiency measures by size class (1994)

Size Class and Average Scores	Input Orientation			Output Orientation		
	VRS	CRS	% ISE	VRS	CRS	% OSE
$Q_{total} \leq 1000$	0.714	0.612	0.20	1.276	1.888	0.15
$1000 < Q_{total} \leq 2000$	0.802	0.646	0.21	1.098	1.794	0.23
$2000 < Q_{total} \leq 4000$	0.671	0.463	0.15	1.168	2.600	0.07
$4000 < Q_{total} \leq 6000$	0.809	0.748	0.39	1.104	1.513	0.30
$6000 < Q_{total} \leq 14000$	0.581	0.426	0.12	1.202	3.051	0.05
$14000 < Q_{total} \leq 30000$	0.914	0.876	0.47	1.076	1.205	0.5
$30000 < Q_{total} \leq 80000$	0.876	0.792	0.39	1.083	1.334	0.28
$Q_{total} > 80000$	0.914	0.764	0.21	1.062	1.383	0.21

Table 22  
Average DEA scores and scale efficiency measures by size class (1995)

Size Class and Average Scores	Input Orientation			Output Orientation		
	VRS	CRS	% ISE	VRS	CRS	% OSE
$Q_{total} \leq 1000$	0.746	0.645	0.33	1.251	1.853	0.18
$1000 < Q_{total} \leq 2000$	0.749	0.658	0.34	1.095	1.786	0.25
$2000 < Q_{total} \leq 4000$	0.652	0.438	0.09	1.170	2.899	0.07
$4000 < Q_{total} \leq 6000$	0.743	0.668	0.44	1.108	1.709	0.21
$6000 < Q_{total} \leq 14000$	0.644	0.546	0.21	1.216	2.242	0.11
$14000 < Q_{total} \leq 30000$	0.906	0.842	0.35	1.085	1.220	0.28
$30000 < Q_{total} \leq 80000$	0.841	0.784	0.32	1.166	1.373	0.42
$Q_{total} > 80000$	0.913	0.709	0.05	1.052	1.464	0.06

Table 23  
Average DEA scores and scale efficiency measures by size class (1996)

Size Class and Average Scores	Input Orientation			Output Orientation		
	VRS	CRS	% ISE	VRS	CRS	% OSE
$Q_{total} \leq 1000$	0.767	0.616	0.2	1.209	1.928	0.18
$1000 < Q_{total} \leq 2000$	0.742	0.645	0.34	1.099	1.890	0.27
$2000 < Q_{total} \leq 4000$	0.730	0.476	0.12	1.137	2.678	0.08
$4000 < Q_{total} \leq 6000$	0.772	0.694	0.32	1.093	1.645	0.19
$6000 < Q_{total} \leq 14000$	0.670	0.561	0.25	1.173	2.092	0.14
$14000 < Q_{total} \leq 30000$	0.843	0.783	0.25	1.120	1.341	0.27
$30000 < Q_{total} \leq 80000$	0.791	0.741	0.43	1.164	1.486	0.3
$Q_{total} > 80000$	0.865	0.761	0.21	1.084	1.353	0.16

Figure 2. Returns-to-scale in DEA (Adapted from Lovell, 1993)

