TRACTOR REPLACEMENT POLICIES

AND COST MINIMISATION

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DISCUSSION PAPER NO. 74

November 1983

AGRICULTURAL ECONOMICS RESEARCH UNIT
LINCOLN COLLEGE
CANTERBURY
NEW ZEALAND

ISSN 0110-7720

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PREFACE

Rapidly rising New Zealand prices of new farm machinery have been one of the features emanating from the annual farm economic survey of New Zealand wheatgrowing farms carried out by the Agricultural Economics Research Unit for New Zealand wheatgrowers. Hence, replacement strategies for tractors have been, and still are, of considerable interest to farmers.

The model reported in this paper has produced results that should be helpful to farmers and advisers in forming tractor replacement strategies. The paper has been written by Dr P.L. Nuthall, and Mr K.B. Woodford, Reader and former lecturer respectively in the Department of Farm Management and Rural Valuation at the College, and Mr A.C. Beck of the A.E.R.U.

It is pleasing to note further usage of the data collected in the Annual Wheatgrowers Survey. This growing set of data is allowing analyses such as that included in this paper to be undertaken. The foresight of the Wheatgrowers Subsection of Federated Farmers of New Zealand (Inc.) is to be applauded in this regard.

P.D. Chudleigh
Director

SUMMARY AND CONCLUSIONS

Calculating the most appropriate replacement policy for farm tractors is a complex exercise made even more difficult because of inadequate data on how resale values and repair costs vary with tractor age and hours of use. Accordingly, it is not possible to make any definitive statements as to exactly at what age a tractor should be replaced. However, analyses indicate that the most appropriate policies tend to be stable despite considerable variations in these parameters and hence a number of general statements and recommendations can be made.

In most situations the fixed costs associated with tractor ownership and replacement are minimised by keeping a tractor for at least 15 years. However, there is considerable flexibility in this policy and in many cases, as long as the replacement cycle is not reduced to five years or less, the additional costs of early replacement may be balanced by other non-quantifiable factors. These factors include pride, satisfaction, and a reduction in the risk of inconvenience and timeliness associated with mechanical breakdowns.

The effect of general inflation in the economy is to increase the real cost of tractor ownership even when machinery costs increase only at the same rate as other costs. This effect increases as the marginal tax rate increases, but it could be eliminated if taxation liability was measured using principles of current cost accounting rather than historical cost accounting.

In times of inflation farmers should avoid saving for machinery replacement by use of a sinking fund. For farmers on high marginal tax rates it is preferable to use borrowed funds, even where hire purchase interest rates have to be paid. However, if a farmer does have the required cash on hand it may be profitable to use the funds for machinery replacement depending on the alternative investments available.

1. INTRODUCTION

Over the last decade new tractor prices and tractor operating costs have risen considerably faster than farm product prices. In 1973 it cost 27.9 bales of wool to buy one specific brand of tractor, but by 1980 this had risen to 78.75 bales (Butchard, 1981). In 1973 100 kg of milkfat would purchase 201 litres of diesel, but by 1980 this had dropped to 95 litres.

Farmers have responded to this financial pressure in various ways. Some have moved towards low cost all grass farming systems, while others have reassessed the most appropriate size of machine, hired contractors, or formed machinery syndicates. Some of these options have been discussed elsewhere (Butchard, 1981; Davison, 1981). However, many farmers have also been giving closer consideration as to when is the best time to replace machinery and what is the best method of financing new purchases. It is these last two questions that are considered in this paper.

2. THE DECISION PROBLEM

Machinery investment decisions are relatively complex to analyse due to the dynamic nature of the problem and the difficulty of estimating the likely returns. The primary decision is usually whether or not an existing machine should be kept for at least one more period (usually a year), or replaced with a different machine. To make this decision it is first necessary to determine the optimal replacement time, in a cost minimising sense, for the new machine. The total costs associated with this optimal replacement cycle are then converted to an equivalent stream of equal annual costs at the appropriate rate of time preference (that is, converted to equivalent annuities). If the costs of holding the existing machine for one more period are greater than the equivalent annuity costs for the new machine then the existing machine should be replaced. Otherwise the existing machine should be retained for one more period and then the position reassessed. This reassessment is a constant requirement due to the ever changing conditions which affect the decision.

