Capital Equipment Replacement Decisions

R.L. Batterham and K.I. Fraser*

This paper reviews the literature on the optimal replacement of capital equipment, especially farm machinery. It also considers the influence of taxation and capital rationing on replacement decisions. It concludes that special taxation provisions such as accelerated depreciation and investment allowances are unlikely to greatly influence farmers' capital equipment replacement decisions in Australia.

1. Introduction

The asset replacement problem can be divided into two general classes: the (relatively long lived) appreciating assets (typically tree crops) and (relatively short lived) depreciating assets such as machinery. In this paper we are considering the latter although the same asset replacement theory is applicable to both classes.

Replacement of assets in agriculture is both a complex economic problem and a problem of considerable practical importance to farmers, especially those faced with decisions involving the replacement of major items of farm equipment. These practical asset replacement decisions are made under conditions of risk and of capital rationing and may be influenced by taxation considerations. However, no attempt is made here to examine the effects of specific details of Australian tax laws on asset replacement decisions.

2. Elements of the Capital Equipment Replacement Problem

The objective of the firm's asset replacement decision is to replace assets at intervals that maximise the net present value of the income stream from the firm.

The information required to solve the replacement problem is as follows:

(a) The purchase price of the asset. This is known with virtual certainty at the time the asset is purchased, but known only within increasingly dispersed probability distributions as a purchase is contemplated further into the future.

(b) The trade-in price of a currently owned asset (if any). At the time of trade, this too is known with certainty. The further into the future that the trade-in is contemplated, the greater is the dispersion of the probability distribution of the trade-in price.

(c) The contribution the asset will make to the income earning capacity of the business. This is both difficult to calculate (and indeed is often ignored in asset replacement theory) and is likely to be stochastic. In production economics terms, the contribution of the asset can only be valued in a multi-input, multi-output analysis. An asset may make virtually no contribution to the output of some potential products produced by the firm (e.g. the influence of a wheat header on wool production). Alternatively it may be virtually impossible to produce particular products without that asset (e.g. the influence of the header on wheat production).

(d) The technical improvement in future assets and hence the obsolesence of current assets. These are assumed to be stochastic. Technical improvements in farm machines, for example, are a major element in the replacement decision.

(e) The operating costs of current and future assets (which are generally known within fairly tight probability distributions).

(f) The repair costs required to keep current and future assets operating to a specified level of service. These can be defined also within probability distributions. In farm machinery it is often the obsolesce factor that limits repair and continued operation, rather than the probabilistic repair cost itself. Associated with the repair

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* University of Sydney and NSW Agriculture respectively. This research was supported, in part, by a research grant awarded jointly by the Grains Research and Development Corporation and the Land and Water Resources Research and Development Corporation.

cost is an increasing probabilistic cost associated with unreliability of operation. 'Penalties' for not maintaining machines to a specified level thus can be defined probabilistically.

(g) The taxation treatment of capital and operating costs are subject to discrete changes. The taxation implications of theses costs which are complex and are influenced by business and personal tax considerations which vary with the business structure(s) adopted by the firm.

(h) Present and future capital rationing largely depends on the income earning capacity of the business. This capacity is clearly stochastic. Taxation implications flow from the different methods that may be used to finance asset purchase. Capital rationing is a major problem following a period of depressed product prices or drought and thus is particularly relevant to the asset replacement decisions currently being made by Australian grain farmers, for example.

(i) The method of acquiring services from capital assets. Hiring contract services (e.g. contract harvesting) is relatively common. Hiring machinery is rare in Australia as compared to the situation that prevails in North America, but it is increasing in popularity. Financial leases, with various terms and conditions, have been common since the 1970s, but operating leases for machinery are still rare. Acquisition of the services of assets by contracting, hiring or leasing can reduce the impact of capital rationing.

(j) Economic indivisibilities. While most assets are available in a wide variety of 'sizes', technical and economic indivisibilities do occur. The economic indivisibilities are largely due to the need to achieve an asset 'size' large enough to give 'economies of size'.

(k) Optimum asset replacement cycles. The optimum asset replacement cycles may be even or uneven. When optimum replacement cycles are actually calculated using operations research methods, typically there are steeply increasing (or decreasing), then relatively flat 'net present value through time' asset earning (or cost) curves. It may be possible to replace assets with new assets, or replace a 'new' asset with an old one ('back-trade') or an old asset with a new one ('trade-up').