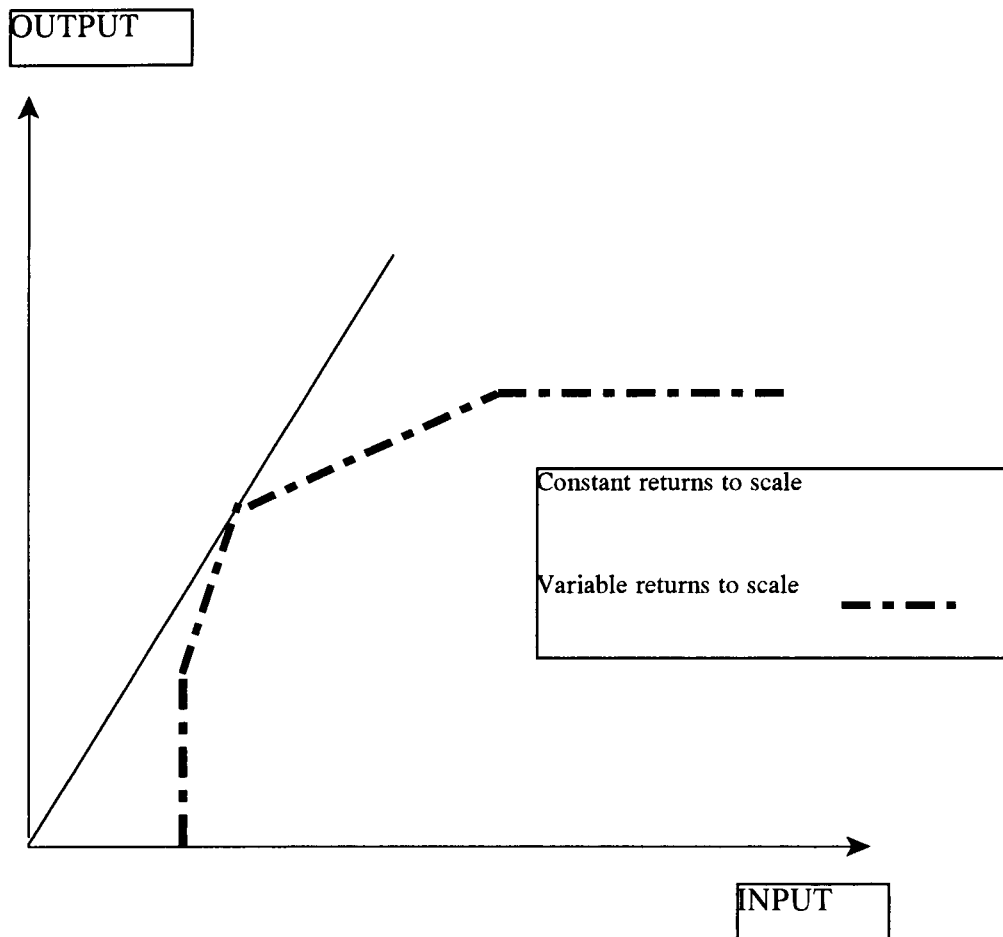


Figure 3

Input Oriented Scale Efficiency, Percentages by Year

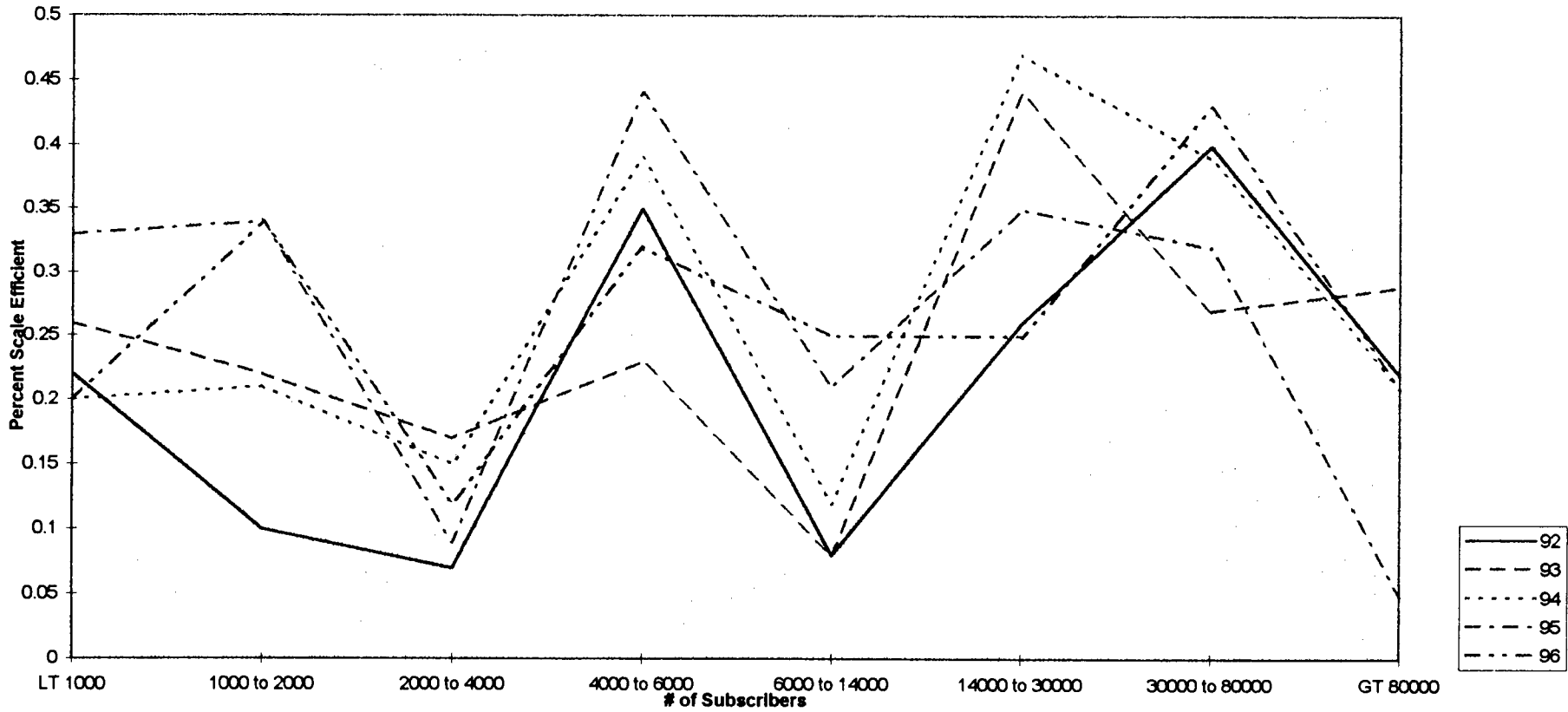
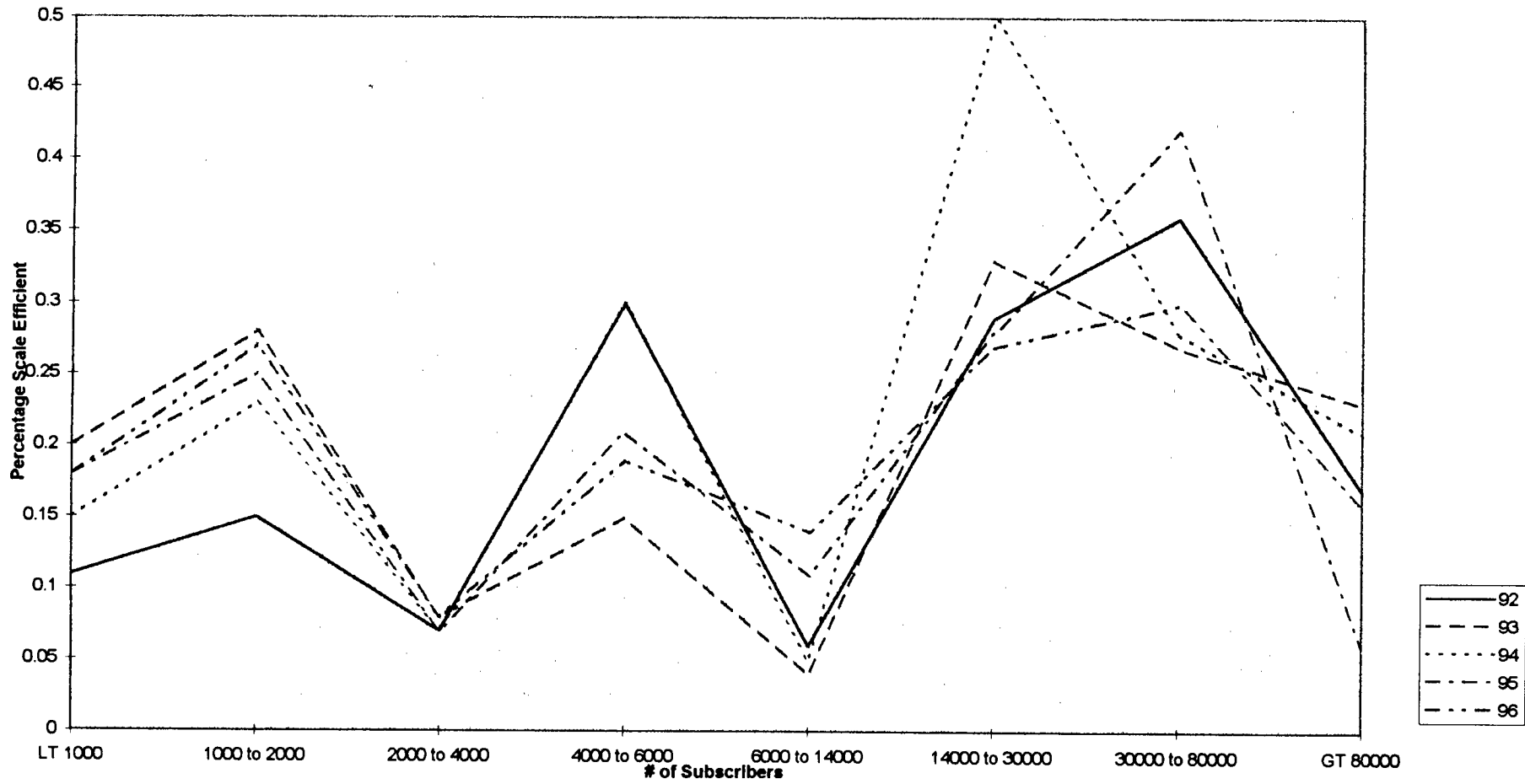


