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The Structure of Costs in the U. S. Motor Carrier Industry

*by Mark Keaton**

IT HAS OFTEN been argued that the U.S. motor carrier industry provides a good example of the conditions necessary for workable competition. In the absence of regulation, there are no apparent barriers to entry or sources of technological economies of scale. The necessary equipment can be purchased or rented in small increments, the roadway facilities are available largely on a pay-as-you-use basis, and even terminal facilities can be rented.

On the other hand, managerial specialization may result in economies of scale. The transition from the small "ma and pa" firm to the larger carrier involves the substitution of a formal and specialized management structure for the individual owner-manager. This may lead to a more efficient and effective use of managerial resources.

Previous statistical studies of the industry have failed to resolve the question of returns to scale. Some authors have found evidence of increasing returns [Warner (1965), Ladenson and Stoga (1974), and Emery (1965)]. Others found economies to be the result of factors unrelated to size [Roberts (1956), Nelson (1959), Meyer et al. (1959)]. Still others found evidence of diseconomies of scale for large firms [Koenker (1977), Friedlaender (1977)].

This study attempts to improve on previous research by incorporating all the relevant variables which can influence motor carrier costs, and by employing a very general functional form for the cost equation. Most of the previous studies have assumed simple linear relationships among the variables, and have not systematically included all relevant variables.

The costs of an individual trucking firm are generally influenced by at least five major factors other than the output of the firm (when output is measured by a single index such as ton-miles). The mix of truckload and less-than-truckload traffic[1] will influence the ratio of pickup and delivery, platform handling, billing and collecting, and perhaps traffic and sales costs per unit of final output. The length of haul of the average shipment will also influence pickup, platform, and billing costs per unit of output, and perhaps the utilization of equipment as well.[2] The average load per truck-mile (in tons) will influence costs per unit when costs are measured on a ton-mile basis. The density of traffic over the route system may influence terminal efficiency and equipment utilization. Finally, the prices of the inputs may vary among firms (primarily prices of labor and leased equipment).

The first four factors described above can be thought of as traffic characteristics. This study incorporates all of these characteristics except route density. It was not possible to accurately quantify this factor. No published data are available to readily determine the extent of a carrier's route system, and, in the case of irregular route authority, the concept of route size itself is hard to define.

A general functional form capable of modeling a variety of cost relationships is essential in a statistical study of the motor carrier industry. Earlier models of the industry have generally specified a linear or log-linear relationship between costs and outputs. This formulation is quite restrictive; it implies that the cost elasticity is constant for all values of the dependent variables. Such a model is not capable of generating the familiar U-shaped average cost curve, where the cost elasticity varies at different levels of output. The functional form used in this study does not restrict the cost elasticity to be constant, but permits the researcher to test the validity of this hypothesis.

A MODEL OF TRUCKING COSTS

Under general conditions, one can estimate either the production function or the cost function and obtain identical information about the cost structure of an industry.[4] Estimation of the cost function is generally easier and yields more reliable parameter estimates.[5] This approach is followed here.

The cost function can be written generally as

$$C = f(Q, Z, P), \tag{1}$$

where C is total cost, Q is an index of output, Z a vector of traffic characteristics, and P a vector of input prices. This function describes the minimum cost for producing any level of output given the traffic characteristics and prices.

The variables in the model are defined as follows: Cost (C) is total operating expense as defined by ICC accounting rules; output (Q) is taken to be revenue ton-miles produced by motor vehicles in intercity service. Traffic characteristics ($Z_1,..,Z_3$) are (1) average load per vehicle mile (ton-miles/vehicle-miles), (2) average haul per ton (ton-miles/tons), and (3) LTL ratio, defined as one plus the ratio of LTL tonnage to total tonnage.[6] The reader will notice that this definition of traffic characteristics follows Friedlaender (1977).

Four inputs are used: labor, owned plant and equipment, leased equipment, and materials and supplies. This latter input is defined as the residual of total costs after labor compensation, depreciation and amortization, and leased equipment costs are subtracted. Prices ($P_1,..,P_4$) for these inputs are developed as follows: the price of labor is annual compensation per employee; the price of owned facilities and equipment is the ratio of depreciation and amortization charges to book value; the price of leased equipment is the ratio of total equipment rents to total mileage of leased vehicles (i.e., cost per vehicle-mile); the price of materials is assumed to be constant for all firms and equal to unity. Material purchases include a large number of items such as fuel, tires, and office supplies, and these prices are not likely to vary greatly among firms.[7]

Leased equipment includes vehicles rented with drivers and without drivers. Thus the price for leased equipment, as developed above, will be influenced by the proportion of equipment leased with drivers to that leased without drivers, and by the arrangements between the lessee and lessor covering maintenance and fuel expenses.