3. Theory of Asset Replacement

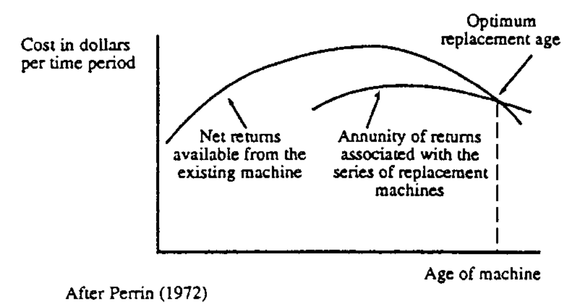
Replacement theory is derived from capital theory and investment theory. The modern version of investment theory can be traced from Bohm-Bawerk, Fisher and Hirshliefer. Virtually everyone now working in the area of investment theory and appropriate criteria for investment decisions refers back to Hirshliefer's work. Hirshliefer's work, and the work that has followed on the growth of the firm, indicates that that a firm should attempt to assemble that bundle of assets that maximises the net present value of the income stream available from firm. Recent work by Dixit and Pindyck suggests that investment evaluation should consider the opportunity cost of foregoing an 'option value' associated with postponing an irreversible investment. Among the implications of their work are possible insensitivities by decision makers to changes in interest rates and taxation policies aimed at stimulating investment. Their work may profoundly influence the theory of investment and the practical application of the theory to problems such as asset replacement.

The literature on asset replacement is quite diverse. Hotelling, in the most influential early work, suggested a replacement model maximising the present value of the future earnings of the asset to determine the optimum replacement time for a single asset cycle. Preinreich produced a model that again maximised the present value of the future earnings of the asset, but included replacement assets in a sequence of continuous replacements. Terborgh and Alchian switched attention from maximisation of the present value of the future earnings of the asset to minimising the cost (or the net present value of the cost) of the sequence of replacement assets. This important change was apparently motivated by the difficulty of estimating the income attributable to individual assets controlled by the firm. Terborgh's work is particularly interesting, in the context of farm machinery, in that it explicitly considers the problem of replacement as technically superior assets are developed.

Applied asset replacement models have been developed in many areas of economics and in operations research. Good discussions of optimal replacement can be found in most operations research textbooks (Winston).

In agricultural economics there are a series of very well known papers on asset replacement. Faris concluded that the 'the optimum time to replace is when the marginal net revenue from the present enterprise is equal to the highest amortized present value of anticipated net revenue from the following enterprise' (p. 766). Chisholm (1966) and Perrin generalised the theory of asset replacement to account for the opportunity cost of investment in all future replacement assets. Perrin's replacement criteria can be characterised as; replace the existing asset ('the defender') with the replacement asset ('the challenger') when the net returns available from the existing asset equal the annuity of the returns available from the (series of) replacement asset(s). This criteria is illustrated in figure 1.

Figure 1: Replacement of a Series of Identical Machines



Burt considered the problem of replacement under risk and suggested a dynamic programming approach to its solution. Several authors have considered replacement with technologically improved assets (Perrin; Mateffy). McClelland *et al.*, and Pagoutatos and Blackwell have considered the problem of replacement with overhaul possibilities.

4. Effect of Taxation on Asset Replacement

Chisholm (1974) modelled the influence of tax on agricultural asset replacement (see appendix) as it was affected by depreciation allowances and investment incentives for Australian farm machinery and extended his analysis to the US situation. He found that the depreciation method and existence of additional first year depreciation or an investment credit had little effect.

Bates, Rayner and Custace used a 'tax adjusted replacement model' to include the interactions between taxes and inflation. They concluded that inflation effectively increased the magnitude of costs and extended the optimal replacement age.

Reid and Bradford built on Chisholm's work using a multiperiod mixed integer programming model of the farm firm to analyse the effect of the *Economic Recovery Tax Act 1981* on optimal replacement of tractors. They found that investment tax credits were the most important tax incentive to early machinery replacement.

Lynne used a simulation model to re-examine the results of Chisolm (1974) and Reid and Bradford to explore the possibility of multiple replacement optima, particularly in relation to the effect of tax benefits. He concluded that 'the profit maximization behavioural rule needs to be supplemented with knowledge about farmer's objectives in order to select the correct optimal reinvestment interval' (p. 179).

