A POLICY ANALYSIS MODEL FOR NEW ZEALAND'S PLANTATION FORESTRY SYSTEM

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ABSTRACT

The wood supplies from New Zealand's plantation forests are expected to increase substantially over the next 30-40 years. Although most of the increase will be available for export, New Zealand's future export markets are most uncertain. This paper discusses a system dynamics model which has been developed to analyse, at the national "strategic" level, the interaction between the demand for, and supply of, wood from New Zealand's plantation forests.

The model contains forest area and forest growing stock sectors, planting policies, cutting policies, land purchasing/selling policies, a market sector, a forecasting sector, and a profit and cash flow sector. The model is used to investigate the effects on the New Zealand plantation forestry system of different future demand scenarios, to measure the effects of demand forecasting errors, and to analyse alternative planting and cutting policies. It indicates that some of these factors have a significant effect on system performance and the model thereby contributes to an understanding of the system.

1. INTRODUCTION

Substantial changes could occur in the New Zealand (N.Z.) forestry sector over the next 30-40 years as a result of the development of vast areas of new plantations in exotic forests (*i.e.*, species not native to N.Z.) since 1960. From 1990 onwards, potential exotic roundwood supplies are expected to increase quite sharply from the present level of 9 million cubic metres (m^3) per year to reach a level of about 18 million m^3 per year

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by the late 1990s. If new plantings are continued as planned, the potential exotic roundwood supplies could reach about 31 million m^3 per year by 2015. This scenario, which is illustrated in Fig. 1, is the "unofficial" projection of N.Z.'s exotic wood supply and it is known as the "continuation scenario" (Elliott and Levack, 1981). Figure 1 also shows the "no new planting scenario" (*i.e.*, new planting is assumed to stop in 1981) together with a projection of N.Z.'s wood consumption, to indicate the potential wood surplus for export.

Figure 1 indicates that, unless some new large-scale import substituting industry such as energy production is developed, virtually all of the potential increase in the exotic wood supplies from the 1990s onwards will be available for export. Thus, to use the projected supply, exports would have to grow by about 200% by the late 1990s, and by about 400% by 2015 if new planting continues.

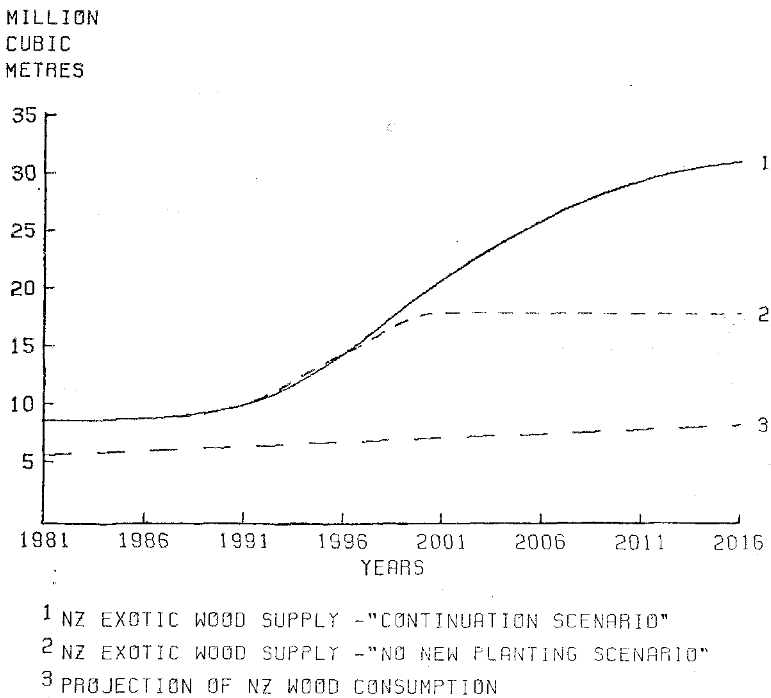

FIG. 1: *New Zealand's potential exotic wood supply and projected wood consumption.* (Source: *Levack, 1979; Elliott and Levack, 1981, Table 6.1; NZFS, 1981, Table 58, p.71*).

The basic assumption guiding the new planting (afforestation) policies in N.Z. in recent years has been that there will be export markets for all the forest products that N.Z. can produce (O'Neill, 1975; Forestry Council, 1981). However, the future prospects for N.Z.'s exports of forest products are not at all clear. For example, N.Z.'s two major export markets, Australia and Japan, which at present jointly take about 70% of N.Z.'s forest products exports (NZFS, 1981: 62), have planted vast areas of forests since World War 2, and they are expected to be much more self-sufficient in forest products by the turn of the century (Fenton, 1979; Byron, 1979; Matsui, 1980). Also further competition is expected from new exporters of softwood (*e.g.*, Chile and Brazil) who have invested heavily in softwood plantations in recent years (NZFS, 1980: 55).