The price of owned plant and equipment defined above is not, ideally, the best measure of the firm's cost of funds. However, firms with a high ratio of depreciation and amortization charges to book value can be expected to have a more modern or more rapidly growing stock of equipment, and are thus likely to be more profitable or to have a better record of growth than firms with a low ratio. The more dynamic firms will probably be able to raise funds on more favorable terms than their less progressive counterparts. Thus the cost of capital is expected to be negatively related to the price index developed here.

All data are taken from TRINC's Blue Book for the year 1976. The sample consists of 109 carriers of general freight in 10 of the largest national territories.[8] All firms which used some of the four inputs and had no particular data problems were included in the sample.

Trucking firms should be able to adjust capacity to output changes rather quickly, and thus we shall assume that the estimated function describes the long-run costs for the firm.

ESTIMATION

The model is estimated using a version of the "translog" cost function suggested by Caves and Christensen (1976). The translog function essentially incorporates "second order" terms for all independent variables in order to provide a quadratic approximation.

The translog function is written

$$\ln C = a_O + a_Q \ln Q + \sum_{i=1}^{3} b_i \ln Z + \sum_{i=1}^{4} p_i \ln P_i + \frac{1}{2} \left\{ c_{QQ}(\ln Q)^2 + \sum_{i=1}^{3}\sum_{j=1}^{3} d_{ij}(\ln Z_i)(\ln Z_j) + \sum_{i=1}^{4}\sum_{j=1}^{4} f_{ij}(\ln P_i)(\ln P_j) \right\} + \sum_{i=1}^{3} g_{Qi}(\ln Q)(\ln Z_i) + \sum_{i=1}^{4} h_{Qi}(\ln Q)(\ln P_i) + \sum_{i=1}^{3}\sum_{j=1}^{4} n_{ij}(\ln Z_i)(\ln P_j) \qquad (2)$$

with $d_{ij}=d_{ji}$ and $f_{ij}=f_{ji}$. Cost is denoted by C, traffic characteristics by Z_i, and prices by P_j. All variables are expressed as deviations from the sample means. Since all cost functions must be homogeneous of degree one in prices, we must impose the following restrictions on (2):

$$\sum_{i=1}^{4} p_i = 1,$$

$$\sum_{i=1}^{4} h_{Qi} = 0,$$

$$\sum_{j=1}^{4} f_{ij} = 0 \text{ for all } i = 1,..,4,$$

$$\sum_{j=1}^{4} n_{ij} = 0 \text{ for all } i = 1,..,4.$$

The cost equation is linear in the parameters, and can be estimated directly using ordinary least squares. However, many of the variables are highly correlated, and the number of independent parameters to be estimated is quite large (36 in this case). Thus, the significance levels are likely to be low. Fortunately there is additional information which can be used to improve the precision of the estimated parameters. From microeconomic theory we know that a firm will purchase quantities of inputs to the point where the share of each input in total cost equals the elasticity of cost with respect to the price of the input.[9] Thus,

$$\frac{P_iX_i}{C} = \frac{\partial \ln C}{\partial \ln P_i} = \frac{\partial C}{\partial P_i}\frac{P_i}{C} \qquad (3)$$

where X_i is the quantity of the i-th input used by the firm. For the translog, we have

$$\frac{P_iX_i}{C} = \frac{\partial \ln C}{\partial \ln P_i} = b_i + h_{Qi}\,(\ln Q) + \sum_{j=1}^{4} f_{ij}(\ln P_j) + \sum_{j=1}^{4} n_{ij}$$

$$(\ln Z_j),\ i=1,.., 4 \qquad (4)$$

These equations should hold along with the cost equation (2). Since the cost shares will sum to one, only 3 are independent. The cost equation and three of the four share equations can be jointly estimated using the iterative procedure suggested by Zellner (1962). Joint estimation adds many additional degrees of freedom without increasing the number of parameters.[10]