Figure 4

Output Oriented Scale Efficiency, Percentages By Year



## APPENDIX A

### Data and Technical Appendix for Translog Cost Function

*Output.* When three outputs are considered, these are the number of direct subscribers,  $Q_1$ , the number of indirect subscribers,  $Q_2$ , and the number of channels with signals provided in the basic tier of service by the CATV operator,  $H$ . When only one output is considered, the unit of output is a subscription to basic service. The subscription level is the "equivalent total" number of subscribers, calculated as the number of direct subscribers to basic service inflated by the ratio of total revenue, from both direct and indirect subscribers, to revenue from direct subscribers. The number of subscribers is thus adjusted to revalue indirect subscribers (*e.g.*, in apartment buildings where cable services are part of the rent) to be comparable to direct subscribers.

*Cable Length and Density.* LSAs comprising relatively larger territories require more cable; LSAs which are relatively more sparsely populated require more cable per subscriber.<sup>32</sup> To reflect the variations in density that exist among the LSAs, subscriber sparsity (inverse density) is measured by the kilometers of cable per wired household.<sup>33</sup>

*Capital inputs.* The level of net assets is as calculated by the CRTC: the historical cost of those assets less accumulated depreciation. The rental price of capital is the sum of depreciation and financing rates. The depreciation rate is obtained directly from the CRTC database. The financing rate used here is given by:  $i$ , the "risk free" interest rate (the average of the monthly ten-year-plus bond rate for a year ending in August),<sup>34</sup> plus a risk premium,  $\gamma\beta$ , where  $\gamma$  is the market risk premium and  $\beta$  is the systematic risk factor. The assumption required for this value for the risk premium is either that the firms are 100% equity-financed, or, equivalently, that the required rate of return on equity is equal to the required rate of return on debt. Following the capital asset pricing model, Noam (1985) calculates a risk premium from the risk premium for the S&P 500 for 1926-1977 of 0.088, multiplied by  $\beta$ , the nondiversifiable (system) risk ( $\beta=1.42$  for cable companies, 1980 Moody's estimate).<sup>35</sup> This value for  $\beta$  of 1.42 was calculated over all of the activities of CATV firms, including involvement in the provision of non-basic services. However, following the capital asset pricing model and Patterson (1990), it is possible to estimate an unlevered  $\beta$ ,  $\beta_u$ , which accounts only for the systematic risk of the provision of basic services. To arrive at this value, Patterson (1990) uses an estimate of  $\beta$  for CATV corporations

and adjusts by a leverage factor to arrive at an estimate of the unlevered  $\beta_u$  for basic service of 0.6. This value is lower than that used by Noam since it incorporates an adjustment for debt and reflects the systematic risk for the provision of basic service only. The provision of non-basic services is likely to be a more risky activity.

Estimated values for the market risk premium in Canada (over long-term government bonds) range from 6.67% to 8.35%, with more recent estimates or estimates over the later parts of the sample periods used in the studies falling at the lower end of the range.<sup>36</sup> The risk premium used is 0.042 from market risk of 7% and  $\beta$  of 0.6.

