FORESTRY COMMISSION
OCCASIONAL PAPER 47

Forestry Expansion – a study of technical, economic and ecological factors

Assessing the Returns to the Economy and to Society from Investments in Forestry

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THE NATURE OF BENEFITS FROM FORESTRY INVESTMENTS

Forestry is a multiple output activity. The planting of forests produces a number of joint outputs and services. Outputs can be positive, taking the form of benefits, or negative, i.e. forests may actually reduce the provision of a service compared with the displaced land use, creating a cost. Much depends on exactly where afforestation takes place. Thus:

1. an afforested area supplies trees as timber and as a source of recreational value;
2. depending on the 'mix' of trees and the treatments applied to them, in-place biological diversity may be increased compared with the number of species and/or total species biomass in the displaced land use;
3. landscape values may be increased or decreased according to the preferences of those looking at the landscape;
4. some watersheds may be protected by afforestation through the prevention of soil erosion. Others may suffer from soil erosion from ploughing and road building activity;
5. water run-off may be reduced by interception to the point where surrounding areas suffer a diminution of water supply, but flood peaks may be reduced once the forest is established;
6. microclimates may be affected by afforestation, but considerable uncertainty surrounds these impacts;

7. afforestation may increase the deposition of airborne sulphur oxides and nitrogen dioxide in the forested area, but, in so doing, will reduce the transport of these pollutants to other areas. This 'acidification stripping' process may then result in increases in waterborne pollutants in the forested areas through leaching, and the effects of acidification of soils;

8. forests act as carbon sinks, and hence afforestation can reduce $C0_2$ emissions stored in the atmosphere, reducing the 'greenhouse effect';

9. economic security for the nation may be advanced by afforestation because of reduced costs from interruptions in flows of imported timber;

10. the decline of rural communities may be lessened through afforestation.[1]

Other benefits widely attributed to afforestation include the creation or protection of rural employment and the saving of imports. These impacts are discussed separately below because they generally will not qualify as allowable benefits in the sense used in this paper. Only some of these outputs or services are marketed. Typically, only timber values are reflected in the assessment of rates of return to plantations. As is well known, such rates of return frequently fall below conventional 'discount rates' employed by private or public agencies. Hence afforestation invariably appears to be 'uneconomic'. However, it is the whole range of outputs that is relevant to economic assessment. Use of timber values alone to determine investment worth is in fact a purely commercial criterion.

Henceforth, we distinguish between commercial rates of return and economic rates of return, the latter encompassing the value of non-marketed outputs and services and other adjustments considered below.

Adopting symbols for the various outputs:

T = timber values
R = recreational value
L = landscape value
B = biodiversity value
W = watershed protection or damage (and other ecological function values)
M = microclimate
A = air pollution value (other than $C0_2$)
P = water pollution values
G = 'greenhouse' benefit – i.e. value of trees as carbon stores
S = economic security
C = community integrity

it follows that the benefit of afforestation can be measured as:

$$B = T + R + L + B + U + M + A + P + G + S + C \ldots\ldots\ldots \qquad (1)$$

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[1] The US Forest Service, for example, has as one of its objectives the maintenance of 'community stability'. This is particularly relevant to the many small communities in the west of the USA dependent upon public timber harvesting. For an evaluation of the 'worth' of this benefit see R. Boyd and W. Hyde, *Forestry Sector Intervention: The Impacts of Public Regulation on Social Welfare*, Iowa State University Press, Ames, 1989.

Equation (l) conceals an aggregation problem because individual components of the aggregate benefits may be inconsistent with each other. Thus a high timber value may be inconsistent with a high recreational value. Growth of broadleaved trees may produce a high value for R, but a low value for T and for S, and so on. In short, there are trade-offs between the component values in the benefit equation. This issue needs to be borne in mind when aggregating benefits.

The costs of afforestation (land acquisition, planting costs, maintenance, thinning, felling etc) will be symbolised by K. If any of the above benefit flows are actually negative – e.g. if reduced water run-off is a cost rather than a benefit – then they will appear as such in the benefit side of the equation. That is, benefits are negative costs, and costs are negative benefits.

The overall comparison is thus between the benefits of afforestation and the costs of afforestation, or

$$\text{Net benefits} = B\text{-}K \ldots\ldots\ldots \qquad (2)$$

ignoring, for the moment, the problem of time.

Afforestation is judged potentially worthwhile if $B > K$, and potentially not worthwhile if $B < K$.

It is important to compute B and K relative to the alternative use of the land. The same exercise should therefore be carried out for such alternative uses. Typically these will be 'wilderness' or agriculture, but in the case of planned 'community forests' afforestation could be at the expense of derelict land, building or recreational land use.

The cost-benefit approach then justifies afforestation if

$$[B_f\text{-}K_f] > [B_a\text{-}K_a] \ldots\ldots\ldots \qquad (3)$$

where 'f' refers to forestry and 'a' to the alternative land use. More strictly, we require (3) to hold in circumstances where 'a' is the highest alternative value of the land: afforestation must be compared with the next best use of the land. Annex 1 sets out the cost-benefit model more formally.

MARKET FAILURE AND THE VALUATION OF FORESTRY BENEFITS

The fact that many of the outputs of forests are not marketed means that the use of purely commercial or 'free market' criteria to determine the amount of afforestation will result in an under-supply of afforestation as long as the non-marketed benefits are positive. This under-supply is an instance of market failure. Basically, markets do not supply the 'right' amount of afforestation[2].

But there are other forms of market failure. We cannot be certain that the use of resources is correctly valued if market prices are used, nor that outputs at market values are correctly valued. For inputs the basic rule is that they should be valued at their opportunity cost, that is, what they would have received had they been put to alternative use.

Labour

In the forestry context the resource that has attracted most attention in this respect is labour. Because afforestation tends to take place in rural areas where alternative employment outlets are few, it can be argued that the opportunity cost of forestry labour is very much lower than the wage rates actually paid. They might, for example, be rates

payable for labour on hill farms, or casual labour in tourist industry, or, if the alternative to forestry employment is unemployment, the cost could be regarded as near zero. In the benefit-cost equation then the labour component of K would be costed at this opportunity cost wage, or shadow wage.

The use of a shadow wage rate is disputed, and the dispute tends to centre on differing interpretations of how labour markets function. Some economists argue that the economic system functions so that, effectively, all markets 'clear'. There is then full employment in the sense that any new job must always take a worker from somewhere else in the system. In the technical language, there is no employment additionality. There may well be income additionality in that the forestry job pays more than the job it displaces. Indeed, one would expect this to be the case if people only move jobs for higher rewards. But if there is no employment additionality, it would be wrong to shadow price a forestry job at zero. Its proper shadow price would be the income in the displaced job. Moreover, if we think of afforestation as investment at the margin, tracing through the various transfers of jobs that enable the forestry job to be filled is likely to result in the shadow wage being very close to the actual wage paid.

If, on the other hand, markets do not clear, then the creation of a job in the forestry sector does result in employment additionality, and lower shadow prices are justified.[3]

Rather than evaluate what is in effect a fundamental disagreement in macroeconomic theory it seems better to adopt two approaches to labour valuation: 1. adopting the ruling wage rate in forestry, and 2. adopting some fraction of this to reflect a lower wage rate. Forestry Commission Occasional Paper 46 provides some evidence on agricultural earnings. A survey of 100 farms in Scotland – 50 in the HIDB area and 83 (overlapping

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[2] It must not be concluded from this that some form of public ownership will therefore necessarily produce the 'right' amount. Public ownership could introduce distortions of its own. Other forms of regulatory intervention may also introduce bigger distortions than those induced by market failure. If so, it may be a matter of opting for the 'least distorted' option, an instance of what economists call the 'second best' problem. There are no *a priori* rules for deciding the form of ownership or regulation. It is an empirical matter. For an evaluation of regulatory options for forestry in the USA, using cost-benefit principles, see Boyd and Hyde, *op cit.*

[3] On employment and income additionality, see I. Byatt, Byatt Report on Subsidies to British Export Credits. *World Economy* 7, 163-178.

sample) in Less Favoured Areas (LFA) – produced an average of £0.62 per hour as the income from farming.[4] However, non-farm activity was used to supplement the low rates of pay in farming. On average, 1227 hours pa were spent in farm activity and 957 hours in non-farm activity. Average farm plus non-farm income was £4964 pa but, if agriculture alone was the alternative occupation, then income averaged only £565 pa, although only 5% of farmers relied on agricultural income alone. Subsidies supplied additional income as did work by other members of the household.

In terms of a 'shadow wage rate' these figures suggest that the maximum rate is around £5000 pa, i.e. some two-thirds of the market wage. Depending on location, the shadow rate could be considerably less than this, but we set the shadow wage rate at 0.67 of ruling market rates.

Imports

The other shadow price that attracts a lot of attention in forestry literature is the value of timber itself. Timber is an internationally traded good and the relevant shadow price for UK timber is therefore the price that it could secure if exported, or the price that has to be paid on world markets for the imports that would otherwise have to be secured. Since the United Kingdom imports some 90% of its timber needs, international trade is particularly important. The shadow price of timber is thus its border price, i.e. its import or export price. Many commentators none the less feel that this price, which is the market price in the UK, still understates the true value of afforestation. They argue that the market fails in at least one of the following ways:

1. The market fails to anticipate future scarcity of timber. Since gestation periods are long, the shadow price to be applied to afforestation now should be the expected real price in, say, 30 years' time allowing for future scarcity. This argument has been particularly powerful in the history of both UK policy – see Forestry Commission Occasional Paper 35 – and in the USA.[5]

2. The market fails to reflect the importance of substituting for imports. There are two strands to this argument:

   a) The market may not anticipate supply interruptions from trade embargoes, political disruptions of supply etc.

   b) The value of an avoided import is somehow higher than the market price paid for that import. This is the 'import substitution' argument.

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[4] See Forestry Commission Occasional Paper 46 and *Very Small Farms in Scotland: an Economic Study*, SAC Economic Report No 10, February 1989.

[5] See Boyd and Hyde *op cit.*

Argument 1. is an argument for forecasting relative prices. A number of such forecasting exercises have been carried out for UK forestry.[6] The required adjustment to prices is then relatively simple. The timber benefit T in equation (1) is at any time period t.

$$T_t = Q_t . P_t$$

Where Q_t is quantity of timber at time $_t$, and P^t is the timber price at time $_t$.
If real prices rise at a rate of p% per annum, then this equation needs to be replaced with:

$$T_t = Q_t . P_{to} (1 + p)^t$$

where *o* is the first year of the investment. Forestry Commission Occasional Papers 36 and 37 discuss various projections for future prices of timber. These are discussed further in Chapter 5 below.

Argument 2a) is a legitimate one for shadow pricing timber output. An evaluation of the chances of such embargoes and other supply interruptions suggests that a small increment in prices of 0.2-1.8% to reflect the shadow value of economic security would be justified.[7]

Argument 2b) is illegitimate. A UK tree does not have a value higher than its border price simply because it displaces an import valued at that border price. The theory of comparative advantage explains why import substitution arguments cannot be used to defend afforestation. The essence of the argument is i) that free trade maximises the well-being of those taking part in trade, ii) that, from a purely 'nationalist' point of view, protection of a domestic industry may be beneficial if the protecting country has monopoly power over the good being traded, and iii) where no such monopoly power exits, any tariff or other protective measure will reduce the volume of a nation's trade, making it worse off. Applied to forestry in the UK, there is no monopoly of timber since the UK is very much a 'price taker', timber prices being determined in world markets. No feasible afforestation programme in the UK could affect world prices. Hence protectionist policies towards forestry in the UK would reduce UK well-being. Subsidising forestry on import substitution grounds is thus illegitimate.

Market failure arguments relating to:

- wages and

- timber output

thus need to be evaluated carefully. There may be a case for using shadow wage rates below market wage rates depending on how the functioning of labour markets is

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[6] See Forestry Commission Occasional Papers 36 and 37. See also D.W. Pearce, A. Markandya and I. Knight, *Economic Security Arguments for Afforestation*, A Report to the Forestry Commission, Edinburgh, November 1988; and D.W. Pearce and A. Markandya, '*Economic Security Arguments for Afforestation*', Department of Economics, University College London, *mimeo*, 1990.

[7] See Pearce, Markandya and Knight, 1988, *op cit*, and Pearce and Markandya, 1990, *op cit.*

interpreted. Of the three arguments for adjusting timber prices – future scarcity, trade interruption, and import substitution – the first two are legitimate and need to be dealt with by forecasting and scenario analysis, while the third is not a legitimate argument for shadow pricing.