SCALE ECONOMIES

Scale economies can conveniently be described by the proportional increase in total cost resulting from a proportional increase in output, i.e., by the elasticity of cost with respect to output. Following Christensen and Green (1976), scale economies are defined as

$$SCE = 1 - \frac{\partial \ln C}{\partial \ln Q} = 1 - \frac{\partial C}{\partial Q}\frac{Q}{C} \qquad (5)$$

This expression will be positive for increasing returns and negative for decreasing returns. For the translog function (2)

$$\frac{\partial \ln C}{\partial \ln Q} = a_Q + c_{QQ}\ln Q + \sum_{i=1}^{3} g_{Qi}\ln Z_i + \sum_{i=1}^{4} h_{Qi}\ln P_i \qquad (6)$$

Scale economies will thus depend, in general, on the values of the prices and traffic characteristics.

Because the translog allows for interaction among all independent variables, it is useful to consider restrictions to simplify the model. If the simplified model is consistent with the data, it should be adopted instead of the full model. In practice, we eliminate certain terms from (2) and estimate this simplified model. We then compare the "goodness of fit" of the two versions; since we are using maximum likelihood estimation, we can compare the logs of the likelihood functions. If the log of the likelihood function of the simplified model is not statistically different from that of the original model, we conclude that the simpler model provides an adequate description of the data. This is essentially a test of the hypothesis that a number of parameters in the original model are simultaneously equal to zero. If we cannot reject this hypothesis, we accept the restricted model.

If a cost function such as (1) can be written as

$$C = f[h(Q),\ g(Z,P)] \qquad (7)$$

the function is said to be separable between output and the other sets of variables. [This function is also described as homothetic; see Brown, Caves, and Christensen (1976).] Separability requires that

$$\frac{\partial\left(\dfrac{\partial C}{\partial C}\right)}{\partial P_i} = \frac{\partial\left(\dfrac{\partial C}{\partial Q}\right)}{\partial Z_j} = 0 \text{ for all i, j.}$$

This implies that the elasticity of cost with respect to output is independent of the values of the prices or traffic characteristics; the degree of returns to scale will depend only on output. We can see from equation (6) that this amounts to restricting all g_{Qi} and h_{Qi} to be zero. [See Brown, Caves, and Christensen (1976) for a more complete derivation of the parameter restrictions necessary for separability.]

Similarly, the cost function could be partitioned

$$C = f[h(Q), g(Z), k(P)]. \qquad (9)$$

This formulation is said to be completely separable. It implies that the cost elasticity with respect to prices depends only on the values of the prices themselves, and similarly for traffic characteristics. The parameter restrictions for complete separability are shown in Table 2.

If the simplified versions are consistent with the data, we conclude that the price and traffic factors have no significant influence on the scale elasticity of the firm. Separability allows us to examine the question of scale economies easily. We can impose restrictions for returns to scale (CRTS) on the translog model and evaluate the "goodness of fit" of this restricted version. For the separable models, constant returns to scale requires that

$$\frac{\partial \ln C}{\partial \ln Q} = a_Q + c_{QQ}\ln Q = 1.$$

This condition is satisfied when $a_Q = 1$ and $c_{QQ} = 0$. The original equations can be estimated with these restrictions. If we fail to reject the restricted model at a reasonable level of significance, we conclude that the hypothesis of constant returns to scale is consistent with the underlying data.

RESULTS

Parameter estimates for the unrestricted, output separable, completely separable, and output separable/CRTS models are shown in Table 1. The average cost curves implied by the first three models are shown in Figure 1. These curves are generated by dividing the predicted costs for various output levels by the values of the output. The prices and traffic characteristics are held fixed at their sample means. Recall that the level of output associated with minimum average cost will not depend on the values of the prices or traffic characteristics except in the case of the unrestricted model.

