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Investment in Water Saving Technology on Horticultural Farms

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A long run programming model for analysing investment behaviour on perennial crop farms is formulated and applied to citrus and wine grape producing farms in the Murrumbidgee Irrigation Area. Prices and technological parameters are defined exogenously, and the optimal replanting pattern of the crops and the optimal mix of irrigation techniques are determined endogenously. The modelling framework, which allows for control over many factors influencing perennial crop investment decisions, has applications in the analysis of the long term consequences of many policy options affecting farm yields or prices.

The model is used to examine likely investment in water-saving irrigation technology at different crop prices and input costs. The results indicate that such investment is not a profitable option at current water charges. However, the adoption decision will be highly sensitive to the potential cost savings. Water-saving technology could be viable if water charges were increased, but only if the preferred option of farm expansion were not available.

Policy Background

The Murray-Darling Basin covers a major part of eastern Australia and produces 60 per cent of the gross value of rural production (Alaouze and Fitzpatrick 1989). It includes all the major temperate irrigation areas in Australia. These areas produce much of Australia's wine and multipurpose grapes, citrus and canning fruit as well as dairy products, prime lambs and irrigated crops, particularly rice. A major irrigation area within the Murray-Darling Basin is the Murrumbidgee Irrigation Area (MIA) centred around Griffith.

Irrigation water charges in the MIA do not meet even the running costs of supplying the water, and certainly not the capital costs (Verdich and Amos 1984; Department of Water Resources 1989). Thus, the cost of irrigation water has been subsidised, and water use has been encouraged beyond the level which would be economically optimal in the absence of a subsidy. Open-furrow irrigation systems are still the principal means of water application in horticultural farms in the MIA. Although this practice has contributed to problems associated with rising ground water in the Basin[1], farmers have generally been indifferent toward investment in water-saving technology (Sinclair and McLachlan 1989).

Horticultural farms have in the past been strictly regulated as to size and, in some areas, ownership. Land use has been restricted by industry regulations governing area expansion, as well as by the agronomic potential of the soils. The institutional restrictions have reduced the scope for autonomous adjustment and hence may have reduced the long run efficiency of the industry. The present structure of the industry could therefore be viewed as a result of heavy subsidisation of a vital input and legal impediments to autonomous adjustment.

These impediments were strongly criticised by the Industries Assistance Commission (IAC 1987) and steps are being taken by state governments to reduce them. For example, in the irrigation areas of New South Wales the legal maximum for a Home Maintenance Area[2] for horticultural farms has recently been increased from 45.33 ha to 100 ha, while that for mixed farms has been raised to 600 ha from the previous ceiling of 425.6 ha. This is an interim measure pending complete deregulation of farm size, expected to be implemented in 1991 (personal communication, D. Mittelhauser, Department of Water Resources, Sydney, August 1990).

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[1]Many horticultural farms in the MIA have tiled drains installed. In this way, horticultural farmers themselves avoid rising water tables while still contributing to the rise of water tables in the region.

[2] This is the farm size defined in the New South Wales *Crown Land Consolidation Act 1913*, as 'an area which, when used for the purpose for which it is reasonably fitted, would be sufficient for the maintenance in average season and circumstances of an average family' (Woodlands and Penman 1981).

Introduction

Throughout Australian irrigation regions farmers are facing impending increases in water charges as water supply authorities move toward complete cost recovery. This is happening at a time when many farmers are encountering narrowing profit margins caused by escalating production costs and declining real commodity prices. Farmers would be expected to react by adjusting their operations to gain productivity improvements and cost savings. These adjustments may take various forms, ranging from rationalising input use to crop diversification. In horticulture, substantial change in the enterprise mix can be slow and complex because of the perennial nature of the horticultural crops. Shifting farm technology toward better water management strategies is an option available to irrigators which could improve farm productivity without substantial changes to the enterprise mix.

The purpose in this paper is to develop a framework for examining the investment behaviour on horticultural farms. More specifically the objective is to analyse the influences of input and output prices and technology on the investment patterns that would be expected in horticultural farms in the Murrumbidgee Irrigation Area. This is part of a broad study being undertaken by ABARE of the effects of water policy on the irrigated farms in the Murray-Darling Basin. In particular, the aims are:

- to analyse the constraints on the adoption of water-saving technology;
- to examine the likely effects of citrus, wine grape and water prices on investment behaviour; and
- to examine the likely effects of deregulation and price changes on horticultural farmers' incomes.

The water saving technology investigated in this paper involves a shift from the high water consuming conventional furrow irrigation system to a drip irrigation system, where water is delivered to the plant at its root system at a given rate over a given duration based on soil, climatic and crop characteristics.