Land Valuing land acquisition for afforestation poses a problem because the land in question is typically used for agriculture which is in receipt of various forms of subsidy under the Common Agricultural Policy. That is, actual land prices will not be the same as those which would rule if the various forms of agricultural policy intervention did not take place. Forestry Commission Occasional Paper 44 suggests that if <u>all forms of support and trade distortion</u> are removed, agricultural land prices might fall by as much as 46%. If so, land costs for afforestation should be recorded as 0.54 of the actual cost, (1986 as the base year). Writing L_s as the shadow price of land, and L_m as the market price, we have as a first approximation:

$$L_s = 0.54\ L_m$$

However, as agricultural support declines over time, agricultural land prices will converge on the free market price, so the 'shadow price' of land will rise relative to the free market price. Put another way, the multiplier of 0.54 would decline over time. Forestry Commission Occasional Paper 44 raises two further caveats to the use of the 0.54 multiplier. First, as land leaves agriculture it is likely to become the subject of an 'amenity' demand, ie a demand from people who simply wish to own land for amenity purposes. Since this compensating demand is not modelled in the procedure used in Occasional Paper 44 the 46% price fall figure is likely to be too high. Second, there is an additional form of demand for land to be held in agriculture for amenity reasons. This is akin to an option of existence value (see Chapter 4), and effectively means that <u>some element of the existing subsidy reflects this value</u>. It is not clear that this form of value applies equally to afforested land regardless of the form of afforestation. It is likely to be true for broadleaved forest, but less true for coniferous forests. The difference between the <u>social</u> value of agricultural land and the free market price is further narrowed by these considerations. Accordingly, we suggest an upper limit:

$$L_s = 0.80\ L_m$$

i.e. the social value of land used in future afforestation is taken to be 0.8 of the market value. Since this figure is likely to be on the high side, and certainly does not allow for the land price effects of any major expansion of forestry, a range of values is used such that:

$$L_s = 0.5\ L_m \text{ to } 0.8\ L_m$$

BENEFITS AND TIME

Benefits and costs accrue over time. Time plays a particularly important role in afforestation economics because timber can take 30, 50 or 100 years to mature for an optimal rotation, depending on the type of wood, the geographical zone, soil type etc. Because economics adopts the standpoint that consumer preferences 'matter', preferences for having benefits now rather than later, and preferences for postponing costs rather than suffering them now, mean that benefits and costs are discounted. The rate of discount is in fact another shadow price. It is the price of consumption now in terms of consumption in the future.

Discounting is controversial because of its potential for shifting forward in time, frequently to another generation, the costs of actions undertaken for benefit now (e.g. the benefits of nuclear power versus the costs of disposing of radioactive waste). In the forestry context the problem is that the discounting of future benefits means that planting costs now figure prominently in the rate of return calculation while the benefits from a rotation in 30 years' time are downgraded significantly. To see this consider a rotation in year 30 yielding, say, £100 000 of timber at projected prices. At the current UK 'target' discount rate of 8%, this would be valued at:

$$\frac{\pounds 100\ 000}{(1.08)^{30}} = \text{approx } \pounds 10\ 000$$

In terms of equation (3) the application of discounting techniques means that afforestation is potentially justified if:

$$d_t(B_{ft}-K_{ft}) > \quad \Sigma d_t(B_{at}-K_{at}) \ \ldots\ldots.. \qquad (4)$$

Where d_t is the 'discount factor' and is equal to $1/(1+r)^t$ (or e^{-rt}), t is time, and Σ means 'sum of'.

Various suggestions have been made for lowering the discount rate applied to afforestation, primarily because it appears unfairly to discriminate against any investment with a long gestation period.[8] The problem with adjusting discount rates downward is that there is no easily derived rule for the quantitative adjustment that is needed. Moreover, if the rate is lowered for forestry why should it not be lowered for other investments?[9] If all discount rates were lowered then it can be shown that the effect could

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[8] See E. Kula, *The Economics of Forestry: Modern Theory and Practice,* Croom Helm, London, 1988. Kula advocates a modified discounting method in which discount factors are weighted according to the structure of the population in terms of its generations. Thus, a benefit to a generation just starting in year N, say, would have a discount factor of 1, not $1/(1+r)^N$. This avoids, Kula claims, intergenerational discrimination. The effect is to give higher weight to future costs and benefits than under conventional discounting. For a debate on Kula's methodology see E. Kula, '*Future Generations; the Modified Discounting Method*', Project Appraisal, 3, 1988, 85-88; K. Thompson, '*Future Generations: the Modified Discounting Method - a reply*', Project Appraisal, 3, (3), 1988, 171-172; C. Price, *Equity, Consistency, Efficiency and New Rules for Discounting.* Project Appraisal, 4, (2), June 1989, 58-65. For an extensive survey of alternative views on the discount rate and its impact on resource and environmental issues, see A.Markandya and D.W. Pearce, *Environmental Considerations and The Choice of Discount Rate in Developing Countries.* Environment Department, World Bank, Washington DC, 1988.

[9] Kula's approach is capable of quantitative estimation using demographic projections of age structure, does effectively lower the discount rate, and would be applied across all investments. See Kula *op cit.*

well be detrimental to the environment, the preservation of which is the main motive for advocating lower rates. The overall detrimental effect comes about because generally lower discount rates would alter the optimal balance between investment and consumption in the economy in favour of investment. In turn, if investment is more polluting than consumption, then the net effect is to encourage more environmental decay.[10]

Many of the arguments for lowering discount rates are in fact arguments for valuing benefits more accurately and comprehensively. Even then, discrimination against forestry seems to remain. This suggests the possibility of lowering the rate for afforestation but not for other investments. This effectively was the situation in the UK whereby afforestation had to achieve a Treasury-approved rate of return lower than that on other projects – a minimum of 3% overall compared with 5% for other public investments. Current (1990) recommended discount rates are 6% on most public investments, with 8% for transport projects. The UK Treasury currently proposes that 6% be used for forestry if non-market benefits are to be included. In the cost-benefit analysis of this chapter we use the 6% rate with a lower 3% rate occasionally being also used for sensitivity purposes.

Note that it would be improper to use the lower rate if it is designed to capture the non-market benefits of afforestation. This is because, as will be seen, the aim here is to derive estimates for the major non-market benefits and to add these to the timber benefits. Making these estimates and lowering the discount rate would be double-counting. However, the 6% rate applies across the board to UK public services (except transport investments) and, for this reason, it is argued that the 6% rate and the integration of non-market benefits is legitimate.

An alternative route is to apply the nation-wide general discount rate to forestry and to introduce a sustainability constraint. Although there are many interpretations of sustainable development a strong case can be made for interpreting it as a) non-declining per capita well-being over time, a condition for which is b) that the stock of overall capital in the economy should also be non-declining. Put more simply, it is a requirement to 'keep capital intact' and is more familiar in business as the need not to 'live off capital'. The precise rationale for this requirement need not detain us here.[11]

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[10] See Markandya and Pearce, *op cit,* and for formal proofs see J. Krautkraemer, *The Rate of Discount and the Preservation of Natural Environments.* Natural Resource Modelling, 2 (3), Winter 1988.

[11] An intuitive analysis is provided in D.W. Pearce, A. Markandya, and E. Barbier, *Blueprint for a Green Economy,* Earthscan, London, 1989. The analytical foundations lie in a sequence of arguments:

1. Sustainable development is about being fair to future generations who should be no worse off than the current generation.

2. Current activities are giving rise to the potential for future generations to be worse off (e.g. greenhouse effects, ocean pollution etc).

3. Hence future generations must be compensated.

4. Setting up 'compensation funds' for the future is hazardous.

5. But we can compensate future generations by passing on a stock of capital assets at least equal to the current stock.

6. Such 'constant capital' rules can be demonstrated to produce constant consumption flows over time, a measure of intergenerational fairness.

In practice the constant capital stock rule could mean two things: a) maintaining a stock of all capital, man-made and 'natural'; b) maintaining a stock of 'natural' capital, ie environmental assets. In the former case it would be legitimate to run down environmental capital (e.g. deforestation would be legitimate) provided other forms of capital were built up. In the latter case, the existing stock of environmental assets must not be run down in the aggregate, but there can be substitution within that stock. On the narrower interpretation of sustainability, then, it could be argued that the UK's stock of forest should not be run down. Put another way, afforestation would be justified at least as compensation for loss of forests, but an expansion of the stock of land devoted to forestry would require additional arguments. The sustainability argument is further complicated by substitution within the stock of existing environmental assets. Thus, forest stocks might be run down in favour of expanded farming. Two observations are in order. First, what constitutes acceptable substitution depends on valuation which is precisely why the approach of 'cost-benefit thinking' has been adopted in this paper. Second, in the UK context the issue is generally one of a longer run decline in land devoted to farming, with afforestation being considered as one of the main alternative uses of some of the released land.

In fact some of the arguments justifying expansion of forestry are already represented in the term G in equation (1) i.e. the benefits of afforestation for 'fixing' $C0_2$ emissions. Equation (1) does not indicate to whom the benefits and costs accrue. UK forestry investment would typically be evaluated according to the benefits and costs to the UK. But benefit G is not confined to the UK. It is a 'global public good'. The sustainability requirement, then, also needs a 'boundary'. If the boundary is the UK, then the only afforestation that would be justified on a sustainability constraint is that which holds the forest stock in the UK constant.[12] But if UK afforestation is seen as a contribution to moves to restore the global forest stock, then the picture is rather different. The UK cannot adopt a stance that any afforestation is good so long as it compensates for a global loss of forests, but there is an alternative approach which would credit UK forest expansion with the benefits of global $C0_2$ reduction.

It seems likely that nations will negotiate a near-global agreement on the containment of greenhouse gases. This agreement will state a 'target' global warming increase above which the world should not go because of the significant ecological disruption that would otherwise be judged to ensue. The upper limit target rate that is widely suggested is 0.1°C per decade of 'realised warming', together with 2°C absolute increase in temperature above pre-industrial levels.[13] Any target can then be translated into 'allowable' greenhouse gas emissions. On the assumption that non-carbon greenhouse gases are severely curtailed – as the 1990 modifications to the Montreal Protocol on the protection of the ozone layer require – the allowable warming target of 0.1°C per decade appears to correspond to significant reductions in $C0_2$ emissions below current (1990) levels.[14] A rational international agreement will allow for carbon 'sinks' as the negative of

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[12] Even this begs the issue of the starting point. Typically, the sustainability requirement operates with its reference point as now.

[13] See F.R. Rijsberman and R.J. Swart, *Targets and Indicators of Climatic Change*. Stockholm Environment Institute, Stockholm, 1990.

[14] See Intergovernmental Panel of Climate Change (IPCC), *Policymakers Summary of the Scientific Assessment of Climate Change*. Working Group 1, May 1990.

an allowable emission, ie the creation of any carbon sink should constitute an 'offset' for any $C0_2$ emissions of equal amounts. The offset idea is effectively the sustainability effectively the sustainability constraint – it embodies the underlying requirement that the total of $C0_2$ emissions should not exceed a fixed annual level.

On this basis, afforestation secures a 'carbon credit' equal in value to the cost of reducing $C0_2$ emissions by other means, eg by substituting non-carbon fuels. This issue is explored further in Chapter 10.

THE NATURE OF ECONOMIC VALUE

Given that non-market values are potentially very important in justifying forestry expansion it is worth dwelling briefly on the components of economic value. Although different authors use different classificatory systems, the following seems most helpful.[15] Economic values may be divided into:

- use values;
- non-use values.

In turn, use values can be divided into direct and indirect values. A direct use value would be, for example, timber harvesting and the use of thinnings. Recreational uses of forests is another direct use value.[16] An indirect use value would be exemplified by an ecological function, such as watershed protection. Another use value is option value which reflects the willingness to pay for afforestation on the grounds that, while not used at present, the option to use the forest is valued.[17]

Non-use values relate to economic values unassociated with any direct or indirect use values. Individuals may, for example, wish to support afforestation on the grounds that they think forests are valuable even though they will never personally make direct use of them. Motives for these 'existence' and 'bequest' values are debated but may include concern for future generations, the adoption of some 'stewardship' role with respect to nature, conferment of 'rights' to nature, and so on.

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[15] The approach here follows that of D.W. Pearce and R.K. Turner, *Economics of Natural Resources and the Environment.* Harvester-Wheatsheaf, London, 1989. See also D.W. Pearce, *Economic Values and the Environment.* The 1987 Denman Lecture, Department of Land Economy, University of Cambridge, 1987.

[16] On the value of UK forests for recreational purposes see K. Willis and J. Benson, *Recreational Values of Forests.* Forestry 62, (2), 1989, 93-110 .

