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Cost Savings from One-Man Operation of Buses: A Re-Evaluation [with Rejoinder]

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# COST SAVINGS FROM ONE-MAN OPERATION OF BUSES

## *A Re-Evaluation*

By Colin W. Boyd\*

Ex-post estimates of the cost savings produced by conversion of bus routes in the United Kingdom to one-man operation have been reported by Lee and Steedman (1970), Quarmby (1974), and Brown and Nash (1972). Of the three studies only that of Brown and Nash was directed towards the estimation of a generalised cost saving figure.<sup>1</sup> They reported that one-man operation had reduced operating costs by an average of 13.7%.

The purpose of this paper is to demonstrate the possibility of exceptionally severe multi-collinearity between certain of the independent variables in the regression used by Brown and Nash. This defect may have produced an unreliable estimate of the cost savings obtained by introduction of one-man operation. This is illustrated by the replication of the Brown and Nash study, applied to more recent data.

To make possible the production of a more reliable estimate, a respecified regression model is presented, which is designed to circumvent the difficulties posed by multi-collinearity within the original data. The results obtained from this model indicate cost savings of 15.6% for an average municipal bus operator introducing one-man operation in the period 1968 to 1974.

## REPLICATION OF THE BROWN AND NASH STUDY

The data used by Brown and Nash were obtained from the municipal trading results published annually in *Bus and Coach* for the period 1964 to 1969, with additional information obtained by questionnaire. Their final sample size was 233. Data for the replication study, for a sample of 31 municipal operators for the period 1968 to 1974, were obtained from standardised accounting and statistical information published by the Municipal Passenger Transport Association up to 1969, and by the Association of Public Passenger Transport Operators from 1970 to 1974. The sample size for the replication study was thus 217.

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<sup>1</sup> Lee and Steedman attempted an empirical test of the hypothesis of economies of scale in bus operations, and incidentally investigated cost savings generated by conversion to one-man operation. Their estimate of 25% cost savings was in excess of the then generally predicted range of potential savings of from 14% to 20%. Quarmby reported results specific to London Transport, a mean saving of 20% being found for 40 routes converted to one-man operation in 1972. This figure may possibly represent savings in direct operating costs only, as the author did not clarify the degree to which overhead costs were incorporated in the calculation.

The dependent variable used in both studies was total working expenses per bus mile, a measure which excludes annual depreciation expenses. The following independent variables were used in the replication study, the nomenclature being that used by Brown and Nash:

- $X_1$  Proportion of annual bus mileage operated by one-man buses.<sup>2</sup>
- $X_2$  Proportion of bus fleet consisting of single-deck vehicles.<sup>3</sup>
- $X_3$  Population of borough or urban district at 1971 Census. The same figure is used for each of the 7 years 1968 to 1974, following Brown and Nash. (Source: Preliminary Reports on the 1971 Census for England and Wales, and for Scotland.)
- $X_4$  Average annual miles per bus.
- $X_5$  Index of regional wage differentials. This is averaged from the average hourly earnings of manual workers in "manufacturing and certain other industries" for each region over the period 1970 to 1972. The same figure is used for each of the 7 years 1968 to 1974, again following Brown and Nash. (Source: Abstract of Regional Statistics.)
- $X_6$  Time trend (1968 = 1).

Introduction of the variable into the multiple regression model used by Brown and Nash produced the following equation ( $t$  values shown in parentheses):

$$\begin{aligned} \text{Log}_{10} Y = & 0.160 - 0.053 X_1 - 0.038 X_2 \\ & (1.99) \quad (-3.17) \quad (-2.14) \\ & + 0.00014 X_3 - 0.562 \text{Log}_{10} X_4 \\ & (5.80) \quad (-15.75) \\ & - 0.098 X_5 + 0.043 X_6 \\ & (-1.79) \quad (27.28) \\ R^2 = & 0.89 \quad D.W. = 1.785 \end{aligned} \quad (1)$$

Equation (1) is easier to interpret when antilogged:

$$Y = (1.442)(0.885)^{X_1} (0.916)^{X_2} (1.00032)^{X_3} X_4^{-0.562} (0.798)^{X_5} (1.105)^{X_6} \quad (2)$$

Equation (2) indicates results similar to those of the Brown and Nash study, as shown in Table 1.

