AUSTRALIAN TREE SPECIES SELECTION IN CHINA

ACIAR Projects 8457 and 8848

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Contents

Abstract

The Australian Centre for International Agricultural Research (ACIAR), through collaborative projects with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, and the Chinese Academy of Forestry (CAF), has been involved in tree species selection trials in southern China since 1984. The trials[1] were aimed at identifying fast-growing species of *Eucalyptus*, *Acacia* and *Casuarina*. The Chinese have been planting Australian tree species for more than 100 years, but before the ACIAR project there had been little progress in determining which species and provenances would be best for the local climate and soils. This paper presents an assessment of the economic impact of research undertaken under two ACIAR-supported projects.

Adoption of some new introductions has been much greater and sooner than previously anticipated. Using a 5% discount rate, base-case benefit estimates suggest the future stream of economic gains to China have a net present value of $A122.3 million in 1996 dollars. The internal rate of return is 35%, indicating the research was a particularly valuable investment. While some uncertainty inevitably remains with this estimate, enough time has passed to be confident about these results. The benefit estimates are large by most standards, particularly for forestry research, which is usually characterized by long lag periods between the research, adoption and harvesting phases. In this case research and adoption lags were short, productivity gains large and adoption levels high.

The Chinese are currently planting more than 85 000 ha of the new introductions annually. In fact plantations of the new introductions are already being harvested. The ‘in-hand’ net present value of the projects to 1999 is A$3.8 million ($1996). This indicates that substantive net economic benefits from the research have begun to flow.

1.The two projects discussed in this paper are:FST/8457: Introduction and cultivation experiments for Australian broad-leaved tree species- Phase I FST/8848: Introduction and cultivation experiments for Australian broad-leaved tree species- Phase I

1. Introduction

The Chinese have been planting Australian tree species for more than 100 years. Little is known, however, of the exact geographic origins of these trees. Collaborative tree species selection research was undertaken in southern China beginning in the early 1980s supported by the Australian Centre for International Agricultural Research (ACIAR), the Chinese Academy of Forestry (CAF) and the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). The research under ACIAR-supported project numbers 8457 and 8848 essentially dealt with the selection of fast-growing species of *Eucalyptus, Acacia* and *Casuarina*. McKenney et al. (1993) and Davis et al. (1994b) previously calculated the potential economic benefits of this research. At the time of those studies numerous assumptions were required to estimate the likely economic gains. Several years have now passed and the opportunity now exists to revisit those studies and examine the veracity of the assumptions and results. This paper re-examines the likely economic benefits of the Australian tree species selection research in southern China. Key assumptions and outcomes are revisited and the likely economic benefits re-estimated.

There are relatively few empirical analyses of the economic returns to research in forestry (e.g. McKenney et al. 1992, 1997; Hyde et al. 1992; Huang and Teeter 1990; Jakes and Risbrudt 1988; Fox 1986) when compared to agricultural research. Many of the analytical advances have occurred in the context of evaluating agricultural research (see Norton and Davis 1981 and Alston et al. 1995). To our knowledge, there are no revisits of research evaluation studies in forestry contexts available in the literature. This adds to the significance of the current study.

2. Background

China's forest area covers 124 million hectares, about 13 per cent of the land area (Dong 1991). More than half of the 100 million cubic metres of wood harvested annually comes from southern provinces, mainly from trees planted by collectives and individuals (Bennett 1988). There is a large domestic demand for fuelwood, poles and sawn timber and a government policy to increase the amount of wood used for paper pulp. Large-scale plantation forestry programs have been initiated supported by organizations such as the World Bank. Plantations of high yielding eucalypts and acacias are now making an important contribution to wood production in southern China, where the climate is conducive to high growth rates (Bai et al. 1998). Casuarinas are widely planted in coastal shelterbelts but to date have had little industrial use.

Eucalypts were introduced into southern China about 1890. These and subsequent introductions came from unselected, and often incorrectly named, trees growing as exotics in a variety of countries. Eucalypts were originally planted as ornamentals and for roadside shade. In the 1950s extensive areas of eucalypts were established. Much of the wood harvested from these plantations has been used as timber in the mining industry (Turnbull 1981). Eucalypt plantations now cover an estimated area of 1.5 million hectares (principally in Guangdong, Guangxi, Hainan Island, Yunnan and Fujian provinces) although this number is somewhat contentious. A further one billion trees planted around fields, homes and villages, and along roads, railways and watercourses provide a significant timber resource, especially in Sichuan and Yunnan provinces (Wang 1991).

