



**SWP 47/87 THE STOCK DEPRECIATION MODEL OF
NEW CAR SALES - A RECONSIDERATION**

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Introduction

This research was stimulated by a desire to see whether any single explanatory model could accommodate the large and fairly rapid changes in demand for new passenger cars in the United Kingdom and other Western European countries over the 20 years to 1984. Preliminary tests suggested that the model based on "stock adjustment" or "stock depreciation" might well prove satisfactory in this respect. The origins and basic features of this model are outlined in Section 1 of this paper.

Section 2 shows that the model remains remarkably consistent with data for the 20 years to 1984, both for the United Kingdom and France, despite the wide variations in demand conditions. In both these countries, if forecasters had been able to predict changes in real consumers' expenditure and the relative prices of cars, application of the model in the early months of one year would have provided a reasonably accurate estimate of new car registrations in that year and the next. For West Germany and Belgium, the model proves less satisfactory, though the results suggest that attempts at refinement may be justified.

Section 3 reports use of prices information to analyse some of the basic assumptions of the model, especially the assumption that the rate of depreciation does not vary with age. The empirical research leads to rejection of this assumption and it is concluded that the apparent success of the model in explaining new registrations in the United Kingdom and France may have been partly fortuitous. }

1. The Basic Model

The origins of the stock depreciation model are generally associated with Stone and Rowe, 1957 (7). It was applied to the demand for passenger cars in the United States by Nerlove (4) and in the United Kingdom by Dicks-Mireaux, O'Herlihy et al (2). O'Herlihy published some revised work relating exclusively to cars in 1965 (5). Further reference to the stock depreciation model with application to the United States appears in work by Smith, published in 1975 (6). The most recent application, again to the United Kingdom, seems to be that of Deaton and Muellbauer (1), who applied it to British data for 1954-75.

The underlying assumption of the model is that desired stock (S^*) measured in new vehicle equivalents (adjustment for vehicle size is sometimes also introduced) has a stable relationship with economic variables (for example, income and price). The model also assumes that the ratio between the value of a car of any age i years and that of the same model aged $i - 1$ is $(n - 1)/n$, where n is the reciprocal of $(1 \text{ minus the annual rate of depreciation})$, normally expressed as an integer. Following Stone and Rowe (7) it has been further assumed that adjustment to desired stock is not achieved during the current year, so that actual stock $S = rS^*$ where r is less than unity.

If $r = 1$ and x is an independent variable to which S^* is linearly related, then new registrations q in year t can be determined by

$$\begin{aligned} q_t &= S_t - \frac{(n - 1)}{n} S_{t-1} \\ &= a + bx - \frac{(n - 1)}{n} (a + b(x - \Delta x)), \quad \text{where} \end{aligned}$$

$$x = x_t \text{ and } \Delta x = x_t - x_{t-1}$$

This simplifies into the following equation:-

$$q_t = a' + b' (x + (n - 1) \Delta x), \text{ where } a' = a/n \text{ and } b' = b/n$$

If $r \neq 1$, then two corrections are required: first, all the terms in the equation need to be multiplied by r . Secondly, an extra term needs to be added in order to take into account the failure to adjust to long-term equilibrium in the previous year. Since, in year $t - 1$,

$$q_{t-1} = r(S^*_{t-1} - S_{t-1})$$

the additional purchases required in year t to compensate for incomplete adjustment in $t - 1$ are given by $(1-r)q_{t-1}$.

The equation to be estimated for a depreciated stock model with k independent variables is, therefore

$$q_t = ra' + rb'_1 (1 + (n-1)\Delta)x_1 + rb'_2 (1 + (n-1)\Delta)x_2 + \dots + rb'_k (1 + (n-1)\Delta)x_k + (1-r)q_{t-1}$$

In order to derive this equation, it is necessary to specify a linear relationship between desired stock and each of the independent variables. All authors quoted above have used this linear specification.

2. Preliminary Testing on Data for Recent Years

A. United Kingdom

It was decided to test a fairly simple model with only two variables, one related to income and the other to the relative price of cars. Preliminary testing confirmed the view received from analysts within the motor industry, that new car registrations were more closely related to consumers' expenditure than to personal disposable income. This may be because the latter includes an element of non-discretionary "savings" (mortgage repayments, etc). The

price variable used in this study was the deflator implied by the figures of consumers' expenditure on cars and motorcycles in the National Income and Expenditure Blue Book. Indices based on list prices of new cars weighted by registrations proved unsatisfactory, possibly because they did not capture the discounting which has taken place in the retail market since 1980. The derived price index for cars was divided by the general index of retail prices in order to produce a relative price index. The regression results for 1964-1984 (21 years) were as follows:-

	<u>Coefficient</u>	<u>Variable</u>	<u>Std.error of coefficient</u>
(i) $q_t =$	-375.87	Constant	123.64
	+0.0155	$(1+3\Delta)CE_t$	0.0008
	-243.58	$(1+3\Delta)P_t$	98.62
	$\bar{R}^2 = 0.942$	DW = 1.36	
(ii) $q_t =$	-392.80	Constant	126.30
	+0.0145	$(1+3\Delta)CE_t$	0.0014
	-204.54	$(1+3\Delta)P_t$	109.97
	+0.075	q_{t-1}	0.089
	$\bar{R}^2 = 0.942$	DW = 1.24	

where CE = consumers' expenditure in millions of pounds at 1980 prices

P = index of prices of cars and motorcycles/index of retail prices 1980 = 1

q_t = new registrations in year t measured in thousands

q_{t-1} = new registrations in year t-1 in thousands

The matrix of correlation coefficients relating to the variables in equations (i) and (ii) appears in the Appendix. This shows that in equation (i) there is no significant correlation between the consumers' expenditure and relative price variables. In equation (ii), there is significant correlation between consumers' expenditure in year t and new car registrations in year t-1. This is probably not

sufficiently serious to distort the coefficient on either of these independent variables.

The estimates provided by equations (i) and (ii) are shown in Figure 1 and Figure 2 respectively. Some features are evident:-

(1) Both equations give a good fit over the entire period; although the Durbin Watson coefficients are inconclusive, this is mainly because of runs of very small residuals.

(2) The value of the reciprocal of depreciation ($n = 4$, equivalent to 25%), which was derived iteratively, is reasonably plausible. This will be examined further in this paper.

(3) The regression coefficient on the previous year's registrations, which is equivalent to $(1-r)$ is not significantly different from zero and the inclusion of this variable does not improve the regression results. This implies that adjustment of S to S^* is achieved within the year in question and that the partial adjustment factor of Stone and Rowe is not necessary in this case.

These results are similar to those reported by Deaton and Muellbauer (1) for UK data covering the years 1954-75. They also used two independent economic variables (real disposable income and price). By iteration (to minimise the standard error of estimate) they found a depreciation rate of 22 per cent ($n = 4.5$) compared with the 25 per cent implied in equations (i) and (ii) above. Evidence from Mogridge (3) and from calculations presented later in this paper indicates that depreciation rates have tended to rise since 1975, the last year in the Deaton and Muellbauer analysis.

These same authors also found that the regression coefficient $(1-r)$ on q_{t-1} was not significantly different from zero implying that r might be close to unity. Both O'Herlihy 1965 (5) and Smith (6) report a similar finding. It may be argued a priori in the case of cars that postponement of purchase decisions by some consumers may be compensated by purchases of other consumers anticipating an improvement in economic circumstances.

As a test of the usefulness of equations (i) and (ii) in short-term forecasting, the following procedure was adopted:-

- (a) regressions equations were calculated for groups of 15 consecutive years, starting with 1964-78 and ending with 1969-83;
- (b) it was assumed that the forecasters were able to predict accurately the behaviour of consumers' expenditure and the relative price of cars in the two years beyond those on which regression had been based;
- (c) in the case of equation (i), the actual values for $(1+3\Delta)CE_t$ and $(1+3\Delta)P_t$ were inserted in order to obtain forecasts of new registrations in the first and second years following those included in the regression;
- (d) in the case of equation (ii) new registrations were forecast for the first year after that covered by the regression, by insertion of the actual values for $(1+3\Delta)CE_t$, $(1+3\Delta)P_t$, and q_{t-1} ;
- (e) also for equation (ii), the result of stage (d) was used as the appropriate value for q_{t-1} in a forecast of new registrations in the second year beyond those covered by the regression.