Consequently, there is a need to examine the broad factors governing the interaction between the demand for, and supply of, wood from N.Z.'s plantation forests. The specific purposes of the model discussed in this paper are, therefore:

(1) To assess the effect to which national planting and cutting policies for N.Z.'s plantation forestry system enable it to take advantage of opportunities, or defend itself against shocks, which may fall upon it from the outside world.

(2) To provide a method of indicating the effects of variations in the future demand for wood on N.Z.'s plantation forestry system.

The method selected for examining these problems was the system dynamics method (Forrester, 1961; Coyle, 1977, 1983), which is particularly suitable for strategic planning studies (Cavana, 1981). The long time delays between planting and felling, the non-linearities in the policies and growth rates, the large number of state variables in the system (*e.g.*, volume and area of forests by age groups, land available for planting) and the multiple feedback loops in the forestry system, all make the evaluation of forest policies very suitable for analysis by the system dynamics method. For other applications of system dynamics in forestry see, for example, Lonnstedt and Randers (1979), Boyce (1980) and Grant *et al.* (1979).

Since the purpose of the model is to analyse the long-term behaviour of the N.Z. plantation forestry system as a whole, no distinction is made between the N.Z. Forest Service and the various private sector companies. This implies an assumption that the several actors in the system all have multiple objectives of meeting financial requirements, maintaining a reasonable age balance of their forests, and generally surviving, and that, over a reasonably long term, they balance these objectives in much the same way. This assumption keeps the model to a tractable size, avoids naive assumptions about the profit-seeking behaviour of forestry companies, and concentrates attention on the purposes selected above.

2. MODEL STRUCTURE

Figure 2 shows the general relationships between the different sectors within the model. For example, it indicates that the control policies for planting, cutting and land purchasing/selling are based on information about the price and demand for wood from the market sector, demand forecasts and information about the area and volume of the plantation forests. These affect the area and volume of forests, and the market sector is influenced by the supply of wood. The annual profit and cash flow are derived, as indicators of system performance, from information about wood prices, costs and forestry activity.

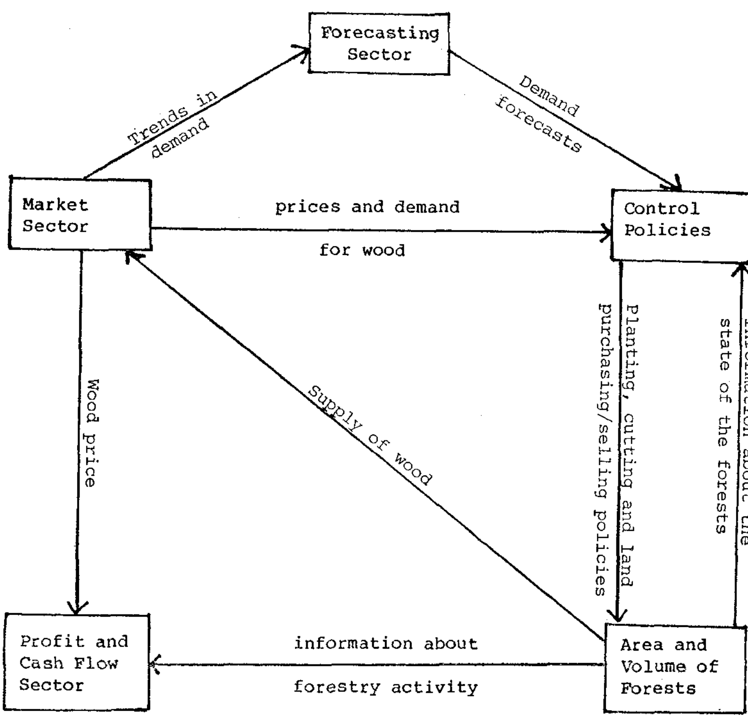

FIG. 2: *Overview of the model.*

The simplified influence diagram for the model is provided in Fig. 3. This diagram provides more information about the policies and structure contained within the model, although it omits some detailed relationships and contains some simplifications for the purposes of clarity, such as the aggregation of the mature and over-mature forests. Also this diagram omits details about the profit and cash flow sector, since it is assumed that there are no feedback links from this sector to the control policies (*i.e.,* the cutting, planting and land purchasing/selling policies).