It is difficult to estimate accurately the true cost for either a proposed new machine or for an existing machine. There are a number of reasons for this:

(1) Machinery costs can take many different forms. Items that need to be considered include:

- purchase cost.
- running costs (fuel and oil)
- repairs and maintenance
- machine operator's wages
- resale prices
- cost of finance
- cost of labour (this may be an opportunity cost as well as a cash cost).

(2) Costs associated with a particular machine occur over many years. This means that both the real time value of money and also the effects of inflation must be considered.

(3) Costs should be evaluated on a post-tax basis taking account of the availability of taxation allowances. Parameters that need to be considered are:

- marginal tax rates
- investment allowances
- depreciation allowances
- depreciation recovered on resale.

(4) Costs can vary considerably depending on the skill of the operator and the standard of maintenance. In addition there is probably a random element in the timing of major breakdowns - two apparently identical machines treated in an apparently similar manner may have quite different repair costs.

(5) Mechanical breakdowns may increase the risk of both crop loss and untimeliness of operations. Purchasing a machine of inadequate capacity may have the same effect.

(6) Technological advances, government policies and other external factors may change resale values in unexpected ways.

In addition, non-financial aspects such as the status associated with owning a new machine may be relevant.

Given the inherent complexities of the problem it is probably unrealistic to expect farmers or their advisers to make these calculations on a regular basis. Although computer programs can facilitate the calculations, the data requirements are considerable and the results are open to misinterpretation. However, the present situation, where many farmers and their advisers tend to make decisions based on intuitive assessments, would also seem less than satisfactory. Accordingly, the objectives of the study reported here were to determine whether or not any general recommendations could be given as to appropriate replacement policies.

3. THE MODEL

In the course of the study a computer model of tractor costs for different replacement policies was built. Two versions were developed; one operates on a programmable calculator as well as a micro-computer, the other on a mainframe computer. The economic principles employed and the results obtained are identical.

The model is similar to a number of models constructed in other countries (Bates, et al. 1978; Chisholm, 1974; Kay and Rister, 1976). The mainframe version simulates projected cash flows associated with buying a new tractor, maintaining it and then eventually selling it at various ages. These cost streams are then converted to equivalent annuities after deflation so that alternative replacement policies can be compared. The other version uses real values throughout. Appendix 3 contains details of this second version for readers interested in the analytical procedures involved.

Tax depreciation schedules, repair cost schedules and resale values at various ages are incorporated into the model. The user is required to enter the number of hours of use per annum, the new purchase price, the inflation rate, the marginal tax rate, any investment allowances, the discount rate, the amount of money borrowed and the interest rate and term pertaining to this loan. Labour costs, fuel and oil have been excluded from the present model since these are unlikely to significantly alter as the age of a machine changes. However, the model could be adapted reaily to incorporate these factors.

4. DATA PROBLEMS

The amount of New Zealand data available for calculating repair costs and resale values is limited. Information on repair costs and how they vary with the age (as measured by hours of total use) and size of tractor is limited to data from the New Zealand Wheatgrowers Survey (Lough et al. 1978, and 1980) and subjective estimates from tractor repair firms. Some further indication of the relationships between age and repair costs can be obtained from overseas data (Bates et al. 1978). Nevertheless, considerable uncertainty as to these cost functions remains. Similarly, information on second hand resale values is restricted to dealer quotations. It is apparent that not only do these functions vary considerably between brands of tractor, but also that the price relationship between new and old tractors can change over time as external economic factors influence the supply and demand for second hand machines. Accordingly, the procedure used in this study was to test a number of alternative functions. Details of repair cost functions used are provided in Appendix 1 and of the resale price functions in Appendix 2.

5. RESULTS

Annuity costs of replacement were calculated for a range of tractor sizes, hours of use per year, marginal tax rates, discount rates and inflation rates. Due to the vast amount of cost data involved it is only possible to provide results for a limited number of situations.