The forecast made "one year earlier" would be made during the first few months of the year to which it referred, because of delays in the availability of statistics. The forecast for the following year would be made at the same time. The results, shown in Table 1, suggest that the stock depreciation model not only provides a satisfactory explanation of changes in the demand for new cars during the period 1964-84 but may also assist practical forecasting.

Table 1 Test of stock depreciation models in forecasting - United Kingdom

Number of new registrations (000s)

<u>Year</u>	<u>Actual</u>	<u>Forecast made</u>	
		<u>1 year earlier</u>	<u>2 years earlier</u>

Equation (i)

1979	1732	1721	-
1980	1536	1396	1426
1981	1514	1423	1377
1982	1639	1540	1521
1983	1871	1835	1818
1984	1764	1726	1721

Equation (ii)

1979	1732	1737	-
1980	1536	1475	1505
1981	1514	1455	1418
1982	1639	1551	1526
1983	1871	1840	1804
1984	1764	1795	1784

B. France

Equations equivalent to (i) and (ii) above for the United Kingdom were calculated for French data covering the period 1965-84. The relative price index was that published by INSEE for new cars, deflated by the general index of retail prices.

	<u>Coefficient</u>	<u>Variable</u>	<u>Std.error of coefficient</u>
(iii) $q_t =$	324.65	Constant	206.8
	+2.67	$(1+3\Delta)CE_t$	0.15
	-363.70	$(1+3\Delta)P_t$	167.6
	$\bar{R}^2 = 0.949 \quad DW = 1.72$		
(iv) $q_t =$	400.29	Constant	184.47
	+3.06	$(1+3\Delta)CE_t$	0.44
	-460.96	$(1+3\Delta)P_t$	197.84
	-0.14	q_{t-1}	0.15
	$\bar{R}^2 = 0.948 \quad DW = 1.81$		

where CE = consumers' expenditure in billions of francs at 1970 prices

P = index of prices of new cars/index of retail prices - 1970 = 100

q_t = new registrations in year t measured in thousands

The matrix of correlation coefficients in equations (iii) and (iv) appears in the Appendix. It will be seen that there is no significant correlation between consumers' expenditure and relative car price but consumers' expenditure in time period t is significantly correlated with new registrations in time period t-1. This probably contributes to the reduced significance of the consumers' expenditure variable in equation (iv).

Figure 3 compares actual new registrations with the estimates predicted from equation (iii) and Figure 4 substitutes those predicted from equation (iv). The

negligible contribution to the regression of the lagged dependent variable is obvious from visual inspection of these two graphs. In the French case there appears to be no justification for inclusion of the lagged variable.

The test of forecasting reliability was therefore based only on the equation which did not include registrations for the previous year (equations with the same specification as (iii) covering 15 year periods from 1965-79 to 1969-83). Results of the test of forecasting capability are shown in Table 2. It is clear that in this French case, the model failed to provide a warning of the sharp decrease in the market which occurred in 1984 and three years earlier use of the model would have indicated an expansion of the market by over 5 per cent, whereas a decrease of nearly three per cent took place. In contrast, the model provided remarkably close forecasts for 1980, 1982 and 1983, still with the assumption that the forecaster was able to obtain accurate predictions of the independent variables.

The French evidence reinforces the conclusion derived from the testing of the model with United Kingdom data, that the model had proved sufficiently robust to justify further research into the validity of its underlying assumptions.

Table 2 Test of stock depreciation model in forecasting - France

Number of new registrations (000's)

<u>Year</u>	<u>Actual</u>	<u>Forecast made</u>	
		<u>1 year earlier</u>	<u>2 years earlier</u>
1980	1873	1879	-
1981	1835	1971	1969
1982	2056	2093	2121
1983	2018	2000	2007
1984	1758	1935	1930

C. Germany and Belgium

German data for the years 1963-83 were used to test four different specifications of the linear stock depreciation model. The best results were obtained with $n = 5$, implying a 20 per cent rate of depreciation. The permutations were based upon the choice of income variable, $(1+4\Delta)$ PDI (personal disposable income) or $(1+4\Delta)$ CE (consumers' expenditure), and whether the lagged dependent variable should be included on the right-hand side of the equation. Without the lagged dependent variable, the better result was obtained using consumers' expenditure but $\bar{R}^2$ was only 0.72 and the Durbin Watson coefficient suggested some autocorrelation of residuals. The regression coefficient on relative price was incorrectly signed, even though this variable was not significantly correlated with consumers' expenditure (the other independent variable).

Inclusion of new registrations from the previous year improved $\bar{R}^2$ and appeared to eliminate the autocorrelation:-

	<u>Coefficient</u>	<u>Variable</u>	<u>Std.error of coefficient</u>
(v) q_t =	-383.71	Constant	697.65
	+0.618	$(1+4\Delta)$ CE _t	0.299
	+1108.75	$(1+4\Delta)$ P _t	680.21
	+0.461 q_{t-1}		0.207

$$R^2 = 0.783 \quad DW = 1.90$$

where CE = consumers' expenditure in billions of Deutschemarks at 1970 prices

P = index of prices of new cars/index of consumer prices - 1970 = 100

The matrix of correlation coefficients for equation (v) is shown in the Appendix, from which it may be noted that the insignificance of consumers' expenditure is due to high collinearity between this variable and q_{t-1} ($r = 0.85$). This equation was not considered satisfactory enough to justify

testing as a forecasting device. However, German data have been used in subsequent analysis of the basic assumptions of the stock depreciation model.

In the case of Belgium, no data were found for personal disposable income at constant prices and two equations were tested, both using $(1+3\Delta)CE$ as the income variable and one including new registrations for the previous year as an independent variable. Data covered the period 1966-82, and the best value for n was found by iteration to be 4 (implying a 25 per cent average rate of depreciation). Without the lagged dependent variable the equation produced an $\bar{R}^2$ of 0.79 but the Durbin Watson coefficient gave strong indications of autocorrelation. Inclusion of new registrations in the previous year as an additional independent variable improved both the overall coefficient of determination and also the distribution of residuals:-

	<u>Coefficient</u>	<u>Variable</u>	<u>Std.error of Coefficient</u>
(vi) q_t	37.82	Constant	78.79
	+0.210	$(1+3)CE_t$	0.102
	-52.28	$(1+3)P_t$	67.90
	+0.447 q_{t-1}		0.215

$$\bar{R}^2 = 0.830 \quad DW = 1.45$$

where CE = consumers' expenditure in billions of francs at 1970 prices

P = index of prices of cars and motorcycles/index of consumer prices - 1970 = 100

The matrix of correlation coefficients is shown in the Appendix.

There was high collinearity ($r = 0.89$) between $(1+3\Delta)CE$ and new registrations in the previous year, which reduced the regression coefficient in each case by half compared with those obtained when the collinear variable was excluded.

As in the German case, the Belgian results did not appear to be sufficiently robust to justify any tests of the forecasting capability of the model. However, some analysis of Belgian depreciation has been included in the overall assessment of the basic assumptions of the stock depreciation model.

3. Tests of the Assumptions

The stock depreciation model outlined in Section 1 and tested in Section 2 assumes that the rate of depreciation is constant for all cars irrespective of age or size. It also assumes that this rate remains constant over time. Thus, for all ages of car i years

$$P_i / P_{i-1} = \frac{(n-1)}{n} \quad (P = \text{price of one model of car})$$

where n remains constant over the periods covered by the regression equations and any extrapolations for forecasting.

Mogridge (3, Appendix 3) has analysed in some detail the prices of cars of different ages at given moments in time, using data from Glass's Guide Services Ltd (unpublished information provided retrospectively to Greater London Council), the Motor Transactions Survey of 1970-1 and the National Travel Surveys of 1965-6 and 1972-3. His conclusions included the following:-

- larger cars depreciate more quickly than small cars and this divergence widened from 1973 to 1981;
- depreciation rates increased over the 1957-81 period;
- "as a first approximation" median stock values show evidence of a constant rate of depreciation after the first year.