Moss, Muraro and Boggess considered the distortion of farmers investment decisions by income tax provisions. They found that the *US Tax Reform Act of 1986* 'reduced the distortionary effects of the tax code on capital investment decisions' (p. 107). They identified the main reason as being the change in the average tax rate under the provisions of the *Tax Reform Act 1986* and its predecessor, the *Tax Equity and Fiscal Responsibility Act 1982*. Smith (1990) also examined the *Tax Reform Act 1986* as it affected agricultural asset replacement. He used a deterministic asset replacement model, and found that the optimal replacement time was inversely related to the size of the investment tax credits and the present value of the depreciation allowances. Further, it was directly related to marginal tax rates. He found the effect of the *Tax Reform Act* was to increase the replacement age for assets with short depreciation lives (e.g. tractors) and decrease it for assets with long depreciation lives (e.g. farm structures).

The effect of including discounting schemes and self-employment taxes on optimal machinery replacement was tested by Van Tassell and Nixon. With these factors the optimal replacement interval was reduced to periods shorter than those determined by Reid and Bradford.

The implications of the *Tax Reform Act 1986* were also reviewed by Innes and Carman in a study of the effects on beef cow replacement strategy. The loss of the capital gains exclusion and restrictions on preproduction expensing were found to have the biggest impact. It was concluded that both the optimum age for culling beef cows and the after tax costs of beef cow would increase.

The trade-off between capital and non-durable inputs (labour) due to taxes and investment incentives and the ensuring resource misallocation was modelled by Traill in the United Kingdom. Burrell, Hill and Williams developed a methodology to analyse the differential impact of grants and tax incentives on investment in capital assets. The impact of changes to the tax system in 1984 in the UK on investment in farm machinery was modelled by Bright. His analysis used the methodologies developed by Burrell, Hill and Williams and Traill, however it varied from previous studies as he also took account of the possibility that farmers cannot take advantage of tax depreciation provisions because of insufficient profit against which to offset allowances. The change analysed was a reduction in the initial capital allowance on plant and machinery from 100 per cent to 25 per cent and the use of tax bands. He found that the incentives to invest in machinery were considerably reduced and the use of tax bands had a further negative effect on investment.

There does not appear to be any substantial Australian work on the influence of taxation on optimal replacement since Chisholm's (1974) paper. However, work by Douglas, Peterson, Kokic and Parameswaram is under way to examine *ex-post* the effects of taxation concessions on investment and the adoption of 'socially desirable' farming practices. In addition, a study of the optimal replacement of farm machinery under conditions of capital rationing is currently being conducted by the authors. The influence of Australian taxation provisions on equipment replacement will be included in this study.

5. Capital Rationing, Asset Replacement and Taxation

There are many different methods of acquiring a flow of services from given items of capital equipment as indicated above. The major option considered in this paper is to acquire the flow of services by owning and successively replacing items of equipment. There are a number of alternatives for financing the replacement of equipment and these financing methods are subject to quite different treatments for taxation purposes. It is relatively easy to calculate the net present value of costs for various replacement cycles for different assets for various discount rates, tax rates, business structures and alternative tax laws using spreadsheet or dedicated programs.

It is much more difficult to solve a replacement problem in the presence of capital rationing. The amount of cash available at the beginning of the planning period, and the cash generated by the firm during the planning period, constrain the choice of financing methods and hence the optimal replacement period. Weingartner showed how the optimal financing decision, including capital rationing, could be modelled using linear programming. However it is difficult to solve for optimal financing under capital rationing, and simultaneously solve the optimum replacement sequence using linear programming because the model size tends to explode.

In the study mentioned above, the authors are examining several methods for solving the problem of optimal replacement for farm machinery. In addition to various linear programming models, spreadsheet formulations of iterative budgeting methods, dynamic programming (Kennedy, p. 136-41, Pagoulatos and Blackwell) and simulation methods are being used.