*Labour and other inputs.* Operating expenses, non-capital-related costs, are total expenses less programming expenses.<sup>37</sup> Operating expenses are salaries plus expenditures on "materials". To derive the price of labour, salaries are divided by the number of staff employed within the LSA. The cost of "materials" is the sum of costs of other inputs in operating expenses other than labour and the price of materials is proxied by the Industrial Product Price Index.<sup>38</sup>

*Revenue.* Revenue is the total revenue from basic service, including revenues from direct subscribers, indirect subscribers, and installation fees.

*Costs.* Total costs,  $TC = \text{operating expenses} + \text{depreciation} + ((i + \gamma\beta) * (\text{net assets}))$ ,

where operating expenses are total expenses less programming expenses and the other components are as defined above under capital inputs. An assumption maintained for this study is that costs are additively separable by output, *i.e.*, considering basic service alone, without including the provision of non-basic services, does not introduce excessive bias.<sup>39</sup>

*Model*

Expanding the translog cost function, given in Equation (2), yields:

$$\begin{aligned}
\log C = & a_0 + a_k \log P_K + a_l \log P_L + a_m \log P_M + a_{q1} \log Q_1 + a_{q2} \log Q_2 + a_h \log H + a_d \log P_D \\
& + \frac{1}{2} a_{kk} (\log P_K)^2 + a_{kl} \log P_K \log P_L + a_{km} \log P_K \log P_M + a_{kq1} \log P_K \log Q_1 \\
& \quad + a_{kq2} \log P_K \log Q_2 + a_{kh} \log P_K \log H + a_{kd} \log P_K \log D \\
& + \frac{1}{2} a_{ll} (\log P_L)^2 + a_{lm} \log P_L \log P_M + a_{lq1} \log P_L \log Q_1 + a_{lq2} \log P_L \log Q_2 \\
& \quad + a_{lh} \log P_L \log H + a_{ld} \log P_L \log D \\
& + \frac{1}{2} a_{mm} (\log P_M)^2 + a_{mq1} \log P_M \log Q_1 + a_{mq2} \log P_M \log Q_2 + a_{mh} \log P_M \log H + a_{md} \log P_M \log D \quad (A1) \\
& + \frac{1}{2} a_{q1q1} (\log Q_1)^2 + a_{q1q2} \log Q_1 \log Q_2 + a_{q1h} \log Q_1 \log H + a_{q1d} \log Q_1 \log D \\
& + \frac{1}{2} a_{q2q2} (\log Q_2)^2 + a_{q2h} \log Q_2 \log H + a_{q2d} \log Q_2 \log D \\
& + \frac{1}{2} a_{hh} (\log H)^2 + a_{hd} \log H \log D \\
& + \frac{1}{2} a_{dd} (\log D)^2
\end{aligned}$$

which is estimated simultaneously with the share equations, from Equation (3):

$$S_k = a_k + a_{kk} \log P_K + a_{kl} \log P_L + a_{km} \log P_M + a_{kq1} \log Q_1 + a_{kq2} \log Q_2 + a_{kh} \log H + a_{kd} \log D; \quad (A2)$$

$$S_l = a_l + a_{ll} \log P_L + a_{lm} \log P_M + a_{lq1} \log Q_1 + a_{lq2} \log Q_2 + a_{lh} \log H + a_{ld} \log D; \quad (A3)$$

$$S_m = a_m + a_{mm} \log P_M + a_{mq1} \log Q_1 + a_{mq2} \log Q_2 + a_{mh} \log H + a_{md} \log D; \quad (A4)$$

where  $C$  = total costs;  $P_K$  = price of capital;  $P_L$  = price of labour;  $P_M$  = price of "materials";  $Q_1$  = number of direct subscribers to basic service; ;  $Q_2$  = number of indirect subscribers to basic service;  $H$  = the number of channels provided in basic service;  $D$  = density; and  $S_K$ ,  $S_L$ , and  $S_M$  are the cost shares of capital, labour, and "materials", respectively.

Table A1  
Descriptive Statistics for Full Sample (All LSAs), 1996, Single Output Measure

Variable	Mean	Std Dev	Minimum	Maximum
Equivalent Total Subscribers, Q	37088.7	152723.8	36	2860943
Mixed Total Subscribers, $Q_1 + Q_2$	14823.0	48810.7	36	714338
Total Cost, C	3350098.29	12083700	7355.16	1.74814000
Price of Capital, $P_K$	0.31583	0.12158	0.012063	1.59437
Price of Labour, $P_L$	39276.59	22289.76	200.00	261285.00
Cost Share of Capital, $S_K$	0.29271	0.13289	0.00051516	0.87070
Cost Share of Labour, $S_L$	0.22442	0.10334	0.0053188	0.78250
Total Kilometers of Cable	350.2	788.6	3.0	11310
Houses Passed (wired for cable)	19227.5	69489.8	53	1159781
Density Measure	0.033935	0.025541	0.0050119	0.31200

Number of Observations: 517

Table A2  
Descriptive Statistics, Full Sample (All LSAs), 1996

Variable	Mean	Std Dev	Minimum	Maximum
Direct Subscribers, $Q_1$	18069.19	51991.18	67	667567
Indirect Subscribers, $Q_2$	1427.15	5379.54	1	71296
Channels, H	23.59	6.00	8	42
Total Cost, C	4420724.38	14190300	8681.35	174814000
Price of Capital, $P_K$	0.31578	0.095772	0.12027	1.59437
Price of Labour, $P_L$	44056.20	22403.30	2556.00	261285.00
Cost Share of Labour, $S_L$	0.22724	0.091340	0.014374	0.65398
Cost Share of Capital, $S_K$	0.30461	0.12703	0.00051516	0.80442
Total Kilometers of cable	451.37634	914.76813	3.3600	11310.10
Houses Passed (wired for cable)	25029.1	80806.5	165	1159781
Density Measure	0.022213	0.037673	0.0050119	0.13641