[17] Some writers regard option value as a non-use value.

Table 1 shows the overall classification system. It also indicates the types of valuation methodology that is appropriate for the various components of 'total economic value'. These methodologies are not discussed further here.[18] The following sections are devoted to drawing up a 'balance sheet' for the cost-benefit assessment of forestry expansion.

Table 1 Valuing forest benefits

Total economic value				
Direct use values	*Indirect use values*	*Option values*	*Existence values*	*Bequest values*
Type of benefit				
T	B	B	B	B
R	W	R	L	
B	M	C		
S	G	L		
L	C			
	A			
	P			
Valuation Technique				
Market prices	Avoided damage costs	CVM	CVM	CVM
HPM	Preventive expenditures			
TCM	Value of productivity changes			
	(Replacement costs)			

Key

HPM = hedonic pricing method
TCM = travel cost method
CVM = contingent valuation method
T = timber
R = recreation
B = biodiversity
S = economic security

C = community integrity
L = landscape
W = watershed/ecosystem function
M = microclimate
G = greenhouse impact
A = air pollution
P = water pollution

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[18] See D.W. Pearce and A. Markandya, *Environmental Policy Benefits: Monetary Valuation.* OECD, Paris, 1989; and P-O. Johansson, *The Economic Theory and Measurement of Environmental Benefits.* Cambridge University Press, Cambridge, 1987.

This section estimates the value of T in equation (1). Table 2 summarises commercial rate of return and NPV data for afforestation under various yield classes and locations, excluding all grants. Full results are to be found in Annex 3. The results are taken from Forestry Commission Occasional Paper 46 but are modified to show:

1. Various assumptions are made about the shadow price of land. In each case 80% of the market value is used. This is taken to be £3000 per hectare in the lowlands and £600/hectare in the uplands, following the arguments presented in Chapter 2. If a different view is taken, by arguing that the amenity value factor in agricultural land prices applies equally well to forestry land, then the lower factor of 50% of market value might be used (see the discussion in Chapter 2). A shadow price of zero may also be applicable in some cases where the alternative value of the land is zero.

2. A once-for-all premium of 1% on timber prices to reflect economic security (see Chapter 11 below).

3. For forest types appropriate to those parts of the country where the shadow price of labour is less than the market wage, the cost of labour is taken to be 67% of its market value (see Chapter 2).

The internal rate of return columns in Table 2 are perhaps the easiest way of seeing the overall private profitability of timber production. At a 6% discount rate only the following are profitable or marginally profitable:

1. Mixed fir, spruce and broadleaves in the lowlands, assuming land has zero opportunity cost.

2. Spruce in the uplands provided land has a zero opportunity cost.

Timber prices

As noted in Chapter 2 timber prices in commercial rate of return calculations should reflect future expectations. Similarly, the relevant price for an evaluation of UK afforestation is the price at which timber is imported to the UK. For this reason, global and world regional prices are the relevant ones for the evaluation exercise.

The sources surveyed in Forestry Commission Occasional Paper 36 suggests various estimates of average annual price rises in the USA:

1. 1-1.1% pa, mostly concentrated after the turn of the century (US Forest Service study). Pulpwood prices rise more slowly than sawlog prices.

2. 0.2-1.2% pa averaged across sawlogs and pulpwood (Resources for the Future), and perhaps higher (IIASA), with sawlog prices rising faster than pulpwood, if there is a high demand.

Table 2 Commercial analysis of afforestation (timber benefits only) (NPV at £1989/90, per hectare, and IRRs) (6% discount rate)

		NPV	*IRR*
FT1	Semi natural pinewoods/uplands		
	land value = 0.5	- 798	3.2
	land value = 0.8	- 975	3.0
FT2	Semi natural broadleaves/lowlands		
	land value = 0.5	- 2940	-
	land value = 0.8	- 3839	-
FT3	Semi natural broadleaves/uplands		
	land value = 0.5	- 1099	-
	land value = 0.8	- 1276	-
FT4	Spruce /uplands		
	land value = 0.0	- 4	6.0
	land value = 0.5	- 288	5.4
	land value = 0.8	- 458	5.1
FT5	Community forests	- 3173	2.6
FT6	Native broadleaves/lowlands		
	land value = 0.5	- 3384	1.0
	land value = 0.8	- 4283	0.9
FT7	Pines/lowlands		
	land value = 0.5	- 1741	3.7
	land value = 0.8	- 2605	3.2
FT8	Fir, spruce, broadleaves/lowlands		
	land value = 0.0	572	7.1
	land value = 0.5	- 819	5.0
	land value = 0.8	- 1653	4.3

Souce: Annex 3

Key: FT = forestry type LV = 0.5 refers to shadow price of land at 50% of market value, similarly for LV = 0.8. '-' under IRR means a negative IRR

Also contrary to the USA, the European picture appears to be more one of rising prices for pulpwood and falling prices for coniferous logs. The difference in the price trends in the two regions reflects the past application of recycling technology more intensively in Europe than the USA, and the consequent more limited scope for further market penetration or recycling. There has also been slower growth in the consumption of European sawn wood. Prices in the two regions are expected to converge. Expected technical change in the European processing industry and large supplies of roundwood are likely to keep prices down.

Pearce *et al.*, survey various price projections and conclude that a range of 0-2% pa in future real prices would embrace all reasonable assessments, and that projections at the lower end of the range are more likely to be realised.[19]

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[19] D.W. Pearce, A. Markandya, I. Knight, *Economic Security Arguments for Afforestation.* Report to the Forestry Commission, Edinburgh, November 1988.

Overall, stable real prices define the lower bound of expected price changes with an upper bound of perhaps 1.5% pa. Table 2 assumes constant real prices only.[20]

THE COMPONENTS OF COST-BENEFIT ANALYSIS: RECREATION (R)

Occasional Paper 39 provides estimates of the net benefits to recreationists of different types of forest plantation. The results are shown in Table 3. It is a matter of local circumstance as to when recreation benefits are likely to accrue. It is assumed here that there are no benefits until year 16 and that thereafter they continue at the same level until the end of the rotation. The benefits are 'gross' in the sense that recreational benefits from the alternative use of land are not accounted for.

Table 3 Recreational consumer surplus by forest type (£1989) per hectare/year

Recreational value	*Uplands*	*Lowlands*
Low	3	n.a.
Moderate	30	50
High	n.a.	220
Very high	n.a.	424

While recreational values are not translatable across continents, it would be surprising if they differed very much. Recent work in the USA suggests a present capital value per hectare of forest of around $1100, i.e. around £690. It is interesting to note that this is consistent with the moderate annual recreational values presented here for the lowlands.[21]

Just as timber prices may rise in real terms over time, so recreational benefits may rise. USA work does suggest rising real values. Walsh surveys the US evidence on the growth of recreation demand.[22] Land-based recreation is forecast to grow by some 1.0% per annum. The 1% growth rate may in fact be too low for the UK (data from the General Household Survey indicates that all recreational activity surveyed has been growing at 3% per annum (participations per adult per year), while walking has grown at 2% pa). Adopting a 1% growth rate for the increase in benefits from forest-based recreation is therefore conservative.

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[20] This is in keeping with the Resources for the Future study mentioned in Occasional Paper 36. Only in a 'high demand' scenario do prices rise at 1.2% pa. The base case scenario suggests 0.2% pa. See R. Sedjo and K. Lyon, *The Long Term Adequacy of World Timber Supply*. Resources for the Future, Washington DC, 1990.

[21] See M.D. Bowes and J.V. Krutilla, *Multiple Use Management: the Economics of Public Forestlands*. Resources for the Future, Washington DC, 1989, Paper 7. The actual value obtained was some $410 per acre at a 7% discount rate, ie some $1000 per hectare, which is consistent with $1100 per hectare at a 6% discount rate.

[22] R. Walsh, *Recreation Economic Decisions: Comparing Benefits and Costs*. Venture, State College PA, 1986.

The final analysis in Chapter 13 shows the effects of including a rising value of recreational benefits. Annex 3 shows the detail for each forest type.

THE COMPONENTS OF COST-BENEFIT ANALYSIS: WILDLIFE CONSERVATION (BIODIVERSITY) (B)

Occasional Paper 40 indicates ranking of desirable forest types in respect of wildlife values. These values are regarded as being a function of 'naturalness', diversity and rarity. Diversity is typically regarded as being most valuable if it is itself natural. The introduction of Sitka spruce does for example increase diversity, but conservationists tend to regard such gains as being at the expense of natural diversity. Most afforestation tends to increase diversity. The ranking that emerges is:

1. New mixed 'native' woodland.

2. Mixed broadleaves and conifers.

3. Non-native broadleaves or conifers alone.

Wildlife impacts depend very much on the actual location of any new forest. Of particular value is planting which links existing woodland, making the connected area larger and thus increasing diversity. Of note is the finding that spruce is probably no better or worse than alternative non-native woodlands for wildlife diversity. The assumption is that afforestation displaces low value agricultural land which, in turn, is regarded as being of low wildlife conservation interest.

THE COMPONENTS OF COST-BENEFIT ANALYSIS: WATER RESOURCE IMPACTS (W)

Occasional Paper 42 indicates a number of water-related ecological impacts on the surrounding watershed of forested areas. These are:

– impacts on water supply;

– impacts on water quality;

– impacts on air pollutant deposition;

– soil erosion;

– fertiliser impacts;

– pesticide impacts;

– harvesting impacts.

Water supply Afforestation involves evaporation losses mainly due to canopy interception: 20-50% of incoming rainfall may be intercepted with streamflow reductions of around 15%. At one well-studied site, reductions in streamflow of about 15% were recorded where 60% of the site was planted with conifers. Current models predict a loss of flow of 15% in the wet uplands from a 75% afforested catchment. The economic importance of such reduced flows depends on the relationship between supply and demand for water. While some monetary estimates of loss have been made, e.g. in terms of additional water extraction or storage costs to water authorities, and reduced hydropower capacity, the data is not currently in a form that enables valuation of the various areas under discussion. The effects are negligible in the lowlands or will appear as a small cost.

Acid water pollution Forests 'scrub' air pollutants so that afforestation has the effect of increasing deposition of various pollutants. Some pollutants are absorbed by leaf and stem surfaces; some, such as SO_2 and 0_3, are absorbed through stomata; and the effect on $N0_2$ and NO appears indeterminate. Co-deposition of NH_3 and $S0_2$ may produce a significant increase in the deposition of both gases. Deposition varies according to the type of forest. The economic significance is two-fold. By scrubbing the pollutants the forest may prevent them from incurring damage elsewhere, depending on the buffering capacity of the recipient soils but by concentrating them in the forested area pollutant concentrations in drainage waters are increased. This impacts on acidification and aluminium content. Technically, the correct 'valuation' of this impact would compute the localised damage due to acidification from forests and then deduct the damage that would otherwise be done by the emissions that initially arise. That is, forests should not be debited with all acidification damage given that the source of the acidification is, say, power station emissions.

Acidification Streams draining forested areas on sensitive sites may be more acidic and may contain more aluminium, although long-term studies have so far failed to detect an impact.

Erosion and sedimentation New planting may cause soil erosion and consequent increased sedimentation of watercourses. Chemical leaching may also occur. Costs to the water industry can be high, with one instance of £180 000 additional costs for a treatment plant to counteract the effects of ploughing for planting in the catchment area. Soil erosion may also be present throughout the rotation. Soil erosion is however common with intensive agricultural systems, and the overall effect may be beneficial.

Fertilisers Fertiliser run-off from forest treatment appears to be of negligible significance as far as rivers are concerned, but can be important if run-off is to lakes and reservoirs. Impacts are likely to be very site-specific and again this is not likely to be bad in areas that were intensively farmed.

Pesticides Insecticides and herbicides are used on a relatively small scale in forestry but can affect water quality. Herbicide impacts can occur through reduced vegetative cover affecting streamwater chemistry.

Harvesting By clearfelling, harvesting modifies the microclimate, results in a sudden increase in debris and interrupts nutrient cycling. Nitrate in drainage waters may be increased. There is no evidence that water treatment costs have increased as a result.

Occasional Paper 42 concludes that ecological impacts are likely to be site-specific and that there is considerable scope for their mitigation through careful forest management. Impacts by forested area are summarised in Table 4. A distinction is made between ecological and economic impacts: significant ecological impacts could occur without them being 'valued' highly, and vice versa. More generally, one would expect them to be similar in magnitude.