Estimates are prepared of the effects of prices on land use and crop plantings. Included are the magnitudes of the likely effects of output prices and water prices on adoption paths, and the sensitivity of the most profitable resource combinations to the policy assumptions chosen.

This analysis is conducted in a 'representative farm' setting based on information from ABARE's Australian Horticultural Industry Survey sample for the Murrumbidgee Irrigation Area (MIA); the results may be applicable to other areas where similar irrigation practices are followed.

Diversification of crop enterprises is limited by agronomic factors, including the influence of soil type. Soil type generally varies across the plain depending on the relationship of the soil to the prior stream systems. The general sequence of soil types ranges from the sandy soils of the prior streams, which make up about 10 per cent of the MIA, through red-brown earth and transitional red-brown earth, to grey and brown earths of heavy texture. The last two soil categories are almost equally distributed throughout the MIA (Woodlands and Penman 1981). Generally the type of soil in each location determines the possible land use. Rice cannot be produced on light soils, nor can tree crops be grown on impermeable soils. Thus, for example, any adjustment out of rice will be into other broadacre crops or pasture, either irrigated or dryland, while expansion of horticulture is likely to be into new areas rather than on to existing broadacre irrigation land. However, there is little unused land suitable for raising horticultural crops in the region.

Removal of the impediments to adjustment, and phasing out of the subsidy on the price of irrigation water, can be expected to have large effects on the structure, technology and income earning capacity of horticultural farms. The directions of farm growth and diversification will be largely governed by the investment behaviour of the farms, which inherently involves decisions over a long period. The likely effects of some of these policy changes are analysed using a multiperiod farm model.

Investment Decisions and Supply Response

Investment decisions involve choices between consumption of current funds and access to future income flows. In perennial crop situations, these choices are complicated by the reinvestment problem — the neeed to allocate investment funds in future time periods to maintain the productivity of the asset. Optimal investment decisions, under conditions of certainty as to the returns from any investment, can be defined as those that maximise the firm's net present value (Hirshleifer 1958). In this simplified view, investment decisions are based solely on the earning power of the alternatives and the prevailing interest rate in an assumed perfect financial market, and do not depend on the decision maker's utility function.

In the real world, however, a host of other factors influence investment. On the farm, the choice of technology, for example, may be influenced by the farm size, the nature of the farm enterprise, the existing resource complement (including both machinery and productive stock), and of course the cost of investment and the availability of capital funds. Though annual cash flow is determined by commodity prices, yields, farm operating expenses and tax obligations, returns to equity are influenced by the farm's leverage position and the cost of funds. On the management side, the farmer's attitude toward risk, access to investment information and perception of public policy directions are equally important.

Although relatively little is known about the effects on the investment behaviour of horticultural farmers with different characteristics (such as farm size and ownership) and price parameters, significant public policy initiatives affecting those variables are apparent over recent years, particularly in relation to irrigation water management (Watson 1990).

Perennial crop producers tend to respond slowly to price signals because of the relative fixity of their investments, and are therefore relatively unresponsive to short term price fluctuations. (Faced with short term low prices, they may decide not to harvest, or to harvest only partially, but this possibility can be neglected in the present context.) Under good husbandry, reliable yield levels can be maintained for horticultural crops over a long period. Significant changes to yield levels may be brought about by changes to planting stock. Given their long term price expectations and yields, the investment behaviour of farmers can be affected by public policy if it alters the relative profitability of investment alternatives. An example is the special taxation provisions for capital costs of conserving or conveying water. Section 75B of the *Income Tax Assessment Act 1936* (as revised) provides for primary producers to claim deductions for capital expenditures on water storage and farm reticulation systems over three years, one-third of the expenditure being deductible in the income year in which it is incurred and one-third in each of the subsequent two years (CCH Australia 1990).

Technological innovations can improve the physical productivity of capital assets, thus influencing potential production capacity and the optimum stock of capital. Drip irrigation technology and improved planting stocks are the two such innovations considered in the present analysis.

Method

The economic problem studied here involves decisions about farm redevelopment and subsequent operation under conditions of certainty. The analysis employs a multiperiod investment programming model (Mipmod) specified with a 20-year time horizon. The model is designed to represent an average horticultural farm in the MIA (based on data from ABARE's Australian Horticultural Industry Survey — see ABARE 1990, pp.25–7) and to be able to analyse the investment decisions involved in switching between citrus and wine grapes and between furrow and drip irrigation. Farms can borrow or invest off-farm, and can invest in farm expansion by purchasing and developing new farm land. (The farm expansion option was omitted in certain simulations to demonstrate the effects of the competing nature of the investments of central interest in this study.) The basic structure of Mipmod is described below, followed by a description of the representative farms and the mechanism used to simulate structural adjustment.

