"MODELLING COST STRUCTURE: THE BELL SYSTEM REVISITED"

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Modelling Cost Structure: The Bell System Reconsidered

ABSTRACT

This paper argues that models of multi-output cost structure using the translog specification are subject to two major criticisms. First, considerable robustness problems of crucial functional properties (like economies of scope and subadditivity) could be present when translog functional forms are used. It is suggested that this non-robustness is due to what is termed the "Flip-Flop" property of the translog model, and it is shown that the available empirical evidence for the pre-divestiture Bell System supports this argument. Second, multi-output translog cost functions may not constitute proper cost function for much of the output space. It is suggested that the analysis should be constrained to that part of output space that is proper. Using the test for natural monopoly proposed by Evans and Heckman (1984) and imposing properness on the test region, we find that the available data for the pre-divestiture Bell System is consistent with a natural monopoly. Furthermore, this result is robust.

I. Introduction

Multi-output cost functions constitute a substantial improvement over earlier single-output production models. In particular, when concepts such as natural monopoly are analyzed, the aggregation into a single output suppresses relevant information about properties such as economies of scope, cost-complementarities, and product-specific returns to scale. The importance of such concepts to determine industry structure, performance, and policy are documented in Baumol, Panzar and Willig (1982).

A popular functional form used frequently to model these multi-product properties is the translog cost function. This form has been criticized by many authors[1]. A major criticism of the translog cost function has been its poor global approximation ability especially when the true cost structure is different from the Cobb-Douglas form (not surprisingly since the translog pivots off the Cobb-Douglas). Nevertheless, the translog continues to be used by researchers when estimating demanding global concepts such as subadditivity.

In particular, it was used by Evans and Heckman (1984) to model technology for the Bell System in order to analyze the question of natural monopoly in the US telecommunication industry. Their influential findings included (Evans and Heckman (1983, pg 272)) "... that the Bell System did not have a natural monopoly over any of the output configurations which were realized between 1958 and 1977". This evidence was presented in US v. AT&T and not only influenced the subsequent decision to break up the Bell System, but also is proving to be rather influential in similar policy decisions in other countries, primarily in Europe.

However, as is shown in Charnes, Cooper and Sueyoshi (1988), considerable problems of robustness exist. Using the TL functional form, the same data set, but a different estimation philosophy, Charnes et al. obtain the opposite conclusion[2]. The same test used by Evans and Heckman now accepts the natural monopoly hypothesis.

This paper argues that existing models of cost structures using the translog specification are unsatisfactory. For once, it is shown that results can be reversed in a variety of ways, besides what Charnes et al. have done. It is suggested that this non-robustness is due to what is termed the "Flip-Flop" property of the translog model, and it is shown that the available empirical evidence from the aforementioned studies of Evans et al. and Charnes et al. supports this argument. Secondly, a modification to the Evans and Heckman test for natural monopoly is suggested, which constraints the local test region further by requiring that the cost function is proper over that region. For the Bell System, this modified local test yields more robust results and does not reject the natural monopoly hypothesis.

The paper proceeds as follows. In section 1, additional evidence of robustness problems are discussed. Section 2 tries to explain the robustness problems with the Flip-Flop property of TL functional forms. Section 3 suggests a modified test for natural monopoly.

II. Translog Cost Functions and Robustness

Illustrating the problem of robustness when using a translog specification using the available data for the pre-divestiture period of the Bell System is not hard. Besides the study of Charnes et al. (1988), a number of other examples can be constructed. In all these cases the functional form, i.e. the translog, is kept constant. The translog cost function (TL) is defined by,

$$(1) \qquad \log(C) = \alpha_0 + \sum_{i=1}^{m} \alpha_i \ln(y_i) + \sum_{i=1}^{n} \beta_i \ln(p_i) + 1/2 \sum_{i=1}^{m} \sum_{j=1}^{m} \alpha_{ij} \ln(y_i)\ln(y_j)$$

$$+ 1/2 \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} \ln(p_i)\ln(p_j) + \sum_{i=1}^{m} \sum_{j=1}^{n} \delta_{ij} \ln(y_i)\ln(p_j),$$

where C is a measure of total cost and $(p_1,..,p_n)$ is a vector of factor prices[3]. The output vector $(y_1,..,y_m)$ consists of two product, local telephone service (local) and long distance telephone service (toll), as well as an index of technological progress. By using Shephard's lemma one obtains the input cost share equations, which are then estimated as a system together with the cost function (see for example Evans and Heckman (1983)),

$$(2) \qquad S_i = \beta_i + \sum_{j=1}^{n} \beta_{ij} \ln(p_j) + \sum_{j=1}^{n} \delta_{ij} \ln(y_i), \quad i=1,..,n$$

In addition, we define the Modified Translog (MTL) using a Box-Cox transformation on the output variables (see Caves et al., 1981), and the Box-Tidwell (BT) functional form is constructed by applying the Box-Cox transformation to all right-hand side variables. The Bell System data for cost, input prices, output quantities, as well as technological progress are described and published in Evans and Heckman (1983, Appendix C)[4].