Because of a timber supply deficit, the availability of land, and an aim to have a eucalypt resource of sufficient size to support a pulp and paper industry, a goal of the Chinese Ministry of Forestry has been to increase the area of eucalypts. When the expansion of the eucalypt area began, the trees were raised from local seed sown in traditional nurseries and planted on infertile sites without fertilizer. Only the robust species survived. Present areas of *Eucalyptus exserta* and *Eucalyptus citriodora* are the product of this selection process. They tolerate infertile soils but have low yields and have wood with relatively poor pulping properties. The average yield of plantation-grown eucalypts in China has been only 5–8 m3/ha/annum (Liu 1988).

Casuarinas have been grown in China for more than 80 years but it was not until the 1950s that large plantation areas were established in southern coastal areas. These plantings were originally established to stabilise coastal sand dunes and protect adjacent farmland. The shelterbelts extend along the coast from Hainan Island to Zhejiang, a distance of about 4000 km, and cover several hundred thousand hectares. They have become an important source of fuelwood and poles (Turnbull 1983; Cao and Xu 1990; Zhong 1990a). The major species planted is *Casuarina equisetifolia*, but there are significant areas of *Casuarina cunninghamiana* and *Casuarina glauca*. The original source of seed of these species is unknown.

In southern China an acacia, *Acacia confusa*, has been widely used in plantings around houses and along roads, railways and waterways. It is relatively slow growing and has a crooked stem so that its principal use is for fuelwood and shelter. As with the eucalypts and casuarinas, the source of the original seed introduction is unknown.

In 1980 an Australian forestry mission to China recommended testing new introductions of species and provenances of eucalypts, acacias and casuarinas to increase plantation productivity (Carter et al. 1981). Subsequently, a project at Dongmen Forest Farm in the Guangxi Zhuang Autonomous Region demonstrated that substantial increases in yield could be obtained through the introduction of new species and provenances of eucalypts and pines and strategic applications of fertilizer (Cameron et al. 1988; McGuire et al. 1988). This project was supported by the Australian International Development Assistance Bureau, and executed by the Queensland Forest Service. A complementary project was implemented in 1985 by the Chinese Academy of Forestry's research institutes in Guangzhou and Beijing, and the CSIRO Division of Forestry, Canberra, the object of which was to test a wider range of Australian tree species and provenances over more diverse environmental conditions in other provinces. ACIAR provided a significant proportion of the funding and was a catalyst for undertaking the research.

3. The ACIAR Collaborative Project

The first phase of the ACIAR project commenced in 1985 with the primary objective of identifying Australian eucalypts, acacias and casuarinas which would be more productive than those currently being used. The project involved introducing, from Australia and elsewhere, a wide range of species and provenances of known origin. Numerous field trials were established. These were located in Yunnan Province in the cool subtropical, high altitude plateau areas of southwestern China: in cool to warm subtropical Fujian Province: and tropical Guangdong and Hainan Island provinces. These are the primary areas targeted for eucalypt plantation development. The trials were designed to test the adaptability of the new introductions. Survival and health were assessed and growth measured. More detailed information on the trials and results are given by Yang et al. (1989), Zhou and Bai (1989), Wang et al. (1989), Wang (1990), Zhong (1990b) and Brown (1994).

At the time of the previous economic studies (McKenney et al. 1993 and Davis et al. 1994b), growth measurements indicated that some of the new introductions were growing much faster than the controls. While the experimental data suggested substantial increases in wood production were possible from introduced species, caution was advised by the scientists involved due to the small plot size. Volume estimates in small plots can be inflated due to edge-effects. Nevertheless, the results at the time provided an indication of the potential of the new species. The lack of reliable seed sources within China affected assumptions about adoption levels and how long it would take to establish plantation areas. However, seed orchards and breeding programs have been established for further improvement of the most promising species. For example, seed orchards of acacia were established in 1988 in Hainan Island and Zhejiang. Breeding plans have been developed for *Eucalyptus globulus*, *Eucalyptus grandis* and *Eucalyptus urophylla* and seed production areas have been established. More than 95% of the seed for the new introductions are now coming from Chinese sources (Bai Jiayu, pers. comm.).

Early indications were that the extensive plantations of *E. exserta* and *E. citriodora* would be replaced by *E. urophylla* in tropical areas with low typhoon risk, *Eucalyptus tereticornis* or *Eucalyptus camaldulensis* in tropical areas with higher typhoon risk and *E. grandis* or *E. urophylla* in subtropical areas. In fact, for the most part *E. urophylla* has been adopted as the major eucalypt species in southern China. (Strictly speaking *E. urophylla* is not a purely Australian species [John Fryer, pers. comm.].) It was also likely that new provenances of *Acacia auriculiformis* would be used extensively in the tropical lowlands, especially for boundary plantings, and that the faster growing *Acacia crassicarpa* and *Acacia mangium* would be planted on the slopes of the hilly land in tropical areas. This has proved to be the case.