Model description

The present model deals with a simplified situation in which the costs and returns of alternative investments are known with certainty. The planning problem is then to identify the long run equilibrium solution to the optimisation problem which comprises the choice of optimal scale and mix of possible investment streams.[3] The nature of the investment decision requires multiperiod analysis, but difficulties arise in the handling of large matrices when the planning horizon is extended. For this reason, a formulation was chosen in which a 20-year planning period was divided into a 10-year farm development phase and a 10-year stabilisation period.

The capital developments are undertaken during the first ten-year period, and the following ten years allow the model to bring to full maturity all the resulting activities. This period allows the maximum sustainable yields of all crop enterprises to be reached. This procedure is supported by the suggestion of Tisdell and De Silva (1986) that consideration of maximum sustainable yields provides a basis for identifying correct replacement patterns for perennial crops.

The Mipmod is used to simulate the behaviour of a number of representative farms by using the same basic matrix with different combinations of resources such as farm area and labour. Yields and other technical coefficients are kept constant.

The objective function and the model specification

Farmers' investment decisions are secondary to meeting their immediate family living commitments. The model therefore provides for drawings of $14 000 a year as living expenses (C, in the representation below). They may also wish to attain various non-immediate family goals — termed discretionary consumption in this analysis. In the allocation of post-tax surpluses, the balance between discretionary consumption and investment is a problem of capital rationing, which will depend on a variety of factors in which the family wealth, stage of development of the farm enterprise in relation to desired goals and current income are major determinants. A ratio of 2:3 between discretionary consumption and investment surpluses was assumed in this analysis — that is, a marginal propensity to consume of 0.4.

The objective function (Z) maximises the net cash surplus (S) at the planning horizon, subject to annual operator drawings and discretionary consumption of annual post-tax surpluses.

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[3] The concept of a long run equilibrium solution to the optimisation problem is well defined only if it can be assumed that the expected values of the exogenous variables do not change (Nerlove 1979).

Maximise

$$S = \sum_{k=1}^{t} s^k(1+r)^{t-k}$$

where s^k is the post-tax operational surplus in year k,

$$s^k = \sum_{j=1}^{n} \left(c_j^k - a_{ij}^k x_j^k . p_i\right)(1-\alpha)(1-\beta) - (a_{1j}^k x_j^k)$$

t denotes the length of the planning horizon,
r is the rate of interest at which annual surpluses are invested off-farm,
c_j^k denotes a vector of returns from activities j,
x_j is the magnitude of activity j,
a_{ij} is the amount of resource i used per unit of activity j,
$a_{ij}^k\ x_j^k$ is the matrix of production and resource coefficients,
p_i is the unit price of resource i,
α is the marginal rate of taxation,
β is the marginal rate of discretionary consumption,
n is the number of activities j, and
m is the number of resources i employed (of which $i = 1$ denotes capital);

subject to :

annual operator drawings $\quad a_{1j}^k\ x_j^k = C;$

and other resource restraints:

$$\sum_{j=1}^{n} a_{ij}^k x_j^k \le a_i^k \quad (i = 1,\dots,m; k = 1,\dots,t);$$

$$\alpha \ge 0; \text{ and } \beta \ge 0.$$

The Mipmod is dynamic in the Hicksian sense — that is, all inputs and outputs are time related — although a dynamic optimisation package was not used to solve the model. The solution of the optimisation problem determines the time path of farmers' decision variables, taking into account all relevant prices and available current and future capital flows. This ensures the capture of the dependence of current decisions on past decisions, which is a key feature of dynamic decision making. All activities are nested via the 'CASH' row for each year (to which all transactions involving cash in that year are connected, rows being named from CASH01 to CASH20) and through resource transfer activities between time periods.

Timing of evaluation and terminal wealth

The model objective is to maximise terminal net cash surplus, which is in this case at the end of the 20 years. By maximising terminal cash surplus, rather than net present value, problems involved in evaluating terminal assets as well as that of choosing an appropriate discount rate, are minimised (Rae 1970). This specification allows each activity to generate its own rate of return, rather than a compounding factor being specified exogenously. The opportunity costs for limited funds during the development phase are determined as shadow prices within the planning process.