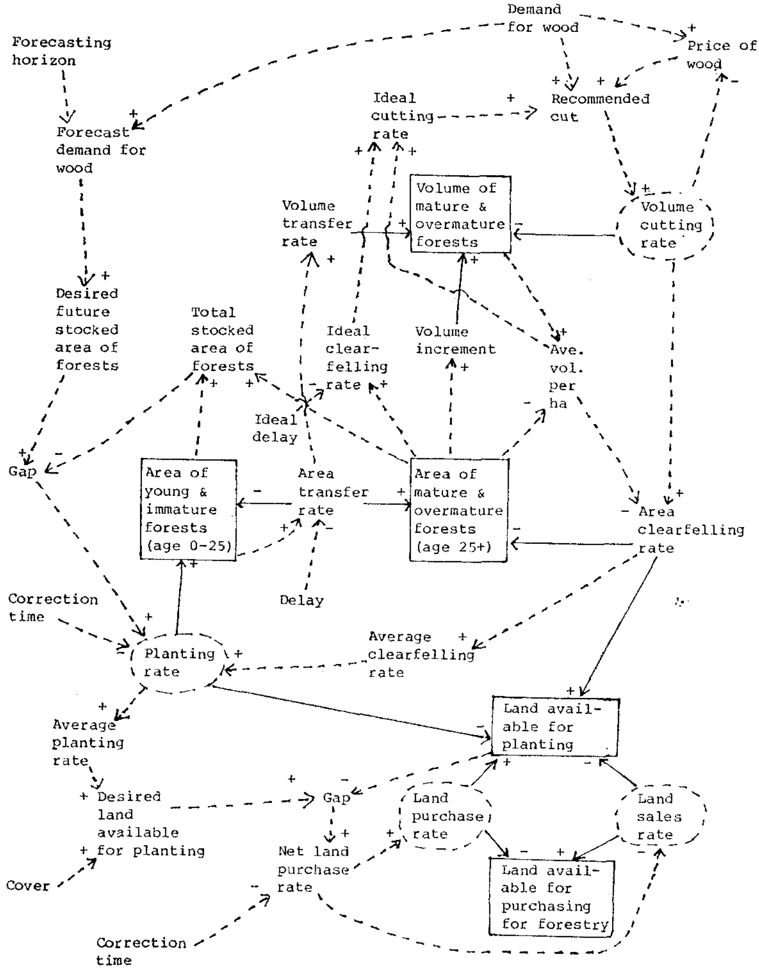

FIG. 3: *A simplified influence diagram for the model.*

This influence diagram was constructed using the system description method developed recently by Wolstenholme and Coyle (1983). This stage provides a rigorous method of translating mental pictures into good systems diagrams, which can be used as a clear form of communication to others, as a means of enhancing understanding of the system, and as a basis for system improvement. The basis of the influence diagram method is that the management of any system involves the act of regulating flows, whether they be of land, labour, money, wood or capital equipment, etc. This regulation takes place on the basis of whatever information managers choose to employ.

The variables appearing in the rectangles in Fig. 3 are called state variables or levels, and they are directly measurable. The flows between the levels (shown at the ends of the solid arrows) are called rates and they are not directly measurable. The solid arrows represent, not the direction of the physical flows, but the consequences or influences arising from these flows. A positive (+) sign on a link indicates that a change in the variable at the tail of a link will cause the variable at the head of a link to change in the same direction, whereas a negative (—) sign indicates a change in the opposite direction. For example, the level shown in a rectangle called the "land available for planting" is increased by the area clearfelling rate and the land purchase rate, and decreased by the planting rate and the land sales rate.

The broken arrows in Fig. 3 indicate the behavioural, information and control links within the system. Information links are extremely important and they can be created directly from the system levels, from exogenous inputs, or as averages from flow rates (*e.g.*, an information link exists between the "average planting rate" and the "desired land available for planting"). Behavioural links represent the way in which part of the system, over which managers have no direct control, reacts to previous managerial decisions through the intervention of natural or biological processes. For example, the area transfer rate from the immature forest age group to the mature forest age group is a natural process which arises from the area of the immature forests and the average time (or delay) spent in this age group. Control links, on the other hand, are the most important part of a system dynamics study as they represent the way in which managers have, or could have, control over the system being studied. The control rates are shown in the dashed ellipses to emphasise the points in the system where managers have direct control (*e.g.*, the planting rate, the volume cutting rate, and the land purchasing/selling rates).

The equations for the model are formulated using the DYSMAP programming language (Cavana and Coyle, 1982), which has been developed at the University of Bradford as a tool for dynamic simulation modelling. A listing of the model (originally called the Improved Demand/Supply Model) is provided in Appendix B of Cavana (1983). Alternatively, the model (renamed WOOD2) can be obtained in either the DYSMAP or DYNAMO (Pugh, 1976) programming languages from Cavana.

The model equations are fully discussed in Cavana (1983). However, one equation will be provided here to illustrate the relative ease by which these equations can be formulated. For example, the equation below shows the calculation for the area of forests in age class 1 (age 0-5 years). This variable (AF1) is calculated as a level (indicated by the letter L at the beginning of the equation), since this is a state variable in the system. The suffix .K indicates the present time period, .J indicates the previous time period, and .JK indicates the interval between the time periods. In this equation the current value of AF1 is calculated as the previous value of AF1 plus the changes during the solution interval (DT). (*i.e.*, AF1 is increased by the planting rate (PLANT) and decreased by the transfer rate to age class 2 (T12)).