Table 4 Summary of water-related ecological impacts by area

	Uplands	*Upland margins*	*Lowlands*
Water loss:			
ecological	-	-	-
economic	-	-	-
Erosion:			
ecological	-	neg	+
economic	-	neg	+
Fertiliser			+
ecological	neg	neg	+
economic	neg	neg	
Pesticide			+
ecological	neg	neg	+
economic	neg	neg	
Deposition			
ecological	++	neg	neg
economic	++	neg	neg
Harvesting			
ecological	-	neg	neg
economic	-	neg	neg

\+ = a benefit
\- = a cost compared to alternative land use
neg = negligible

THE COMPONENTS OF COST-BENEFIT ANALYSIS: LANDSCAPE EVALUATION (L)

Occasional Paper 41 assesses the role of forests in landscape evaluation. Aesthetic qualities include enjoyment, psychological well-being, child education and development, artistic and creative stimuli and a 'sense of security'. Occasional Paper 41 indicates that there is a general consensus about what constitutes landscape value. These values contribute both to land and property values, and to option and existence value (c.f. Table l) not revealed in market places. Occasional Paper 41 also argues that the demand for landscape conservation is growing. Landscape value is highest with multipurpose non-monocultural forests. As with biodiversity, native woodlands are assigned the highest landscape value. Also echoing the biodiversity discussion, landscape value depends critically upon the location and design of forests, so that no general conclusion can be reached about non site-specific values. Overall, however, the ranking for landscape values would appear to be very similar to that for biodiversity.

THE COMPONENTS OF COST-BENEFIT ANALYSIS: GREENHOUSE EFFECT (G)

Trees take carbon dioxide from the atmosphere and fix it in perennial tissue. The $C0_2$ is eventually released as the wood decays or is burned. Some uses of the wood 'lock up' the carbon for long periods, and this period of lock-up overlaps the next rotation of tree growing so that rates of accumulation of carbon exceed rates of decay. This net gain is not indefinite and is probably around 100 years plus, after which fixation is then matched by decay and there is no further increase in storage. In areas of organic rich soils, an increase in CO_2 output from the soils as a result of increased decomposition of pre-existing soil organic matter, consequent on drying produced by tree growth, may have to be set against any carbon credit due to carbon fixing in tree biomass.

For a period of at least 100 years, then, afforestation produces a net gain in carbon fixing capacity and hence a 'carbon credit' is due to afforestation on this basis. Carbon fixing by forests has thus to be seen as a means of postponing global warming. The extent of this effect can be modified by at least two further factors. If timber end-uses are changed then net fixation could be increased, e.g. by using more timber in durable uses. Second, there may be carbon losses from soil if afforestation occurs on peaty soils. These may offset, to some extent, the CO_2 fixation effects of afforestation.

Occasional Paper 35 provides figures for the equivalent carbon stored by different yield classes. Table 5 summarises the carbon storage figures, allowing for decay rates in timber products.

Table 5 Carbon storage in forests

		(tonnes C $ha^{-1} yr^{-1}$)
Upland:	Sitka spruce	1.7
	Scots pine	1.4
	Birch	1.0
Lowland:	Scots pine	1.7
	Corsican pine	2.7
	Oak	1.5
	Poplar coppice	4.0

What is the value of fixing a tonne of $C0_2$? There are two approaches that might be used:

1. the <u>damage avoided</u> approach would suggest that a tonne of fixed $C0_2$ is equal to the avoided damage that would be done if the carbon was not fixed;

2. the <u>offset</u> approach would suggest that the value of carbon fixing is equal to the cost of offsetting $C0_2$ emissions by investing in $C0_2$ reduction technology. Since $C0_2$ removal is not currently feasible, this amounts to saying that the value is equal to the cost of substituting a non-carbon fuel for a carbon fuel at the margin.

Pursuing the damage avoided approach, global warming damage estimates have been produced by Nordhaus and by Ayres and Walter.[23] They are highly speculative but suggest the following figures:

	Per tonne $C0_2$ (carbon weight) (1989$)
Nordhaus	$3 (minimum) - $25 (maximum)
Ayres and Walter	central guess = $5-10

Nordhaus' 'medium damage' scenario calculates an optimal reduction in greenhouse gases consistent with a benefit per tonne $C0_2$ reduction of $12.6, or around £7 per tonne. These figures relate to losses of GNP and Ayres and Walter suggest that other costs may be significantly higher.

Taking the ruling exchange rate as the appropriate converter, and conservatively allowing a small premium for non-GNP costs, the damage estimates would be equal to perhaps £8 per tonne $C0_2$ carbon weight.[24] Annex 2 shows in detail how carbon fixing values have been estimated. Detailed carbon fixing values are also shown by forest type in Annex 3. Table 6 summarises the resulting <u>present values</u> of 'carbon credits'.

Table 6 Summary carbon credits (damage approach)
(present values, 6% discount rate , £ per hectare)

<u>Forest type</u>	
FT1	142
FT2	187
FT3	200
FT4	210
FT5	213
FT6	246
FT7	167
FT8	254

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[23] W. Nordhaus, '*To Slow or Not to Slow: The Economics of the Greenhouse Effect*'. Yale University, February 1990, *mimeo*; J. Walter and R. Ayres, '*Global Warming: Damages and Costs*', and R. Ayres and J. Walter, '*Global Warming: Abatement Policies and Costs*', International Institute for Applied Systems Analysis, Laxenberg, Austria, January 1990, *mimeo.*

[24] Strictly, a purchasing power parity converter should be used.

The offset approach will produce different results. Anderson has made some preliminary estimates of carbon credits for a 'typical' forest and, after allowing the decay of the wood wood products, suggests figures of £527-554 per hectare (present value at 6% discount rate).[25] These figures are approximately twice those suggested by the damage avoided approach. In the final summary cost-benefit we use the lower figures, but their conservative nature needs to be borne in mind.

THE COMPONENTS OF COST-BENEFIT ANALYSIS: ECONOMIC SECURITY (S)

Markandya and Pearce have evaluated the arguments for ascribing a credit to afforestation on grounds of economic security.[26] Economic security refers to the benefits of avoiding the costs that would be imposed by import supply interruptions such as might occur with a trade embargo. Economic security does not refer to 'import savings'. While it is difficult to estimate the welfare gains from economic security, the Markandya-Pearce work suggests that the border price for timber might be raised by between 0.2% and 1.8% to reflect economic security, depending on demand conditions. Overall, adding 1% to border prices would seem justified. This premium is already allowed for in the timber valuations in Table 2.

THE COMPONENTS OF COST-BENEFIT ANALYSIS: COMMUNITY INTEGRITY (C)

Community integrity relates to the value that society puts on the conservation of rural communities. It is not to be confused with the benefits of creating rural <u>employment</u> (which may be zero as discussed earlier), but nevertheless has a link to employment. Essentially, some or all of what society spends to create rural employment in sparsely populated areas could be regarded as a reflection of willingness to pay for conserving rural communities and the rural 'way of life'.

SUMMARY OF COST-BENEFIT ANALYSIS

Table 7 brings together the various <u>quantified</u> items in a cost-benefit assessment of new afforestation. Annex 3 provides the detail. Table 7 allows for timber, recreation and carbon fixing values, but assumes a zero timber real price rise. It does allow for rising recreational values relative to the general price level, and makes various assumptions about shadow wages and land prices. It <u>omits</u> the items for landscape (L), biodiversity (B), watershed (W), microclimate (M), non-$C0_2$ air pollution (A), and community values (C). At present, these have proved too difficult to value. Their directional nature was indicated in Table 5.

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[25] See D. Anderson, *The Forestry Industry and the Greenhouse Effect.* Report to the UK Forestry Commission and the Scottish Forestry Trust, Edinburgh, 1990.

[26] Markandya and Pearce, *op cit.*

Table 7 Representative cost-benefit appraisals (£1989/90 present values, per ha)

	Forest type							
	FT1	*FT2*	*FT3*	*FT4*	*FT5*	*FT6*	*FT7*	*FT8*
Timber	- 975	- 3 839	- 1 276	- 458	- 3 173	- 4 283	- 2 605	- 1 653
Recreation	314	547	261	268	2 091*	547	476	412
Carbon	142	187	200	210	213	246	167	254
Total	-519	-3 105	- 815	20	- 869	- 3 490	- 1 962	- 987
IRR %	4.1	0.1	-	6.0	4.8	1.6	3.8	4.9

*high recreational value assumed

(r = 6%, land value = 0.8, shadow wages = 0.67, moderate recreational value)

Annex 3 shows that the results in Table 7 are highly sensitive to assumptions made about land values and recreational values. Thus, FT8 (fir, spruce and broadleaves in the lowlands) shows a 4.3% IRR for timber alone if land is valued at 80% of market prices, but a 7.1% IRR with zero shadow land values. This rises to 16.9% for zero land values, high recreational values and the carbon credit.

Certain conclusions may be drawn from the analysis on the assumption that the net effect of the unquantified items is not significant, or that they cancel each other out. Table 8 shows the circumstances in which forest expansion is justified at the 6% discount rate.

Table 8 Justification for afforestation

Forest type	Assumptions giving positive NPV at 6%
FT5 Community Forests	Very high recreational values
FT4 Spruce in uplands	Moderate recreational values and land values at 0.5 market values
FT8 Fir, spruce, broadleaves in lowlands	High recreation values and land values at 0.8 market values
FT7 Pine in lowlands	Moderate recreational value and land values at 0.5 market values

Obviously, trade-offs would be possible. Lower recreational values could be acceptable if the opportunity cost of land was also lower. It is important, however, to relate land price assumptions to the yield class assumptions. Higher than assumed yield classes might be obtained, but at the price of more expensive land, and vice versa.

It is important to note also that the case for justifying an expansion of the forest types in Table 8 depends also on assumptions about a range of environmental values. So, for example, an expansion of spruce in the uplands might not be justified for poorly designed, monoculture forests where landscape values might be negative, but might be justified where planting would result in well designed, multipurpose forests.

On the basis of the analysis above, options other than those listed in Table 8 do not have an immediate economic justification. These are: native broadleaves managed for timber, semi-natural pinewoods in the uplands, and semi-natural broadleaves in the uplands or lowlands. But it is important to note that these forest types are likely to have benefits which are currently unquantified, especially biodiversity conservation. Semi-natural pinewoods in the uplands, for example, with moderate recreational value and a shadow land price of 0.5, shows an overall quantified negative NPV of £344 per hectare. Society may well be willing to pay this sum to conserve the associated biodiversity. A similar argument applies to the other forest types.

SUMMARY OF COST-BENEFIT MODEL

The present value of the benefits is given by:

$$PV(B) = {}_t\{[A.T_t.e^{pt}] + [R.e^{vt}] + [G_t]\}.e^{-rt}$$

$$= {}_t\{A.T_t.e^{(p-r)t} + R_t.e^{(v-r)t} + G_t.e^{-rt}\}$$

and

$$PV(C) = {}_t\{b\text{-}L_t + w.W_t + O_t\}.e^{-rt}$$

where

A = 1 + economic security premium (0.01)
T = timber value
p = real price rise for timber (assumed = O in text)
r = discount rate (6%)
R = recreation values
V = growth rate of relative recreation values (1% pa)
G = carbon fixing value
b = shadow price multiplier for land (0.0, 0.5 and 0.8)
w = shadow wage rate multiplier (0.67)
O = other costs

ANNEX 2

CALCULATING CARBON FIXING CREDITS FOR UK FORESTRY

Methodology

Carbon fixing data were supplied by the Forestry Commission Research Station at Alice Holt. The carbon fixing functions allow for repeated rotations and for a 'typical mix' of end uses of wood. The end uses are significant because once felled, carbon is released from wood, but in varying degrees according to the uses made of wood. The end-use mix assumed here is:

Branches, lop and top – 100% to waste, bark and fuel

Small diameter roundwood – 51% to pulpwood
37% to particleboard
1% to medium density fibreboard
8% to fencing
3% to mining

Large diameter sawlogs – 13% to waste, bark and fuel
10% to pulpwood
23% to particleboard
1% to medium density fibreboard
14% to pallet and packaging
19% to fencing
13% to construction
5% to mining
2% to 'other'

Typical 'fixation and decay' curves are shown in Figures A1-A9.

Since we are not interested in detailed accuracy at this stage, the 'average carbon in fixed form' curves in Figures A1-A9 have been approximated by a generalised function of the form:

$$F = M(1-e^{-gt}) \qquad (1)$$

Where F = average carbon in fixed form, i.e. a moving average of <u>accumulated</u> carbon fixation.

To obtain <u>annual</u> additions to carbon fixation, we require:

$$\frac{dF}{dt} = Mge^{-gt} \qquad .... \qquad (2)$$

Equations (1) and (2) are estimated below for one option to illustrate the calculations.