The model includes a mechanism for screening out activities which generate rates of return (after tax) less than a market opportunity rate, specified exogenously as the returns to off-farm investment of annual investible cash surpluses. (A real rate of 6 per cent was used, consistent with the real borrowing rate of 8 per cent used.) This also simulates a situation of automatic compounding, as any activity which enters the model in an earlier period is given preference over activities that enter the model in later periods (Candler 1960). The specification improves on Candler's original suggestion, because off-farm investment is a parallel activity to the between-year capital transfer activity. Thus, the two activities compete for the use of post-tax surpluses from each year in the subsequent year, filtering out activities which yield a return less than that of off-farm investment (an exogenously specified interest rate). This condition is equivalent to setting the 'marginal productive rate of return' at the market interest rate to obtain optimal investment decisions, as proposed by Fisher (Hirshleifer 1958). The specification thus ensures tracing the enterprise combinations yielding the highest present value between time periods. The rate of return of the marginal enterprise is equivalent to the internal rate of return in project analysis.

The Mipmod specification has no activities to directly reflect terminal wealth. Such activities are replaced by the last ten years of the planning horizon in which stabilisation takes place without any development activities. The off-farm investment activity is the only investment avenue during this phase. This allows the model to generate its own valuations of the terminal stock based on the revenue generating potential of the alternate investment activities originated in the development phase.

The representative farm and the resource base

The model simulates activities of hypothetical farms representing average structures and management practices of the horticultural farms in the Murrumbidgee Irrigation Area. In the MIA about 90 per cent of horticultural farms are exclusively horticultural without any broadacre activities. Therefore the treatment of horticultural farms as separate entities in this analysis is not unrealistic.

The base model represents a mixed horticultural farm growing citrus and wine grapes. A total cultivable area of 15.5 ha is used by these two crops. Out of 6.6 ha planted to citrus, 2.2 ha of the trees are young while 4.4 ha consists of aged trees earmarked for replanting at some time during the 10-year development phase. Similarly, the grape area (8.9 ha) is composed of 4.1 ha of young stands and 4.8 ha of aged vines which are to be replanted. The young plantings of both crops have been established over the previous ten years, and hence fall into ten yearly age categories.

All crops are presently irrigated by the open furrow method. The farm is owner operated, with contract labour hired for specialised tasks and occasional casual supplements. It is assumed that the operator is able to find off-farm employment to supplement farm income during slack periods. After allowing for time spent by the farmer on routine farm and non-farm activities, 48 weeks of operator labour is available for farm operations and off-farm employment.

The main data source used was the ABARE Australian Horticultural Industry Survey (AHIS), which provides detailed economic data on a sample of farms in the major irrigation areas including the MIA. The other major sources of data are the publications of the New South Wales Department of Agriculture and Fisheries and the South Australian Department of Agriculture (Sinclair and McLachlan 1989; Hansen, Cook and Oborne 1983). These sources have been supplemented by telephone discussions with experts in the field.

The crop prices used are net of harvesting and cartage costs. Seventy per cent of citrus output is earmarked for processing while the balance is sold for the fresh market. All the prices are in 1988-89 dollars and real interest rates are used.

The farm has an initial investible capital endowment of $12 000. A living expense of $14 000 is deducted for every year for the operator out of the farm cash flow. Overhead expenditures are also deducted, having the values of $10 000 for the first seven years, $12 000 for years 8–13, $15 000 for years 14–16 and $17 000 for years 17–20.

Where crop yields are declining because of vine or tree age, replanting with material of better quality and at higher densities will allow greater productivity. Incorporation of these options allows the model to evaluate various circumstances under which farmers could afford a shift towards capital-intensive drip systems.

Since replanting disrupts any drip irrigation system already in place, and since new drip irrigation systems require heavy capital investment and affect intertemporal cash flows and labour use, such investment is allowed only for blocks not earmarked for replanting. Blocks to be replanted become available for conversion to the drip system upon completion of replanting activity. The model allows the testing of replanting and modernisation of irrigation systems together as well as separately, in order to reveal the maximum benefits obtainable from complementary relationships in resource use among activities.

Intertemporal cash flows and taxation

The flow of activities in the model follows the fund flows illustrated in Figure 1. It takes into account all the capital and current account flows, and includes taxation with a progressive tax structure based on linear segments. This method was preferred over the approach suggested by Vandeputte and Baker (1970) both for the ease of accounting different income flows and because it avoids 'nonsense' combinations and sequences of activities appearing in response to oversimplified incentives.