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L    AF1.K=AF1.J+DT*(PLANT.JK—T12.JK)
N    AF1=264000
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The model is initialised to commence simulation in the year 1981 and the initial value for the area of forests in age class 1 (AF1) appears on the N statement below the level equation. The value of 264 000 hectares is obtained from Elliott and Levack (1981: 25). The solution interval, DT, which is the gap between successive values of the levels, is set equal to 0.25 (or ¼ of a year) using the method described by Cavana and Coyle (1982: 3).

The simulation length used for the experiments with this model is 100 years. Standard system dynamics practice is that the duration of the simulation should be about 2-3 times the longest time period in the system which, in this case, is the average desired rotation length for radiata pine. No attempt is being made to "forecast" particular values for 100 years; rather the intention is to determine the conditions under which particular behaviour modes would occur.

2.1 *The Forest Areas and Growing Stock*

The exotic forests in N.Z. have been classified into two major crop types (NZFS, 1980: 9-12). These are the "old crop", which consists of plantings before 1940, and the "new crop", which consists of plantings since 1940.

The main differences between the old and new crops are that the remaining old crops contain several species and they received very little silvicultural attention, whereas the new crops consist mostly of radiata pine and have undergone (or are expected to undergo) more pruning and thinning to produce better quality sawlogs. Also the new crops are expected to be clearfelled at an average age of 30 compared with the old crops which are being currently clearfelled at an average age of 45-50. Clear-felling at an earlier age will have the effect of reducing the average wood yield per hectare and reducing the average log size.

The forest age groups are classified according to a combination of age, development and treatment characteristics. These are briefly:

(a) The young forests (age 0-10 years) which are non-productive, and include the establishment and silvicultural stages, where the crops are pruned and thinned.

(b) The immature forests (age 10-25 years) which could potentially be removed (by early clearfellings or commercial thinnings) as pulplogs, poles, or small sawlogs. However, since most of N.Z.'s plantation forests are being managed to produce sawlogs, which are removed by clearfelling on maturity (*i.e.*, from about age 25), it is assumed that these forests are non-productive.

(c) The mature forests (age 25-40 years) which contain wood that is at the desirable age for clearfelling.

(d) The over-mature forests (aged 40+ years) which contain slow growing forests beyond the desirable age for clear-felling.

Average wood yield curves are derived for the old and new crops and these yields are used to calculate the initial volumes of wood in each age group at the beginning of the simulation (*i.e.*, 1981) and the annual volume increment of the growing stock. The use of an average for the whole of N.Z. is justified by the purpose of the model being directed towards the overall behaviour of the system.

2.2 *The Market Sector*

The market sector deals with the demand for wood and the market price for wood at the forest ride (*i.e.*, the forest roadside).

(a) *Demand for Wood*

The demand for wood is assumed to be exogenous to the model and it includes both the N.Z. and the international demand for wood from N.Z.'s plantation forests. Although any linear or time-dependent pattern can be input into the model, three demand scenarios are considered: low, medium and high. It is assumed that the demand for wood at the "normal price" (discussed below) from N.Z.'s plantation forests in 1981 was 9 million m^3. The medium demand scenario assumes an annual growth rate in demand of 0.3 million m^3, which is approximately equal to the average linear annual rate of growth of roundwood removals from N.Z.'s exotic forests over the period 1950-1980 (NZFS, 1981:22). This is used as the Base Case of the model. Model experiments are also performed with a low demand scenario which assumes an annual growth rate of 0.1 million m^3, and a high demand scenario which assumes an annual growth rate of 0.5 million m^3.

(b) *Market Price of Wood*

The market price of wood at the forest ride is calculated as the "normal" price of wood modified by a price multiplier. The "normal price" is based on N.Z. Forest Service sales of exotic wood during the 1970s. It is calculated as the sum of the average stumpage value of $5/$m^3$ (NZFS, 1981) plus the average logging and loading costs of $5/$m^3$ (O'Dea *et al.*, 1979: 45-9). Consequently a "normal price" of wood of $10/$m^3$ (in 1978 prices) is derived, which is assumed, for the purposes of this study, to be the same for the "new crop" as well as the "old crop" (since very little information is currently available on average prices for the new crop).

The purpose of the price multiplier is to incorporate the effects of changes in market conditions on the normal price of wood. Very little information is available on the price elasticity of demand for wood from N.Z.'s forests. Consequently, it is assumed that, if the actual volume of wood supplied from N.Z.'s plantation forests is less than the quantity of wood demanded (*i.e.*, the demand scenario) at the normal price, then this will cause only a slight increase in price (*i.e.*, demand is very "price elastic"). However, if the actual volume of wood supplied is greater than demand at the normal price, then it is assumed that the price will decrease more sharply (*i.e.*, demand is less "price elastic" or "price inelastic").