Calculation of first-year depreciation is complicated by lack of information about actual prices paid for individual models of new cars, that is prices net of discount. Such discounts are likely to vary according to the balance of supply and demand. The subject of discounting was discussed within the industry in the countries concerned. It appears that discounting has become a major factor in the United Kingdom market mainly since 1979, though some effective discounts through trade-in allowances, favourable credit terms or rebates for cash purchases, as well as special arrangements for multiple buyers, have existed for many years. In France and Germany discounts have been less substantial, partly because of the smaller proportions of cars sold to business buyers, although there are suggestions that the practice of discounting has increased in the past few years. The only way to find out about actual prices paid for cars would be a survey of purchasers, as the subject is surrounded by commercial security because of intensive competition in this particular area. Such a survey, which would require a large stratified sample, lies beyond the resources available for this study. *Other start*

For each of the three countries, United Kingdom, France and West Germany, it was decided to confine the analysis of car prices to cars aged from 2 to 9 years. Nine years was taken as the maximum because model changes make it very difficult to compare cars older than this with any equivalent new vehicle.

The simple stock depreciation model used in Section 2 and in previous studies quoted in Section 1 assumes that in the following equation the coefficients b_1 and b_2 would be zero:

$$(1 - d)_i = b_0 + b_1 i + b_2 p \quad (\text{vii})$$

where d = rate of depreciation in any single year

i = age of car in years (integer)

p = price of corresponding new car (a proxy for the size and "quality")

The simple model also assumes that b_0 is constant over time.

A. The United Kingdom

In the case of the United Kingdom, this equation was tested for the period 1972 to 1984. Data were taken from Motorists' Guide to New and Used Car Prices (Blackfriars Press) for the months of March, June and September of each year. The dependent variable was the ratio of the price of a second hand car to that of a vehicle of the same model registered exactly one year earlier.* Analysis was confined to models available as new at the survey date where changes in style etc had not perceptibly affected prices at the time of their introduction. In most cases this confined data to about seven years, though there were some runs to a maximum value of nine years.

Equation (vii) was then tested with

i = age in years from 2 to 9

p = list price of car new in terms of 1983 general prices (in £ thousands)

$(1-d)_i$ = ratio of price of car of age i to that of same model of age $i - 1$.

Observations were pooled for each calendar year. The results of the computation are summarised in Table 3.

*Because of irregular observations it was necessary to adjust some data covering slightly longer or shorter periods. Care was taken to avoid distortion by registration letter changes. Thus a car aged five years bears the registration letter of a car first registered exactly five years earlier.

Table 3 Test of equation (vii) with UK data

	Coefficients (std error in parenthesis)			Numbers of		$\bar{R}^2$
	b_0	b_1	b_2	Models	Observations	
1972*	0.9066 (0.0080)	-0.0094 (0.0011)	-0.0054 (0.0009)	13	162	0.37
1973*	0.8330 (0.1071)	-0.0014 (0.0153)	0.0068 (0.0108)	23	278	0.00
1974	0.8824 (0.0050)	-0.0069 (0.0008)	-0.0032 (0.0005)	20	317	0.26
1975	0.8519 (0.0078)	-0.0049 (0.0012)	-0.0033 (0.0009)	20	341	0.08
1976	0.8596 (0.0076)	-0.0060 (0.0013)	-0.0040 (0.0008)	16	291	0.15
1977	0.8664 (0.0076)	-0.0042 (0.0012)	-0.0045 (0.0006)	13	239	0.21
1978	0.8575 (0.0097)	-0.0022 (0.0012)	-0.0057 (0.0010)	13	241	0.12
1979	0.8596 (0.0096)	-0.0049 (0.0010)	-0.0024 (0.0016)	16	314	0.07
1980	0.8772 (0.0101)	-0.0081 (0.0013)	-0.0051 (0.0014)	14	285	0.15
1981	0.8537 (0.0085)	-0.0092 (0.0012)	-0.0013 (0.0012)	12	229	0.21
1982	0.8803 (0.0077)	-0.0165 (0.0012)	-0.0031 (0.0006)	10	206	0.52
1983	0.8701 (0.0011)	-0.0150 (0.0017)	-0.0002 (0.0013)	11	211	0.26
1984	0.8760 (0.0114)	-0.0212 (0.0018)	-0.0001 (0.0009)	10	200	0.42

* Based on data for March and June only.

(a) Depreciation constant irrespective of age?

If the annual depreciation rate did not vary with age then b_1 would tend to zero. Table 3 shows that the coefficient was negative throughout and was significantly different from zero for all years except 1973 and 1978. The results also suggest that the impact of age on the depreciation of cars has tended to increase over the years. Older cars depreciate at a faster proportionate rate than cars of more recent registration and the difference appears to have been widening. }

The year 1973 was unusual, in as much as a combination of supply difficulties in the UK industry and import restrictions meant that some demand for new cars was not immediately satisfied. Cases were reported in that year where prices of almost-new second-hand cars exceeded the list prices quoted by manufacturers. It is not surprising that the prices of some older cars received a positive boost. The 1978 exception is harder to interpret.

The distorting effect of the assumption that depreciation is constant with respect to age may be gauged from Figure 5. This is based on calculations relating to a car worth £5,000 new at 1983 prices. The "actual" depreciated values derived from the regression results for 1984 are compared with those which would have applied with a constant rate (the geometric mean over the eight year period) of 24.3 per cent (depreciated value = 0.757^{i-1} for ages i from 2 to 9). It should be noted that the acceleration of depreciation with age was greatest in 1984, of any year included in the analysis and therefore the distortion would also be most pronounced in that year.

(b) Depreciation constant irrespective of original model price?

In the analysis price was used rather than engine size, as a guide to the size and quality of the car.

The coefficient b_2 relating the value retention factor (1-d) to car price is negative in every year except 1973, indicating that more expensive cars depreciate more quickly. The coefficient was significantly different from zero in eight of the 13 years. The results for 1983 and 1984 strongly suggest that in those years the original price of the car had a negligible effect on depreciation. It is possible that the market had changed in the last two years. }

(c) Depreciation constant over time?

Since b_1 and b_2 are not equal to zero, it is not possible to assess changes in depreciation rates simply by the evolution of b_0 . Table 4 shows for an "average" car with list price at 1983 prices of £5,000 the ratios of depreciated values of cars aged six and nine years to those of corresponding models aged one year. These ratios are derived from the equations in Table 3. In addition a notional 12-year cumulative depreciation ratio is shown, based on an extrapolation of the regression results for years 2 - 9 reported in Table 3. Finally, the geometric mean rates of depreciation over the years 1 - 9 and 1 - 12 are shown.

Table 4 Depreciation implied by regression results

<u>Year</u>	<u>Price of car aged i years</u>				<u>Annual average depreciation(%)</u>	
	<u>"</u>	<u>"</u>	<u>"</u>	<u>1 year</u>	<u>1 to 9</u>	<u>1 to 12*</u>
	<u>i = 6</u>	<u>i = 9</u>	<u>i = 12*</u>			
1972	0.423	0.220	0.103		17.2	18.7
1973	0.474	0.297	0.184		14.1	14.3
1974	0.415	0.222	0.109		17.1	18.2
1975	0.361	0.182	0.087		19.2	20.0
1976	0.361	0.179	0.083		19.3	20.2
1977	0.387	0.206	0.105		17.9	18.5
1978	0.371	0.198	0.103		18.3	18.7
1979	0.389	0.206	0.103		17.9	18.7
1980	0.369	0.180	0.080		19.3	20.5
1981	0.349	0.162	0.067		20.3	21.8
1982	0.325	0.128	0.041		22.7	25.2
1983	0.346	0.145	0.051		21.4	23.7
1984	0.308	0.108	0.029		24.3	27.5

* notional (see preceding paragraph)

The table shows that, except in 1973 which was an exceptional year, depreciation rates (as indicated by second-hand car prices) were fairly stable during the 1970's. Between the ages of 1 and 9 years the mean rate of depreciation varied within the range 17.1 to 19.3 per cent. Since 1981 depreciation appears to have accelerated and the effect of age is more pronounced.

- (d) How serious is the distortion resulting from the invalid assumptions?

The stock depreciation model assumes that in equation (vii), $(1 - d)_i = b_0 + b_1 i + b_2 p$, the coefficients b_1 and b_2 are zero and b_0 is constant over time. The results reported above show that all three assumptions are invalid.

Why then does the use of the model to explain new registrations over the period 1964-84 provide the close fit reported in Section 2? How serious is the distortion from adoption of the oversimplify assumptions?