Both studies suggest that a strategy of conversion to single-deck operation would have produced cost savings almost as great as those apparently produced by conversion to one-man operation. This is a surprising finding, given that the dependent variable excludes depreciation costs and thus does not reflect the lower capital cost of single-deck vehicles. Intuitively, whatever marginal reductions in operating costs are produced by conversion to single-deck operation cannot be expected to be of the order of the 9% of total costs indicated by the regression results.<sup>4</sup> This suspicious result suggests some fault in the model.

<sup>2</sup> Lack of detailed data forced Brown and Nash to use the proportion of bus fleet fitted for one-man operation as their measure of the degree of an operator's involvement in one-man operation.

<sup>3</sup> Brown and Nash used proportion of fleet consisting of double-deck vehicles. This minor respecification is designed to facilitate subsequent discussion of positive correlation between  $X_1$  and  $X_2$ .

<sup>4</sup> Specifically, fuel, tyre, cleaning, maintenance and insurance costs may be expected to be lower for single-deck operation. But these categories do not represent a substantial proportion of total operating costs.

TABLE 1

	<i>Brown and Nash</i> %	<i>Replication</i> %
Cost savings from one-man operation	13.7	11.5
Cost savings from single-deck operation	9.7	8.4
Annual rate of cost inflation	6.4	10.5

The model used in the replication study suffers from severe multi-collinearity. In particular, variables  $X_1$  and  $X_2$  appear highly correlated. This is suggested by the effect on  $R^2$  of stepwise elimination of variables  $X_1$  and  $X_2$  from equation (1). After elimination of the insignificant variable  $X_3$  from the equations, stepwise elimination of  $X_1$  and  $X_2$  produces the following results, taken from the full equations:

$X_1$	$X_2$	$R^2$	Equation
-0.064 (-4.18)	-0.027 (-1.61)	0.89	(3)
-0.079 (-6.62)	—	0.89	(4)
—	-0.071 (-5.20)	0.88	(5)

Of particular note is equation (5). The elimination of  $X_1$  has a marginal effect on the explanatory power of the equation, and  $X_2$  becomes highly significant, indicative of collinearity between  $X_1$  and  $X_2$ . This is confirmed by the simple correlation coefficient  $r_{X_1, X_2}$ , which is found to be 0.639 (significant at 1% level). There is good evidence to show that this correlation is not spurious.

Before 1966 there were statutory restrictions against the use of double-deck vehicles for one-man operation.<sup>5</sup> Any operator wishing to introduce one-man operation before 1966 could only do so by acquisition of single-deck vehicles. Although the lifting of restrictions on one-man operation of double-deck vehicles might have been expected to sever the link between one-man operation and fleet composition, it is possible that there were delays in the acquisition of suitable double-deck vehicles. Time lags in the design, purchasing and delivery of suitable vehicles may have been of the order of 3 to 4 years. This view is confirmed by the Confederation of British Road Passenger Transport (1975), who state that single-deck deliveries peaked around 1969, with delivery of double-deck buses increasing after that time. It would therefore appear inevitable that, from 1968 to 1974, the composition of operators' fleets would be influenced by the extent of their involvement in one-man operation. Support for this view can be found from a survey of operators undertaken by the Department of Environment Working Group on One-Man Operation (1971). It was found that, in the year to 31 March 1970, 86% of one-man operated mileage was undertaken on single-deck vehicles, and only 14% on double-deck vehicles.

<sup>5</sup> Brown and Nash note this point in the first paragraph of their paper, but only in the context of discussion of the reasons for the extension of one-man operation to urban routes.

TABLE 2

<i>Financial year ending</i>	<i>Simple correlation coefficient <math>r_{X_1, X_2}</math></i>
1968	0.93
1969	0.88
1970	0.80
1971	0.78
1972	0.52
1973	0.47
1974	0.41

These characteristics are clearly indicated by the correlation coefficients  $r_{X_1, X_2}$  for each of the individual years 1968 to 1974, as shown in Table 2. (All coefficients are significant at 5% level.) For the replication study this multi-collinearity may render the values of the estimates of cost savings produced by one-man operation and single-deck operation seriously imprecise and unstable. Brown and Nash utilised data from an earlier time period including a period when it was illegal to operate one-man double-deck vehicles, and for them the problem must have been more severe. This might be considered to cast doubt on the reliability of their coefficients for one-man operation and fleet composition as best least squares estimators.