The natural monopoly test developed by Evans and Heckman is a necessary local test for subadditivity, which rejects global subadditivity on the basis of rejecting subadditivity for the local region. In this sense, their test is a definite improvement over tests requiring global cost information. The test compares the gain (or loss) in total production costs of two-firm industry configurations with the monopoly configuration. The natural monopoly hypothesis is rejected in a given year if any of the two-firm industry configurations (represented by a pair (p,w); see Evans and Heckman (1984) for precise definition) produces at lower total cost than the monopolist, i.e. the gain to divestiture is positive for some (p,w). The test is a local test, because the two-firm industry configurations restricts each of the two firms to operate in a local region around the data. Using this test and the BT functional form, Evans and Heckman found positive gains from divestiture for all years 1958-1977.

I have re-estimated the system (1) and (2) for the BT specification using the iterative Zellner method, rather than the Zellner method used by Evans and Heckman[5]. Table 1 shows the re-estimated percentage gain from divestiture for 1961 for different two-firm industry configurations.

Insert Table 1 about here

Since all gains are negative, the test concludes that the Bell System was a natural monopoly at 1961 production levels. Furthermore, the same result holds for all years, except for 1963-67. Thus, the Evans and Heckman test can not reject the natural monopoly hypothesis for the Bell System at most output levels, including the latest ten years where production levels were highest[6].

III. The Flip-Flop Property

In this section, an attempt is made to explain the robustness problem. It centers around a particular characteristic of translog cost functions termed the Flip-Flop property. Assume that all α_{ii}'s in the above translog specification are estimated to be negative but small in absolute value. Then,

$$\lim_{y_i \to 0} C(y_1,\ldots,y_n) = 0$$

This implies that the estimated cost surface is approaching zero along the axis, leading to (trivially) diseconomies of scope and, hence, the natural monopoly hypothesis is confidently rejected. Alternatively, assume that by employing a slightly different estimation technique, the estimates of α_{ii} change marginally; however they change signs. Now the limiting behavior of the TL becomes,

$$\lim_{y_i \to 0} C(y_1,\ldots,y_n) = \infty,$$

i.e. costs along axis approach infinity, economies of scope are necessarily present and the natural monopoly hypothesis cannot be rejected. Thus, as one or more outputs approach zero, i.e. as production processes are modelled along the axis in output space, the estimated cost surface will either be zero or infinite, depending largely on the signs of parameter estimates[7]. In other words, a change in sign of α_{ii} will flip-flop the cost surface around, leading to a fundamentally different cost structures - globally as well as locally - and different policy conclusions.

To support this argument, let us look at the α_{ii}'s of the Evans and Heckman model as well as Charnes et al. model. Evans and Heckman estimate the MTL, as well as the BT functional forms, which are not as degenerate as the TL. Nevertheless, it seems that these forms are still subject to the same Flip-Flop property especially when data points are far removed from the axis. As can be seen in Table 2, most squared output parameters, i.e. the α_{ii}'s, for the Evans and Heckman model are negative, leading (trivially) to diseconomies of scope, and falling costs as firms specialize their production process. It is hardly surprising that this cost structure rejects the natural monopoly hypothesis.

Insert Table 2 about here

Alternatively, both squared output terms in Charnes et al. have positive parameter estimates. According to the Flip-Flop argument, this leads to a fundamentally different cost structure that experiences rising costs from specialization, resulting in the opposite conclusion, i.e. a natural monopoly is likely to be found.

To illustrate the Flip-Flop property visually, I have plotted the Evans and Heckman as well as the Charnes et al. cost structures in Graphs 1 and 2 respectively (note that in Graph 2 costs are cut off as they tend towards infinity). It is rather clear that the two cost surfaces are fundamentally different and lead to opposite policy conclusions with respect to economies of scope. Graph 1 shows a cost structure tending towards zero as production specializes (necessarily leading into economies of scope), whereas Graph 2 illustrates a cost structure that has costs going off towards infinity with increased specialization (necessarily leading into diseconomies of scope).