In the cooler highlands of Yunnan, Sichuan and Guizhou provinces and in the coastal Zhejiang Province, there is likely to be an increased role for temperate eucalypts (Wang et al. 1992). However, seed from Australia was in short supply and was expected to inhibit the adoption of faster growing temperate eucalypts. In the previous study (McKenney et al. 1993) it was assumed that the cool sub-tropical highland component of the research would result in relatively low benefits and so temperate eucalypts were excluded. However, since the previous studies, plantation areas of *Eucalyptus smithii*, another temperate eucalypt, have been more widely established as a result of the ACIAR trials. Benefit estimates for the temperate eucalypts are included in this study.

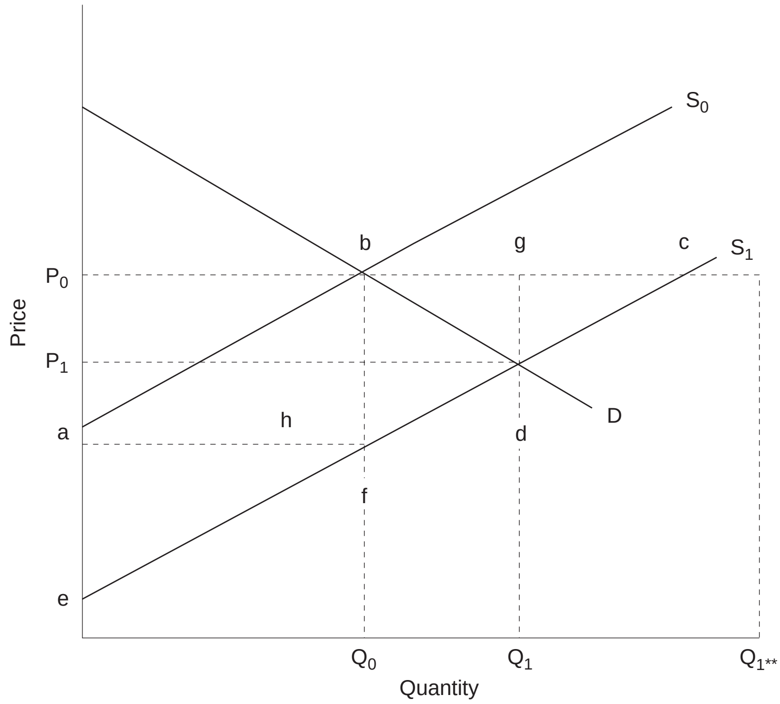
During the course of this update, it became apparent that some of the assumptions of the previous studies have proved to be incorrect. For example, the assumption that new introductions of casuarina would be adopted at a rate of 10 000 ha per year has not occurred. Casuarina is still being used for coastal belt plantings but the new introductions appear to be too costly relative to old sources and casuarina does not have as many industrial uses as the eucalypts or acacias (Bai Jiayu, pers. comm.). This study therefore focuses on acacias and eucalypts. The three classes of tropical, sub-tropical and temperate eucalypt has been modified to two classes: (i) tropical and subtropical, and (ii) temperate eucalypts. Better data are now available on plantation yields and the actual plantation areas established from the introductions.

4. Impact Assessment

A range of research evaluation frameworks has been employed in past assessments of the impact of research. Some have used very simple models which estimate the value to society of the research as the expected increase in product output valued at the current or expected price. Others have used economic welfare theory-based measures of the impact of technology with multi-stage, multi-regional traded good models incorporating research spillovers between regions to estimate the potential value to society of the research (e.g. Davis et al. 1994a). Generally the evaluation framework used should depend on the use of the information. For some situations the information generated by a simple framework will be all that is required, while for others more complex inter-regional interactions and relative distribution of benefits between consumers and producers may be of interest.