$M = 80$ t.C/ha

when

$F = 60$ t.C, $t = 60$

Hence $60 = M(1-e^{-60g})$ from (1)

$$= 80(1-e^{-60g})$$

Therefore $0.25 = e^{-60g}$

Therefore $g = 2.3\%$ pa ($g = 0.023$)

Substituting in (2) we have

$$\frac{dF}{dt} = 80\ (0.023)e^{-0.023t}$$

$$= 1.84e^{-0.023t} \qquad (3)$$

So that $t = \frac{dF}{dt}$ (tonnes C/ha)

0	1.84
10	1.46
20	1.16
50	0.58

Note that dF/dt allows for carbon decay from the first rotation.

These gains need to be <u>discounted</u>. At 6%, for example, equation (3) becomes:

$$F_{dt} = 1.84e^{-0.023te-0.06t}$$

$$= 1.84e^{-0.083t} \qquad (4)$$

F_{dt} takes on a value of only 0.03 t.C/ha for year 50, so virtually all carbon 'credits' are captured by calculating present values up to the time horizon $t = 50$. The present value of F_{dt} is then:

$$PV(F_{dt}) = \int_{1}^{50} 1.84e^{-0.083t}.dt$$

$$= 1.84 \int_{1}^{50} e^{-0.083t}.dt \qquad .... \qquad (5)$$

$$= 1.84 \left[\frac{-e^{-0.083t}}{0.083}\right]_{1}^{50}$$

$$= \left[\frac{-0.0158}{0.083} + \frac{0.920}{0.083}\right] 1.84$$

For option 1, therefore the relevant carbon credit is 20 tonnes C/ha.

Damage costs for global greenhouse gases – expressed as $C0_2$ equivalents have been estimated by Nordhaus (1990) at some US \$10-25 tonne C, or £6-15 tonne C.

The option 1 carbon credit therefore becomes £120-£300 per hectare.

The results for the various options are summarised below. It should be remembered that these estimates are based on fairly crude form of curve fitting. Ideally, function (1) needs to be fitted using a regression package.

Option	*PV carbon* (t ha^{-1})	*Value PV carbon* (£ ha^{-1})
1. Sitka YC12	20.0	120-300
2. Scots pine YC6	17.8	107-267
3a. Sitka YC16	31.1	187-467
3b. Douglas fir YC16	35.2	211-528
4. Corsican Pine YC16	27.7	166-415
5. Oak YC6	30.7	184-460
6. Birch YC4	23.4	140-354
7. –	–	–
8. Oak/pine YC6	19.6	118-294
9. Poplar YC12	20.2	121-303
10. Poplar coppice	33.7	202-506
		AV 156-389