IV. A Modified Test for Natural Monopoly

In this section, a modification of the Evans and Heckman test for natural monopoly is suggested, which is shown to resolve the above mentioned robustness problems. The test is modified by imposing an additional constraint on the local test region, viz. the requirement that the cost function is proper[8].

The rational for this is twofold. Firstly, testing for natural monopoly requires the correct modelling of cost at every point of the cost surface, since all it takes to reject natural monopoly is one other industry configuration producing the same output vector at lower costs. There is a fundamental asymmetry between showing that a cost structure exhibits subadditivity, and showing that it does not. To show that a cost structure is subadditive, the cost surface has to pass the test of subadditivity at all output points; whereas rejecting subadditivity needs to have the test fail only once. Due to this asymmetry, it seems appropriate to ensure that the estimated cost structure is well-behaved over the region for which extrapolations are made. Secondly, the degenerate limiting behavior of TL functional forms raises the question as to how reliable the TL cost surface is elsewhere, including local regions around the data. If costs must be falling to zero as firms specialize, is it not better to be careful extrapolating cost away from the data? Imposing properness on the local region requires that marginal costs are still positive, ensuring that degeneracy is not excessive.

Table 3 reports the percentage gain from divestiture and the marginal cost schedules for both hypothetical firms for the production levels of 1962 using the TL cost function. Whenever the Bell System's cost structure is found not to be subadditive (i.e. gains from divestiture > 0) with respect to an industry configuration, marginal costs are negative. In other words, each time a more efficient industry structure is detected, the very costs of that hypothetical industry structure are taken from an improper cost function. Furthermore, this result holds for all years, i.e. 1947-1977.

Insert Table 3 about here

Note that the higher the specialization of the two hypothetical firms (i.e. small p and large w), the more degenerate the cost surface and the larger the gain from divestiture. This is hardly surprising since specialized firms extrapolate costs far away from the data when costs are improperly modelled. In such regions, marginal cost are falling fast (due to the limiting property of the TL), thereby translating necessarily into tremendous savings from divestiture[9].

Thus, it can be stated, that the test by Evans and Heckman does not reject the natural monopoly hypothesis over any of the output configurations which were realized between 1947-1977, if constrained to a proper cost region. Moreover, this result holds as well for the BT functional, and we know it must hold for the Charnes et al. model. Imposing properness on the analysis thus eliminates much of the robustness problems.

V. Conclusion

It is clear that in the face of privatization and deregulation movements for the telecommunication sectors as well as other protected government monopolies (especially in Europe), the question of natural monopoly is an important one. Whether or not these large government protected monopolies are of the natural kind, remains largely an empirical problem. In this context, one needs to ask: what can we learn from the empirical analysis of the Bell System case?

This paper demonstrates that the (unconstrained) translog specification may have a robustness problem, as in fact it has in the literature. It is suggested that this non-robustness is due to what is termed the "Flip-Flop" property of the translog model, and it is shown that the available empirical evidence for the pre-divestiture Bell System supports this argument.

Secondly, if the analysis is constrained to the proper part of the cost function much of the robustness problems are eliminates. Finally, it should be noted that the data available in this case are rather limited and little scope information is contained in them.

For these reasons the following suggestions are made. First, due to the limiting degeneracy of the TL world and the resulting difficulties in modelling economies of scope, natural monopoly tests should not extrapolate cost information in a region that constitutes an improper cost function. By doing so one assumes a more conservative role in testing for natural monopoly, as well as eliminates some of the robustness problems. Second, other functional forms should be considered to model scope technology. For example, the Quadratic Cost Function, suggested by Baumol and Braunstein (1977), may perform well in this regard. Third, obtain more "spread" in the data, such that scope is less determined by the choice of functional form.

Endnotes

1. See Guilkey and Lovell (1980); Burgess (1975); Gallant (1981); Fuss and Waverman (1981); also see Guilkey, Lovell and Sickles (1983).

2. In a rejoinder to Charnes et al (1988), Evans and Heckman (1988) argue that a comparison of the two studies is without basis since the data as well as the the functional form differ.