All three models show declining average costs over the lower ranges of output, and rising costs thereafter. Average cost reaches a minimum at approximately the output of the average firm in the sample for the unrestricted and completely separable models. Minimum average cost for the output separable model comes at approximately twice the output of the average firm, and well be-

FIRM SIZE AND AVERAGE COST

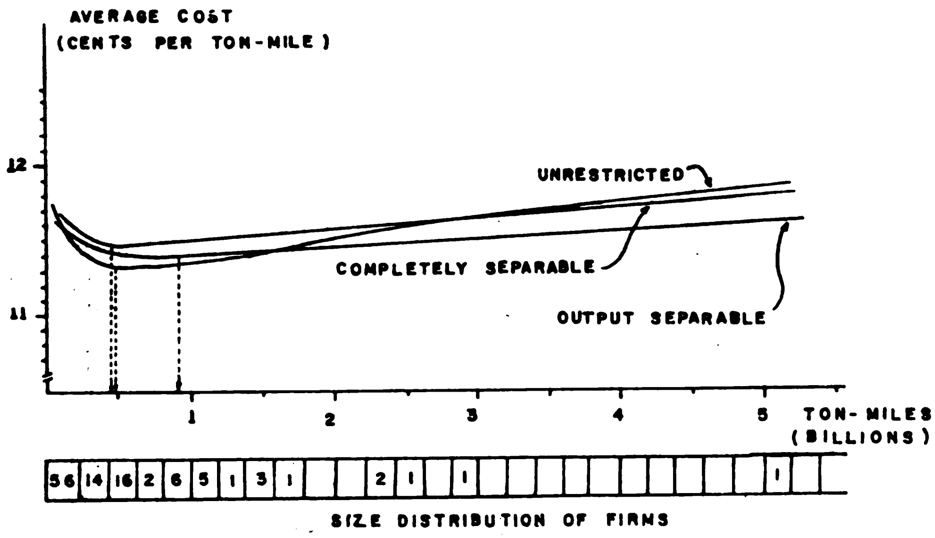

FIGURE 1

TABLE 1

PARAMETER ESTIMATES

(t-values in parentheses)

	MODEL			
Variable	**Unrestricted**	**Output Separable**	**Completely Separable**	**Output Separable CRTS**
Constant	.111 (4.080)	.119 (4.437)	.127 (4.912)	.126 (4.881)
Q	1.000 (35.188)	.997 (47.217)	.999 (51.075)	
QQ	.014 (.587)	.005 (.416)	.007 (.560)	
L	—.586 (3.710)	—.567 (4.777)	—.548 (5.164)	—.575 (4.914)
LL	.533 (3.777)	.509 (4.131)	.595 (5.405)	.502 (4.069)
H	.229 (3.575)	—.231 (5.143)	—.234 (6.209)	—.242 (6.321)
HH	.050 (.447)	.018 (.224)	—.003 (.045)	.025 .325
R	1.735 (8.320)	1.962 (11.666)	1.549 (10.685)	1.977 (11.936)
RR	.315 (.185)	—.124 (.076)	—.988 (.650)	.062 (.039)
QL	—.025 (.437)			
QH	—.016 (.371)			
QR	—.204 (1.769)			
LH	—.238 (1.990)	—.267 (2.312)	—.270 (2.530)	—.264 (2.293)
LR	.584 (1.379)	.341 (.881)	.313 (.868)	.387 (.999)
HR	—.688 (3.102)	—.877 (4.502)	—.736 (4.106)	—.900 (4.633)
W	—.002 (.164)	—.004 (.337)	—.004 (.229)	—.004 (.363)
D	.004 (1.787)	.003 (1.194)	—.003 (1.393)	.003 (1.194)
P	.011 (.673)	.009 (.608)	.008 (.528)	.009 (.632)
WW	.055 (2.421)	.064 (2.765)	.038 (1.673)	.069 (2.984)
WD	—.014 (2.043)	—.009 (1.510)	—.013 (2.323)	—.010 (1.588)

Variable	Unrestricted	Output Separable	Completely Separable	Output Separable CRTS
WP	.010 (.625)	.009 (.601)	.039 (2.183)	.009 (.583)
DD	.008 (2.175)	.007 (2.029)	.009 (2.652)	.007 (2.061)
DP	.011 (4.335)	.012 (4.655)	.010 (3.931)	.012 (4.647)
PP	—.022 (1.039)	—.019 (.903)	—.043 (1.954)	—.017 (.848)
WQ	.002 (1.377)			
DQ	.009 (.403)			
PQ	.006 (.802)			
WL	—.012 (.351)	—.007 (.197)		—.006 (.180)
DL	—.014 (2.436)	—.013 (2.253)		—.013 (2.226)
PL	.049 (1.057)	.046 (1.024)		.044 .979
WH	—.003 (.140)	—.005 (.270)		—.007 (.351)
DH	.001 (.212)	.004 (1.059)		.004 (1.048)
PH	—.026 (.977)	—.010 (.404)		—.008 (.344)
WR	.572 (7.512)	.566 (7.454)		.564 (7.485)
DR	—.013 (1.010)	—.017 (1.318)		—.017 (1.299)
PR	—.523 (5.343)	—.520 (5.426)		—.522 (5.458)
Log of Likelihood Function	590.875	584.072	555.314	583.833