The preliminary results from the study, generated in spreadsheet simulations, indicate that the net present value of costs decline steeply as replacement intervals increase from very short intervals (yearly or every two or three years). The costs then flatten and there tend to be multiple replacement optima. This result that is similar to that produced by Lynne. Further, replacement at a non-optimum time, on the flat part of the curve, does not have a large opportunity cost. Costs then rise again as the replacement interval increases. These results are consistent with economic theory and may, in part, reflect the operation of a well informed market in new and used farm machinery.

6. Policy Issues

There are more important issues in considering taxation policy for the rural sector than those associated with asset replacement. Some major issues are of enormous importance for personal and business taxation across the whole economy (see Smith 1993 for a historical development of these issues). Those issues of particular interest to the rural sector have been considered in the past (BAE; Australian Tax Research Foundation) or are addressed in this current forum.[1]

While asset replacement could be influence by broad taxation policy changes (e.g. change in emphasis from income taxes towards consumption taxes) the policies that currently influence asset replacement are:

(a) the treatment of depreciation for taxation purposes;

(b) investment allowances;

(c) the different taxation treatment of alternative methods of financing the replacement of assets.

The influence of these policies can be judged against a 'neutral' tax system. Under such a system asset replacement decisions would be the same before and after the taxation implications of the decision were considered.

6.1 Depreciation and Investment Allowances

A major policy question concerning depreciation is; why does virtually every government in the western world allow a rate of depreciation for taxation purposes that is greater than the 'economic' rate and do these accelerated depreciation rates matter in an economic sense?

There are several possible explanations for the first part of the question, but none are very convincing to an economist. First, accelerated depreciation rates have been used for a long time and are now accepted as accounting conventions. Second it is possible, for countries such as Australia, that there are foreign competition arguments, i.e. firms may not invest here if they can get a better investment deal in another country. Third, it is sometimes argued that accelerated depreciation represents some compensation for risk taking. This argument can be rejected in the light of the theory of decision making under risk. Fourth, governments may wish to deliberately encourage investment and/or the adoption of new technology knowing that their decisions will bias resource allocation.

With regard to the second part of the question, it is easy to show that accelerated depreciation rates do matter by simply calculating the optimum replacement age of assets in the presence and absence of accelerated depreciation, or at different rates (see Chisholm 1974). The empirical question of how much they matter is not pursued in this paper.

The theory pertaining to the treatment of depreciation for tax purposes is contained in Samuelson who argued that depreciation rates for tax purposes should be the same as the 'economic' rate of depreciation. Edwards in a definitive paper, discussed depreciation for taxation purposes and investment allowances in the context of Australian agriculture. He argued that accelerated depreciation (which he called accelerated amortisation) will effectively result in an interest free loan to any tax payer allowed this accelerated rate. The size of the loan depends on the marginal tax rate of recipient and the duration depends on the 'the extent to which the depreciation period is shortened for tax purposes' (p. 24). He argued further that 'investment allowances provide the recipients with a "cash grant" in the form of a reduction in income tax liability' (p. 24). He shows that the 'loan' and the 'grant' increase the after tax return on investment. This argument can be extended to asset replacement in which case the 'loan' and/or the 'grant' will reduce the optimal replacement interval.

6.2 Taxation of Alternative Methods of Finance

Again, it is easy to show that different financing methods can influence the optimum investment and the replacement age by making a few spreadsheet calculations. The difference in the taxation treatment of lease finance as compared to forms of borrowing to purchase an asset is particularly striking. Briefly, in the case of leasing, the lease 'rental' and operating expenses are regarded as expenses for taxation purposes. Leasing tends to be attractive to taxpayers with high marginal tax rates and can lead to the use of lease finance in tax shelter arrangements. For cash purchase and purchase using various types of loan, depreciation, interest costs (if any) and operating costs are considered as expenses. The optimum method of financing will vary for various marginal tax rates, discount rates

[1] Similar attention is given to the taxation provisions applying to other industries from time to time. The Industries Assistance Commission considered the problem of depreciation of capital assets in the mining sector.

and levels of capital rationing. Clearly the treatment of different financing methods is not 'neutral' as defined above.