Provision was also made for tax deductions allowable for capital investments on irrigation improvements (CCH Australia 1990). Reid, Wesley and Martin (1980) report a specification for handling investment tax credit in a multiperiod setting. That specification was not used because, unlike investment tax credit, the deduction of capital expenditure is not a dollar-for-dollar reduction in taxes but a reduction in taxable income, the benefit of which depends on the farm's marginal tax rate. The specification used here follows a normative approach: an allowable deduction is treated as a cash cost in the year of investment, and tax credits on after-tax profits are allowed at a selected marginal rate for the deductions in the relevant subsequent periods. (A rate of 29 cents in the dollar was used, based on the average rate of tax paid in the model over the first ten years, when the investments are allowed.) This avoids numerical difficulties in the computation and sufficiently captures the benefit of deductions. The farm is assumed to be owned and operated by a farm family, and a single taxpayer for the household is assumed in the formulation. (This assumption is relaxed at a later stage, when the response of a two-party partnership is briefly investigated.)

All income-generating activities in each year contribute to a single row named CASHk, from which all the farm operating expenditure is deducted. Residual CASHk therefore represents 'gross profit before tax' (GPBTk) from all farm and non-farm operations. After allowing for capital depreciation, 'taxable income' for each period is obtained. This GPBTn is channelled through a series of progressive tax constraints to calculate the tax liability and post tax surpluses (NPATk).

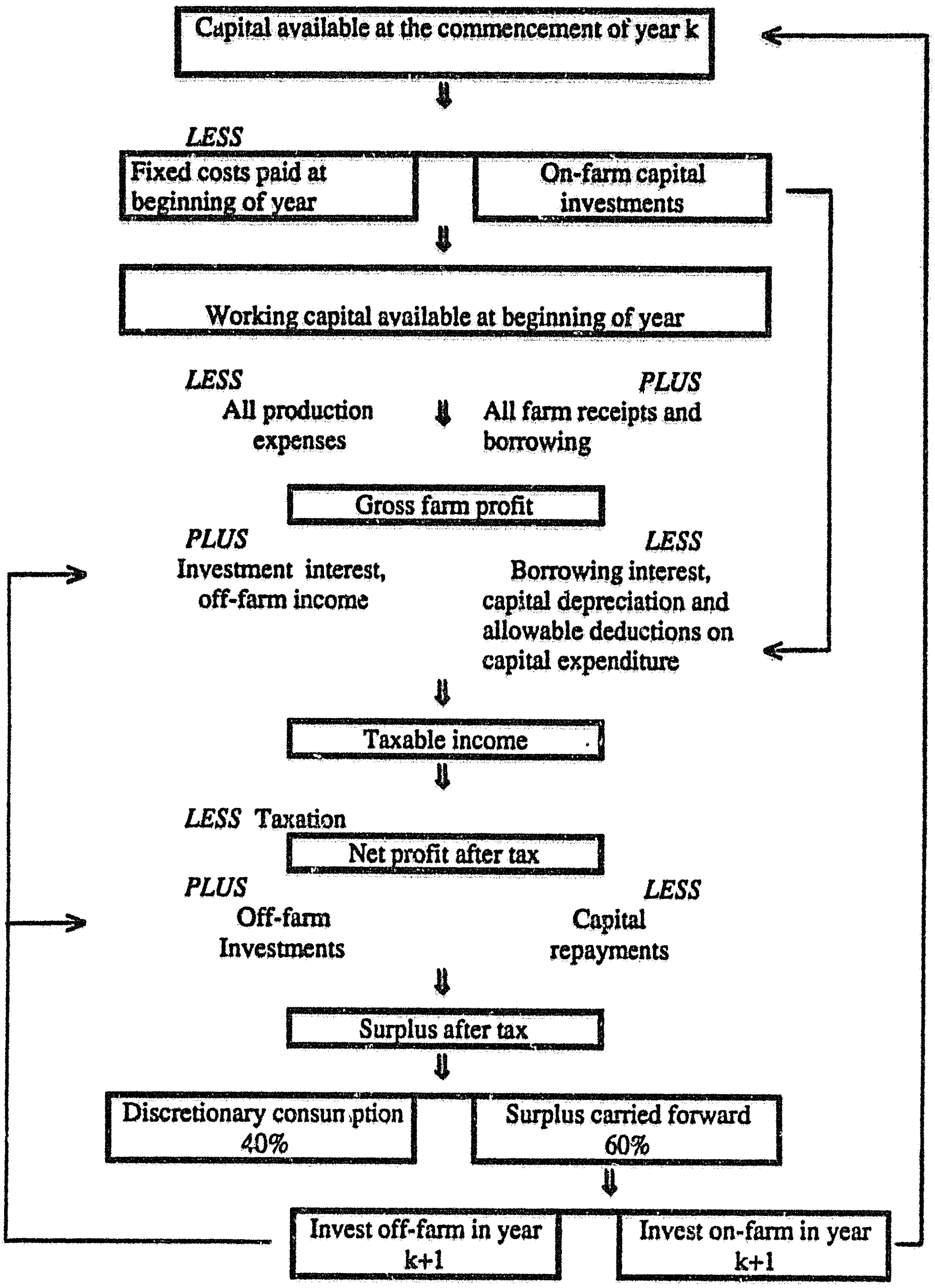

FIGURE 1 — A schematic representation of intertemporal cash flows in Mipmod

Table 1 specifies the accounting framework, including the progressive tax structure, as a linear programming tableau.