TABLE 1

Annuity Costs of Replacing a 52 KWATT (70 H.P.) Tractor at Different Ages Assuming 400 Hours of Use per Annum and a Purchase Price of $17,864

Conditions	1	2	3	4	5	6	7	8	9	10
Discount Rate (%)	0	5	5	5	10	0	5	5	5	10
Inflation Rate (%)	15	15	15	15	15	15	15	15	15	15
Marginal tax/$	.35	0	.35	.60	.35	.35	0	.35	.60	.35
Repair Costs Assumpt.[a]	1	1	1	1	1	4	4	4	4	4
Resale Assumpt.[b]	1	1	1	1	1	2	2	2	2	2
	$									
After 1 yr	4276	7380	5275	3770	6264	2329	4582	3255	2363	4239
After 2 yrs	2689	4506	3515	2806	4344	2021	3642	2873	2371	3735
After 3 yrs	2132	3562	2879	2340	3638	1947	3313	2676	2265	3469
After 4 yrs	1842	3100	2539	2137	3254	1774	3013	2452	2093	3197
After 5 yrs	1667	2833	2325	1962	3009	1613	2764	2254	1927	2965
After 6 yrs	1538	2664	2168	1813	2829	1502	2598	2113	1800	2786
After 7 yrs	1443	2551	2050	1691	2695	1393	2457	1982	1674	2647
After 8 yrs	1380	2474	1967	1605	2598	1293	2383	1866	1561	2578
After 9 yrs	1339	2420	1908	1542	2526	1220	2238	1778	1477	2419
After 10 yrs	1315	2383	1866	1496	2472	1167	2164	1710	1413	2341
After 11 yrs	1302	2358	1836	1463	2431	1127	2104	1657	1363	2279
After 12 yrs	1298	2343	1816	1439	2400	1083	2043	1603	1312	2219
After 13 yrs	1301	2335	1803	1422	2377	1049	1994	1559	1272	2171
After 14 yrs	1309	2333	1795	1410	2359	1010	1944	1514	1230	2124
After 15 yrs	1322	2335	1792	1402	2346	991	1910	1486	1204	2091

[a] Refer to Appendix 1 for details

[b] Refer to Appendix 2 for details

The examples presented in Table 1 are indicative of the situation at present facing many farmers. It should be noted that the discount rate is a post-tax figure and is a measure of the real rate of time preference additional to any inflationary effects. Quite clearly, early tractor replacement is expensive in all situations. This is especially so where farmers are on low marginal tax rates and are unable to obtain full value from investment and depreciation allowances.

Although in all cases presented here the minimum cost is associated with a replacement policy in the vicinity of 15 years (the available data does not go beyond 15 years), in most cases the rate of decline in the annuity costs decreases rapidly after about five years. This suggests that in practice, and especially if there are non-financial aspects of early replacement to be considered, that there is considerable flexibility as to when a machine should be replaced as long as it is not in the first five years. Consequently, if farm income tends to fluctuate from one year to the next then it makes good sense to replace in a year when the marginal tax rate is high so as to obtain maximum benefit from the investment allowance and first year depreciation.

5.1 The Effects of Increased or Decreased Hours of Use

Estimates from the Wheatgrowers Survey (Lough et al., 1978 and 1980) indicate that on cropping farms the average tractor is worked for approximately 400 hours per annum. Obviously some tractors will do at least twice this amount of work, while on many sheep and dairy farms the figure will be considerably less.

The figures presented in Table 2 indicate, as expected, that as the number of hours a tractor is used increases, so does the annuity cost of replacing the machine at any specified age. Although in absolute terms the increases are greatest for long replacement cycles it would still appear to be unwise even with high hours of annual use to replace a machine until it is at least five years old. Given the uncertainty as to what the resale value and repair cost functions for any particular machine may be, it is impossible to state with any confidence as to what exactly is the cost minimising policy in this situation, but a replacement policy in the vicinity of five to ten years would seem to minimise the risk of a bad decision. Where a tractor is used for low hours, a replacement policy in excess of ten years would seem appropriate.

It is interesting to note that the physical life of a tractor is commonly estimated by engineers as being in the vicinity of 12,000 hours. At an annual rate of 400 hours per year this would suggest a physical life of 30 years, and at 200 hours it would be 60 years. This would seem to emphasise that tractor replacement is more a question of economics and changing technology than the physical wearing out of a machine, although the availability of spare parts is clearly a relevant factor.