Even if a simple framework is considered appropriate, care is required in the choice of the framework and especially the estimation procedures adopted. For example, the estimated value of the expected increase in output should be used with care. Figure 1 illustrates the approach used to measure of the gains from research. A single-region, non-traded, single good model is represented. Demand is represented by *D*. The product supply before research is S_0. After research the cost of producing the product is reduced, shifting the supply to S_1. The economic welfare theory-based measures of the gains from research suggest that the area *abde* is a close approximation of society's gains. For a given cost reduction due to research, in this case *bf*, the area, *abfe*, will remain the same regardless of the supply and demand characteristics of the product involved. The rest of the welfare gains, here *bdf*, will change depending upon the supply and demand characteristics (elasticities). In the extreme, this area can be as large as *bcf*. In most cases this variable area is a relatively small share of the total welfare gain estimate. See McKenney et al. (1993) for further details. Clearly the estimate of the gains can be sensitive to the assumptions regarding the supply and demand conditions.

Figure 1. The economic assessment framework (see text for details).



For consistency we continue to use the same simple welfare theory-based measure adopted by the previous studies to estimate the expected gains from the research. There is a clearer theoretical basis for this measure as opposed to the 'value of the change in output', and in addition, it is in general likely to be less sensitive to the often uncertain underlying supply and demand conditions. For reasons highlighted in Davis and Bantilan (1991) the cost reduction, that is *bf*, will be used to estimate the research gains not the output increase (*bc* or *bg*). This assessment continues to use only wood values to estimate benefits. Non-wood benefits are ignored for the quantitative assessment but are noted in the discussion.

In practical terms, the analysis proceeded as follows. The cost per cubic metre (i.e. unit cost) of growing wood from plantations (before and after research) was calculated by compounding all establishment and maintenance costs to rotation length. This approach was used to provide an estimate of the unit cost reduction due to the productivity (volume) gains from the new introductions. Note that there are additional costs and changes in rotation lengths associated with the new introductions which means the unit cost reductions are not linearly related with the volume gains. The annual research *gross* benefits were estimated in two parts. First, the area *abfe* in Figure 1 was estimated.

This area is the same as the area $P_o bfa$ where:

$P_o bfa$ = Q_o ¥ '*bf*' (cost reduction per cubic metre)
= Area planted to new species ¥ pre-research yields per ha ¥ '*bf*'.

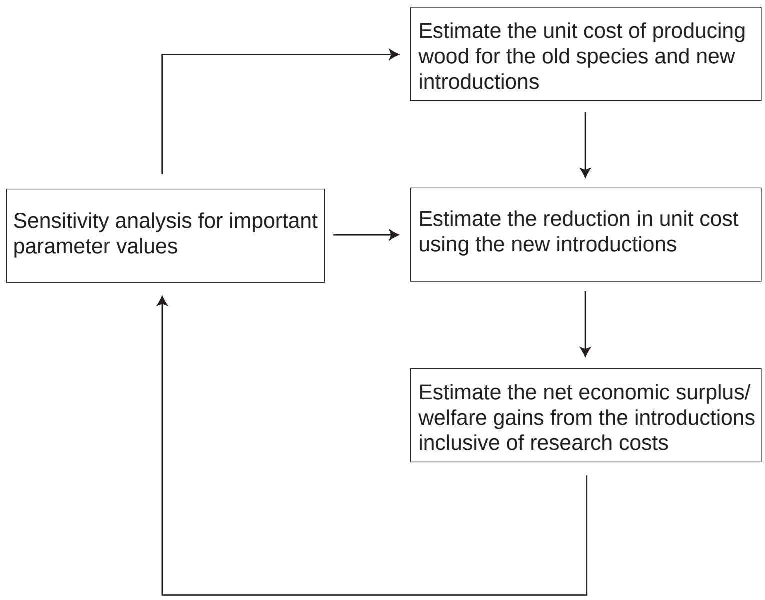
Second, the area *bcf*, was estimated using the formula for the area of a triangle, 0.5 ¥ base ¥ height, where the base is the cost reduction '*bf*', and the height is '*bc*' which is equal to the change in ouput ($Q_1{}^{**} - Q_o$). Thus:

bcf = 0.5 ¥ '*bf*' ¥ (new yields/ha – pre-research yields/ha)
¥ area planted to new tree species.

Note that an assumption of perfectly elastic demand (i.e. a horizontal demand curve in Figure 1, $P_0 - c$) was used. This means that in Figure 1, the estimation of research benefits is based on $Q_1{}^{**}$, not Q_1. This further implies that standing timber prices would be unaffected by the increased output due to the research. This would appear to be a reasonable assumption for several reasons. Prices are generally administered in China and even though large volumes are being produced from these plantations, *in toto* they represent a small share of total wood output in China and in proportion to world production. Also, the plantation programs have been developed to support domestic pulp mills (Bai Jiayu, pers. comm.) and the analysis has a relatively long term perspective. Over the longer run especially, the impact on prices of production from any single region would most likely be negligible (D.W. McKenney and M.S. Common, unpublished data).