2.3 *Demand Forecasts*

The demand forecasts are calculated to be the true demand for wood (*i.e.*, the demand scenarios discussed above) multiplied by a factor to represent forecast errors. Specific inclusion of forecasting errors in the demand forecasting equations allows the modeller to test the sensitivity of the system's behaviour to forecasting errors (Coyle, 1977: 148).

The perfect (or true) forecast of demand depends on the demand scenario and the forecasting horizon, which is set equal to the desired rotation age (*i.e.*, the desired length of time between planting and clearfelling a stand of trees). The forecast error reflects management's constant long-term pessimism or optimism about the future demand prospects for wood. This is combined with a short-term variable which reflects management's relative optimism or pessimism about the future depending on whether the current ideal wood supply (allowable cut) is below or above the current level of demand. In the Base Case run of the model, demand is assumed to be perfectly forecast.

2.4 *Cutting Policies*

The cutting policies are based on a comparison between demand and supply factors. The ideal wood supply (or allowable cut), which is based on forestry factors such as the desired rotation age, volume of mature and over-mature forests, is compared with the demand for wood and the policy guidelines are different depending on whether the allowable cut is greater or less than the demand for wood. When the allowable cut is greater than demand the actual quantity cut depends on the minimum reservation price, which is the lowest price at which forestry owners would be prepared to sell wood from their forests. When the allowable cut is less than demand, the actual cut depends on the number of years annual demand needs to be covered by the volume of forests in the mature and over-mature age groups, and to the desired rotation length.

2.5 *Planting Policies*

The planting policy is calculated as the difference between the desired and actual total stocked area of forests corrected over a period of time plus the average area clearfelled each year. The desired future stocked area of forest is based on a forecast of the area of forest required to satisfy the future demand for wood.

The policy parameter, time to correct the area of forest, depends on a normal correction time modified by a correction multiplier, which is based on the ratio of the actual to desired area of mature and over-mature forests. A higher ratio leads to a higher multiplier and consequently a lower planting rate.

2.6 *Land Purchasing/Selling Policies*

The land purchasing/selling policies are calculated to depend on the difference between the desired and actual area of land available for planting corrected over a period of time. If the area of land available for planting is less than the desired area, then this suggests that land should be purchased. Conversely, if the actual area is greater than the desired area, then this suggests that land should be sold. The desired area of land depends on the average annual planting rate multiplied by the number of years cover required.

2.7 *The Profit and Cash Flow Sector*

This sector is included in the model because information about the profit and cash flow generated by the forestry system provides a useful measure of the system's financial and economic performance. However, it is assumed for the purposes of this analysis that there are no feedback effects from this sector to the control policies in the model. All monetary values in the model are expressed in terms of constant 1978 N.Z. dollars.

Annual profit is calculated as the revenue from wood sales at the forest ride less the forest management costs plus the change in value of the growing stock. The forest management costs include separate costs for land preparation and planting, other establishment activities, silviculture, overheads and administration, and logging and loading.

Annual net cash flow is calculated as the cash inflow rate less the cash outflow rate. The cash inflow rate equals the revenue from wood sales at the forest ride plus the revenue from land sales. The cash outflow rate equals the forest management costs plus the cost of land purchases.

3. MODEL VALIDATION

Before a model can be used for policy analysis, the model user or client must have sufficient confidence in the "soundness and usefulness" of the model (Forrester and Senge, 1980: 210). The usual process by which this confidence is generated is by a process called "validation". In a recent paper, Coyle (1983) discusses the main tests which should be used to validate a system dynamics model. These include:

(1) Verification tests, which are concerned with verifying that the structure and parameters of the real system have been correctly transcribed into the model.

(2) Validation tests, which are concerned with demonstrating that the model actually generates the same type of behaviour that would be expected from the real system.

(3) Legitimation tests, which are applied to determine that the model obeys the laws of system structure or any generally accepted rules.

The purpose of applying these rigorous tests is to show that there is nothing in the model that is not in the real system and nothing significant in the real system that is not in the model. The model described in this paper is fully validated using these tests (Cavana, 1983: 245-52).

4. EXPERIMENTS WITH THE MODEL

Various experiments with this model have been discussed in Cavana (1983); however, only the main experiments will be summarised here. These include a discussion of the model behaviour for the Base Case (medium demand scenario), simulation runs with the low and high demand scenarios as the exogenous inputs, an experiment with demand forecasting errors, and policy experiments with the desired rotation age increased from 30 to 37.5 years and with an alternative planting policy. Finally the numerical performance indices for each of the experiments are summarised.