The significantly negative value of b_2 would be important only if the composition of the car stock by size (price) changed over time and the coefficient was so large that the average depreciation rate was affected. Analysis of the car stock by engine size* shows that the proportional distribution has changed insufficiently for the small values of b_2 to have much effect. Throughout this part of the validation exercise the value of p was assumed to be 5.0.**

Of greater possible significance are the changing values of b_0 and b_1 . In order to assess the distortion it was decided to compare the values of depreciated stock implied by equations (i) and (ii), using a 25% annual depreciation rate for all cars, with those derived by use of the coefficients for each year shown in Table 3.

*Using data for cars and light vans from the Department of Transport and predecessors, published in Transport Statistics, HMSO.

**£5,000 being an approximate average new car price in 1983 - it should be re-emphasised that the size of the b_2 coefficient means that the calculation is not sensitive to this figure and a laborious calculation of actual average price, while feasible, was not necessary.

First year depreciation must be considered in the calculation of a depreciated stock figure using the regression results, which describe depreciation only during the second to the ninth year of the lives of cars. In 1972 and 1973, the first two years covered by the analysis of car-price data, the new car market was very buoyant and discounting was probably less extensive than it has been at any subsequent time. In these two years the observed average actual ratio of the price of one-year old cars to the current price of the same model brand new was almost exactly the square of the ratio derived from the equation:-

$$(1-d) = b_0 + b_1(\text{times } 1.0) + b_2(\text{times } 5.0)$$

in 1972 one would derive $(1-d) = 0.865$ whereas the average actual ratio of the price of a one-year old car to that of a new car was 0.750;

in 1973 the derived figure would be 0.872 whereas the actual average ratio was 0.761.

This principle, of applying $(1-d)^2$ to estimate first-year depreciation was used throughout the calculation of depreciated stock values.

The other assumption necessary for this calculation was that the coefficient b_1 (relating annual depreciation to age of car) could be extrapolated beyond the age of 9 for ages 10-15. This assumption is less dangerous than it may appear, because differences in incremental depreciation have little effect (in terms of new car equivalents) on the value of cars which after nine years have already lost over 85 per cent of their initial value.

For the years 1973 to 1981 the calculated depreciation coefficients were applied to the distribution by age of cars and light vans in Great Britain. The published statistics

show ages by pairs of years up to age 15 and it was necessary to interpolate for individual years, a procedure which was aided by the use in the published tables of different pairs in consecutive years. For 1982 to 1984 data were obtained from the Department of Transport for vehicles of car-body type, showing individual years up to age 15. In the case of those vehicles aged over 15 years, an average age of 17 was assumed - the estimate of depreciated stock in new car equivalents is not sensitive to this assumption.

The definition of the depreciated stock values in Table 4 may be summarised algebraically (each variable refers to an individual year).

$$\begin{aligned}
 m_i &= \text{number of cars of age } i \text{ years with current licence} \\
 b_j &= \text{coefficients derived from equation (vii) for individual year} \\
 (1-d)_i &= b_0 + b_1 i + 5b_2 \quad \text{for } i = 2 \text{ to } 17 \\
 C_0 &= 1.0 \quad \text{no depreciation on current year's registrations} \\
 C_1 &= (b_0 + b_1 + 5b_2)^2 \quad \text{first year depreciation} \\
 C_i &= C_{i-1} (1-d)_i \quad \text{cumulative depreciation for } i = 2 \text{ to } 17 \\
 Z &= \text{number of cars aged over 15 years.}
 \end{aligned}$$

In Table 4 the estimate of stock "derived from regression" is given by

$$S_1 = \sum_{i=0}^{15} C_i m_i + C_{17} Z$$

while that resulting from "25% constant depreciation" is given by

$$S_2 = \sum_{i=0}^{15} 0.75^i m_i + 0.75^{17} Z$$

TABLE 5 Comparative estimates of depreciated stock

	Derived from equation (vii) (S_1)	25% constant depreciation (S_2)	S_2 as % of S_1
Cars and light goods vehicles (million new car equivalents)			
1973	6.44	4.93	77
1974	5.84	4.78	82
1975	5.13	4.66	91
1976	5.11	4.56	89
1977	(no car stock figures published)		
1978	5.46	4.92	88
1979	6.01	5.22	87
1980	5.95	5.28	89
1981	5.80	5.31	92
Vehicles of car body type (million new car equivalents)			
1982	5.91	5.46	92
1983	6.36	5.71	90
1984	6.34	5.91	93

In 1973 the prices of second hand cars appear to have been boosted by the delayed deliveries of new models, and in 1974 the new car market was disrupted by the rise in the price of oil and its effects both on the economics of car ownership and on the economy as a whole. It is clear from Table 5 that, except in those two years, the estimate of depreciated stock derived from a constant 25% depreciation rate is very close throughout to 0.90 of that derived from the regression results.

Closer correspondence between the two estimates was obtained when the depreciation rate was reduced to 22 per cent ($n = 4.55$), which accords with the iterative regression results of Deaton and Muellbauer (1) up to 1975. Use of this figure in equations (i) and (ii) for 1964 - 84 reduced $\bar{R}^2$ slightly and the Durbin-Watson coefficients more substantially. The

results do however demonstrate that the assumption of constant depreciation at somewhere within the range 20 to 25 per cent produces an estimate of depreciated stock not far removed from that derived from empirical analysis.

Table 6 Use of 22 per cent depreciation

	Derived from equation (vii) (S_1)	22% constant depreciation (S_3)
Cars and light goods vehicles (million new car equivalents)		
1973	6.44	5.40
1974	5.84	5.28
1975	5.13	5.17
1976	5.11	5.09
1977	-	-
1978	5.46	5.43
1979	6.01	5.73
1980	5.95	5.83
1981	5.80	5.86
Vehicles of car body type		
1982	5.91	6.01
1983	6.36	6.26
1984	6.34	6.49

B. Tests of assumptions in overseas countries

Analysis for France, Germany and Belgium has been confined to prices at one point in time but has also been applied to

$$(1 - d)_i = b_0 + b_1 i + b_2 p \quad \text{where } i = \text{age in years} \\ p = \text{price of a new car}$$

France

Data were taken from l'Argus (13 June 1985) for second-hand prices and from Automarque (June 1985) for new. Runs were obtained for 25 models, extending in some cases to nine years with 97 price and age observations in total.

For $i = 2$ to 9 the results were as follows:-

	<u>Coefficient</u>	<u>Standard error</u>	<u>Comment</u>
b_0	0.855	0.014	Constant
b_1	-0.0205	0.0026	Age (2 to 9)
b_2	0.00034	0.00009	New price in 000 Francs

$$\bar{R}^2 = 0.47$$

The main difference from the United Kingdom is the positive value of b_2 indicating that in France more expensive cars lose their value less quickly. The coefficient with time is fairly similar and Figure 6, which shows cumulative depreciation in France of a car with a new price of 60,000 Francs, is remarkably similar to Figure 5 for the United Kingdom, because the combination of coefficients gives a very similar equation for the depreciation rate annually to that for a £5,000 car in the UK in 1984.

$$\text{France: } (1 - d)_i = 0.875 - 0.0205i$$

$$\text{UK: } (1 - d)_i = 0.876 - 0.0212i$$

There is no information about discounting in France - the price of a one-year old car was on average only 68% of that of the corresponding new car, slightly less than the corresponding UK average of 70 per cent. If, as we were told, discounting is less prevalent in France, this suggests that the loss of value in France during the first year is relatively greater.

Germany

Data were taken from DAT-Marktspiegel for March 1985. Runs were obtained for 23 models, extending in some cases to nine years; the total number of observations was 97.

For $i = 2$ to 9 the results were as follows:-

	<u>Coefficient</u>	<u>Standard error</u>	<u>Comment</u>
b_0	0.900	0.011	Constant
b_1	-0.0093	0.0019	Age (2 - 9)
b_2	-0.00026	0.00025	New price in 000 marks (not significant)
$R^2 = 0.20$			

This time b_2 is not significant, suggesting that new price has no effect on depreciation rates - consistent with the 1984 evidence for the United Kingdom but contrasting with France. In the German case (see Figure 7, which applies to a car with new price of DM20,000) the lower rate of acceleration of depreciation with age means that the assumption of constant depreciation over the range 2 to 9 years is less invalid (it should be noted that the average depreciation rate over this age range is only 15 per cent per annum). There is no information about discounting in Germany - the average price of a one-year old car was only 67 per cent of that listed for a corresponding new car. This proportion is higher than in the UK and France, despite the subsequently much lower rate of depreciation. The combination of the higher first-year depreciation and the much lower subsequent figures may explain why German data do not fit satisfactorily the depreciated stock model, with its assumption that depreciation is constant with respect to age.