Project research costs are then summarized and subtracted from the gross benefits to estimate the *net* benefits. Present values in 1996 Australian dollars of all costs and benefits were calculated using a real discount rate of 5% and a Chinese Yuan to Australian dollar exchange rate of 6.4786 to 1. The steps in the analysis are summarized in Figure 2.

Figure 2. Steps in evaluating the impact of species selection research.



4.1 Unit Costs of Production

The unit cost of producing wood is calculated by compounding all plantation establishment and management costs forward to the end of the plantation's life and dividing by harvest yield. The costs are then expressed per unit of production (e.g. Yuan or dollars per cubic metre). The interest rate for compounding costs was assumed to be 5%; this being a real rate (net of inflation) for plantation-forest types of investments (e.g. see Row et al. 1981). The discount rates used to estimate net present values of the research investment were real rates of 5%. Internal rates of return for the research investment are also presented. These are unaffected by the discount rate used for the net present value calculations.

Typical plantation costs for acacias and eucalypts before and after the adoption of the new introductions are given in Tables 1 and 2. When multiple products are realised from plantations the issue of cost allocation arises. Here the unit cost of production has been calculated based on total wood yield only. The allocation of costs among joint products is generally arbitrary and can lead to biased cost estimates for each product (Bowes and Krutilla 1989; Hof et al. 1985). Given that some products can be produced before the final harvest at the end of the rotation, this approach can provide an overestimate of the unit cost. Hence the resultant benefit estimates reported here could be construed as conservative.

Plantation costs from the previous studies formed the basis for unit cost calculations. However, researchers at the Research Institute of Tropical Forestry re-examined these costs. Many of the costs were the same, others increased and some decreased. However, land costs do appear to have increased substantially. These new land costs were not used here since the increased productivity of the new plantations would be capitalised into increased land values. It would seem more reasonable to attribute this increase to the research.

Adoption costs for the new introductions are primarily the costs of seed procurement and some modified silvicultural practices, such as more intensive site preparation. Some seed is being purchased from overseas but this is a small proportion (less than 5%) of the total requirements (Bai Jiayu, pers. comm.). As noted above, the Chinese have generally chosen to develop their own seed sources (e.g. seed orchards, seed production areas, and so on) at cost that is three to six times more per kg than the previous sources of seed. This seed cost is still a small proportion of the overall cost of plantations. In the previous studies some seed orchard costs were included in the unit cost calculations as part of the adoption cost. The seed orchard costs have been dropped as they are embedded in the seed purchase costs. Inclusion would imply double counting this component.

Table 3 summarizes the yield and unit cost reduction estimates used in study. The unit cost reductions due to research range from 28.6 yuan per m^3 for tropical acacias to 10.7 yuan per m^3 for eucalypts. In percentage terms these represent production cost reductions ranging from 19% (eucalypts) to 55% (acacias) corresponding to 30% and 177% volume production increases. This result demonstrates the lack of direct correspondence between volume increases and cost reductions. Contributing to these unit cost reductions are short rotation lengths for both eucalypt and acacia plantations. Rotation length for the introduced species is seven years (the primary products being pulpwood). Thus even though plantation establishment and management costs have increased, they are compounded over a shorter period of time for the unit cost calculations and divided by a greater yield. The compound rate used was 5%. In general, the higher the compound rate, the higher the unit cost, and hence the unit cost reductions would actually be larger.

Table 1. Plantation cost estimates for acacia (yuan per hectare).

Old selections (10 year rotation)										
Year	1	2	3	4	5	6	7	8	9	10
Land costs	30	30	30	30	30	30	30	30	30	30
Seed purchase	15									
Seedling production	300									
Site preparation	600									
Planting	600									
Fertilizer	300									
Survival assessment										
Maintenance		30	10	10	10	10	10	10	10	10
Total cost	1845	60	40	40	40	40	40	40	40	40
Compounded cost @5%	2862	89	56	54	51	49	46	44	42	40
Total compounded costs										3333
New selections (7 year rotation)										
Land costs	30	30	30	30	30	30	30			
Seed purchase	45									
Seedling production	300									
Site preparation	900									
Planting	300									
Fertilizer	450									
Survival assessment		300								
Maintenance		600	10	10	10	10	10			
Total cost	2025	930	40	40	40	40	40			
Compounded cost @5%	2714	1187	49	46	44	42	40			
Total compounded costs							4122			

Source: Bai Jiayu, Chinese Research Institute of Tropical Forestry—representative costs of old and new plantations.