4.1 *The Base Case (Medium Demand Scenario)*

The Base Case of the model assumes that the medium demand scenario (*i.e.,* growth in demand equals 0.3 million m^3 per year) is the exogenous input to the model and all the other parameters have the values shown in the main program of WOOD2 (available from Cavana or listed in Appendix B of Cavana (1983)). The behaviour of the model for the Base Case, which provides a frame of reference for comparing all the remaining experiments, can be explained with a discussion of Fig. 4.

Figure 4 (a) shows how well the system is meeting its objective, that is, how well supply is matching demand. During the 1980s the ideal wood supply (or allowable cut), ICUT, is below demand (DEMAND). However, the cutting policies allow the actual wood supply (ACUT) to equal demand over this period. Because of the initial conditions — *i.e.,* the distribution and area of forests in 1981 — the allowable cut (ICUT) is much greater than demand over the period 1990-2020. Although a much greater quantity of wood is offered to the market than is demanded at the normal price, the pricing mechanism allows a greater quantity of wood to be sold, but at a lower price. The actual wood supply (ACUT) will depend on the reservation price which is set by forestry managers (*i.e.,* the policy parameter MINPR in the model). Thus over the period 1990-2020 the price of wood at the forest ride (PRICE) is depressed. After about the year 2020 the policies in the model become effective in controlling the allowable cut (ICUT) to match the demand for wood (DEMAND).

Figure 4 (b) shows the behaviour of the other control policies — *i.e.,* the planting rate (PLANT) and the land purchasing/selling rates (LPR and LSR). It also shows the behaviour of the average planting rate (APLANT) and the average area clearfelled each year (AVACF). Both the planting rate and the average area clearfelled increase steadily during the simulation run. However, land is sold during the 1980s since the initial value for the land available for planting is higher than necessary for this demand scenario. From 1990 onwards the land purchasing rate (LPR) increases steadily and then remains constant from about the year 2020 to the end of the simulation run.

4.2 *Experiments with Different Demand Scenarios*

These experiments involve running the model with the low and high demand scenarios as the exogenous inputs to the model and with all other parameter values remaining the same as the Base Case. Only the main differences from the Base Case (shown in Fig. 4) will be noted.

(a) *Low Demand Scenario*

The low demand scenario assumes that the demand for wood from N.Z.'s plantation forest grows at a linear rate of 0.1 million m^3 per year.

Figure 5 (a) indicates that there is a considerable over-supply of wood relative to demand between 1990-2035. This is mainly due to the combination of the large area of plantation forests and uneven age class distribution at the beginning of the simulation (1981), and the assumption of low demand for wood. However,

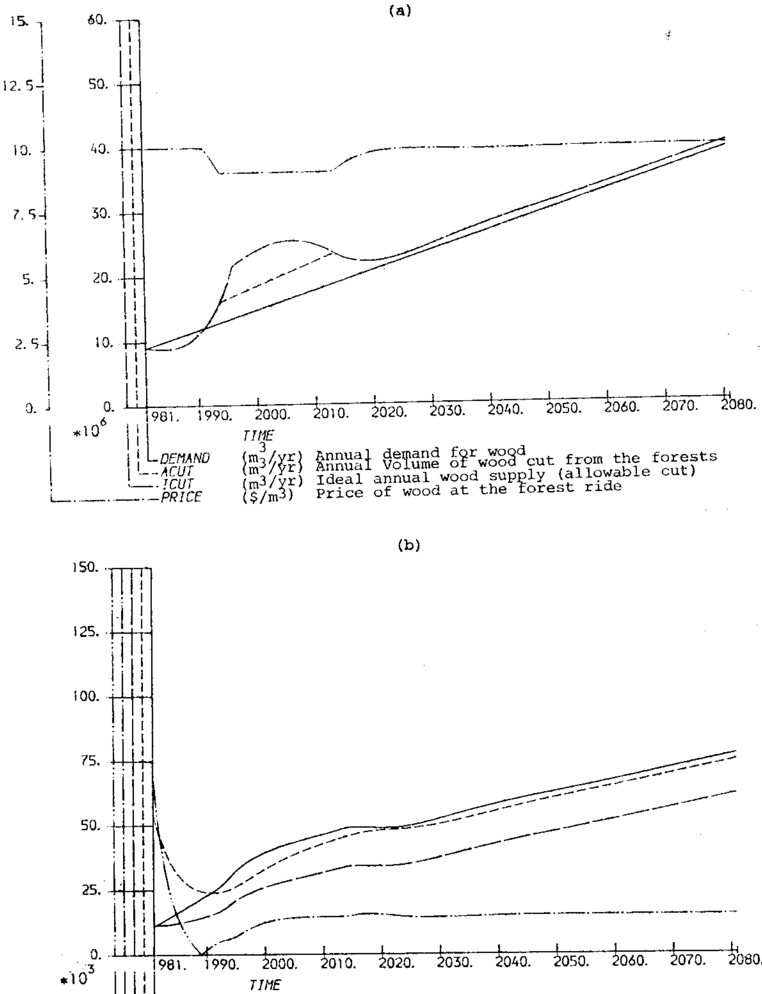

FIG. 4: *Model behaviour for the Base Case (medium demand scenario). (Prices in constant 1978 dollars)*