TABLE 1

Layout of the Accounting Tableau

	Activity (j)														
	Production				Selling	Farm investment	Off-farm investment	Profit transfer	Taxation						Fund transfer
Row	P_1	P_2	P_3	P_n	$S_1...S_n$	I^*(a)$/I_1..I_n$	I_o	T_p	T_0	T_1	T_2	T_3	T_4	T_5	T_n
OBJECT(Z)															1
$CASH_k$	x_1	x_2	x_3	x_n	$-c_1...-c_n$	x^*	$-i_o$	1							
$CASH_{k+1}$															
$CPTL_k$(b)						X^* $X_1..X_n$	X_o								
$CPTL_{k+1}$							$-X_o$								
Yields row	$-y_1$	$-y_2$	$-y_3$	$-y_n$	1										
Gross profit								-1	1	1	1	1	1	1	
Taxation constraints															
TAXLIMA									1						
TAXLIMB										1					
TAXLIMC											1				
TAXLIMD												1			
TAXLIME													1		
TAXLIMF														1	
Taxation									0	-.21	-.29	-.39	-.47	-.48	
$NPAT_k$									-1	-.79	-.71	-.61	-.53	-.52	1
$NPAT_{k+1}$						$-dn$									-1
$NPAT_{k+2}$						$-dn$									
$NPAT_{20}$															1

(a) I* is the investment activity on drip irrigation, for which deductions dn are allowed as credits on subsequent years net profit after tax (NPAT). (b) CPTL denotes capital expenditure.

Experiments

An initial optimal solution to the model was obtained for the base formulation as described in the previous section. Then an appraisal of the irrigation development options and crop re-planting strategies was undertaken in a series of experiments in which the model parameters were systematically altered.

In three of these experiments prices and costs were changed one at a time with the rest held at base levels. The prices and costs changed were those of water, grapes and citrus, and electricity (for driving water pumps to pressurise the drippers). Farm size was varied in a fourth experiment, with and without the option of farm expansion. The base values and those applied in the experiments are presented in Table 2. By examining net farm incomes and investment patterns in these experiments, differences in adoptive behaviour in various situations can be examined and the desirability of different government operating policies can be evaluated.

TABLE 2

Base Prices and Price Changes Used in Model Simulations

Variable	Unit	Base value	Test values			
Crop prices						
Oranges	$/t	180.00	144.00	162.00	198.00	216.00
Wine grapes	$/t	210.00	168.00	189.00	231.00	252.00
Pumping cost	$/ML	7.83		9.78	11.74	20.63
Water charge	S/ML	11.75	15.00	17.00	21.00	24.00
Farm size	ha	15.50	33.00	60.00		100.00

Results and Discussion

The results of the study indicate that investment behaviour of horticultural farmers will be sensitive to their pre-development farm size, to their opportunities for farm expansion and to changes in irrigation water charges and the cost of electricity for pumping. Change in crop prices will affect only the choice of crops for replanting. Under the specified technological and policy constraints, conversion to drip irrigation will generally be an optimal investment only when farmers do not have the option of expanding their farm area and when water charges are above current levels. The model responses are sensitive to the availability of off-peak electricity tariff rates for irrigation pumping.

Summary results from solutions under some of the experimental specifications are given in Table 3, followed by a brief discussion on selected aspects of individual experiments.

Farm expansion as an investment option

In the model, investment behaviour varies with farm size, as the latter directly influences the pre-development farm income and hence the choice between farm expansion and technological innovation. Investment on farm expansion receives priority in allocation of capital among small farms while large farms favour improvements in farm productivity. This is because of the relative scarcity of capital in small farms and of labour in the larger. In the absence of a land buying option, holders of larger farms will put a higher proportion of the farm under drip irrigation than will those of small farms — the influencing factors being available cash flow and the increasing marginal benefits from the tax deductions for drip investment as income reaches higher tax brackets. As was observed by French, King and Minami (1985), expected future production from existing plantings has a significant effect on planting decisions.