Belgium

Data were taken from a guide published by Autokrant in Antwerp showing the prices net of tax in May 1985 of individual models of cars first registered in the years 1977 to 1983. The figures are based on vehicles of average mileage (between 10 and 20 thousand kilometres a year).

The reason for using figures net of tax is that in Belgium there is a registration tax payable on the purchase of

second hand cars, which is calculated on the basis of nominal depreciation from the original price (corrected for general inflation). The net prices for consecutive years of second hand cars are directly comparable; they cannot easily be compared with the prices of the corresponding new vehicles.

Runs of data for six or seven years were obtained for 56 individual car models with ages from 3 to 8 years and 334 observations in total. To test the consistency of depreciation of car prices of Belgium with that observed in other countries, we regressed price ratios against the age of the car and also the price of a two-year old model. The results were as follows:-

	<u>Coefficient</u>	<u>Standard error</u>	<u>Comment</u>
b_0	0.828	0.113	Constant
b_1	-0.0106	0.0014	Ages 3 to 8
b_2	+0.0045	0.0016	Price of 2-year old car in 100,000 Francs

$$\bar{R}^2 = 0.16$$

As in France the coefficient b_2 is positive - more expensive cars depreciate more slowly. Although depreciation accelerates with age this effect is less pronounced than in any of the other three countries (see Figure 8 which refers to a car with a two-year old price in 1985 of 400,000 Francs). No information is available about first year depreciation and it is therefore not possible to analyse whether this might partly explain the relatively poor fit of the model in the Belgian case.

4. Some Conclusions

In the case of the United Kingdom the detailed analysis of depreciation of cars as revealed by secondhand prices shows

that two basic assumptions of the stock depreciation model are invalid. There is significant statistical evidence that the rate at which the value of a car depreciates increases with its age and also that depreciation rates have tended to increase over time. Evidence from France, Germany and Belgium, which relates only to car prices during 1985, confirms that depreciation increases with age but the nature of this relationship differs between the countries.

The relationship between depreciation and the quality of the car (as indicated by the purchase price of a band new vehicle) is not consistent between the four countries. In the case of the United Kingdom more expensive cars have tended to lose their value more quickly although this feature has lost statistical significance in 1983 and 1984. In France more expensive cars appear to depreciate more slowly and this is also suggested by the evidence from Belgium; in Germany the price of the car does not seem to affect the rate of depreciation.

The regression results summarised in the two previous paragraphs do not include depreciation during the first year of a vehicle's life. Because of lack of information about the scale of discounting, it is not possible to estimate first-year depreciation with any accuracy; evidence from 1972 and 1973, when discounting in the UK is believed to have been relatively minor, suggests that first-year depreciation is approximately double that which occurs in the second year. Estimates of depreciated car stock based on a constant depreciation rate were found to be fairly close to those based on the regression results for the United Kingdom, with the added assumption of double depreciation in the first year. This may explain why the stock depreciation model gives a reasonably good fit. The correspondence of the two values may be somewhat fortuitous, reflecting the distribution of the car stock by age over this particular period. In Germany, where the assumption

that depreciation does not change with the age of the car is more valid, the model gives a less satisfactory fit, presumably because it is less able to accommodate variations in depreciation over time and also the problem of disproportionate depreciation in the first year.

The stock depreciation model "works" for the United Kingdom and France, in the sense that a relatively simple regression model based upon it explains most of the variation in car registrations over a period of about twenty years. It also "works" as a forecasting method, assuming that forecasters had been able to predict changes in consumers' expenditure and in the relative price of cars. However, the conclusions of the analysis of car prices suggest that further work is necessary to explain why the model does "work" so well even though its fundamental assumptions may be invalid. This further work would need to focus on first-year depreciation and also on the mechanism whereby depreciation in stock is translated into purchases of new vehicles. Direct surveys of car purchasers would be required for this purpose. Meanwhile, there is a case for further regular testing of the model and possibly its tentative use in forecasting.

APPENDIX 1 CORRELATION MATRICESUNITED KINGDOM

	<u>New Car Regs (t)</u>	<u>Relative Price (+)</u>	<u>Consumers' Expenditure (+)</u>
Relative Price +	0.139		
Consumers' + Expenditure	0.964*	0.277	
New Car Registrations (t-1)	0.773*	-0.073	0.733*

FRANCE

Relative Price +	0.265		
Consumers' + Expenditure	0.970*	0.381	
New Car Registrations (t-1)	0.899*	0.158	0.919*

WEST GERMANY

Relative Price +	0.272		
Consumers' + Expenditure	0.833*	0.041	
New Car Registrations (t-1)	0.860*	0.120	0.843*

BELGIUM

Relative Price +	-0.131		
Consumers' + Expenditure	0.892*	0.012	
New Car Registrations (t-1)	0.904*	-0.114	0.885*

+ This variable specified throughout in the (1+3A) format.

* Significantly different from zero at the 5 per cent level
(or less)

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FIGURE 1

U.K.: TEST OF MODEL WITH $N = 4$: 1964-84
equation (i)

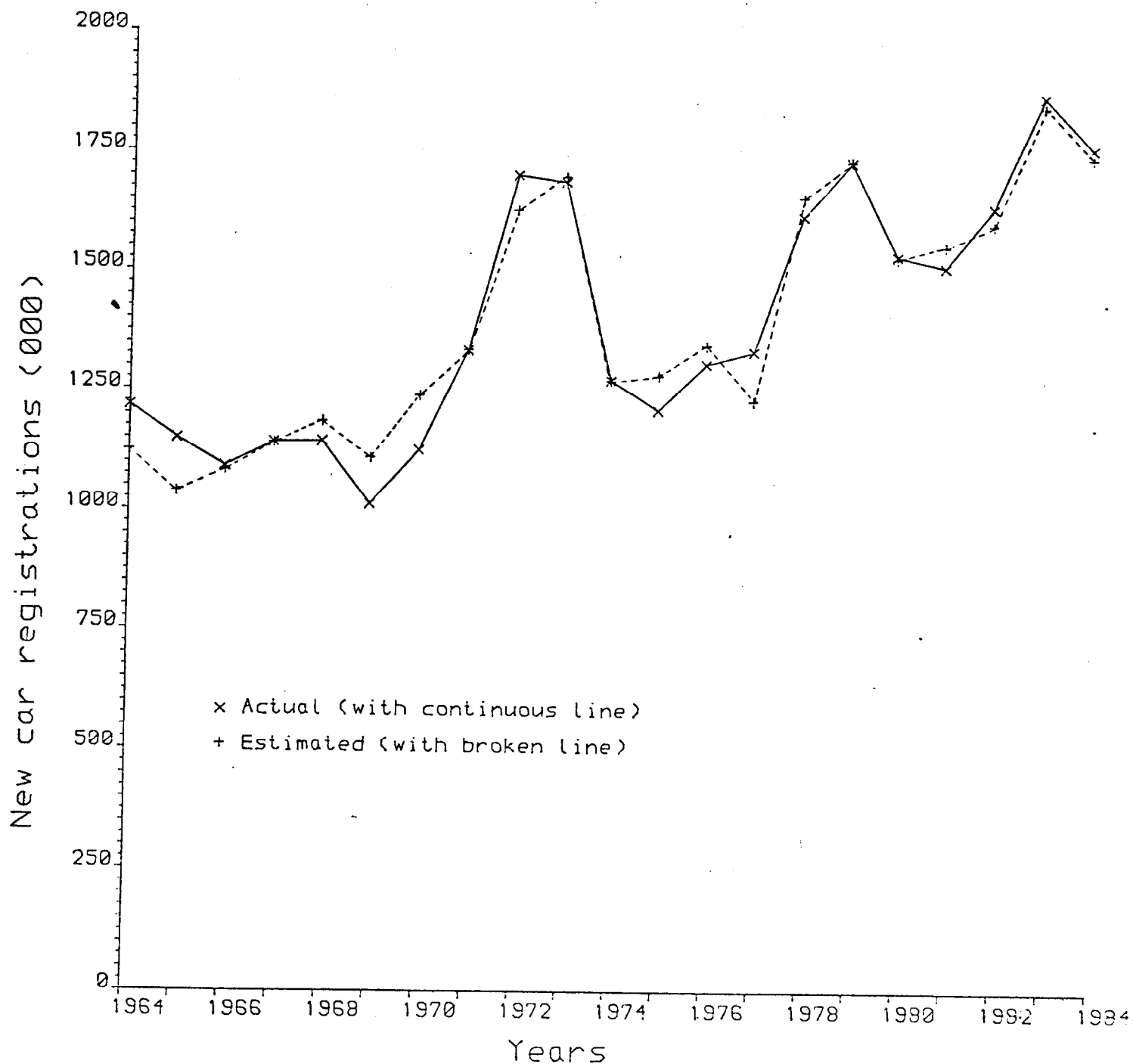


FIGURE 2

U.K.: TEST OF MODEL WITH $N = 4$: 1964-84
equation (ii)