The results of the replication study are in fact seriously affected by further multi-collinearity, the most important of which is related to the time trend of  $X_1$ . From 1968 to 1974 virtually all operators in the sample steadily increased their involvement in one-man operation, resulting in a significant strong correlation between  $X_1$  and  $X_6$ . This feature, and others, further lessen the reliability of the results of the replication study. Again, this may also be considered to lessen the validity of the results of the Brown and Nash study.

#### ADAPTATION OF THE BROWN AND NASH MODEL

In order to calculate a more reliable estimate of the cost savings generated by one-man operation, a variety of changes were made to the model used by Brown and Nash. The changes were as follows:

##### *1. Adjustment for cost inflation*

In the replication study described above an  $R^2$  of 0.69 was obtained by regressing the dependent variable against the time trend variable alone. This shows that a substantial proportion of the explained variance in the full regression equation is attributable to the influence of time. The time trend variable is most probably acting as an index of cost inflation in the full equation. An obvious improvement to the model is to express operators' costs in inflation adjusted terms. To do so may well render the time trend variable insignificant.

## 2. Respecification of variables

The semi-log form of the Brown and Nash model implies a constant percentage cost saving for each 1% of mileage converted to one-man operation. This specification produces easily interpretable results, and may produce negligible distortion when applied to the absolute variables. However, it is more likely that cost per bus mile is a linear function of the proportion of bus mileage that is one-man operated. Also any distortion produced by the semi-log specification may be magnified if, as noted below, a transformation to first differences is utilised so as to eliminate the effects of multi-collinearity. Accordingly another improvement is to use a linear model, though this causes difficulties in interpretation of the coefficients. In the Brown and Nash model the fixed component of costs per bus mile is assumed to bear a constant negative elasticity with miles per bus ( $X_4$ ). This is estimated by including the logarithm of  $X_4$  as one of the influences on the logarithm of  $Y$  (total working expenses per bus mile). In a linear model this relationship may be modelled by assuming fixed costs per bus mile to vary with the reciprocal of miles per bus.

## 3. Transformation to first differences

The changes noted above do not deal with the collinearity between the absolute levels of degree of one-man operation and proportion of single-deck vehicles in operators' fleets. A transformation to first differences should partially or fully eliminate this problem. Though the absolute values of these variables are correlated, there is little reason to presume that changes in them over the period 1968 to 1974 are correlated.

## 4. Elimination of variables

If a first difference transformation is utilised, the two exogenous independent variables that are held constant over time in the Brown and Nash model may be discarded. Brown and Nash assumed variables  $X_3$  (population) and  $X_5$  (index of regional wage differentials) to be constant over the period 1964 to 1969.

The implementation of these changes produces the regression model shown in equation (6):

$$\Delta Y = b_0 + b_1 \Delta X_1 + b_2 \Delta X_2 + b_4 \Delta \left( \frac{1}{X_4} \right) \quad (6)$$

Where  $\Delta$  is the first difference operator

$Y$  is the total working expenses per bus mile measured in terms of the January 1970 average earnings of manual workers in "Transport and Communications Industries". (Source: *Department of Employment Gazette*.)<sup>6</sup>

$b_0$  is a constant, representing the time trend of unmodelled annual change in indexed costs per bus mile

$X_1$  is proportion of mileage that is one-man operated

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<sup>6</sup> The Retail Price Index would not have been an appropriate index to use, since bus operating costs over the period 1968 to 1974 rose faster than retail prices. The predominant proportion of bus operating costs are labour costs, so an index of relevant earnings in similar industries appears to be the most suitable. The use of an index of hourly earnings in road passenger transport would be inappropriate, since it might itself be affected by one-man operation sufficiently to cause problems of identification.