Figure A1 Sitka spruce YC12

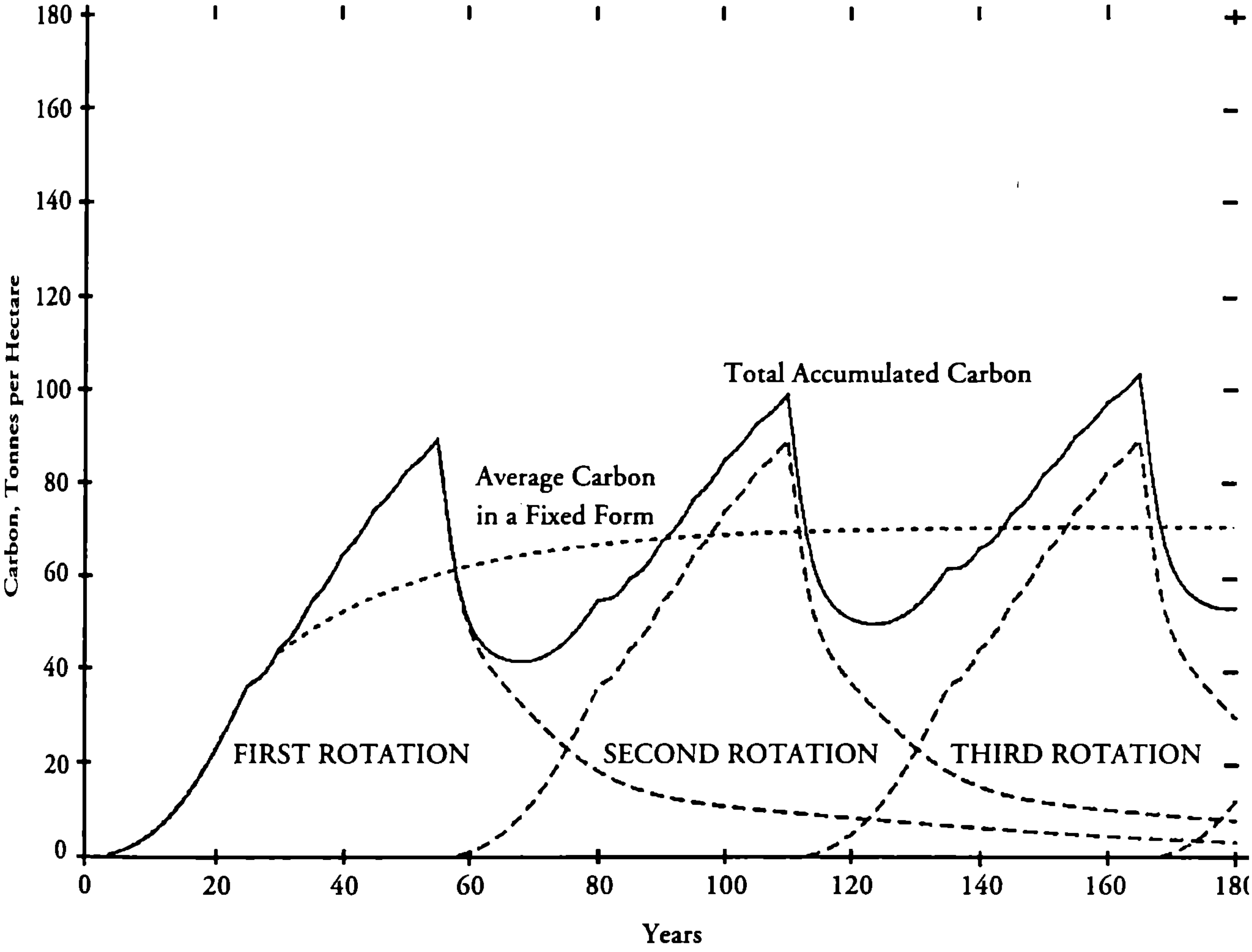


Figure A2 Scots pine YC6

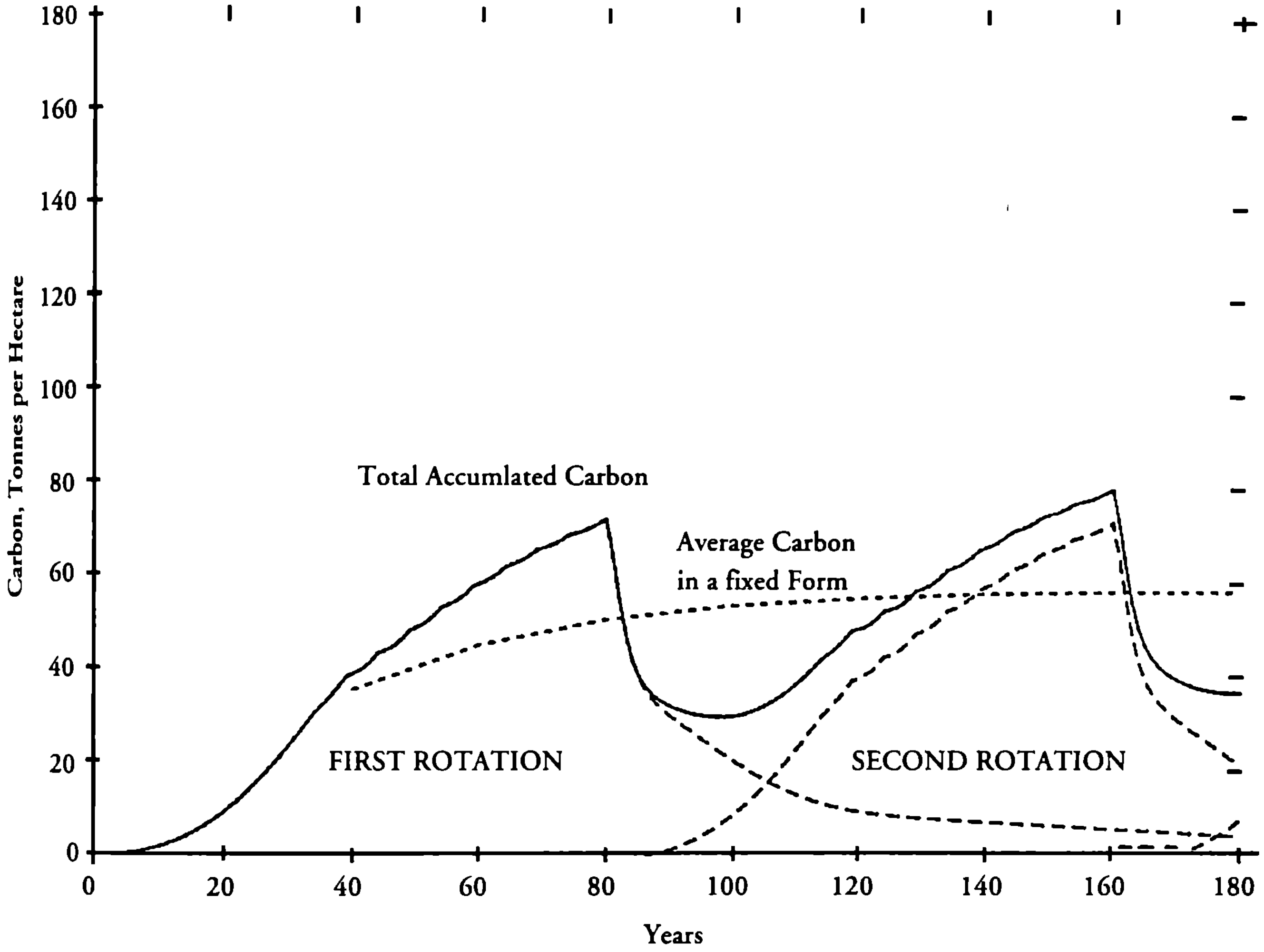


Figure A3a. Sitka spruce YC16

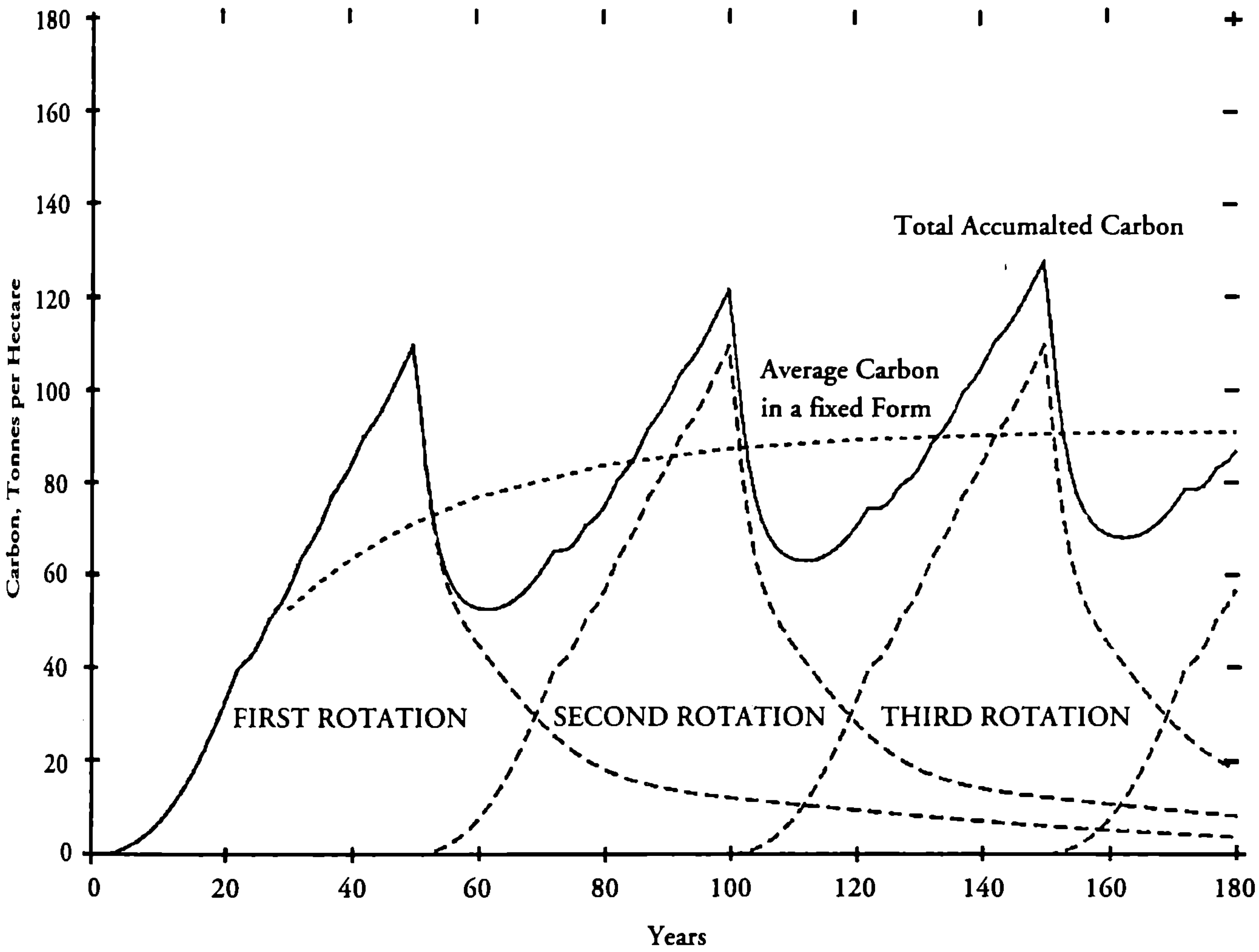


Figure A3b. Douglas Fir YC16

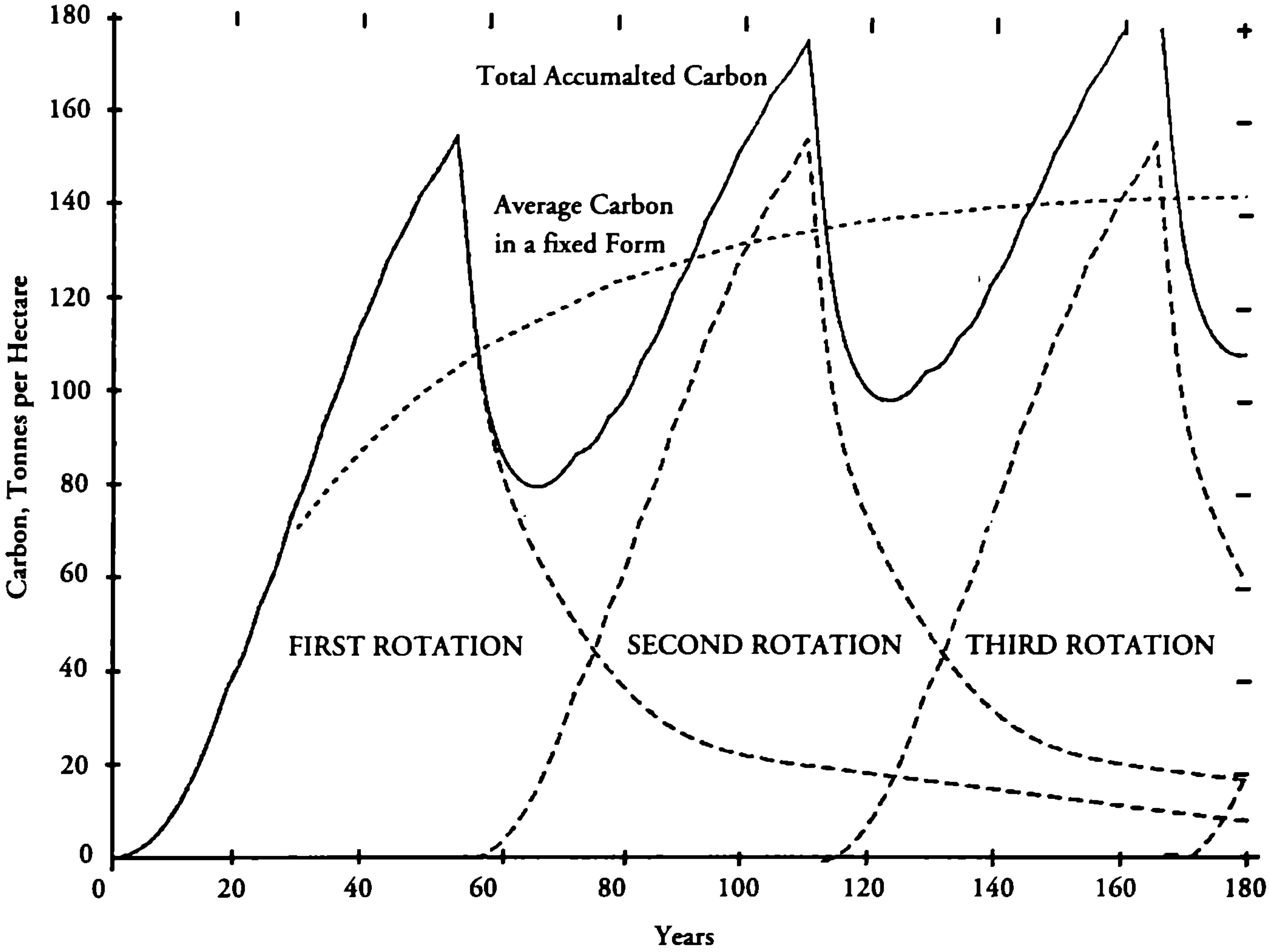
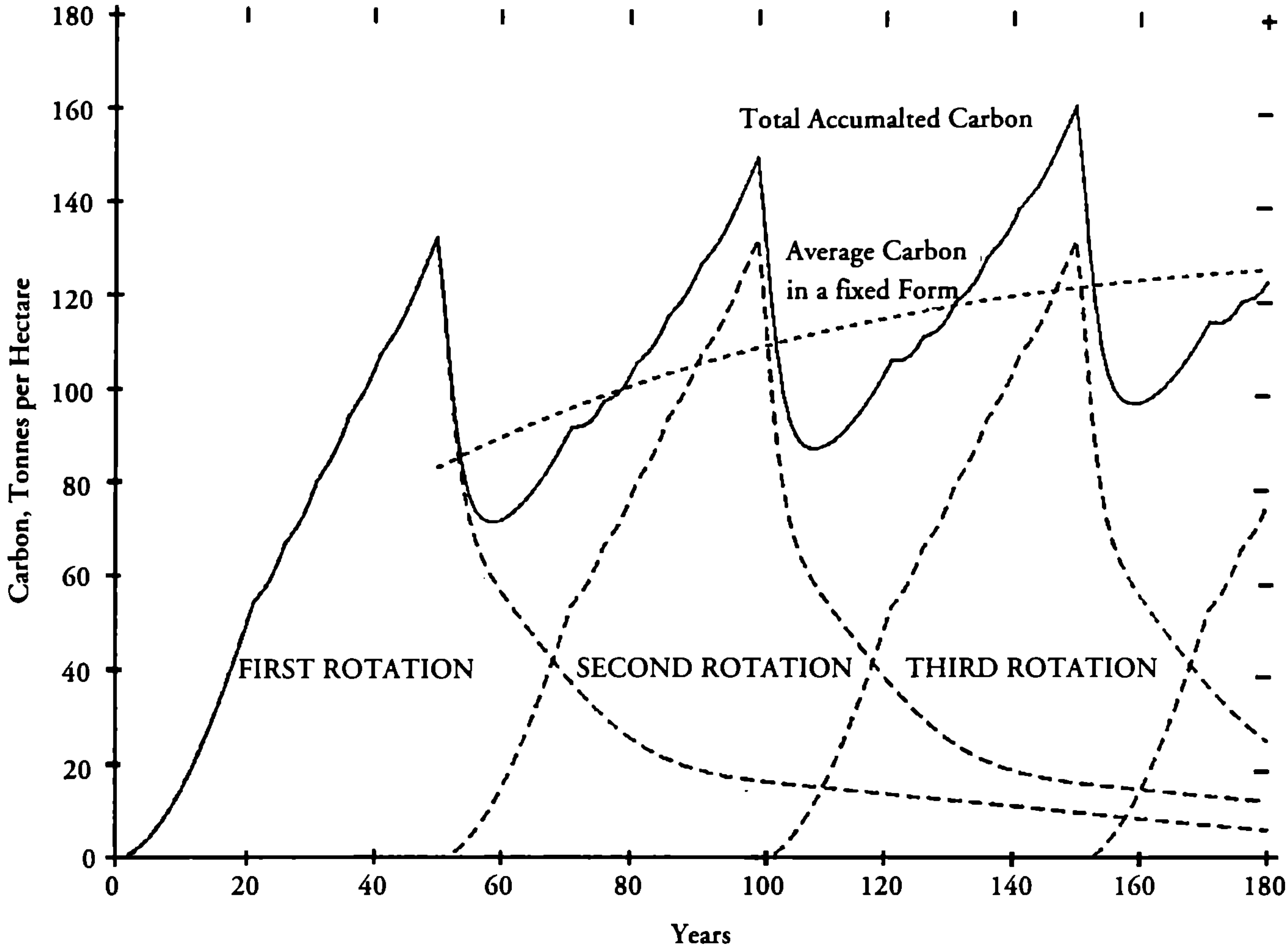


Figure A4 Corsican pine YC16



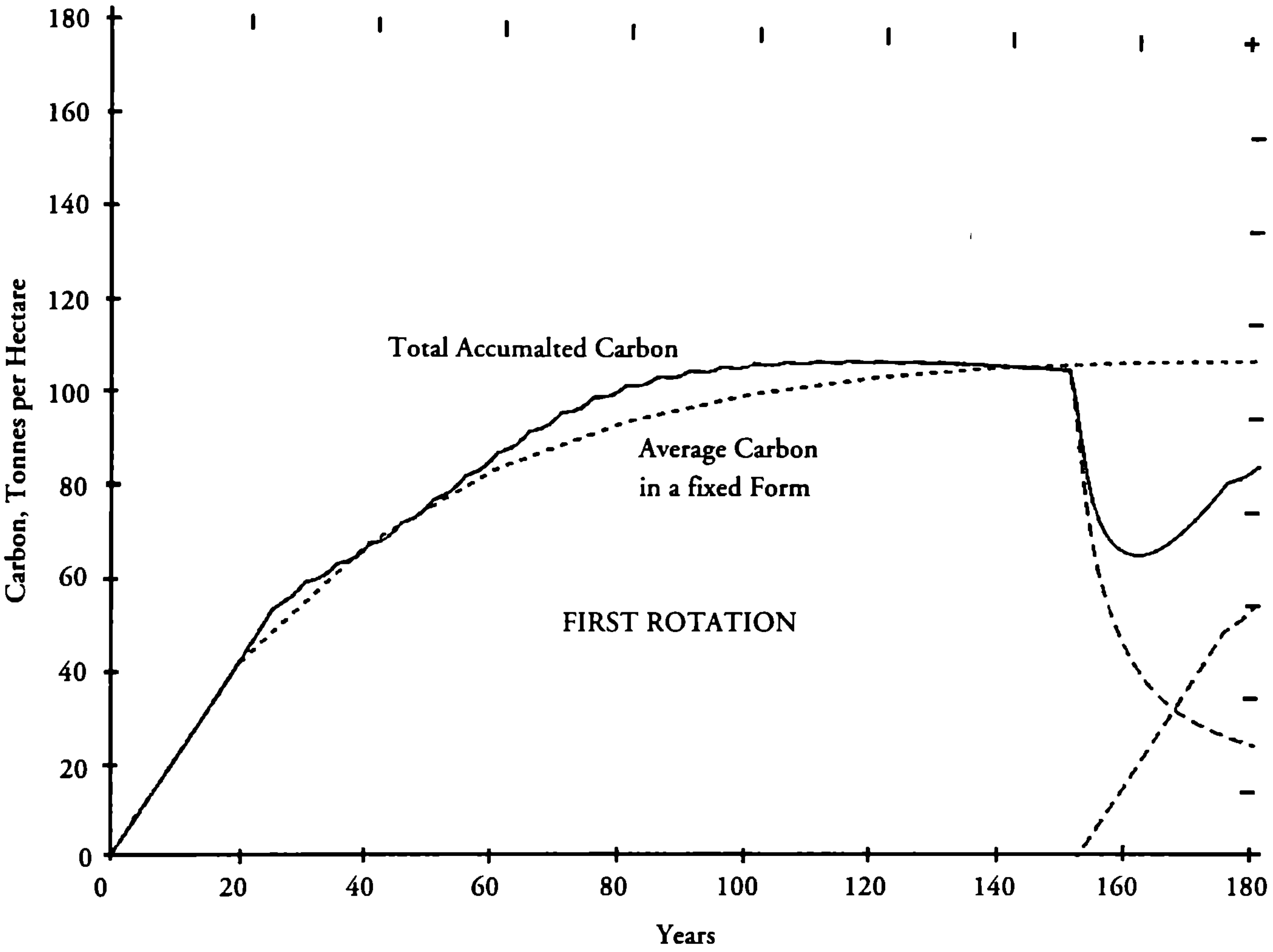

Carbon, Tonnes per Hectare
180
160
140
120
100
80
60
40
20
0
Total Accumalted Carbon
Average Carbon
in a fixed Form
FIRST ROTATION
0
20
40
60
80
100
120
140
160
180
Years