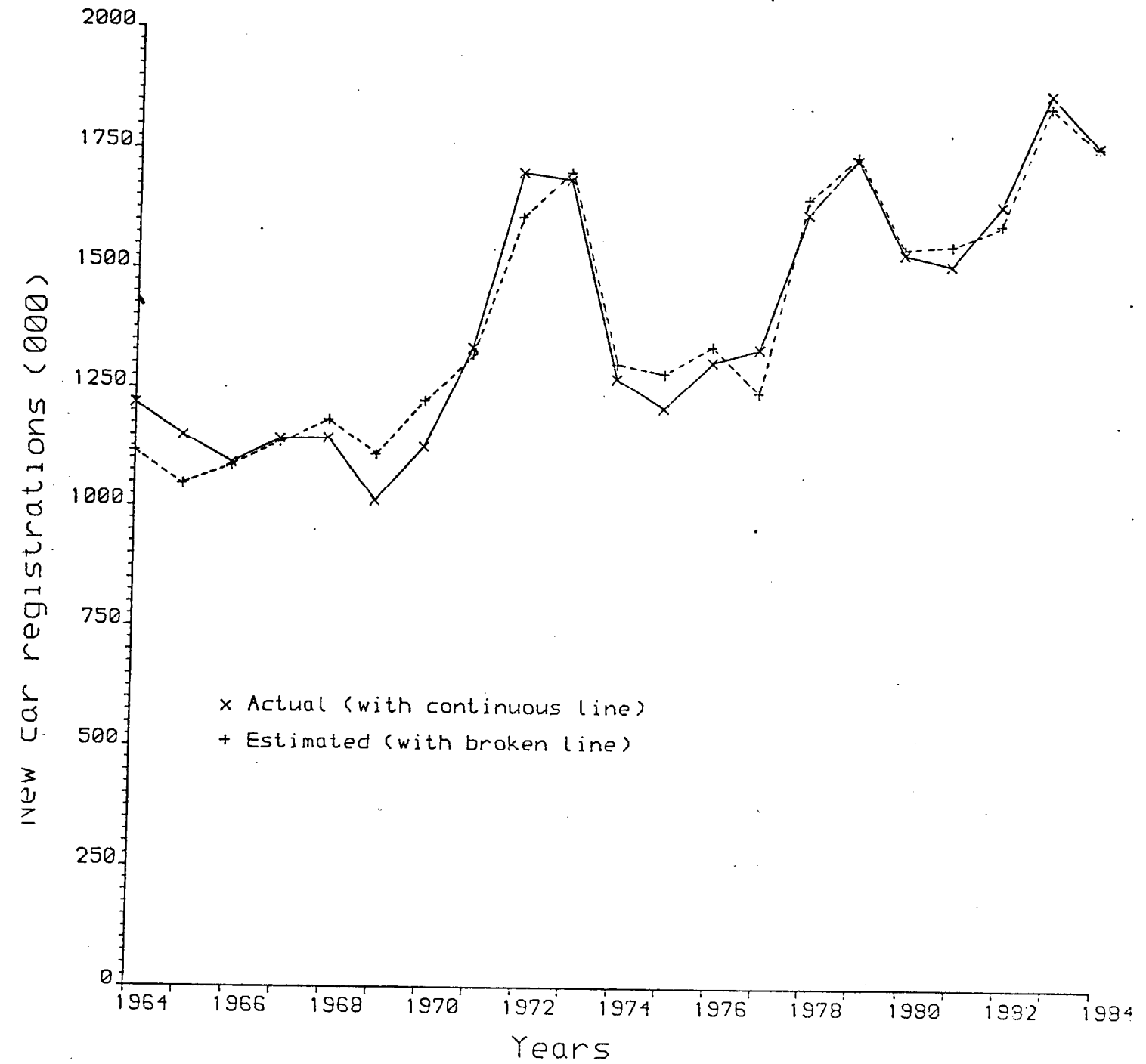


FIGURE 3

FRANCE: TEST OF MODEL WITH $N = 4$: 1965-84
equation (iii)

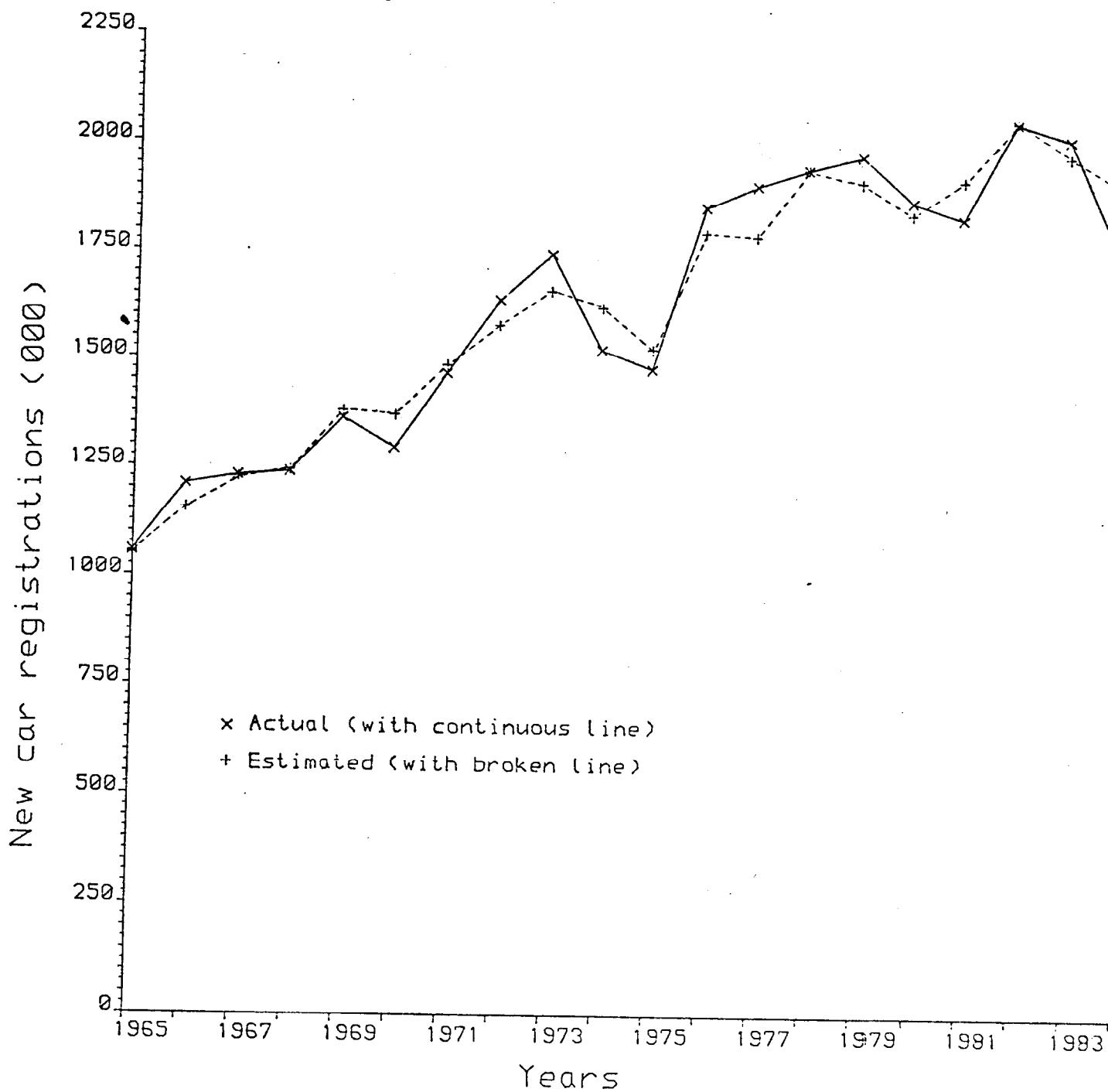


FIGURE 4

FRANCE: TEST OF MODEL WITH $N = 4$: 1965-84
equation (iv)