Table 2. Plantation cost estimates for eucalypts (yuan per hectare).

Old selections (10 year rotation)										
Year	1	2	3	4	5	6	7	8	9	10
Land costs	60	60	60	60	60	60	60	60	60	60
Seed purchase	60									
Seedling production	150									
Site preparation	375									
Planting	525									
Fertilizer	600	300	300							
Survival assessment										
Maintenance	150	150	150	150	150	150	150	150	150	150
Total cost	1920	510	510	210	210	210	210	210	210	210
Compounded cost @5%	2179	754	718	281	260	255	243	232	221	210
Total compounded costs										6160
New selections (7 year rotation)										
Land costs	60	60	60	60	60	60	60			
Seed purchase	360									
Seedling production	300									
Site preparation	750									
Planting	900									
Fertilizer	600	300	300							
Survival assessment		100								
Maintenance	150	150	150	150	150	150	150			
Total cost	3120	610	510	510	510	510	510			
Compounded cost @5%	4181	779	620	243	231	221	210			
Total compounded costs							6485			

Table 3. Yields and cost reductions.

Species group	Wood yields and cost reduction				
	Old (m^3)	Average rotation length in years — old species	New (m^3)	Average rotation length in years — new species	(Yuan/ m^3)
Acacias	65	10	180	7	28.4
Tropical and subtropical eucalypts	108	10	140	7	10.7
Temperate eucalypts	108	10	140	7	10.7

Source: Yields from Bai Jiayu, Chinese Research Institute of Tropical Forestry; unit cost reductions calculated by dividing compounded plantation costs (Tables 1 and 2) by yields and determining the difference in unit costs between the old and the new.

4.2 Adoption Levels of the New Introductions

Annual plantings for the introductions are summarized in Table 4. Plantation establishment levels for *Acacia* are currently 20 000 ha per year and expected to rise to 25 000 ha per year in the near future. Tropical and subtropical eucalypts are being planted at a rate of 65 000 ha per year and expected to rise to 70 000 ha per year by the turn of the century. Temperate eucalypts are currently being planted at a rate of 500 ha per year. The rapid adoption of the introductions is the major contributing factor to the results. Some of the early plantations of these species are already being harvested (Bai Jiayu, pers. comm.).

Table 4. Annual planting levels for new introductions (ha).

Year	*Acacia*	Tropical and subtropical eucalypt	Temperate eucalypt	*Casuarina*
1989	600	100		
1990	800	1000		
1991	10 000	10 000	100	20
1992	12 000	20 000	200	15
1993	13 000	30 000	300	18
1994	17 000	50 000	300	20
1995	18 000	60 000	300	14
1996	20 000	60 000	500	10
1997	20 000	65 000	500	20
1998	22 000	65 000	500	16
1999	23 000	70 000	500	18
2000	23 000	70 000	1000	19
2001	24 000	70 000	1000	20
2002	24 000	70 000	1000	20
Beyond 2002	25 000	70 000	1000	20

Note: Over the longer run it is anticipated that most, if not all, of the currently 1.5 million hectares of eucalypt plantation area in China will likely adopt the new faster growing species (Bai Jiayu, pers. comm.). Given the small level of adoption of casuarina, this species category has been omitted from the quantitative analysis.
Source: Bai Jiayu, Chinese Research Institute of Tropical Forestry.

4.3 Project Research Costs

Table 5 summarises the costs of the project from 1985 through 1992. The costs include those incurred by ACIAR, CSIRO and CAF. The research costs for CAF, and especially CSIRO, are both direct and indirect (e.g. the use of existing buildings and equipment) costs.

Table 5. Project costs.

Year	ACIAR A$	CSIRO and CAF[a]	Total costs (nominal A$)	Total costs in constant 1996 A$
1985	83 550	–	83 550	138 008
1986	111 400	101 500	212 900	327 376
1987	63 500	85 000	148 500	212 682
1988	128 018	84 000	212 018	283 383
1989	183 554	245 000	428 554	526 993
1990	222 670	250 000	472 670	546 454
1991	284 524	250 000	534 524	592 947
1992	89 959	250 000	339 959	370 181

[a] *China Academy of Forestry.*
Source: Project documents and estimates for CAF and CSIRO for the last three years. Nominal research costs are converted to 1996 dollars using an Australian consumer price index. To avoid confusion, the discount rate for estimating net present values of the research is net of inflation.