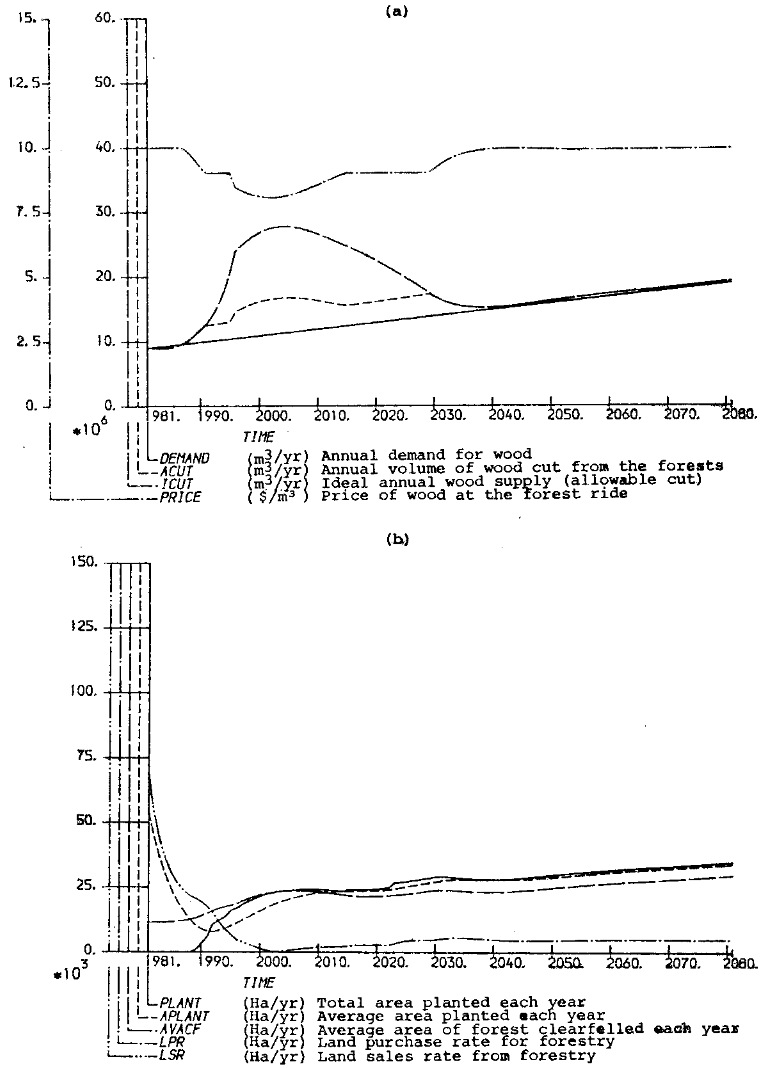

FIG. 5: *Model behaviour with the low demand scenario. (Prices in constant 1978 dollars)*

the actual wood supply (ACUT) is above demand over this period and this causes a depression, for a relatively long period of time, in the price of wood at the forest ride (PRICE). After the year 2035 the policies finally manage to control the system so that the allowable cut (ICUT) is approximately equal to the demand for wood (DEMAND) over the last 45 years of the simulation.

The other control policies shown in Fig. 5 (b) indicate that the planting rate remains zero throughout the 1980s, increases rapidly during the 1990s and then increases gently over the remainder of the simulation run. Until the turn of the century, land (LSR) is sold from forestry, because of the high initial conditions for the land available for planting and because there is little or no restocking until the mid-1990s. However, beyond 2000 small areas of land are purchased (LPR) each year to allow future supply to meet the slight degree of expansion in the future demand for wood.

This experiment suggests that, if low demand is the scenario for the future, then it will take approximately 50-55 years before control is restored to the system. This is mainly because past changes in government policy (discussed in Cavana (1983: 21-34)) have caused a large imbalance in the area and age distribution of the forests in 1981 (*i.e.*, the beginning of the simulation). This suggests for further policy analysis that, either the government and the private sector may have to encourage the use of wood (*i.e.*, increase the demand), or lower prices will have to be accepted for wood if stability is to be restored earlier.

(b) *High Demand Scenario*

The high demand scenario assumes that the demand for wood from N.Z.'s plantation forests grows at a linear rate of 0.5 million m^3 per year.