Number of Observations: 358

**APPENDIX B**  
**Selected Results from 1985-1991**

Table B1  
 Descriptive Statistics for LSAs (All Classes), 1985 and 1991

		Mean	Std. Dev.	Minimum	Maximum
Number of subscribers, Q	1985	12119.5	31636.8	72	314380
	1991	17504.8	47139.7	68	612398
Total cost, TC	1985	1294234.37	3421592.50	8771.90	40287300.00
	1991	3329390.54	10048000.00	17521.81	139554000.00
Price of capital, P <sub>K</sub>	1985	0.35438	0.08024	0.16189	1.03192
	1991	0.34418	0.17340	0.15000	3.39730
Price of labour, P <sub>L</sub>	1985	21599.19	10147.08	1167.33	63842.00
	1991	30646.78	16345.21	300.00	163872.61
Kilometers of cable	1985	242.6	457.9	1.0	3571.0
	1991	378.5	729.0	2.1	9587.0
Houses passed (wired for cable service)	1985	16744.1	49519.8	89.0	607780.0
	1991	23192.6	69695.9	88.0	1012266.0
Density measure	1985	0.026266	0.015305	0.0011976	0.11192
	1991	0.030489	0.020622	0.0025794	0.15515
Revenue	1985	1510398.40	3996828.79	7853.00	45815100.00
	1991	3674900.73	10660700.00	17561.00	151172000.00
Average revenue	1985	148.16	45.61	63.21	338.75
	1991	234.10	69.54	102.29	741.26

Source: Law (1997, 334-346)

Table B2  
 Q<sub>min</sub>, the number of subscribers for which ATC is at a minimum  
 (evaluated at sample mean values for other variables)

YEAR	ALL LSAs	CLASS 1 LSAs	CLASS 2 LSAs	PART 3 LSAs	SINGLE-LSA FIRMS	MULTI-LSA FIRMS
1985	64300	15500**	12700	4.06 x 10 <sup>6</sup> <sup>b</sup>	19700 <sup>c</sup> (7750)	354000 <sup>b</sup>
1986	29900*	22900 <sup>c</sup> (36600)	17400	1780 <sup>**c</sup> (1230)	290000 <sup>b</sup>	195000 <sup>b</sup>
1987	22500 <sup>c</sup> (11900)	21900 <sup>c</sup> (39200)	9550	2470 <sup>c</sup> (1070)	51900 <sup>c</sup> (9430)	61800 <sup>b,c</sup> (8130)
1988	24700*	25600 <sup>**c</sup> (41600)	6700**	6220	15600 <sup>c</sup> (7340)	135000
1989	13100 <sup>**c</sup> (12200)	36100 <sup>**c</sup> (42800)	6990**	1740 <sup>**c</sup> (1490)	10100 <sup>c</sup> (6940)	20300 <sup>c</sup> (13500)
1990	13600 <sup>**c</sup> (13500)	24500**	3510 <sup>**c</sup> (3140)	2390 <sup>**c</sup> (1720)	12000	11500 <sup>b,c</sup> (12400)
1991	18900 <sup>**c</sup> (17200)	21300**	3380 <sup>b,c</sup> (4430)	2800 <sup>**c</sup> (1910)	14300 <sup>c</sup> (9620)	--- <sup>a,c</sup>

Source: Law (1997, 130)

a = no estimate available ( $a_{qq}$  is too small relative to  $a_q$  for an estimate of  $Q^*$  to be generated);

b = hypothesis that second order condition fails cannot be rejected,  $a_{qq}$  not significantly different from zero, 95% level;

c =  $a_q$  not significantly different from one, 95% level; the relevant sample mean value for  $Q$  is provided (in parentheses) where this condition holds, *i.e.*, where the hypothesis of constant returns to scale cannot be rejected.

\*\* = significant at 99% level, \* = significant at 95% level

Table B3  
Average values for  $Q^*$ , the number of subscribers for which ATC is at a minimum

YEAR	ALL LSAs	CLASS 1 LSAs	CLASS 2 LSAs	PART 3 LSAs	SINGLE-LSA FIRMS	MULTI-LSA FIRMS
1985	72700 (21000)	17600 (6650)	15000 (7300)	8110000 (1.28 x 10 <sup>7</sup> )	25800 (16700)	561000 (576000)
1986	35600 (15900)	27600 (13700)	18400 (3720)	1930 (583)	275000 (99600)	253000 (94300)
1987	41300 (40100)	27800 (16000)	11300 (3850)	6250 (19200)	56900 (6660)	77700 (16200)
1988	37500 (20400)	33600 (21500)	8280 (3730)	7980 (2610)	20100 (7000)	143000 (88200)
1989	16400 (6170)	38900 (7450)	6850 (1180)	1890 (572)	18600 (16200)	24300 (9420)
1990	14000 (2920)	26600 (7180)	3420 (890)	2110 (545)	15300 (9130)	29200 (27200)
1991	20000 (5490)	24700 (7900)	3530 (500)	2970 (673)	16900 (5990)	53800 (59800)

Source: Law (1997, 129)

Standard errors are in parentheses and are provided for comparison only;

these standard errors are not useful for the usual tests for significance

(exact equalities of  $b_0 = \log \beta_0$ ,  $b_i = \beta_i$ , and  $b_{ij} = \beta_{ij}$  with no sample error would need to be assumed).