5. Estimated Project Net Benefits —the Base Case

As mentioned, the net present value (NPV) of the research trials is calculated by subtracting the present value of the research costs from the gross benefits. The gross benefits are estimated using the unit cost reductions and the framework discussed earlier. Although it is clear these introductions are being used, and being harvested, many of the plantations have not yet reached maturity. Net benefits have been calculated over a 30-year period from 1985 to 2014, inclusive. This is the time horizon ACIAR is using in other project evaluations.

Table 6 provides the benefits estimates. Appendix 1 also provides a detailed tabular summary of the nominal and discounted costs and benefits by year. Note the lags between the research, plantation establishment of the new introductions, and harvesting. The NPV is estimated as A$122.3 millions ($1996) and the internal rate of return (IRR) as 35%. The IRR represents the discount rate that would be required to make the present value of the costs equal to the present value of the benefits. By most standards these returns are exceptionally high. The total research investment was A$2.3 million ($1996).

Table 6. Net benefit estimates of Australian tree species selection trials in southern China.

Case—key assumptions		Net present value and IRR (A$1996 millions)	Internal rate of return (IRR) (%)
Base case	uses values noted in Tables 3–5; 5% discount rate	122.3	35
Sensitivity 1—Higher discount rate.	uses values noted in Tables 3–5; 10% discount rate	43	35
Sensitivity 2—Longer time horizon.	uses values noted in Tables 3–5; 5% discount rate Time horizon to 2030 instead of 2015	192.4	35
Sensitivity 3—Lower realised yields.	uses values noted in Tables 3–5; but realised yields are lower than those in Table 3 (see text for values) New unit cost reductions Acacia —17.6 yuan/m^3 Eucalypt —4.7 yuan/m^3	54	28
Sensitivity 4—Someone else would have done the research at a later date.	uses values noted in Tables 3–5; but planting of new tree species starts 10 years later than in Table 4	75.4	35
Sensitivity 5—Inelastic demand curve.	uses values noted in Tables 3–5; 5% discount rate; but demand is perfectly inelastic (the demand curve in figure 1 is vertical)	86.9	32
Sensitivity 6—A higher exchange rate for the Yuan — (see text for the value)		266.9	35

Comparison of base case results with earlier results

The results are slightly lower than the previous studies. The larger, faster adoption rates and the shorter rotation periods for the new plantations of *Eucalyptus* and *Acacia* partly make up for the loss of the contribution of *Casuarina* that was assumed in the previous studies but failed to eventuate. The previous studies also assumed higher yields for both old and new plantations than the realised yields. In addition, an exchange rate of 6.4786 Yuan per Australian dollar was used in this study as compared to 3 in the previous studies.

5.1 Sensitivity Analyses

This section discusses six sensitivity analyses designed to test the robustness of the base case estimates to changes in key assumptions. Table 6 also includes estimates of research benefits for a range of alternative assumptions for selected key parameters.

Sensitivity analysis 1: the discount rate

Using a 10% discount rate instead of a 5% rate on the overall benefit estimates reduces the NPV to A$43.0 from A$122.3 million ($1996). The higher discount rate was used for comparative purposes because it was used in the earlier study. The IRR of course remains the same.

Sensitivity analysis 2: the time horizon

The previous studies calculated benefits to the year 2030. Using the same 2030 time horizon and a 5% discount rate gives a value of A$192.4 million (IRR of 35%).

Sensitivity analysis 3: lower realised plantation yields

Another sensitivity analysis was performed in which the realised after-research plantation yields were decreased from those in Table 3 to 122.4 m3/ha, and 123.9 m3/ha. This sensitivity could, for example, represent a case where insects or diseases target these new introductions and decrease yields. In this case the NPV decreases from A$122.3 to A$54.0 million ($1996; 5% discount rate). The IRR decreases to 28%.

Sensitivity analysis 4: someone else would have undertaken the research at a later date

Once an agency decides to undertake a particular research project the decision set changes for all other potential funding agencies. It would be irrational for an agency to fund a project that has already been undertaken. But if ACIAR did not undertake the research would it have occurred anyway?

Discussions with researchers in China suggest that, without the ACIAR projects, it would have taken an absolute minimum of 10 years before research would have occurred that would have identified more productive tree species. To account for this line of thinking, NPVs were calculated with an additional 10-year lag, on both research costs and benefits. Under this scenario, the NPV of the project in $1996 becomes A$75.4 million (5% discount rate) (see Table 6). This compares to A$122.3 million

($1996) in the base case. It would seem reasonable to argue that the difference between these values (122.3 – 75.4 = A$46.9 million at 5%) are the absolute minimum amounts that should be attributed to ACIAR for this research. These values are still remarkably high by most standards.