TABLE 3

Summary of Experimental Results

Experiment	Objective value (net surplus at year 20)	Investment pattern
Baseline model with farm expansion option	$134 698	No investment on drip irrigation; farm area expanded with borrowed funds to twice the original size.
Baseline model with no farm expansion option	$56 332	No drip investment; priority given to replanting; very low borrowings.
Higher water charges, with no farm expansion option	$54 966 at $24/ML	Gradual shift in the area under drip irrigation with increasing water charges; full conversion to drip at $24/ML.
Depressed citrus prices — (a) $144/t, (b) $162/t — with farm expansion option and grape price at base level	(a) $112 865 (b) $121 742	Reduction in area expansion with decreasing crop prices; in new plantings, substitution toward high priced crops; gradual increase in unpaid debt.

Adoption of new technology

Zilberman (1984) argued that the effective marginal adoption cost of a technological change declines with farm size, and that in consequence there is a critical farm size where profits are equal under both technologies. At a given set of prices and costs, farms smaller than the critical size do not adopt the new technology, while those above do so at a rate which increases with size. The rate of adoption will be influenced by the cost of water, the cost of pumping, the price of crops and the extent of water saving achieved by the new technology. In the present study the water saving asociated with a move from furrow to drip irrigation was assumed to be 40 per cent. The model responses for different values of the first three variables are discussed in turn below, with the other variables left at their base levels in each case (unless otherwise stated), and with no farm expansion option.

Effects of water charges

Figure 2 shows the effects of the irrigation water charge on investment in irrigation technology, farm income and water use. Changes in water charges have a more pronounced influence on adoption of drip irrigation as a water saving technology and on water use than on farm income.

From the results shown, the elasticity of demand for water (estimated through a double log function) was -0.55.

Net surplus per hectare declines as water charges increase, but only slowly. (Per-hectare measures are used in this case because results from the range of farm sizes are combined.) However, at water charges of $15/ML or above, the farm household cannot afford any discretionary consumption during the development phase. The forgone consumption opportunities are to a large extent compensated by increased availability of tax-free cash during the stabilisation phase. As a result the average discretionary consumption over the 20-year period under higher water charges is only slightly lower than that in the base case.

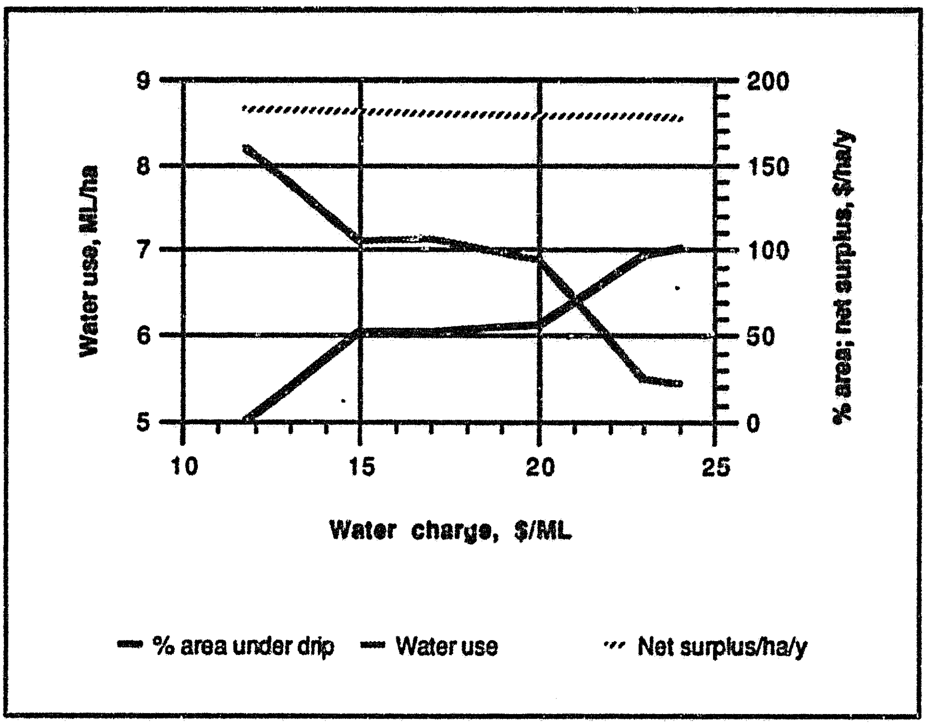

FIGURE 2 — *Effect of changing water charges on investment and farm income*

Effects of costs of electricity for pumping

The effects of variations in variable irrigation costs for drip irrigated areas — specifically, of four different electricity prices — are shown in Table 4 for the case where water costs $24/ML. As the pumping cost rises from $7.83/ML (the base) to $20.63/ML, the optimal area under drip irrigation drops from 100 per cent to zero. The base pumping charge reflects the electricity costs for off-peak operations prevailing in 1990; $20.63/ML is based on regular electricitycharges during normal operations. Results clearly indicate that investment in drip irrigation is sensitive to the price differential between water and electricity charges. At current water charges, pumping cost is not a limiting factor on investment in drip irrigation.