TABLE 2

The Effect of Annual Hours of Use on
Replacement Cost of a $17,864 Tractor

Conditions	1	2	3	4	5	6
Hours of Use	200	800	200	800	200	800
Discount Rate (%)	5	5	5	5	5	5
Inflation Rate (%)	15	15	15	15	15	15
Marginal Tax/$	·60	·60	·60	·60	·60	·60
Repair Cost Assumpt.[a]	1	1	4	4	2	2
Resale Function Assumpt.[b]	1	1	2	2	1	1
	$					
After 1 yr	3659	3987	2333	2421	3668	4022
After 2 yrs	2679	3097	2335	2459	2683	3054
After 3 yrs	2248	2755	2222	2381	2247	2637
After 4 yrs	1979	2577	2042	2236	1973	2383
After 5 yrs	1738	2477	1869	2098	1728	2210
After 6 yrs	1553	2425	1736	1998	1539	2085
After 7 yrs	1422	2404	1604	1899	1402	1993
After 8 yrs	1324	2405	1484	1812	1300	1924
After 9 yrs	1250	2422	1394	1753	1222	1873
After 10 yrs	1192	2452	1323	1714	1160	1835
After 11 yrs	1146	2491	1267	1688	1110	1808
After 12 yrs	1110	2536	1210	1662	1069	1789
After 13 yrs	1080	2585	1164	1645	1035	1774
After 14 yrs	1055	2639	1116	1626	1007	1766
After 15 yrs	1034	2697	1085	1623	983	1763

[a] Refer to Appendix 1 for details

[b] Refer to Appendix 2 for details

5.2 The Impact of Inflation

The impact of general inflation in the economy, with machinery costs increasing at the same rate as other costs, is shown in Table 3. The results are presented in 1979/80 dollars. It is apparent from these results that there is an interaction between inflation and marginal tax rates, with the effect being greatest where replacement is at an early age. (Note that where the tax rate is zero, the inflation rate has no effect on the annuities. This is the extreme case.) This interaction is because, with historical cost accounting (as practised in New Zealand), inflation reduces the real value of taxation allowances.

TABLE 3

The Influence of Inflation on Tractor Replacement Costs
(New Price $17,864, 400 hours/annum)

Conditions	1	2	3	4	5	6
Discount Rate (%)	5	5	5	5	5	5
Inflation Rate (%)	0	10	15	0	10	15
Marginal Tax/$	0	0	0	.60	.60	.60
Repair Cost Assumpt.[a]	4	4	4	4	4	4
Resale Assumpt.[b]	2	2	2	2	2	2
	$					
After 1 yr	4582	4582	4582	432	1822	2363
After 2 yrs	3642	3642	3642	963	1990	2371
After 3 yrs	3313	3313	3313	1109	1962	2265
After 4 yrs	3013	3013	3013	1109	1841	2093
After 5 yrs	2764	2764	2764	1071	1712	1927
After 6 yrs	2598	2598	2598	1039	1613	1800
After 7 yrs	2457	2457	2457	1003	1522	1674
After 8 yrs	2333	2333	2333	996	1441	1561
After 9 yrs	2238	2238	2238	936	1375	1477
After 10 yrs	2164	2164	2164	911	1321	1413
After 11 yrs	2104	2104	2104	890	1276	1363
After 12 yrs	2043	2043	2043	867	1232	1312
After 13 yrs	1994	1994	1994	848	1196	1272
After 14 yrs	1944	1944	1944	828	1161	1230
After 15 yrs	1910	1910	1910	815	1135	1204

[a] Refer to Appendix 1 for details

[b] Refer to Appendix 2 for details

In addition, much of this depreciation is likely to be recovered on resale. These results indicate that many farmers, in particular those involved in horticultural and cropping activities involving large machinery investments, would greatly benefit from the acceptance for taxation purposes of current cost accounting. Such an accounting system would remove this interactive effect. This is particularly evident in condition set 4. The zero inflation rate assumption means the tax advantage of the investment allowance, combined with first year depreciation where tax is 60%, is not eroded at all, leading to the very low cost of a one year replacement policy. The replacement cost increases for a two year policy as the investment allowance effect is spread over two years.

5.3 The Impact of Financing Method

The analyses so far presented have taken no consideration of financing method. It has been assumed implicitly that new machines are purchased out of cash funds and the question as to how these funds are obtained has been ignored. However, in practice the gap between new price and resale value is often too great to be bridged by cash resources and farmers must resort to borrowing. Typically, such loans will be from banks or finance companies (hire purchase) at effective interest rates of 20 to 24 per cent. (These interest rates are often quoted on either a flat or nominal basis and hence appear to be lower than this).