Key: Q = ton-miles
L = average vehicle load
H = average length of haul
R = LTL ratio
W = price of labor
D = price of owned equipment
P = price of purchased transportation

yond the size of most firms in the sample.

Thus, when CRTS is not imposed on the cost function, our best estimates indicate U-shaped average cost curves. The extent of the economies implied by the curves in Figure 1 is quite modest, however. The minimum average cost predicted by the unrestricted model is less than 4 per cent below that predicted for the output of the smallest firm in the sample. Hence, if the smallest firm were to expand to the size where average cost is minimized, it could expect a reduction of less than 4 per cent in unit costs in the long run (from approximately 11.8 cents per ton-mile to 11.35 cents). The output separable and completely separable models imply an even more modest decline in average cost.

Next we consider tests of the significance of the various models.[12] We proceed in two stages, first testing the restrictions for separability, and then testing the hypothesis of constant returns to scale for the model which we accept in stage one. The results of the tests are shown in Table 2. We see that we cannot reject the restrictions of the output separable model at the 99 per cent confidence level.[13] However, we can reject the completely separable version at the same confidence level.

Now we consider the restrictions for CRTS for the output separable model. From Table 2 we see that we cannot reject the CRTS hypothesis at a level of significance of 65 per cent or higher. Thus we conclude that the CRTS model is consistent with the data. This conclusion is reinforced by an examination of the coefficients of the output terms a_Q and c_{QQ} in Table 1. The first term is highly significant and virtually equal to one; it is not significantly different from one at a reasonable confidence level for any of the models. Similarly, the second term is not significantly different from zero at a reasonable confidence level.

SOME IMPLICATIONS OF THE COST FUNCTION

Figure 2 shows the estimated relationship between average cost and length of haul for various LTL ratios and average truck loads for the quality separable/CRTS model. Curve C shows the average cost for a full truckload operation with an average vehicle load. With no LTL traffic, we see that the length of haul has no significant effect on the firm's average cost. This is undoubtedly due to the fact that pickup and delivery, platform handling, and billing and collection costs are small in relation to

TABLE 2

TEST STATISTICS FOR RESTRICTED MODELS

Model	**Parameter Restrictions**	**Number of Restrictions = q**	**Test [(a)] Statistic**	**$\chi^2_{.01,q}$**	**Decision**
Output Separable:	QL = 0 QH = 0 QR = 0 WQ = 0 CQ = 0 PQ = 0	6	13.61	16.81	Do Not Reject
Completely Separable: above plus	WL = 0 CL = 0 PL = 0 WH = 0 CH = 0 PH = 0 WR = 0 CR = 0 PR = 0	15	71.12	30.56	Reject
CRTS:	Q = 1 QQ = 0	2	.478[(b)]	9.21	Do Not Reject

(a) Twice the difference between the log of the likelihood function of the unrestricted model and the log of the likelihood function of the restricted model is assymptotically distributed as Chi-Square with degrees of freedom equal to the number of independent restrictions imposed.

(b) Compared to output separable model rather than unrestricted model. The probability of χ^2 greater than .478 is approximately .35.

line haul expenses for these firms. As the percentage of LTL traffic increases (curves B and A), so does average cost and the economies from longer hauls.

Curves D and E show the effect of increasing vehicle loads with the LTL mix held constant at the sample mean. As we would expect, heavier loads imply lower costs per ton-mile, and the effect is more pronounced as the length of haul increases. Finally, the cost for a full truckload operation with a 30-ton average load is shown by F. Under these conditions, firms can easily enjoy costs of less than four cents per ton-mile, when average haul exceeds approximately 600 miles.

CONCLUSIONS

We find that there is extremely weak evidence for increasing returns to scale for the smaller firms in the general commodity motor carrier industry when we control for other factors. Economies of scale, if any, are quite modest. Average vehicle load, length of haul, and LTL traffic strongly influence costs.