Sensitivity Analysis 5: a perfectly inelastic demand curve

With an unrealistic assumption of perfectly inelastic demand, the base case results decrease from A$122.3 to A$86.9 million, still a large NPV. The IRR in this case only slightly declines from 35% to 32%. Recall the base case assumed perfectly elastic demand. The determination of actual price elasticities could also be the subject of further research but this seems somewhat unnecessary given the outcome of the study. However this sensitivity gives an indication of the maximum size of the triangle '*bcf*'. In the base case we assumed the largest possible size for the triangle '*bcf*'. In this sensitivity, the triangle '*bcf*' does not exist, its area is zero. The difference between the base case result and the estimate in this sensitivy is A$35.4 million. This is the area of the triangle in the base case, which is about 29% of the base case estimate of the NPV.

Sensitivity Analysis 6: a higher exchange rate between the Yuan and the dollar

In the base case, an exchange rate of 6.4786 Yuan per Australian dollar was used, this being the 1996 rate that ACIAR is using in other project evaluations. However, an exchange rate of 3 was used in the previous studies. Using an exchange rate of 3 increases the NPV of the research investment to A$266.9 million ($1996 with a 5% discount rate).

Non-market benefits

Other benefits from plantations of the introductions include an estimated 80% gain in essential oils harvested from some tropical, sub-tropical and temperate eucalypt plantations. Note that prices for this product have dropped by almost half in the last 10 years in southern China (Bai Jiayu, pers. comm.). The new introductions of acacias fix nitrogen and produce tannin in larger quantities than the previously used species. Up to 230 kg/ha/year of nitrogen are being added to the soil in these plantations which is expected to decrease fertilizer usage. Up to 750 kg/ha/year of tannins are expected from some plantations. Given the high returns from the wood component of the research, it was deemed unnecessary to include an estimate of economic value of these benefits. For many other environmental problems in China, the planting of any suitable tree species would be beneficial, hence it was considered inappropriate to attribute non-wood benefits to species selection research that were for the most part aimed at increasing wood production. These benefits, if quantified, would add to the already large benefits from the research.

6. Concluding Remarks

This assessment has considered only gains likely to be achieved in the provinces of southern China. It is possible that there will be spillover gains (e.g. adoption of faster growing Australian tree species) to other countries in South-East Asia from this research. Some of this could be attributed to the ACIAR project however this would inevitably involve conjecture as other research and aid agencies also fund efforts to increase productivity in fast-growing plantations. There is also increased interest in fast growing eucalypt plantations in Australia, but again it is difficult to make a link between t his research and increased production in Australia. Different species are used and to date relatively little of the Australian national plantation estate is eucalypt or other non-coniferous species. This could be the subject of further investigation. In principle, there could also be short-term price effects (decreases) in China and internationally as these plantations areas are harvested and supplies of wood products increase. However, domestic prices for final products like plywood and fibreboard have at least doubled in the last 10 years (Bai Jaiyu, pers. comm.). These plantations are being used to satisfy domestic demand for wood products and they still represent a relatively small proportion of total Chinese production (Bai Jiayu, pers. comm.).

The main reason for the large returns is the level of adoption of the more productive eucalypts and acacias. These new introductions also have greater yields over shorter rotation periods than previously used species and they have an immediate commercial use—helping to fill domestic demand for pulpwood. The research trials have had little impact on the use of *Casuarina* species in China. In this case the new introductions do not appear to have had a significant commercial application or use. Also the new introductions of casuarina are in fact more expensive to use. Seed is in short supply and more expensive to obtain, hence there has been little incentive to adopt the new introductions, despite their faster growth rates. This information may be of use in future deliberations of possible research projects.

Given the inherent uncertainties in long-term research projects, economic analysis of research impacts should, as a general rule, consider the sensitivity of the results to changes in important assumptions (e.g. costs, lag periods, adoption rates). In this case enough time has passed since the research that plantations of the new introductions are already being harvested and economic gains beginning to flow from the research. This lends much more credence to the results. The costs of the research in net present value terms through 1999 is A$3.8 million ($1996). Despite this, it should be realized that the numbers are an approximation of the net benefits of the research. For example, average costs and yields were used to determine the unit cost reductions. There is undoubtedly some variation in these costs and yields across southern China. Nevertheless the sensitivity analysis reported here should suggest even to the harshest critics that the project has had, and is continuing to provide, large returns. Non-wood benefits are also likely to lead to substantial economic returns that have not been included in this analysis. This includes increased production of essential oils, tannins and plant-available nitrogen.

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