3. In addition, linear homogeneity and symmetry restrictions are usually imposed.

4. These data were originally submitted by L.R. Christensen in his written testimony in US v. AT&T.

5. The stochastic assumptions as well as the maintained hypothesis are the same as in Evans et al.

6. Other examples of highly sensitive results with respect to small data changes can be constructed. For example, since I was unable to obtain the exact parameter estimates as reported in Evans and Heckman (1983), I recreated the data base from the original data base as submitted by Christensen in US v. AT&T. However, this data base is slightly different from the one reported in Evans and Heckman (1983). These adjustments in the data not only lead to variations in the point estimates of cost function parameters, but more importantly, translate into a reversal of cost function properties. This newly created data base leads to stronger scale properties in almost every year (except for 1956 and 1957) and in each year (except for 1977) the Bell System is now operating with increasing returns to scale, i.e. ray average costs are falling, implying that costs are ray subadditive. To further investigate such robustness issues, I have re-estimated the MTL and BT functional forms adding a small amount of noise to the toll output. The noise was normal with mean zero and variance 1/10 of sample variance. Comparing the "noisy" MTL and BT to the "non-noisy" MTL and BT results lead to surprisingly different conclusions. Under the added noise both cost function specifications display economies of scale and scope, thereby suggesting that subadditivity is quite possible (economies of scale and scope are not sufficient for cost subadditivity). Without noise, both functional forms are not subadditive (economies of scope are necessary for subadditivity). Hence, it seems entirely possible that a slight disturbance in the data set could lead to opposite policy conclusions.

7. For a three-or-more-output translog cost function, it is possible that the limit is not degenerate if the parameters of the squared output terms have mixed signs.

8. A proper cost function is defined in Baumol et al. (1982) pages 448-449. In particular, the cost function should be nondecreasing in its outputs if free disposal is assumed.

9. Note that the region over which natural monopoly is tested resembles more and more simple ray analysis, i.e. p and w are similar. This makes sense since the data resembles a ray in output space. There is very little information about economies of scope in this data set, and ultimately this determines the region over which extrapolation is meaningful.

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Table 1[a]

Percentage Gain from Divestiture in 1961
(BT Specification - Iterative Zellner Method)

w = \ p =	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.0	-33										
0.1	-32	-31									
0.2	-30	-31	-30								
0.3	-27	-29	-30	-30							
0.4	-23	-26	-28	-29	-29						
0.5	-18	-22	-25	-27	-29	-29					
0.6	-13	-18	-22	-25	-27	-29	-29				
0.7		-12	-17	-21	-24	-27	-29	-30			
0.8				-16	-20	-24	-27	-29	-30		
0.9							-24	-27	-30	-31	
1.0									-28	-31	-33

[a]Percentage gain from divestiture is defined as,

$$[C(y_1,y_2)-C(py_1,wy_2)-C((1-p)y_1,(1-w)y_2)]/C(y_1,y_2)$$

Table 1[a]

Percentage Gain from Divestiture in 1961
(BT Specification - Iterative Zellner Method)

w =											
0.0	-33										
0.1	-32	-31									
0.2	-30	-31	-30								
0.3	-27	-29	-30	-30							
0.4	-23	-26	-28	-29	-29						
0.5	-18	-22	-25	-27	-29	-29					
0.6	-13	-18	-22	-25	-27	-29	-29				
0.7		-12	-17	-21	-24	-27	-29	-30			
0.8				-16	-20	-24	-27	-29	-30		
0.9							-24	-27	-30	-31	
1.0									-28	-31	-33
p =	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

[a]Percentage gain from divestiture is defined as,

$$[C(y_1,y_2)-C(py_1,wy_2)-C((1-p)y_1,(1-w)y_2)]/C(y_1,y_2)$$

Table 2

Squared Output Parameter Estimates[a]

Functional Form	Local² Coefficient	Toll² Coefficient
Evans and Heckmann[b]		
TL	-2.640 (1.132)	-5.276 (1.700)
TL-AR(1)	-4.241 (1.314)	-8.018 (2.170)
MTL	-3.951 (4.118)	-6.531 (4.905)
MTL-AR(1)	-3.249 (3.788)	-6.837 (4.892)
BT	.491 (.567)	-2.999 (1.432)
BT-AR(1)	-6.848 (5.983)	-14.545 (7.853)
Charnes, Cooper and Sueyoshi[c]		
TL Constrained Regression	4.546	5.656

[a] Standard errors in parenthesis.
[b] Source: Evans and Heckman (1983), pages 259-260.
[c] Source: Charnes, Cooper and Sueyoshi (1988), page 11.