Figure A6 Birch YC4

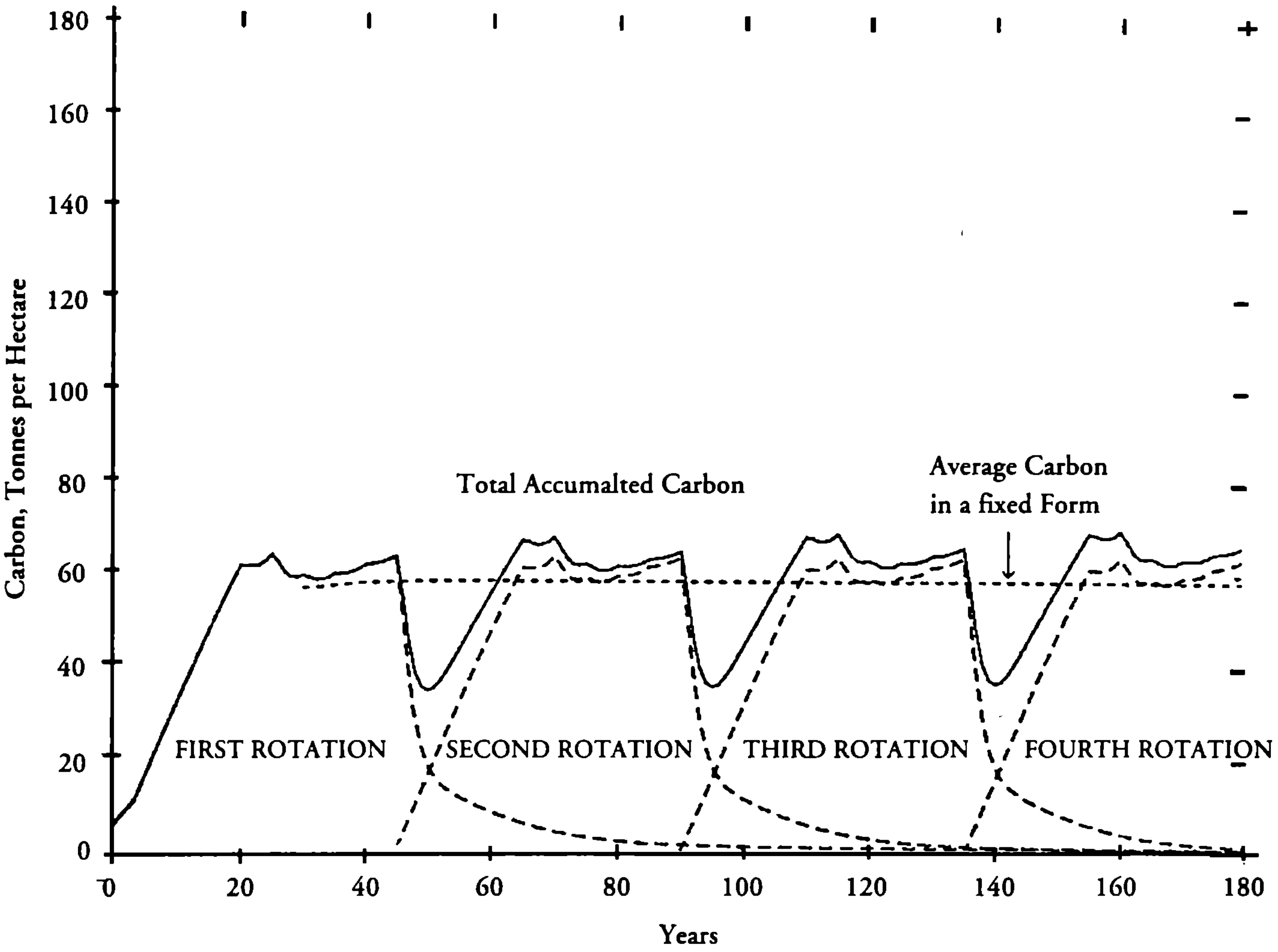


Figure A8 Oak/pine YC6

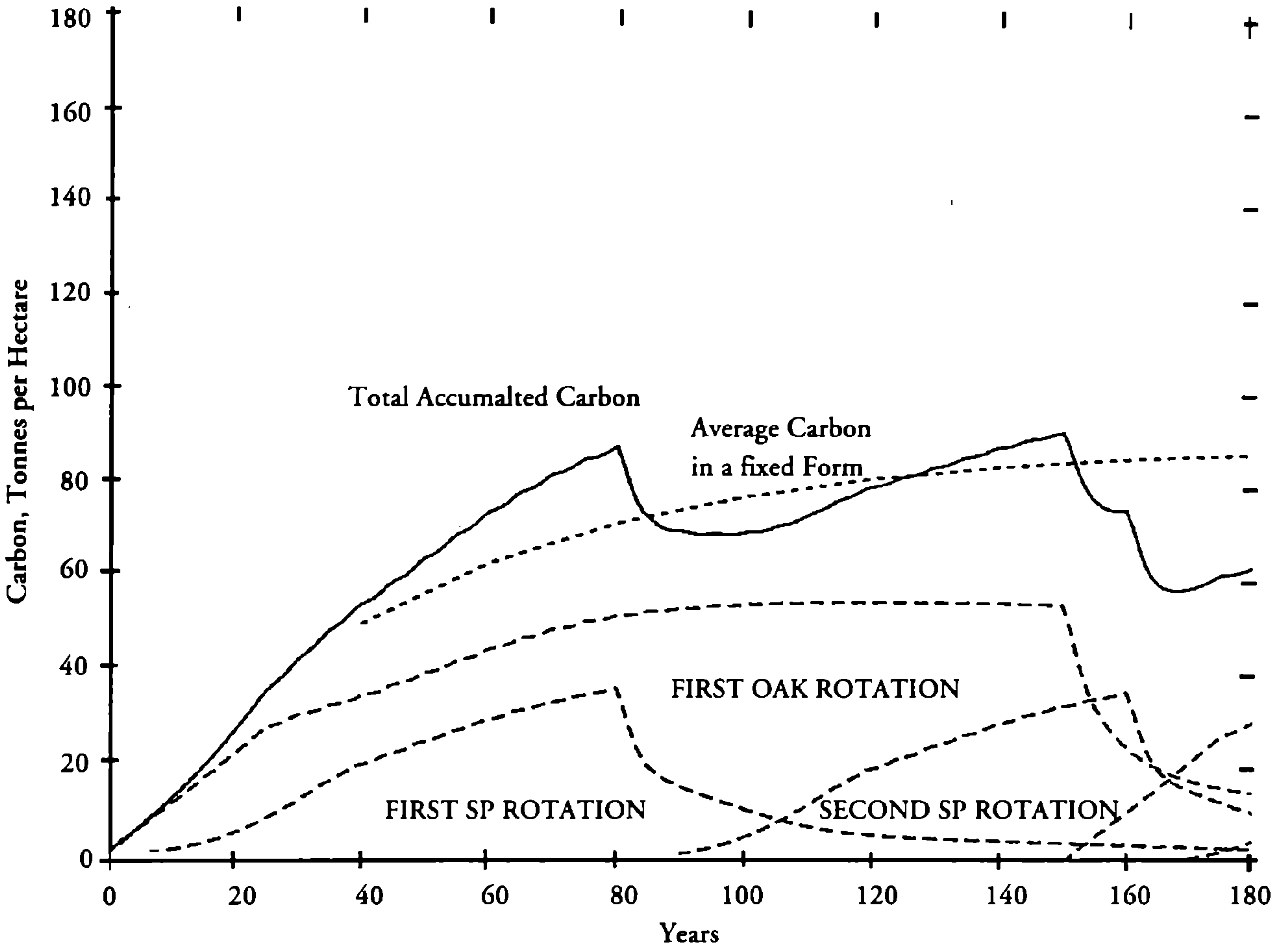
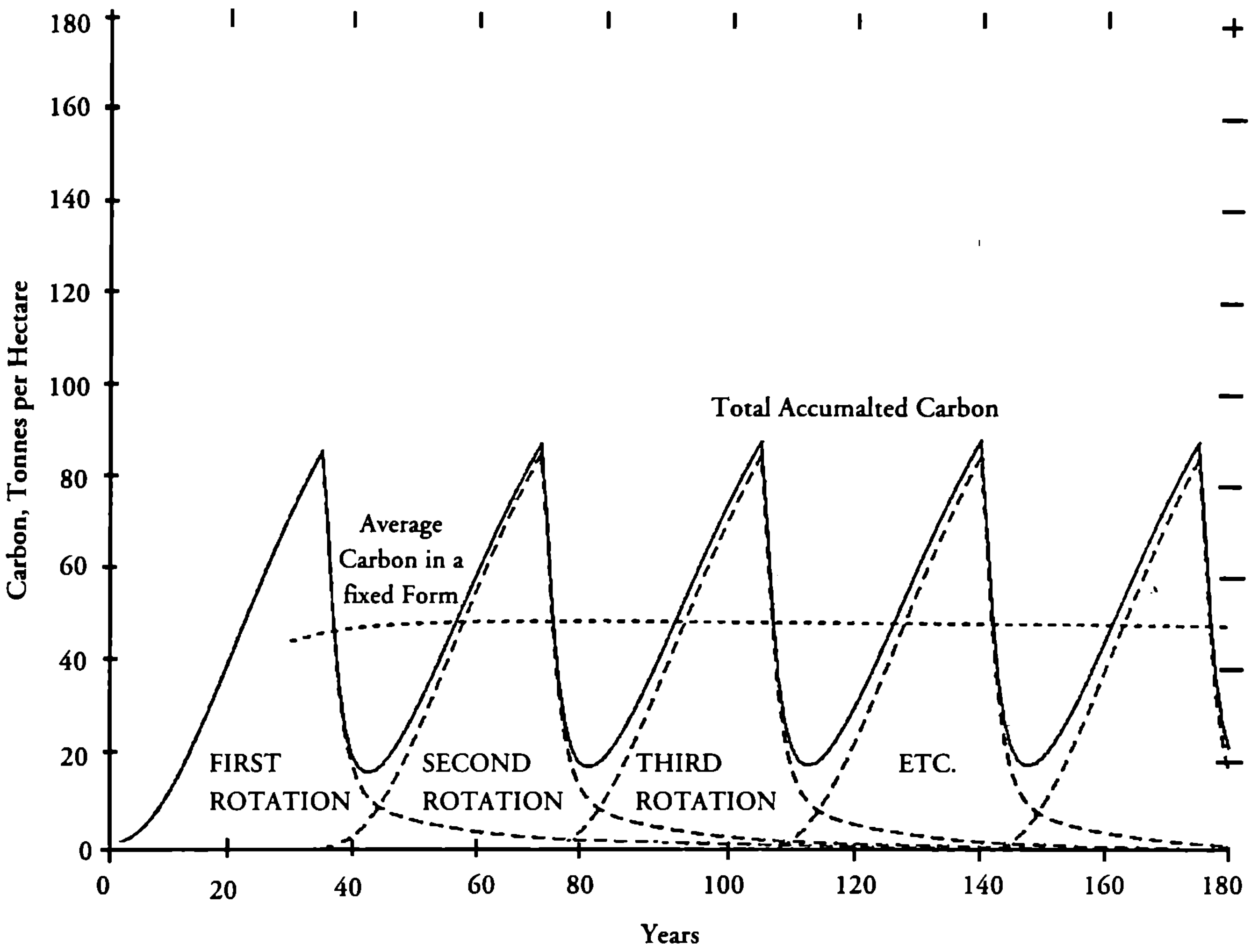


Figure A9 Poplar YC12



COST BENEFIT CALCULATIONS BY FOREST TYPE

FT 1: Semi-natural pinewoods in the uplands (based on Table 2a of Occasional Paper 46.)