Table B4  
Returns to scale,  $\mu$  (evaluated at sample means)

YEAR	ALL LSAs	CLASS 1 LSAs	CLASS 2 LSAs	PART 3 LSAs	SINGLE-LSA FIRMS	MULTI-LSA FIRMS
1985	1.11**	0.891**	1.12**	1.21**	1.10**c	1.19**
1986	1.07**	0.958**c	1.12**	1.07**c	1.18**	1.27**
1987	1.04**c	0.954**c	1.07**	1.08**c	1.13**c	1.16**c
1988	1.06**	0.946**c	1.07**	1.14**	1.09**c	1.21**
1989	1.01**c	0.976**c	1.10**	1.03**c	1.05**c	1.07**c
1990	1.00**c	0.934**	1.02**c	1.05**c	1.11**	1.03**c
1991	1.01**c	0.912**	1.04**c	1.06**c	1.05**c	1.12**c

Source: Law (1997, 131)

c = CRS cannot be rejected,

\*\* = significant at 99% level, \* = significant at 95% level

Table B5  
Number of LSAs that are SMALL relative to Q\*

YEAR		ALL LSAs		CLASS 1 LSAs		CLASS 2 LSAs		PART 3 LSAs		SINGLE-LSA FIRMS		MULTI-LSA FIRMS	
		#	%	#	%	#	%	#	%	#	%	#	%
1985	TOTAL	416		123		191		102		94		39	
	SMALL	395	95%	44	36%	186	97%	102	100%	89	95%	39	100%
1986	TOTAL	445		121		205		119		111		35	
	SMALL	406	91%	63	52%	200	98%	85	71%	110	99%	35	100%
1987	TOTAL	476		120		199		157		130		61	
	SMALL	440	92%	57	48%	184	92%	139	89%	124	95%	59	97%
1988	TOTAL	518		118		214		186		149		58	
	SMALL	475	92%	57	48%	181	85%	179	96%	136	91%	56	97%
1989	TOTAL	517		123		224		170		116		39	
	SMALL	428	83%	79	64%	194	87%	122	72%	104	90%	31	79%
1990	TOTAL	486		124		199		163		121		40	
	SMALL	378	78%	57	46%	102	51%	110	67%	111	92%	34	85%
1991	TOTAL	377		127		106		144		79		26	
	SMALL	296	79%	50	39%	21	20%	104	72%	70	89%	23	88%

Source: Law (1997, 135)

## NOTES

1. *JEL* Classification codes: L5 Regulation and Industrial Policy; L9 Industry Studies: Transportation and Utilities.
2. The authors would like to thank Bryan Ferguson and John Rowcroft for helpful comments. Law acknowledges financial support from UNBRF 29-4. The usual caveats apply.
3. Additionally, we explore whether the evidence supported the relaxation of entry restrictions.
4. Before 1986, the CRTC used discretionary criteria based on guidelines that were suggestions, rather than requirements. For the regulations relevant to this study, see the *Cable Television Regulations, 1986*, SOR/86-831, and amendments (*Canada Gazette*).
5. A cable *system* is the cable network around one local head end. The head end is the location of the equipment that receives the signals that are sent down the cable to the subscriber. Head end apparatus can include such devices as satellite dishes, large antennas for the reception of over-the-air broadcasts, fibre optic links, video relay equipment, and microwave towers. Within a *licensed service area*, if it is large enough, there may be more than one cable system, although only one operator. A *CATV firm* is an operator of one or more cable systems which may be located in one or more LSAs.
6. The point at which the CRTC evaluates broadcast reception is the head end of the CATV system. The quality of reception of over-the-air broadcasts decreases with the distance between the broadcasting antenna and the receiving antenna (at the head end). It is possible to map out contours of broadcast signal quality; on a flat surface with no obstructions these contours would be circular. If the head end (or, where there is more than one, the head end that receives the majority of the programming services) in a licensed service area is within the Grade B contour of two or fewer broadcast stations, the CRTC exempts the LSA from the rate regulations in Part II.
7. Regulations differ by type of service: *basic* service covers the package of local broadcast stations, plus community channels (if any) and any other channels the CATV operator is required or applies to include; *pay* services are marketed individually or in several packages, usually including movie channels, music channels, and other specialty channels; and *extended basic* service which is typically a single package that subscribers can add on to their basic service to augment the choice of channels. The CRTC makes the determination of whether a set of channels can be offered in a pay or extended basic package, or whether channels must be part of the basic subscription. Consumers are required to subscribe to the basic service in order to obtain any of the other services.
8. An example of the distinction arises in the allowable increases for added services (channels): in 1988, Class 1 licensees could apply for increases of \$0.03 for each specialty service if operating in a francophone market, \$0.02 otherwise; Class 2 licensees could apply for increases of \$0.06 for each service if in a francophone market, \$0.04 otherwise. One explanation for the linguistic discrimination is that there are fewer francophone services available for CATV firms to carry so that offering a francophone service in the basic package restricts the number available to be offered in discretionary (non-basic) packages proportionally more than for anglophone services. Under this argument, the CRTC needs to offer a larger incentive for CATV firms operating in francophone markets to expand their basic package, giving up the revenues from offering a service in a non-basic package, since these opportunity costs of foregone revenues are presumed to be higher for francophone services.
9. This benchmark relates to profit before interest and taxes as a fraction of net fixed assets, *i.e.*, return on net fixed assets (RNFA), and is compared to the RNFA of the licensee over a 7-year period: the average RNFA over the past 5 years, the current year, and projected RNFA for the following year. The maximum increase allowed for this kind of increase in rates was eventually set at 10%.
10. Additional details on the specification, characteristics, and performance of the cost model in the context of the Canadian CATV industry are available in Law (1997).