TABLE 4

Model Response to Change in Pumping Costs (a)

Pumping cost	Area under drip	Water saving
$/ML	%	ML/y
7.83	100	45
9.78	50	14
11.74	48	13
20.63	none	none

(a) Water charge $24/ML.

Effects of crop prices

The results for investment behaviour at different crop prices over a price range of ±20 per cent, with the other variables held constant, are presented in Table 5. Changing the relative prices of the crops affected only the substitution pattern of crops for replanting, so both crop prices are varied by the same percentage. The analysis was undertaken at those water prices favouring

TABLE 5

Model Response to Changes in Crop Prices (a)

Variation in crop price	Area under drip	Average discretionary consumption (b)	Average net farm surplus (c)	Remarks
%	%	$/y	$/y	
-20	0	9 748	1 742	Replantings financed through borrowings
-10	18	14 760	2 267	Limited investments over the last three years
+10	100	22 740	3 237	Delayed investment; low borrowings
+20	100	27 030	3 660	Investment delayed until the last three years

(a) Water charges $21/ML. (b) Average over the 20-y period. (c) Final surplus divided by 20.

drip irrigation under base crop price assumptions, and with water charges held at $21/ML, at which price 50 per cent conversion to drip irrigation takes place at the base crop prices. When farm expansion is allowed, there is no adoption of water saving irrigation technology at any crop prices. Results are therefore reported only for the case where farm expansion is not an option.

Effects of taxation arrangements

In the model, taxation provisions concerning irrigation improvements have a significant influence on the investment decisions, particularly on larger farms where heavy tax commitments are involved. Two alternative tax regimes were modelled. Under one of these, involving a depreciation schedule, conversion to drip irrigation is not as sensitive to water charges as under the normal specification. The present cost deductibility taxation provision acts as a capital supplement encouraging investment. The welfare implications of such programs deserve further analysis (Stoneman and David 1986).

The second alternative taxation regime was a two-party partnership arrangement which reduces tax liabilities. Here, the entire area is converted to drip irrigation at base prices for both crops and water, as more after-tax funds are in this case available for investment.

Concluding Comments

The analytical framework employed in this study, allowing for control over many factors affecting investment decisions, appears to capture the important features of investment behaviour of perennial crop farmers. Model simulations of this kind could be used to inform farmers about the likely long term consequences of investment decisions; they also provide a tool for analysing farmers' decision processes, and for testing likely investment responses to policy changes. The model can be used to similarly examine any other farm management options affecting farm yields or prices, by adding appropriate coefficients to the model skeleton. The length of the planning horizon can be easily altered to suit the problem under investigation. However, the model has some limitations.

Like other models, it relies heavily on farm management data, the accuracy of which determines the validity of the results. Among its weaknesses, the most limiting is the difficulty of incorporating a wider choice of investments, due to the computational problems associated with handling a large matrix. However, more activities could be added to the model at the expenses of the time period covered. Also, handling stochasticity and nonlinear technological and utility relationships are currently beyond the scope of the model.[4]

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[4] These aspects of long term decision making may be more easily analysed in a recursive framework. See Hall, Mallawaarachchi and Batterham (1990).

Bearing in mind these limitations, the exploratory objectives relating to the modelling techniques have been achieved. The results of the study in relation to investment behaviour are also of interest in themselves. They provide insights into factors limiting the growth of investment in modern irrigation technology, and confirm the importance — stressed by Caswell and Zilberman (1985) — of economic considerations for decisions on the adoption of such technologies. They also demonstrate the need to consider the structural characteristics of individual farms and the actual farm accounting framework in micro-level analyses of farmers' investment behaviour. Farmers' leverage positions, farm ownership arrangements and type of tenure were ignored in this analysis, but these too may have a significant bearing on the investment pattern.

Though the limited availability of data, and the use of a representative farm with a narrow range of variants, do not permit generalisation of the findings over a large domain of horticultural farmers, the model framework provides a useful means for testing policy options which may affect investment behaviour. The analysis demonstrates that water price policies and tax incentives are important determinants of the adoption of water saving technologies. Further analysis incorporating a choice between diversification, technological and marketing options would provide useful information for policy analysis.

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