Table 3

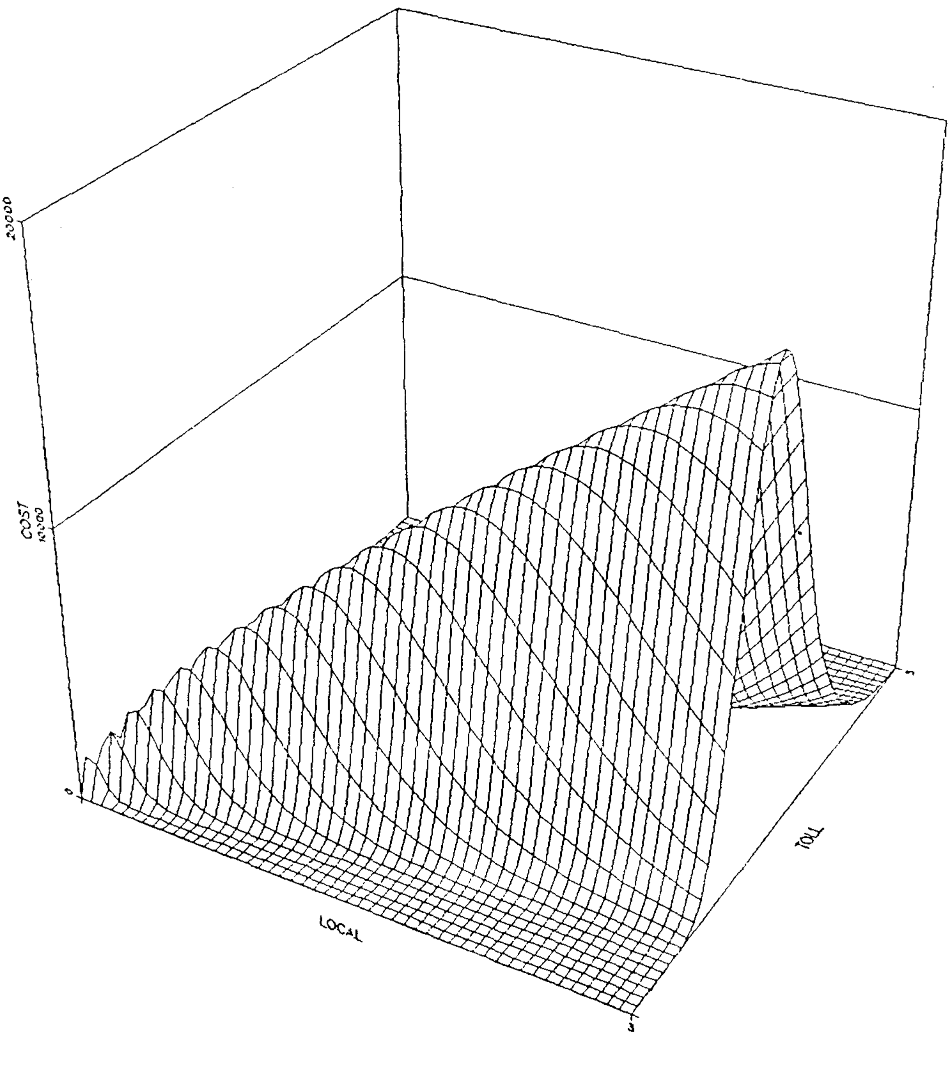
Percentage Gain from Divestiture for 1962 (TL)[a]

p	w	Percentage Gain from Divestiture	Hypothetical Firm A Marginal Cost Schedules for: Local	Toll	Hypothetical Firm B Marginal Cost Schedules for: Local	Toll
0.0	0.0	-6	-	+	+	-
0.0	0.1	-10	+	+	+	+
0.0	0.2	-11	+	+	+	+
0.0	0.3	-10	+	-	+	+
0.0	0.4	-7	+	-	+	+
0.0	0.5	-2	+	-	-	+
0.0	0.6	4	+	-	-	+
0.1	0.1	-8	+	+	+	-
0.1	0.2	-10	+	+	+	+
0.1	0.3	-11	+	+	+	+
0.1	0.4	-9	+	-	+	+
0.1	0.5	-5	+	-	+	+
0.1	0.6	0	+	-	-	+
0.2	0.2	-9	+	+	+	+
0.2	0.3	-11	+	+	+	+
0.2	0.4	-10	+	+	+	+
0.2	0.5	-8	+	-	+	+
0.2	0.6	-4	+	-	-	+
0.2	0.7	3	+	-	-	+
0.3	0.3	-10	+	+	+	+
0.3	0.4	-11	+	+	+	+
0.3	0.5	-10	+	-	+	+
0.3	0.6	-6	+	-	+	+
0.3	0.7	-1	+	-	-	+
0.4	0.4	-11	+	+	+	+
0.4	0.5	-11	+	+	+	+
0.4	0.6	-8	+	-	+	+
0.4	0.7	-4	+	-	-	+
0.4	0.8	1	+	-	-	+
0.5	0.5	-11	+	+	+	+
0.5	0.6	-10	+	+	+	+
0.5	0.7	-7	+	-	+	+
0.5	0.8	-2	+	-	-	+
0.6	0.7	-9	+	-	+	+
0.6	0.8	-5	+	-	-	+
0.6	0.9	0	+	-	-	+
0.7	0.8	-8	+	-	+	+
0.7	0.9	-3	+	-	-	+
0.8	0.9	-6	+	-	-	+
0.8	1.0	0	+	-	-	+
0.9	1.0	-4	+	-	-	+