11. The parameters for the original function can be recovered from the following conversions (where  $b_0$  is an estimate of  $\log \beta_0$ ,  $b_i$  is an estimate of  $\beta_i$ , and  $b_{ij}$  is an estimate of  $\beta_{ij}$ ):

$$b_0 = a_0 - \sum_i a_i \log \bar{X}_i + \frac{1}{2} \sum_i \sum_j a_{ij} \log \bar{X}_i \log \bar{X}_j + \log \bar{C}; \quad b_i = a_i - \sum_j a_{ij} \log \bar{X}_j; \quad b_{ij} = a_{ij}.$$

However, with the exception of Wald tests for parameter stability across CRTC groupings, these conversions are not necessary as all other hypothesis testing will be conducted at sample mean values.

12. For a discussion of some properties of translogarithmic cost functions and derivations of share equations see Berndt (1991), or see Fuss and Waverman (1978).

13. Shephard's lemma, or  $L = \frac{\partial C}{\partial P_L}$  in the case of labour for example, can be re-written to yield

$$L \frac{P_L}{C} = \frac{\partial \log C}{\partial \log P_L}, \text{ or } S_L = \frac{\partial \log C}{\partial \log P_L} \text{ which is the cost share equation for labour.}$$

14. See, *e.g.*, Berndt (1991, 485).

15. Homotheticity was not imposed; however, restrictions for homotheticity, linear homogeneity in output and some non-nested specification trials were conducted on data from earlier years (1985-1991) and the results can be found in Law (1997).

16. For further discussion of CATV licensing and subscription characteristics, including regulatory and subscriber concentration measures for 1985-1991, see Law (1997, 147-152).

17. See Law (1997).

18. Button and Weyman-Jones (1992).

19. Charnes *et al.* (1978), Banker *et al.* (1984).

20. The "radialness" of the efficiency measure implies that the projected point to the efficient frontier will possess the same proportions of inputs (or outputs, depending upon orientation) as that actually used by the firm.

21. Lovell (1993).

22. With CRS imposed, the input-oriented efficiency score and the output-oriented efficiency score are simply numerical inverses of each other.

23. McCarty *et al.* (1993).

24. Further research will attempt to bootstrap confidence bounds on the measures of returns to scale. See Ferrier *et al.* (1997).

25. Fare *et al.* (1994).

26. McFadyen, Hoskins, and Gillen (1980), Law (1997).

27. Note that this argument relies on subadditivity of the cost structure.

28. There might remain a role for the CRTC to maintain its vigilance over signal content or program quality assurance.

29. CRTC Public Notice 1997-49, Ottawa, 1 May 1997 "Applications by Telephone Companies to Carry On Broadcast Distribution Undertakings".

30. CRTC *Broadcasting Distribution Regulations, 1998*. The URL for these regulations is (last checked by the authors on November 24 1998), <http://www.crtc.gc.ca/eng/legal/bdue.htm>

31. In which deregulation was followed by re-regulation, see *inter alia* Rubinovitz (1993).

32. Unfortunately, the CRTC database does not divide cable length into above-ground and below-ground lengths. As McFadyen, Hoskins, and Gillen (1980, 235) demonstrate, the cost of wiring below ground are substantially higher than the cost of cabling above ground. Typically, however, most below-ground wiring is done in urban settings where density is highest. Variations in total cost due to different cabling may be captured by a measure of density: the effects of density on total cost would then be biased by the inability to distinguish these types of cabling costs (upward bias in urban regions with more below-ground cabling, downward bias in rural regions with more above-ground cabling).

33. The specification of cost functions typically used in comparative studies of cable television operations often give rise to some potential difficulties in disentangling the effects of scale from those of density. Since density is the number of subscribers per unit of distance (from the head end) or per unit of area (within the LSA) then two variables -- subscribers and miles of cable -- may be included within the scope of this measure; similarly, the effect of increasing the scale of operations is the effect on costs of an expansion and acquiring more subscribers may require more miles of cable. Consider the following formulations which are inconsistent, although each is internally consistent:

(i) Estimating the effect of increasing subscription levels, holding the number of cable miles fixed, is akin to estimating the effect of varying the scale of operations, since the level of output has increased; holding the number of subscribers fixed and estimating the effect on costs of varying the number of cable miles required to serve them is the same as varying the density of the subscription distribution, since for the same number of subscribers more miles of cable would necessarily result from lower density;

(ii) Holding the number of cable miles fixed and varying the number of subscribers examines the effect of intensive growth on costs and hence measures economies of density; holding the number of subscribers fixed and varying the number of cable miles measures the effects on costs of the extensive growth involved in changing the (physical) size of the distribution plant and hence measures economies of scale.

Some studies (Noam (1985), for example) have attempted to resolve the issue of cabling by creating an "output" which is the "potential" of becoming a subscriber. However, the primary source of revenue and hence the appropriate unit of output for a cable company is a subscription. Any cabling needed to provide service to the subscriber is an input to cable service provision, or an intermediate good in an integrated structure where the downstream market is the market for subscriptions. Following the above argument, and in line with earlier research, this study will employ the first formulation of scale, from varying the level of output, although the other formulation is equally valid. Unlike either of the approaches suggested above, though, the effect of the density of the potential subscriber population on the cost structure is estimated directly.

34. Source: Statistics Canada, CANSIM database, series B14003, Government of Canada bond yields, average, ten year and over, monthly, average of Wednesdays; source for Statistics Canada is the Bank of Canada.

35. Noam (1985, 102). Interestingly, this calculation yields a net rental price for capital that is approximately 0.23 over the sample period, which corresponds closely to the rate of return that the CRTC considers the minimum level to generate the desired level of investment.

36. Calvet and Lefoll (1988), Hatch and White (1988), in Patterson (1990, 28).

37. Programming expenses are removed because they belong to an activity of CATV firms which is distinct from the provision of basic service.