7. Concluding Remarks

The clear conclusion that can be drawn from the review of the literature is that taxation is influential in agricultural asset replacement decisions in the USA, the UK and Australia. Just how important it is can be determined from studies similar to the 'farm management' oriented ones cited, and from statistical work such as that of Douglas, Peterson, Kokic and Parameswaram. There is little evidence on the importance of taxation in asset replacement in Australia. Chisholm's (1974) work indicates that it may be important in individual management decision making especially for those with high marginal tax rates. The work of Douglas, Peterson, Kokic and Parameswaram indicates that, in aggregate, taxation provisions may not be very important in investment decisions. Interestingly, this observation is consistent with deductions that can be made from the theory of investment postulated by Dixit and Pindyck. It is obvious that there is scope for further research in this area.

Many factors complicate the asset replacement decision. Risk is clearly evident in many elements of the decision. It is also likely that many factors that are difficult to quantify in economic terms are influential. Capital rationing is also an important factor in the decision. Markets catering for contract and daily hire of agricultural services, and financial markets may develop further to alleviate this problem.

References

ALCHIAN, A.A. (1958), *Economic Replacement Policy*, Rand Corporation, Santa Monica.

AUSTRALIAN TAX RESEARCH FOUNDATION (1988), *Taxation and the Rural Economy*, Australian Tax Research Foundation, Sydney.

BATES, J.M., RAYNER, A.J. and CUSTACE, P.R. (1979), 'Inflation and farm tractor replacement in the US: a simulation model', *American Journal of Agricultural Economics* 62(2), 331-334.

BOHM-BAWERK, E.R. (1959), *Capital and Interest*, Libertarian Press, South Holland.

BRIGHT, G. (1987), 'Tax changes and machinery investment', *Journal of Agricultural Economics* 38(1), 39-49.

BUREAU OF AGRICULTURAL ECONOMICS (1985), *The Implication of Taxation Reform for the Rural Sector*, AGPS, Canberra.

BURRELL, A.M., HILL, G.P. and WILLIAMS, N.T. (1983), 'Grants and tax relief as investment incentives', *Journal of Agricultural Economics* 34(2), 127-138.

BURT, O.R. (1965), 'Optimal replacement under risk', *Journal of Farm Economics* 47(2), 324-46.

CHISHOLM, A.H. (1966), 'Criteria for determining the optimum replacement pattern', *Journal of Farm Economics* 48(1), 107-12.

CHISHOLM, A.H. (1974), 'Effects of tax depreciation policy and investment incentives on optimal equipment replacement decisions', *American Journal of Agricultural Economics* 56(4), 776-83.

DIXIT, A.K. and PINDYCK, R.S. (1994), *Investment under Uncertainty*, Princeton University Press, Princeton.

DOUGLAS, R.A., PETERSON, D., KOKIC, P. and PARAMESWARAM, B. (1995), 'A note on accelerated depreciation and investment allowances' invited paper to the Australian Agricultural Economics Society Rural Income Taxation Forum, Perth, 13 February.

EDWARDS, G.W. (1968), 'The effect of income tax provisions on returns to investment in agriculture' *Quarterly Review of Agricultural Economics* 21(1), 22-36.

FARIS, J.E. (1960), 'Analytical techniques used in determining the optimal replacement pattern', *Journal of Farm Economics* 42(4), 755-66.

FISHER, I. (1930), *The Theory of Interest*, Macmillan, New York.

HIRSHLIEFER, J. (1958), 'On the theory of optimal investment decision', *Journal of Political Economy* 66, 329-52.

HOTELLING, H. (1925), 'A general mathematical theory of depreciation', *Journal of the American Statistical Association* 20, 320-53.

INDUSTRIES ASSISTANCE COMMISSION (1976), *Petroleum and Mining Industries*, AGPS, Canberra.

INNES, R. and CARMAN, H. (1988), 'Tax reform and beef cow replacement policy' *Western Journal of Agricultural Economics* 13(2), 254-66.

KAY, R.D. and RISTER, E. 'Effects of tax depreciation policy and investment incentives on optimal equipment replacement decisions: comment', *American Journal of Agricultural Economics* 58(2), 355-358

KENNEDY, J.O.S. (1986) *Dynamic Programming: Applications to Agriculture and Natural Resources*, Elsevier, London.

LYNNE, G.D. (1988), 'Machinery replacement, multiple optima, and the 1986 Tax Reform Act', *Southern Journal of Agricultural Economics* 20(1), 179-87.

MCCLELLAND, J.W., WETZSTEIN, M.E. and NOLES, R.K. (1989), 'Optimal replacement policies for rejuvenated assets', *American Journal of Agricultural Economics* 71(1), 147-57.