$X_2$  is proportion of operators' fleets consisting of single-deck vehicles

$\frac{1}{X_4}$  is the reciprocal of annual average miles per bus

and  $b_1, b_2, b_4$  are constants.

It should be noted that the use of the model cannot be expected to produce substantial values for  $R^2$ . First difference models, by their very nature, cannot be expected to produce as high a proportion of explained variance as do models applied to absolute variables. Additionally, as noted above, the use of inflation-adjusted costs should be expected to eliminate the high proportion of explained variance that was attributable to the use of the time trend variable in the replication study, and presumably in the results reported by Brown and Nash.

## RESULTS

The initial results obtained through use of the model shown in equation (6) were unsatisfactory, since they showed one-man operation to have reduced costs by only around 9%. Further investigation of the data revealed that changes in costs per bus mile were not only affected by concurrent change in degree of one-man operation, but also by the prior year's change in degree of one-man operation. The discovery of this time lag in the full realisation of cost savings produced by one-man operation was unexpected but not surprising: the savings are mainly labour savings, and the shedding or absorption of the excess labour produced by introduction of one-man operation must take some appreciable time to accomplish. Since the data are annual data, it is only possible to conclude that the full realisation of cost savings takes place over a two-year period. If monthly data had been available it would be possible to determine more accurately the time taken to produce the full savings.

The regression results are shown in Table 3. The variables  $\Delta X_{1,t-1}$  and  $\Delta X_{1,t-2}$  represent changes in the degree of one-man operation in the year of measurement of the change and in the prior year, respectively, in costs per mile. The variable  $\Delta X_{1,t-2}$  represents the summation of variables  $\Delta X_{1,t-1}$  and  $\Delta X_{1,t-2}$ , being change in degree of one-man operation over the two-year period. This substitution for the variables representing the individual year's changes reduces the standard errors of estimates of the effect of one-man operation.<sup>7</sup>

In Table 3 it can be seen that the variable representing proportion of operators' fleets consisting of single-deck vehicles does not emerge as significant, even when the variables representing one-man operation are excluded. This suggests that, as predicted, single-deck operation has no significant effect on operators' costs. This result contradicts the unusual results produced by the Brown and Nash study and the replication study, and indicates that the first difference transformation eliminates the multi-collinearity that marred those studies.

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<sup>7</sup> It should be noted that, because of double counting, any estimate of the coefficient of variable  $\Delta X_{1,t-2}$  must be doubled to obtain an estimate of the effect of one-man operation on costs per mile.

TABLE 3

*Regressions Explaining Variation in  $\Delta$  Total Working Expenses per Bus Mile Across 31 Municipal Bus Operators Over the Period 1968 to 1974*

$\hat{b}_0$ (Constant)	$\hat{b}_1$ $(\Delta X_{1t-1})$	$\hat{c}_1$ $(\Delta X_{1t-1}^2)$	$\hat{d}_1$ $(\Delta X_{1t-2})$	$\hat{b}_2$ $(\Delta X_2)$	$\hat{b}_4$ $\left(\Delta \left(\frac{1}{X_4}\right)\right)$	$R^2$	Regression Number
0.0006 (0.46)	-0.022 (-2.51)	-0.018 (-2.19)		-0.004 (-0.24)	1.259 (3.48)	0.15	(7)
	-0.021 (-2.92)	-0.017 (-2.24)			1.263 (3.64)	0.15	(8)
-0.0027 (-2.90)				-0.011 (-0.69)	1.282 (3.47)	0.07	(9)
0.0006 (0.46)			-0.021 (-3.64)	-0.005 (-0.33)	1.276 (3.60)	0.15	(10)
0.005 (0.42)			-0.021 (-3.71)		1.255 (3.61)	0.15	(11)
			-0.019 (-5.08)		1.276 (3.72)	0.15	(12)
			-0.017 (-4.29)			0.07	(13)
-0.0029 (-3.34)					1.236 (3.41)	0.07	(14)

The time trend is shown to be negligible in all equations in which one-man operation is modelled; this indicates that the use of inflation-adjusted costs eliminates time as an important determinant of variation in costs per bus mile. All the variables representing one-man operation are significant at the 5% level. The coefficients may be interpreted as follows:

*Reduction in costs per bus mile  
for each percentage point increase  
in degree of one-man operation*

	<i>Pence</i>
In year of introduction of one-man operation	0.021
In year following introduction of one-man operation	0.017
Total reduction	0.038

An average operator in the sample had total working expenses of 23.1 pence per bus mile,<sup>8</sup> and an average of 34% of mileage one-man operated. With a total of 0.038 pence per bus mile saved per percentage point of one-man-operated mileage, these results indicate that an average operator introducing 100% one-man operation over the period 1968 to 1974 would have experienced a 15.6% reduction in total working expenses per bus mile.<sup>9</sup>

<sup>8</sup> All costs are expressed in January 1970 pence.

<sup>9</sup> The 95% confidence interval for this estimate is 9.7% to 21.1%.

## SUMMARY

This paper has reported the results of a replication of the study reported by Brown and Nash (1972) in this journal of cost savings produced by one-man operation. The replication produced similar results to those of the original study: both results indicated an unacceptably high level of savings produced by use of single-deck vehicles. This, and other aspects of the replication study, cast some degree of suspicion on the reliability of the results produced by Brown and Nash. By adaptation of their model, the deficiencies which were considered to affect their original study were eliminated. The results of the adapted model, applied to data for the period 1968 to 1974, indicate that one-man operation reduced costs by 15.6%, a figure which conforms well to *a priori* expectations.

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*A Rejoinder*

By C. A. Nash\* and R. H. Brown†

We should like to offer a few brief comments on Boyd's paper:

It would require a great deal of effort to reconstruct exactly the data set we used ten years ago, but we do not believe that the correlation between  $X_1$  (the proportion of the fleet fitted for one-man-operation) and  $X_2$  (the proportion of the fleet that was double-deck) was nearly as serious as Boyd implies. Indeed, we have checked back for the first year in our study, 1964, and found the simple correlation coefficient to be only  $-0.11$ . The reason appears to be that in the mid 1960s two-man operation of single-deck vehicles was common in municipal operators. The average value of  $X_1$  (%)

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fitted for one-man operation) in 1964 was 4.4%, whereas on average 12.3% of the fleet comprised single-deck vehicles. Moreover, of the 22 undertakings which then had no one-man operation, the mean proportion of single-deck vehicles was 12.0%.

Even if there were greater multicollinearity in subsequent years, any imprecision this caused should be reflected in inflated standard errors on the relevant coefficients. In our original paper, both  $X_1$  and  $X_2$  are highly significant (at better than a 1% level); the 95% confidence interval for the saving from one-man operation is given as 9.1%–18.2%.

We do believe that single-deck vehicles on average have lower fuel consumption and maintenance costs than double-deck. For instance, from the 1968 *Commercial Motor* Tables of Operating Costs, we find that the difference in weekly cost (excluding depreciation, interest and crew) between a 41-seat and a 60-seat vehicle amounts to £15.8 per week. The total cost (excluding depreciation and interest) of the 41-seater is given as £131.1. This lends credence to a figure of around 10–12% as the difference in operating cost between single and double-deck vehicles. We suggest that the reason that the proportion of the fleet that is single-deck ceases to be significant in the first difference equation is not that it is irrelevant, but that the degree of variation in this variable is so greatly reduced that its effect is minimised.

We do not consider that a linear relationship between working expense per bus mile and proportion one-man operated is *a priori* more plausible than a semilog one. The main reasons why working expenses vary between companies concern the remuneration and utilisation of the workforce; thus high-cost companies stand to gain more than low-cost companies in reduction in cost per mile from one-man operation. This led us to postulate a constant percentage reduction in costs across companies, rather than a constant absolute amount.

However, we accept that adjusting directly for inflation, moving to first difference form, and examining the lag structure of adjustment to changes in the proportion one-man-operated, are all sensible moves. Moreover, in terms of the spread of values and quality of the data on the extent of one-man operation, Boyd has a much more useful set of data than was available to us in 1970. Thus we welcome this further confirmation that on average the savings realised by conversion to one-man operation were of the order of 15%.