TABLE 4

The Effect of Borrowing on Tractor Replacement Costs
(New Price $17,864)

Conditions	1	2	3	4
Discount Rate (%)	5	5	5	5
Inflation Rate (%)	15	15	15	15
Marginal Tax/$	0	0	.60	.60
Repair Cost Assumpt.[a]	4	4	4	4
Resale Assumpt.[b]	2	2	2	2
Loan Principal ($)	0	10,000	0	10,000
Loan Interest Rate (%)	0	22	0	22
Term of Loan (Years)	0	5	0	5
	$			
After 1 yr	4582	4690	2363	1521
After 2 yrs	3642	3738	2371	1629
After 3 yrs	3313	3397	2265	1615
After 4 yrs	3013	3086	2093	1526
After 5 yrs	2764	2828	1927	1438
After 6 yrs	2598	2652	1800	1407
After 7 yrs	2457	2504	1674	1330
After 8 yrs	2333	2375	1561	1253
After 9 yrs	2238	2277	1477	1196
After 10 yrs	2164	2199	1417	1154
After 11 yrs	2104	2137	1363	1123
After 12 yrs	2043	2074	1312	1087
After 13 yrs	1994	2023	1272	1059
After 14 yrs	1944	1971	1230	1028
After 15 yrs	1910	1936	1204	1012

[a] Refer to Appendix 1 for details

[b] Refer to Appendix 2 for details

The impact that borrowing can have is shown in Table 4. It is interesting to note that this loan has reduced the annuity cost for a farmer who is on a high marginal tax rate, and increased the annuity cost for a farmer paying no tax. This is because the interest is tax deductible and hence the post-tax interest rate is much lower for the farmer on a high tax rate.

The option of entering into a lease agreement as an alternative to hire purchase has not been specifically investigated. However, the situation can be expected to be very similar in both cases. With leasing the total rental payment and the investment allowance are tax deductible to the farmer but there is no depreciation allowance. With a hire purchase agreement there is both depreciation and an investment allowance but only the interest portion of the loan repayments are tax deductible. These factors usually balance each other out.

It is sometimes advocated that farmers should plan for machinery replacement by setting aside an annual sum of money in a sinking fund. The model as presently set up does not allow investigation of this option but it is clear that in times of inflation such a plan would be financially very poor, especially for farmers on high tax rates. For example, early 1983 interest rates on term deposits were generally of the order of 12 to 15 per cent, and after taxation at 60 cents in the dollar this reduces to 4.8 to 6 per cent. This is considerably less than half the present rate of inflation and it is clear that in real terms a considerable loss is being sustained. Accordingly, in general the use of a sinking fund is not to be recommended. The only exceptions where it should be considered are where the savings period is to be short (preferably no more than two years) and for farmers on very low tax rates. In all other situations it is recommended that machinery purchases be financed wherever possible by borrowing (or possibly leasing) rather than saving.

5.4 Additional Considerations

All models, be they simple budgets or complex mathematical programming models, have inherent assumptions and simplifications incorporated into them. These assumptions and simplifications should be considered when analysing the results. With the machinery replacement model described in this paper there is an implicit assumption of stationary technology. In practice improved tractors are regularly coming on the market. This can mean that existing tractor models can become outmoded and that it is economic to replace a machine at an earlier age than was envisaged at the time of the purchase. The implications of future technological advance on present planning are complex, but it would seem sensible to delay purchase of a new machine in those situations where major advances or changes in technology are obviously close at hand.

The second point that must be stressed is that resale values are not necessarily constant over time but vary with supply and demand. For example, if most farmers were to delay replacement then there would be less late model second hand machines available and the resale value of these machines would rise. This would make early replacement less costly.

6. A COMPARISON WITH EXISTING PRACTICE

The information in Tables 5 and 6 has been extracted from the 1979/80 New Zealand Wheatgrowers Survey (Lough et al., 1980). Most farmers in the survey have a tractor less than five years old and it is only the presence of second and third tractors which raises the average age to seven years. Given that the average annual usage of these tractors is only 400 hours, it would seem that many farmers are following a sensible replacement policy but that there are others who are prepared to either pay a considerable premium for the pleasure of owning a new machine or else are unaware of the additional costs associated with early replacement.