38. Source is Statistics Canada, CANSIM database, series D694193, IPPI, all industries, excluding food and beverage industries, average of 12 months ending August 31, with a base year of 1986.

39. Given that the CRTC permits price increases based on the level of investment undertaken by rate-regulated cable television firms for the purpose of providing basic service, there is an incentive for these licensees, when they file their reports, to divide their assets in such a way as to make the basic component as large as possible under the reporting rules established by the CRTC. This incentive would tend to increase the degree to which the costs of Class 1 and Class 2 LSAs differ from Part 3 LSAs, as well as aggravate any upward bias in the measures of efficient scale.

## REFERENCES

- Banker, R.D., A. Charnes and W.W. Cooper (1984) "Some models for estimating technical and scale efficiencies in data envelopment analysis" 30 (9), *Management Science*, 1078-1092.
- Berndt, E.R. (1991) *The Practice of Econometrics: Classic and Contemporary* (Don Mills: Addison-Wesley Publishing Company).
- Bertin, A., T.F. Bresnahan, and D. Raff (1996) "Localized competition and the aggregation of plant-level increasing returns: blast furnaces, 1929-1935" 104, *Journal of Political Economy*, 241-266.
- Besanko, D. and D.F. Spulber (1992) "Sequential-equilibrium investment by regulated firms" 23, *The RAND Journal of Economics*, 153-170.
- Bresnahan, T.F. (1982) "The oligopoly solution is identified" 10, *Economics Letters*, 87-92.
- Button, K.J. and T.G. Weyman-Jones (1992) "Ownership structure, institutional organization and measured X-efficiency" 82, *American Economic Review*, 439-445.
- Charnes, A., W.W. Cooper and E. Rhodes (1978) "Measuring the efficiency of decision making units" 2, *European Journal of Operational Research*, 429-444.
- Correll, R.J. and T.M. Horbulyk (1993) "The choice of policy instruments in Canadian television programming" Department of Economics, University of Calgary Working Paper, May 1993.
- Demsetz, H. (1968) "Why regulate utilities?" 11, *Journal of Law and Economics*, 55-66.
- Denny, M., M. Fuss, and L. Waverman (1979) "The measurement and interpretation of total factor productivity in regulated industries, with an application to Canadian telecommunications" University of Toronto Working Paper No. 7911.
- Fare, R., S. Grosskopf and C.A.K. Lovell (1994) *Production Frontiers* (New York: Cambridge University Press).
- Ferrier, G.D. and J.G. Hirschberg (1997) "Bootstrapping confidence intervals for linear programming efficiency scores: with an illustration using Italian baking data" 8, *Journal of Productivity Analysis*, 19-33.
- Fuss, M. and L. Waverman (1978) "Multi-product multi-input cost functions for a regulated utility: the case of telecommunications in Canada" University of Toronto Working Paper No. 7810.
- Good, L. MacRae (1974) *An Econometric Model of the Canadian Cable Television Industry and the Effects of CRTC Regulations*, PhD dissertation, Department of Economics, University of Western Ontario.
- Henderson, J., A. Elek, and C. Gibson (1992) "A financial and regulatory analysis of the Canadian cable television industry to the year 2001" in *A View to the Future*, Submission to the CRTC Structural Policy Hearing NPH-1992-13 (Ottawa: CCTA).
- Laffont, J.-J. and J. Tirole (1993) *A Theory of Incentives in Procurement and Regulation* (Cambridge: MIT Press).

## REFERENCES, continued

- Law, S.M. (1997) *Economic Policy Interactions: Intellectual Property Rights and Competition Policy; Exclusive Licensing and Rate Regulation*, PhD Dissertation, Department of Economics, University of Toronto.
- Law, S.M. (1998) "The problem of costs and market size for Canadian cable television regulation" Department of Economics, University of New Brunswick, Working Paper 98-05.
- Law, S.M. (1999) "Holding the line: the CRTC and the pricing of basic Canadian cable television services" *Canadian Journal of Economics*, forthcoming.
- Lovell, C.A.K. (1993) "Production frontiers and productive efficiency" in *The Measurement of Productive Efficiency: Techniques and Applications*, eds.: H.O. Fried, C.A. Knox Lovell, and S.S. Schmidt (New York: Oxford University Press).
- McCarty, T.A. and S. Yaisawarng (1993) "Technical efficiency in New Jersey school districts" in *The Measurement of Productive Efficiency: Techniques and Applications*, eds.: H.O. Fried, C.A. Knox Lovell, and S.S. Schmidt (New York: Oxford University Press).
- McFadyen, S., C. Hoskins, and D. Gillen (1980) *Canadian Broadcasting: Market Structure and Economic Performance* (Montreal: IRPP).
- Noam, E.M. (1985) "Economies of scale in cable television: a multiproduct approach" in *Video Media Competition: Regulation, Economics, and Technology*, ed. Eli Noam (New York: Columbia University Press).
- Patterson, C.S. (1990) *Rate of Return Measures and Profitability Benchmarks for the Cable Television Industry* (Toronto: Report prepared for the CRTC).
- Rubinovitz, R.N. (1993) "Market power and price increases for basic cable service since deregulation" 24, *The RAND Journal of Economics*, 1-18.
- Spiegel, Y. and D.F. Spulber (1992) "The capital structure of regulated firms" Northwestern University Working Paper, Nov. 1992.
- Spulber, D.F. (1989) *Regulation and Markets* (Cambridge: MIT Press).
- Williamson, O.E. (1976) "Franchise bidding for natural monopolies -- in general and with respect to CATV" 7, *Bell Journal of Economics*, 73-104.