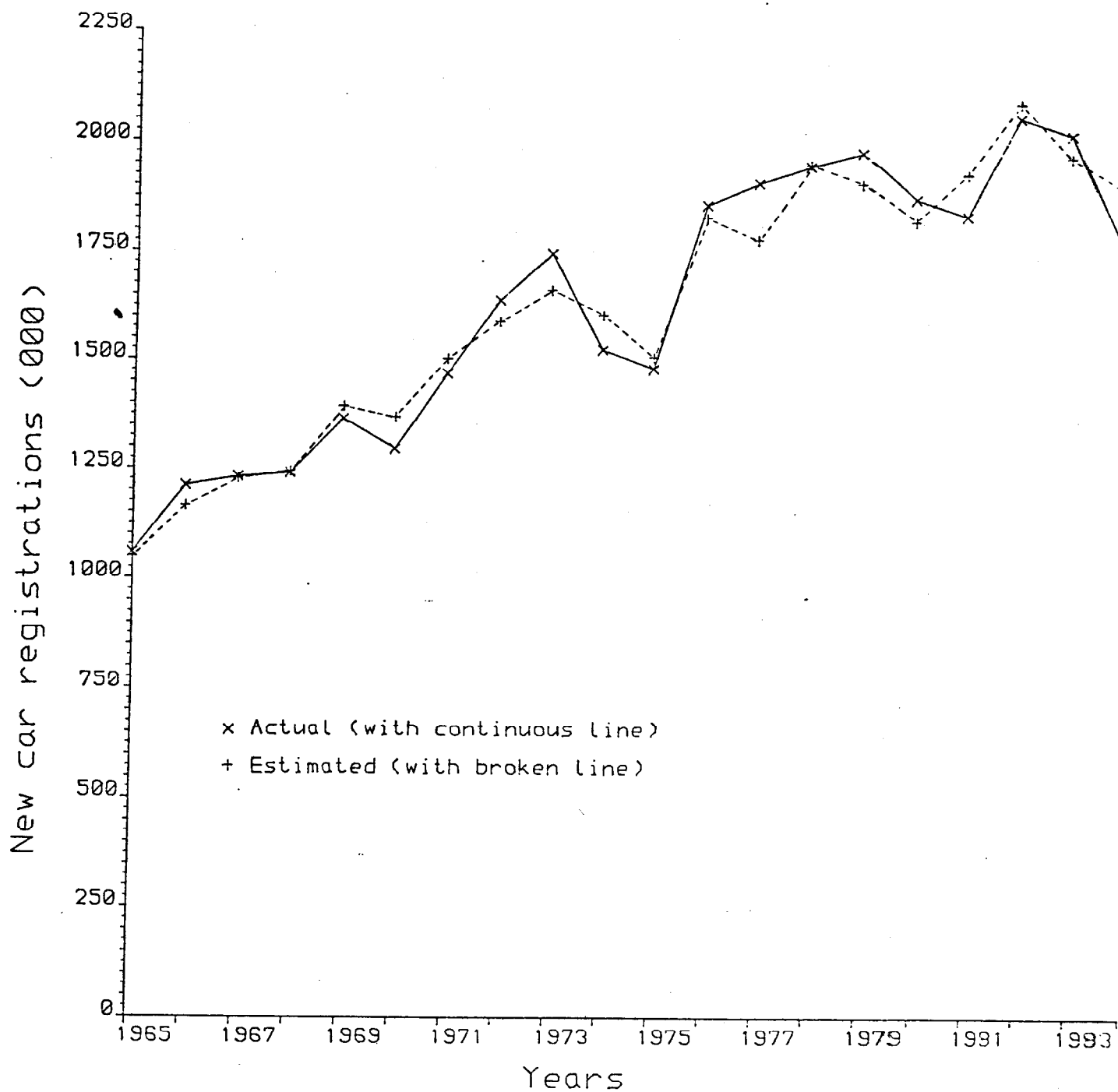


FIGURE 5

UK CUMULATIVE DEPRECIATION IN 1984

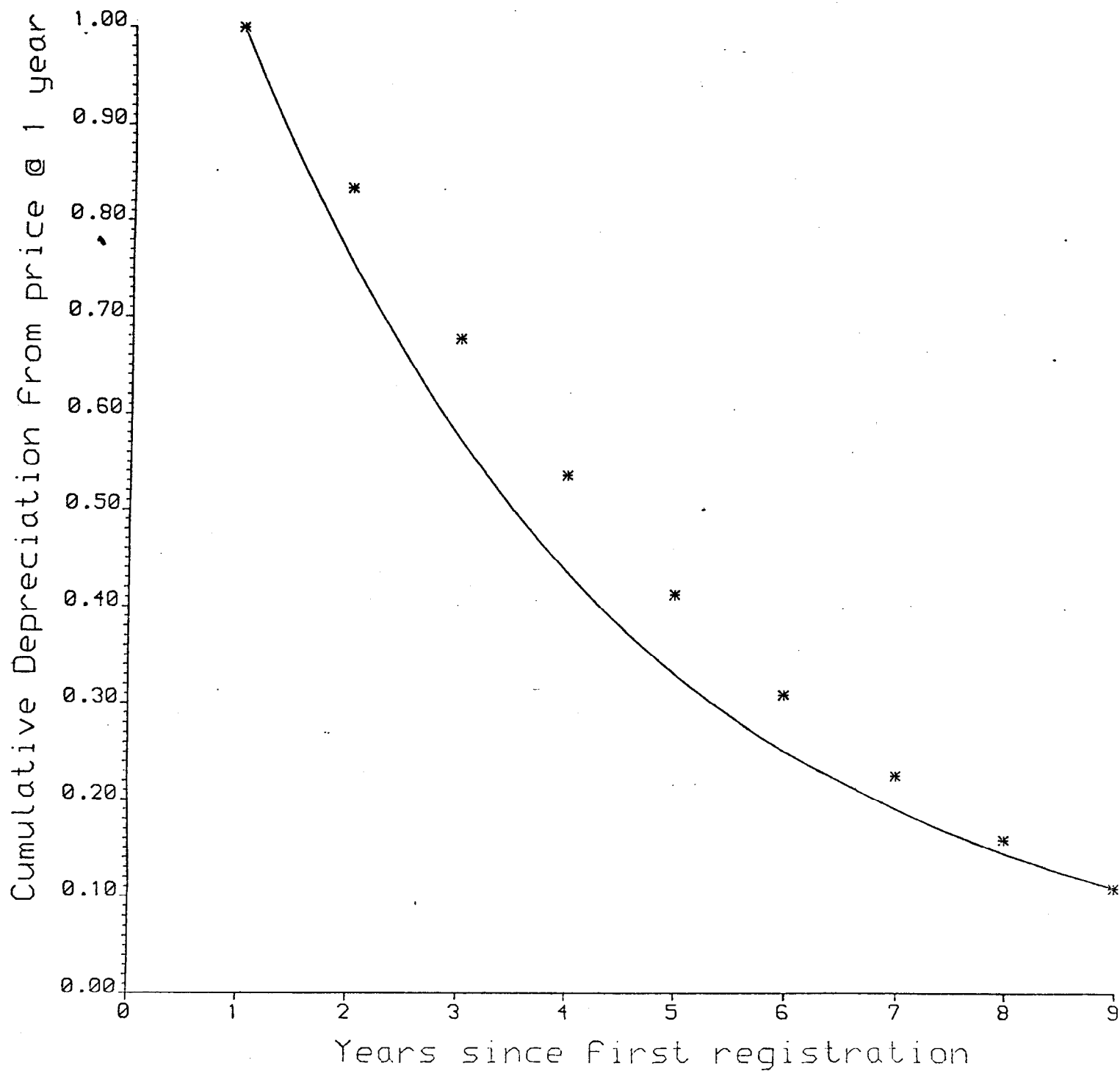


FIGURE 6

FRANCE: CUMULATIVE DEPRECIATION IN 1985