TABLE 5

Number of Tractors of Various Ages on Wheat Farms

Age	Number of Tractors	Percentage of Total
1 to 4 years	127	45
5 to 8 years	73	26
9 to 12 years	37	13
13 to 16 years	28	10
17 to 20 years	13	4
20 plus	6	2
	284	100

SOURCE: 1979/80 Wheatgrowers Survey (Lough et al., 1980)

TABLE 6

Average Age of Tractors by Power[a] on Wheat Farms

Power (Kwatts)	< 44.4	44.4–63.0	> 63.0
No. of Tractors	82	151	51
Average age in years	12.2 years	5.5	3.0

[a] 1 HP = 1.35 Kwatt

SOURCE: 1979/80 Wheatgrowers Survey (Lough et al., 1980)

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APPENDIX 1

MAINTENANCE COST FUNCTIONS

Analysis of maintenance cost data obtained from the 1979/80 New Zealand Wheatgrowers Survey (Lough, et al. 1980) indicated a wide scatter of costs with a tendency for two groups to emerge. One group tended to have distinctly lower costs than the other. This could be due in part to the care taken by one group but is probably mainly due to the discrete nature of major repairs. To cover the possibilities two functions were estimated, one for each of the distinct groups. Perhaps surprisingly, there appeared to be no clear relationship between the size of tractor and repair costs, at least for tractors of less than 63 Kwatts. Although tractors greater than 63 Kwatts do appear to have increased costs there was insufficient data available to develop a separate function using regression methods. The composite relationships developed were based on 1979/80 prices:

(1) Cost Function 1 (high cost group)

$$M_j = \frac{.327Y^*_j - 116.8^*}{H_j} \qquad (R^2 = 0.76)$$

where Y_j = total hours on the clock at the start of the jth year.

M_j = the hourly maintenance cost in year j in \$.

H_j = the number of hours used per year.

No. of observations = 106.

* = significant at 5% level.

(2) Cost Function 2 (low cost group)

$$M_j = \frac{.1297Y_j^* - 3.263}{H_j} \qquad (R^2 = 0.73)$$

where Y_j = total hours on clock at the start of the jth year.

M_j = the hourly maintenance cost in year j in \$.

H_j = the number of hours used per year.

No. of observations = 120.

* = significant at 5% level.

Alternative cost functions were also subjectively estimated taking into account additional information from other countries and estimates from tractor repair firms. These are:

(3) Cost Function 3 (tractors less than 44.4 Kwatt)

$$M_j = 0.20 + 0.000135\ Y_j$$

(4) Cost Function 4 (44.4 – 63.0 Kwatt)

$$M_j = 0.29 + 0.000245\ Y_j$$

where M_j = <u>hourly</u> maintenance cost in year j in $

Y_j = hours on the clock at the start of the jth year.

APPENDIX 2

TRACTOR RESALE VALUES

The following function was developed from dealer quotation prices as at January 1980 (Resale Function 1).

$$\text{Log } Y = 3.6395 + 0.00002506 X_1 - 0.0000405 X_2 - 0.01441 X_3 \quad (R^2 = 0.78)$$

where Y = resale value in \$

X_1 = new price in \$

X_2 = hours on clock

X_3 = age in years

number of observations = 106.

Despite the reasonably high R^2 and the significance of all variables at the one per cent level, some reservations remain as to the high rate of decline in value in the first few years. Furthermore, the observations of resale value on which the function is based only covered the range \$2,000 — 16,000 (1980 prices). The function produces plausible results for new prices between \$6,000 and \$40,000. Accordingly, an alternative function was subjectively constructed with value estimated as a function of years of age (Resale Function 2).

Age of Machine (years)	Resale Value as a Proportion of New Cost (Constant Value Dollars)
1	0.80
2	0.70
3	0.60
4	0.53
5	0.48
6	0.43
7	0.39
8	0.36
9	0.33
10	0.30
11	0.27
12	0.25
13	0.23
14	0.22
15	0.20

APPENDIX 3

CALCULATING THE ANNUAL REPLACEMENT COST

As the estimated cost is used for determining the optimal replacement time only costs that vary with time need be included. Costs which remain constant, or nearly constant, due to their invariant nature, do not influence the optimal replacement time. The major variable costs include repairs and maintenance, interest charges, and taxation (both the direct effects and those caused by inflation). It is necessary to use real values when making comparisons (i.e. dollar sums that have been equated to a given time) due to inflation. All costs are reduced to present values.

The model developed was based on one presented by Bates et al. (1978). Some modifications were necessary to correct an error and also to simplify slightly the calculations necessary. The model is described by considering each component in turn. These are:

1. replacement cost;
2. maintenance costs;
3. depreciation benefits through tax deductions;
4. tax balancing costs or benefits resulting from discrepancies between book and sale values.