[a]Analysis of the Evans and Heckman test for the year 1962 using the TL cost function. See Evans and Heckman for precise definition of p and w. "+" denotes positive, "-" denotes negative marginal cost schedules.

Graph 1

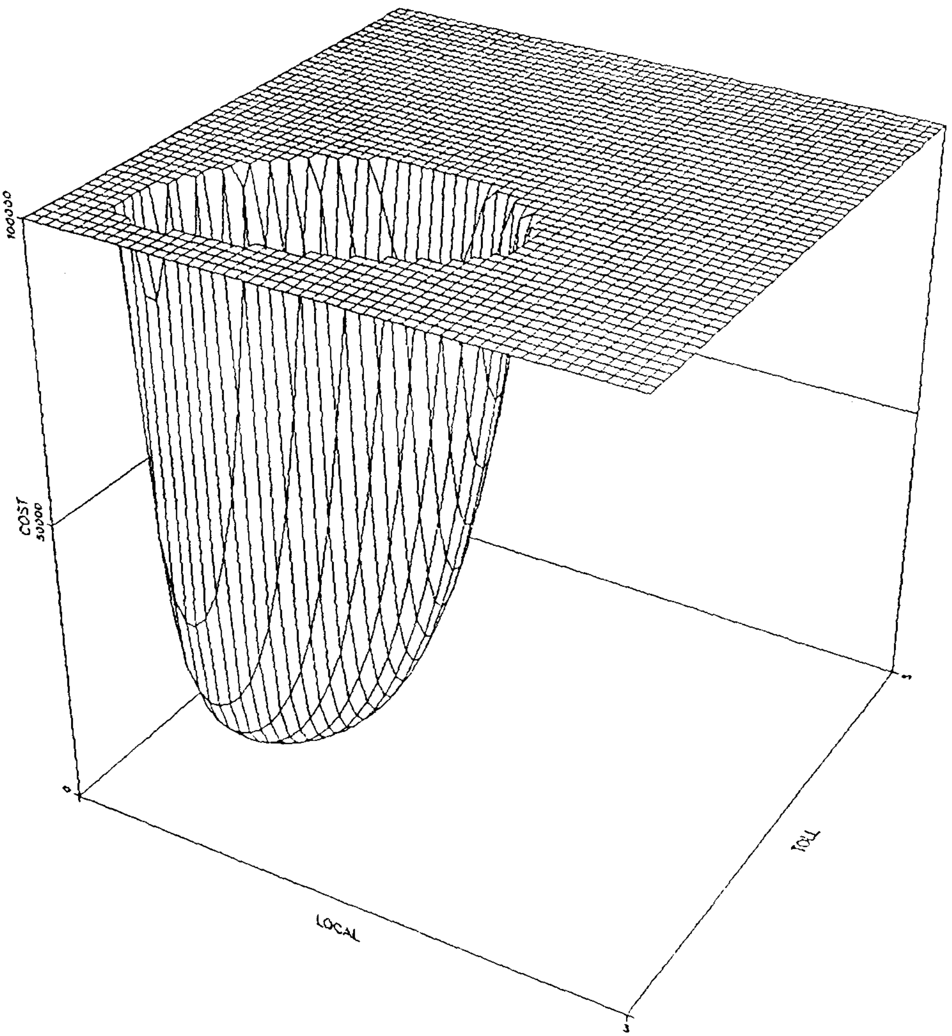
Estimated TL Cost Function for the Bell System (Evans & Heckman).



Input Prices and Technology Index are kept at sample mean.

Graph 2

Estimated TL Cost Function for the Bell System (Charnes, Cooper and Sueyoshi).



Input Prices and Technology Index are kept at sample mean.
Costs are cut off at 100,000.

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