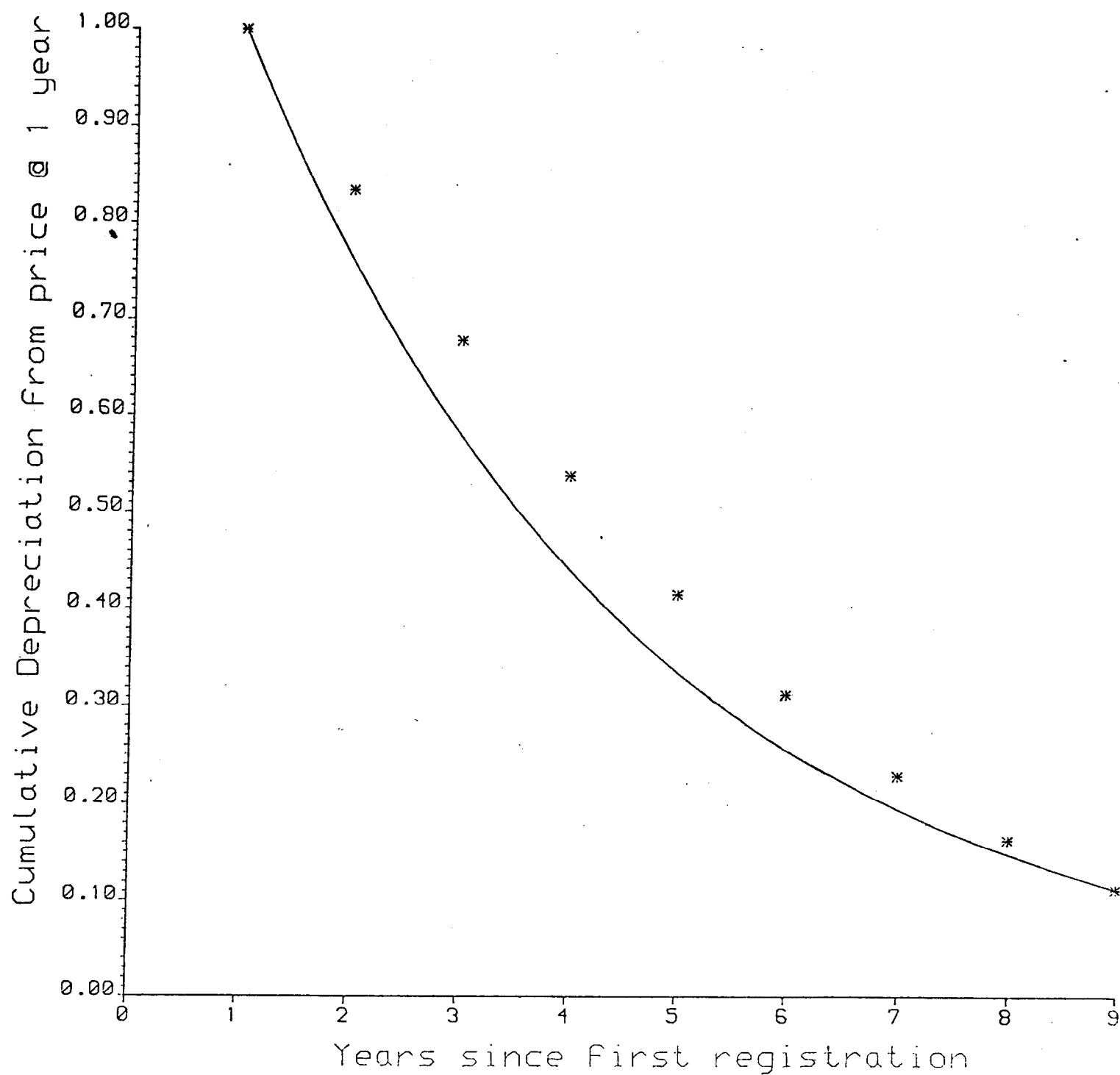


FIGURE 7

GERMANY: CUMULATIVE DEPRECIATION IN 1985

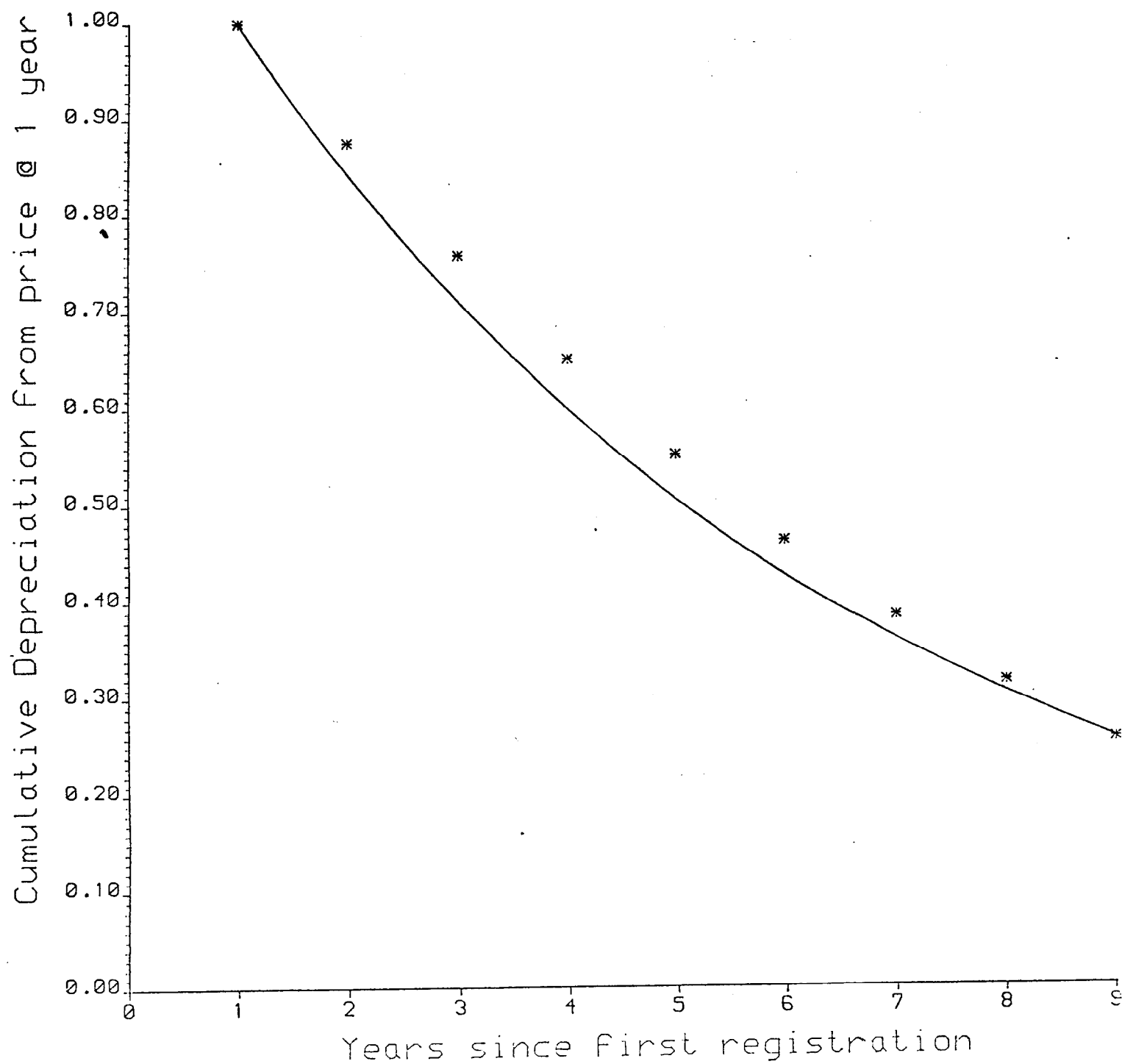


FIGURE 8

BELGIUM: CUMULATIVE DEPRECIATION IN 1985