1. Replacement Costs.

Using AC_r^n to represent the equivalent annual cost (i.e. an annuity) of the periodic, but regular, lump sum required to replace the machine after n years, this cost is given by:

$$AC_r^n = \frac{C_o + C_n}{(1+n)^n} \times \frac{1}{A}$$

where C_o = the real purchase price of a new machine

C_n = the real sale price of the machine when it is sold at the end of the nth year

i = the real discount rate (interest rate) expressed as a fraction

$\frac{1}{A}$ = a factor for converting the discounted replacement cost into a constantly recurring annuity assuming the replacement policy continues to infinity. This factor is:

$$\frac{i}{1 - \frac{1}{(1-i)^n}}$$

If it assumed the farmer does not already own a tractor, the replacement cost function must be adjusted by adding iC_o.

It is interesting to speculate on i. As it reflects the preference an individual has for consumption now rather than putting it off a year, it will vary from one farmer to another. Furthermore, it is unlikely to be greater than 5% as, while interest rates of around 15% are common, by the time tax is paid on any profit and the income is not received for six to twelve months, tax and inflation have whittled down the true value of the return. The effective real interest is markedly less than the nominal interest.

2. Maintenance Costs

Where AC_m^n is used to represent the annuity equivalent of the net maintenance costs after allowing for tax reductions resulting from incurring the expenditure, this cost is given by:

$$AC_m^n = \sum_{t=1}^{n} \left[\frac{M_t}{(1+i)^t} - \left(\frac{zM_t}{1+f}\right)\left(\frac{1}{(1+i)^{t+1}}\right)\right] \times \frac{1}{A}$$

where M_t = real maintenance costs incurred in the t^{th} year of the life of the machine

z = marginal tax rate paid by the farmer (expressed as a fraction)

f = the inflation rate (expressed as a fraction).

The first term brings in the discounted cost of the repairs while the second term allows for the tax saved from setting the maintenance cost against income. This sum must be adjusted for inflation as it is not received for approximately one year later due to the lags in the tax system. This is also why this sum must be discounted an extra year ($(1+i)^{t+1}$).

3. Depreciation Benefits

Letting AB_d^n represent the benefits, expressed as an annuity, of being able to set the standard depreciation allowances off against income for taxation purposes, the depreciation benefits are given by:

$$AB_d^n = \left[\left(\frac{C_o(d_1+d_2)z}{1+f} \times \frac{1}{(1+i)^2}\right) + \sum_{t=2}^{n}\left(\frac{B_t d_3 z}{(1+f)^{t+1}} \times \frac{1}{(1+i)^{t+1}}\right)\right] \times \frac{1}{A}$$

where d_1 = investment allowances (expressed as a fraction)

d_2 = first year depreciation (expressed as a fraction)

d_3 = second and subsequent years depreciation (expressed as a fraction)

B_t = book value of the machine

where $B_1 = C_o$

$B_2 = C_o - C_o d$

$B_t = B_{t-t} - B_{t-1} d_3$ for t=3,4...

The first term accounts for the tax benefits of the investment allowance and first year depreciation. Again, because tax benefits are lagged the benefit must be adjusted for inflation to convert it to a real value as well as discounted for two years due to this lag. The second term allows for depreciation in subsequent years. As the book value is a nominal figure the tax benefit must be deflated for t+1 years (the denominator) to convert it to a real value. It must also be discounted for this number of years to allow for time preference.

4. Balancing Costs

If AC_b^n is used to represent the costs associated with paying additional tax resulting from the differences between the sale price and book value in year n, then this is given by:

$$AC_b^n = \frac{(S_n(1+f)^n - B_n)z}{(1+f)^{n+1}} \times \frac{1}{(1+i)^{n+1}} \times \frac{1}{A}$$

where S_n = the real sale value of the machine at the end of the year (it is assumed that all transactions occur at the end of the year). However, if $S_n(1+f)^n$ is greater than C_o it must be set equal to C_o as the difference is a tax free capital gain.

If the book value exceeds the sale value AC_b^n will be negative. In allowing for the balancing charge the inflated sale value must be compared with the book value and related to the marginal tax rate. The numerator of the first term achieves this. This must then be deflated (thus the denominator) and converted to an annuity (1/A).

Putting all these components together gives the net annuity equivalent of replacing the machine every n years. Thus, where AT^n is this annuity,

$$AT^n = AC_r^n + AC_m^n - AB_d^n + AC_b^n$$

To find the cost minimising n it is necessary to calculate AT^n for n = 1,2,3 ... and select the n with minimum AT^n.

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