Assumptions:

1.	Land price:	50% and 80% of market value (£600);
2.	Labour cost:	67% of market wage rates;
3.	Timber price:	constant in real terms, with single 1% premium to reflect economic security;
4.	Recreation	moderate value for the uplands = £30 $ha^{-1} yr^{-1}$ low value for the uplands = £3 $ha^{-1} yr^{-1}$;
5.	Carbon:	value of fixing one tonne carbon is £8. PV of carbon fixed = 17.8 t; at £8 t^{-1}, value = £142 ha^{-1}.

Results:

	NPV at 6% (89/90)	IRR
Timber value only		
- land value 50%	- 798	3.2
- land value 80%	- 975	3.0
Timber and recreation value		
- land value 50% moderate recreational value	- 483	4.1
- land value 80% moderate recreational value	- 661	3.8
- land value 50% low recreational value	- 768	3.3
- land value 80% low recreational value	- 946	3.1
Timber, recreational and carbon-fixing value		
- land value 50% moderate recreational value	- 344	4.5
- land value 80% moderate recreational value	- 522	4.1
- land value 50% low recreational value	- 628	3.7
- land value 80% low recreational value	- 806	3.4

FT2: Semi-natural broadleaves in the lowlands (based on Table 6a of Occasional Paper 46)

Assumptions:

1. Land price: 50% and 80% of market value (£3000);
2. Labour cost: market wage rates;
3. Timber price: constant in real terms, with single 1% premium to reflect economic security;
4. Recreation high value for the lowlands = £220 ha^{-1} yr^{-1}
   moderate value for the lowlands = £50 ha^{-1} yr^{-1};
5. Carbon: value of fixing one tonne carbon is £8.
   PV of carbon fixed = 23.4 t; at £8 t^{-1}, value = £187 ha^{-1}.

Results:

	NPV at 6% (89/90)	IRR
Timber value only		
- land value 50%	- 2940	-
- land value 80%	- 3839	-
Timber and recreation value		
- land value 50% high recreational value	- 557	4.5
- land value 80% high recreational value	- 1456	3.2
- land value 50% moderate recreational value	- 2393	-
- land value 80% moderate recreational value	- 3292	-
Timber, recreational and carbon-fixing value		
- land value 50% high recreational value	- 370	5.0
- land value 80% high recreational value	- 1269	3.6
- land value 50% moderate recreational value	- 2206	0.2
- land value 80% moderate recreational value	- 3105	0.1

(IRR "-" indicates a negative IRR)

FT3: Semi-natural broadleaves in the uplands (based on Table 7 of Occasional Paper 46)

Assumptions:

1. Land price: 50% and 80% of market value (£600);
2. Labour cost: 67% of market wage rates;
3. Timber price: constant in real terms, with single 1% premium to reflect economic security;
4. Recreation moderate value for the uplands = £30 $ha^{-1} yr^{-1}$
   low value for the lowlands = £3 $ha^{-1} yr^{-1}$;
5. Carbon: value of fixing one tonne carbon is £8.[1]
   PV of carbon fixed = 25 t; at £8 t^{-1}, value = £200 ha^{-1}.

Results:

	NPV at 6% (89/90)	IRR
Timber value only		
- land value 50%	- 1099	-
- land value 80%	- 1276	-
Timber and recreation value		
- land value 50% moderate recreational value	- 838	-
- land value 80% moderate recreational value	- 1015	-
- land value 50% low recreational value	- 1075	-
- land value 80% low recreational value	- 1251	-
Timber, recreational and carbon-fixing value		
- land value 50% moderate recreational value	- 598	-
- land value 80% moderate recreational value	- 775	-
- land value 50% low recreational value	- 835	-
- land value 80% low recreational value	- 1012	-

(IRR "-" indicates a negative IRR)

FT4: Predominantly spruce in the uplands (based on Table 1 of Occasional Paper 46)

Assumptions:

1. Land price: 0%, 50% and 80% of market value (£600);
2. Labour cost: 67% of market wage rates;
3. Timber price: constant in real terms, with single 1% premium to reflect economic security;
4. Recreation moderate value for the uplands = £30 ha^{-1} yr^{-1}
   low value for the uplands = £3 ha^{-1} yr^{-1};
5. Carbon: value of fixing one tonne carbon is £8.
   PV of carbon fixed = 26.2 t; at £8 t^{-1}, value = £210 ha^{-1}.

Results:

	NPV at 6% (89/90)	IRR
Timber value only		
- land value 0%	- 4	6.0
- land value 50%	- 288	5.4
- land value 80%	- 458	5.1
Timber and recreation value		
- land value 0% moderate recreational value	- 264	6.7
- land value 50% moderate recreational value	- 19	5.9
- land value 80% moderate recreational value	- 190	5.6
- land value 0% low recreational value	- 21	6.0
- land value 50% low recreational value	- 262	5.4
- land value 80% low recreational value	- 433	5.1
Timber, recreational and carbon-fixing value		
- land value 0% moderate recreational value	- 467	7.3
- land value 50% moderate recreational value	- 183	6.4
- land value 80% moderate recreational value	- 13	6.0
- land value 0% low recreational value	- 224	6.6
- land value 50% low recreational value	- 60	5.8
- land value 80% low recreational value	- 230	5.5

FT5: Community forests (based on Table 9 of Occasional Paper 46)

Assumptions:

1. Land price: 80% of market value (£3000);
2. Labour cost: market wage rates;
3. Timber price: constant in real terms, with single 1% premium to reflect economic security;
4. Recreation very high value for the lowlands = £424 ha^{-1} yr^{-1}
   high value for the lowlands = £220 ha^{-1} yr^{-1};
5. Carbon: value of fixing one tonne carbon is £8.
   PV of carbon fixed = 26.1 t; at £8 t^{-1}, value = £213 ha^{-1}.

Results:

	NPV at 6% (89/90)	IRR
Timber value only	- 3173	2.6
Timber and recreation value		
- very high recreational value	- 873	7.1
- high recreational value	- 1082	4.6
Timber, recreational and carbon-fixing value		
- very high recreational value	- 1086	7.4
- high recreational value	- 869	4.8

FT6: Native broadleaves on better land managed for timber production (based on Table 5 of Occasional Paper 46)

Assumptions:

1. Land price: 50% and 80% of market value (£3000);
2. Labour cost: market wage rates;
3. Timber price: constant in real terms, with single 1% premium to reflect economic security;
4. Recreation high value for the lowlands = £220 $ha^{-1} yr^{-1}$
   moderate value for the lowlands = £53 $ha^{-1} yr^{-1}$;
5. Carbon: value of fixing one tonne carbon is £8.
   PV of carbon fixed = 30.7 t; at £8 t^{-1}, value = £246 ha^{-1}.

Results:

	NPV at 6% (89/90)	IRR
Timber value only		
- land value 50%	- 3384	1.0
- land value 80%	- 4283	0.9
Timber and recreation value		
- land value 50% high recreational	- 1001	4.1
- land value 80% high recreational	- 1900	3.3
- land value 50% moderate recreational value	- 2836	1.6
- land value 80% moderate recreational value	- 3736	1.3
Timber, recreational and carbon-fixing value		
- land value 50% high recreational	- 755	4.6
- land value 80% high recreational	- 1655	3.6
- land value 50% moderate recreational value	- 2591	1.9
- land value 80% moderate recreational value	- 3490	1.6

FT7: Pines in the lowlands (based on Table 4 of Occasional Paper 46)

Assumptions:

1. Land price: 50% and 80% of market value (£3000);
2. Labour cost: market wage rates;
3. Timber price: constant in real terms, with single 1% premium to reflect economic security;
4. Recreation high value for the lowlands = £220 $\text{ha}^{-1}\,\text{yr}^{-1}$
   moderate value for the lowlands = £50 $\text{ha}^{-1}\,\text{yr}^{-1}$;
5. Carbon: value of fixing one tonne carbon is £8.
   PV of carbon fixed = 20.9 t; at £8 t^{-1}, value = £167 ha^{-1}.

Results:

	NPV at 6% (89/90)	IRR
Timber value only		
- land value 50%	- 1741	3.7
- land value 80%	- 2605	3.2
Timber and recreation value		
- land value 50% high recreational value	- 332	6.5
- land value 80% high recreational value	- 532	5.3
- land value 50% moderate recreational value	- 1265	4.2
- land value 80% moderate recreational value	- 2129	3.6
Timber, recreational and carbon-fixing value		
- land value 50% high recreational value	- 498	6.8
- land value 80% high recreational value	- 365	5.5
- land value 50% moderate recreational value	- 1099	4.5
- land value 80% moderate recreational value	- 1962	3.8

FT8: Mixed Douglas fir, spruce and broadleaved forest on better land in the lowlands (based on Table 3 of Occasional Paper 46)

Assumptions:

1. Land price: 0%, 50% and 80% of market value (£3000);
2. Labour cost: market wage rates;
3. Timber price: constant in real terms, with single 1% premium to reflect economic security;
4. Recreation high value for the lowlands = £220 ha^{-1} yr^{-1}
   moderate value for the lowlands = £50 ha^{-1} yr^{-1};
5. Carbon: value of fixing one tonne carbon is £8.
   PV of carbon fixed = 31.3 t; at £8 t^{-1}, value = £254 ha^{-1}.

Results:

	NPV at 6% (89/90)	IRR
Timber value only		
- land value 0%	572	7.1
- land value 50%	- 819	5.0
- land value 80%	- 1653	4.3
Timber and recreation value		
- land value 0% high recreational value	2464	14.7
- land value 50% high recreational value	1073	7.5
- land value 80% high recreational value	239	6.2
- land value 0% moderate recreational value	984	8.1
- land value 50% moderate recreational value	- 407	5.4
- land value 80% moderate recreational value	- 1241	4.7
Timber, recreational and carbon-fixing value		
- land value 0% high recreational value	2717	16.9
- land value 50% high recreational value	1327	7.9
- land value 80% high recreational value	493	6.5
- land value 0% moderate recreational value	1237	8.8
- land value 50% moderate recreational value	- 154	5.7
- land value 80% moderate recreational value	- 987	4.9

'FORESTRY EXPANSION: A STUDY OF TECHNICAL, ECONOMIC AND ECOLOGICAL FACTORS'

This is one of a series of papers which form part of a study to consider the scale, location and nature of forestry expansion in Britain.

The Forestry Commission invited fourteen specialist authors, including economists, foresters, ecologists and biological scientists to write about current knowledge and to assess the main factors bearing on decisions about the future direction of forestry expansion. It is intended that the papers will form the basis for future discussions of the location and type of forestry that will best meet the demands of society for wood products, jobs, recreation, amenity, wildlife conservation, carbon storage and the other uses and public benefits supplied by the country's forests.

Published by the Forestry Commission on 19th July, 1991.

The full list of papers is as follows:

Occasional Paper No	Title	Author
33	Introduction	Professor Ian Cunningham, Macaulay Land Use Research Institute
34	British Forestry in 1990	Hugh Miller, University of Aberdeen
35	International Environmental Impacts: Acid Rain and the Greenhouse Effect	Melvyn Cannell and John Cape, Institute of Terrestrial Ecology
36	The Long Term Global Demand for and Supply of Wood	Mike Arnold, Oxford Forestry Institute
37	UK Demand for and Supply of Wood and Wood Products	Adrian Whiteman, Forestry Commission
38	Development of the British Wood Processing Industries	Iain McNicoll and Peter McGregor, University of Strathclyde and Bill Mutch, Consultant
39	The Demand for Forests for Recreation	John Benson and Ken Willis, University of Newcastle
40	Forests as Wildlife Habitat	John Good, Ian Newton, John Miles, Rob Marrs and John Nicholas Greatorex-Davies, Institute of Terrestrial Ecology
41	Forestry and the Conservation and Enhancement of Landscape	Duncan Campbell and Roddie Fairley, Countryside Commission for Scotland
42	The Impacts on Water Quality and Quantity	Mike Hornung and John Adamson, Institute of Terrestrial Ecology
43	Sporting Recreational Use of Land	James McGilvray and Roger Perman, University of Strathclyde
44	The Agricultural Demand for Land: Its Availability and Cost for Forestry	David Harvey, University of Newcastle
45	Forestry in the Rural Economy	John Strak and Chris Mackel, Consultants
46	New Planting Methods, Costs and Returns	Jim Dewar, Forestry Commission
47	Assessing the Returns to the Economy and to Society from Investments in Forestry	David Pearce, University College London

The summary document is free; each of the 14 papers is available at £2.00 (including postage) and the full set is priced at £25.00 (including postage) from: Publications, Forestry Commission, Alice Holt Lodge, Wrecclesham, Farnham, Surrey GU10 4LH, Tel: 0420 22255 .