MATEFFY, V.K. (1987), Economic Life Optimisation of Major Construction Equipment, Unpublished MEngSc Thesis, University of Sydney.

MOSS, C.B., MURARO, R.P. and BOGGESS, W.G. (1989), 'Distortionary impacts of the 1982 and 1986 US tax codes on capital investment: a case study of investment in orange groves' *Southern Journal of Agricultural Economics* 21(2), 107-114.

PAGOULATOS, A. and BLACKWELL, M. (1992) 'On the optimal tractor replacement decision: the case of a 110hp tractor with overhauling', University of Kentucky.

PENINREICH, G.A.D. (1940), 'The economic life of industrial equipment', *Econometica* 8, 12-44.

PERRIN, R.K. (1972), 'Asset replacement principles' *American Journal of Agricultural Economics* 54(1), 60-67.

REID, D.W. and BRADFORD, G.L. (1983), 'On optimal replacement of farm tractors' *American Journal of Agricultural Economics* 65(4), 326-31.

SAMUELSON, P.A. (1964), 'Tax deductibility of economic depreciation to insure invariant valuations' *Journal of Political Economy* 72(6), 604-606.

SMITH, J.P. (1993) *Taxing Popularity: The Story of Taxation in Australia*, Australian National University, Canberra.

SMITH, V.H. (1990) 'The effect of changes in the tax structure on agricultural asset replacement', *Southern Journal of Agricultural Economics* 22(1), 113-21.

TERBORGH, G. (1949), *Dynamic Equipment Policy*, McGraw-Hill, New York.

TRAILL, B. (1982), 'Taxes, investment incentives and the cost of agricultural inputs', *Journal of Agricultural Economics* 33(1), 1-12.

VAN TASSELL, L.W. and NIXON, C.J. (1989), 'A further look at the effect of Federal tax laws on optimal machinery replacement', *Southern Journal of Agricultural Economics* 21(2), 77-84.

WEINGARTNER, H.M. (1963), *Mathematical Programming and the Analysis of Capital Budgeting Problems*, Prentice-Hall, Englewood Cliffs.

WINSTON, W.L. (1991), *Operations Research: Applications and Algorithms*, PWS-Kent, Boston.

Appendix: The Chisholm Model

Chisholm (1974) developed a model that can be used to calculate the after tax present value cost of a single machine and from it the the optimum replacement pattern for a perpetual chain of machines over an infinite planning horizon. The model can be used also to demonstrate the importance of taxation in the machinery replacement decision. The following equation gives the after tax present value cost of a single machine as:

$$Q_n = (M_0 - M_n\,[1+r]^{-n}) + 1-T\left\{\sum_{k=1}^{n} R_k\,[1+r]^{-k}\right\} - T\left(I[1+r]^{-k}\right) - T\left\{\sum_{k=1}^{n} D_k[1+r]^{-k}\right\} + T\left\{\sum_{k=1}^{n} D_k - M_0 + M_n[1+r]^{-n}\right\}$$

where

n	=	replacement age in years
r	=	after tax discount rate
M_0	=	acquisition cost of new machine
M_n	=	resale value of machine at year n
R_k	=	operating cost of machine in year k
D_k	=	depreciation allowance in year k
I	=	investment allowance
T	=	tax rate

The components of the above equation may be interpreted as follows:

$(M_0 - M_n\,[1+r]^{-n})$	is the initial cost of the machine minus its discounted resale value
$1 - T\left\{\sum_{k=1}^{n} R_k[1+r]^{-k}\right\}$	is the discounted sum of the after tax operating costs of the machine
$T\,(I\,[1+r]^{-k})$	is the tax saving associated with any investment allowance I
$T\left\{\sum_{k=1}^{n} D_k\,[1+r]^{-k}\right\}$	is the discounted sum of the tax saving associated with the depreciation allowed on the machine
$T\left\{\sum_{k=1}^{n} D_k - M_0 + M_n\,[1+r]^{-n}\right\}$	is the discounted after tax value of any 'balancing' charge associated with difference between the depreciation allowed on the machine and its resale value

It is a simple algebraic task to demonstrate the importance of taxation on the net present value of the cost of a single machine using the above equation.