The question of returns to scale has played an important role in the debate over regulation of the motor carrier industry. However, this paper suggests that there are several issues which are probably more important in appraising current regulatory policies. These questions concern the ability of the carriers to obtain commodity and route authorities which maximize the length of haul and load per vehicle. Another question concerns the extent to which TL and LTL traffic are complementary. It has been suggested that firms which can combine these two types of traffic in an optimal mix can operate at a lower total cost than two separate firms, each specializing in only one type of freight. These issues are beyond the scope of this paper, however.

FOOTNOTES

1 Average shipment size is another index of this effect. I have chosen to use the TL/LTL mix because data on this factor is more plentiful.

2 The simple correlation between average haul and annual mileage per vehicle (owned and leased) is .024 for this sample, suggesting no correlation between haul and utilization.

3 The amount of interline traffic has been suggested as another factor. However, Klem, (1977) has found that this influence is not particularly significant, and it has been ignored in the present study.

4 See Brown, Caves, and Christensen (1976) for a discussion of these conditions.

5 Estimation of the production function may involve simultaneous equation bias; see Walters (1963), pp. 14-21.

6 The sample means of these variables are as follows: total expenses = $46.91 million; ton-miles = 461.49 million; average vehicle load = 12.63 tons; average haul = 445.19 miles; average LTL ratio = 1.31.

7 The sample means of the prices are as follows: wages = $18,483; capital = .23; purchased transportation = $.84 per vehicle mile; materials = 1. Firms with capital prices greater than .4 and purchased transportation prices greater than $2.50 per vehicle mile were excluded from the sample. The sample maximum wage is $25,796.

8 These are: East-Midwest, South-Central, East-South, Southern, Pacific-Mountain, Transcontinental, Mississippi Valley, East-Southwestern, Eastern, and Eastern-Central.

LENGTH OF HAUL AND AVERAGE COST

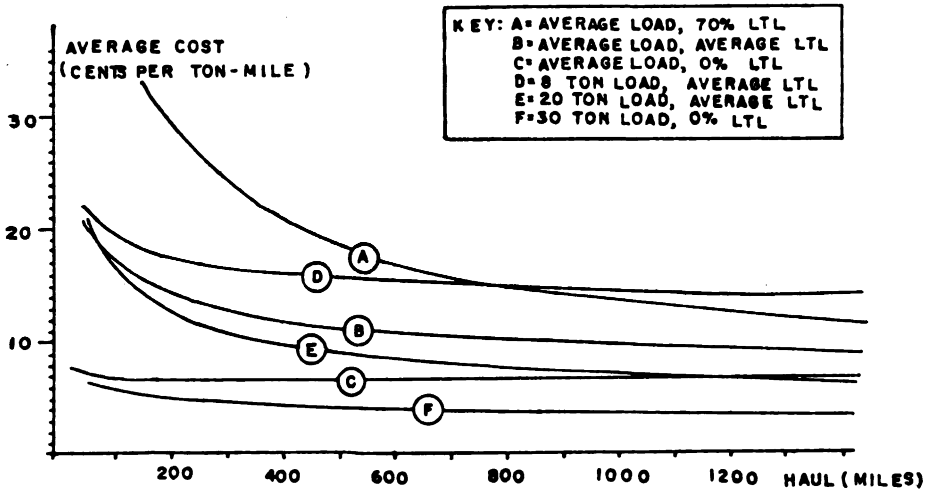

FIGURE 2

[9] This result is known as Shepard's Lemma: see Shepard (1970).

[10] The model was estimated using the iterative maximum likelihood procedure LSQ in the TSP computer package.

[11] These concepts are more fully described in Brown, Caves, and Christensen (1976).

[12] The tests involve a comparison of the log of the likelihood function of the restricted and unrestricted models. This is a measure of the improvement in the "fit" of the unrestricted model over the restricted one. Twice the difference between the log of the likelihood function of the unrestricted model and the log of the likelihood function of the restricted model is assymptotically distributed as Chi-square with degrees of freedom equal to the number of independent restrictions imposed. The maintained hypothesis is that the restrictions are consistent with the data; when the test statistic exceeds the critical value, we reject the maintained hypothesis.

[13] We choose very strict confidence levels to minimize the risk of accepting the simpler model when the more elaborate one is better.

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