Figure 6 (a) indicates that the allowable cut (ICUT) is below the demand for wood (DEMAND) until the mid-1990s. However, the cutting policies operate to adjust the actual volume of wood cut (ACUT) to equal the demand for wood during this period. Between 1995 and 2010 the allowable cut (ICUT) is slightly above DEMAND. However, all the wood offered for sale is actually cut during this period, but at slightly reduced prices, as indicated by the drop in PRICE (the market price of wood at the forest ride). Beyond 2010 the control policies operate very efficiently to match the allowable cut (ICUT) with DEMAND, and the system is very stable for the remainder of the run.

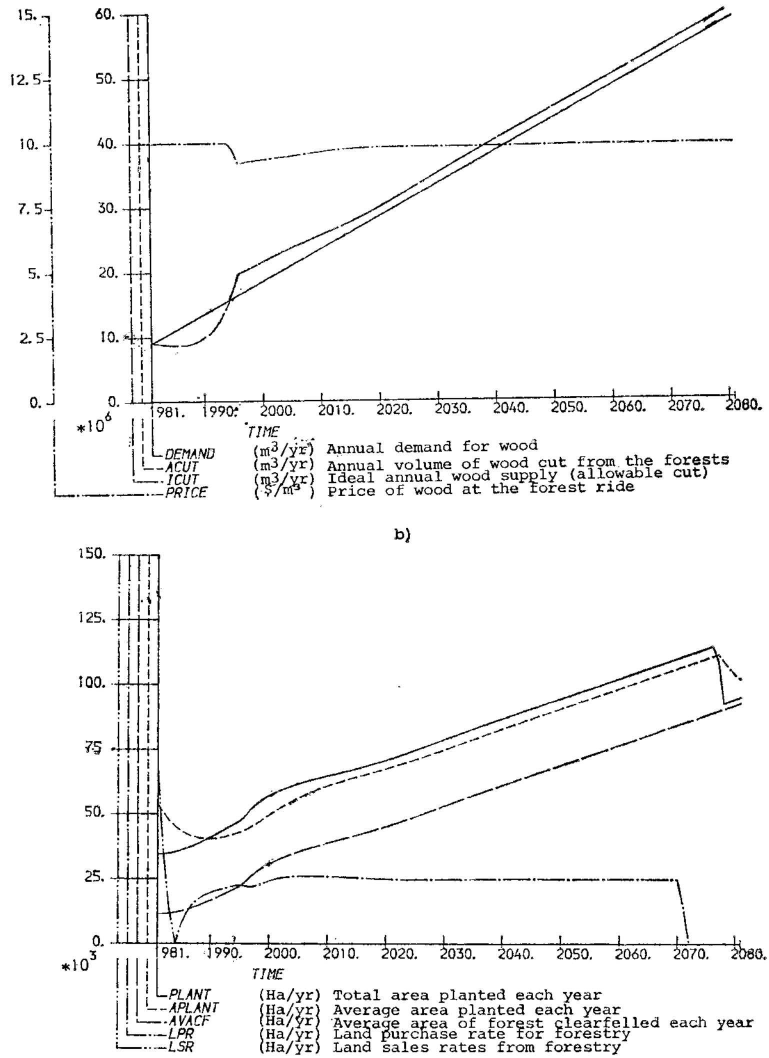

FIG. 6: *Model behaviour with the high demand scenario.*

(Prices in constant 1978 dollars)

Figure 6 (b) indicates that the annual planting rate (PLANT) increases rapidly to about the year 2075. At this point the land available for purchasing for forestry (LAPUR in the model) is depleted and this acts as a further constraint on expansion, and consequently no further land purchases are possible.

4.3 *Experiment with Demand Forecasting Errors*

In the Base Case of the model is was assumed that the demand for wood was perfectly forecast. In this experiment that assumption is relaxed and it is assumed that there is relative bias in the demand forecasts. This experiment investigates the situation where managers believe that the future demand for wood will be up to 25% higher than the actual value when the current level of the demand is above the allowable cut, and up to 25% lower than the actual level when the current level of demand is below the allowable cut.

This experiment, because of the alternative optimistic and pessimistic forecasts of the demand for wood, has introduced minor cycles into the system. This can be seen by comparing Fig. 7 with the Base Case (Fig. 4). For example, the over-supply of wood during the 1990s causes managers to take a pessimistic view of the future and consequently the planting rate drops (PLANT in Fig. 7 (b)). This results in shortages of wood relative to demand between 2015-2040, and therefore the planting rate increases again. However, by the end of the simulation run the control policies have managed to restore stability to the system.

4.4 *Policy Experiments*

Policy experiments with the model involve either keeping the structure of the control policies fixed but varying the policy parameter values within them (ordinary policy parameter experiments), or changing the structure of the control policies by adding or deleting variables from the policy equations (structural policy parameter experiments). An example of the first type of policy experiment is described below and this involves running the model with the desired rotation age increased from 30 to 37.5 years. The second type of policy experiment is also provided below and this involves a simulation run with an alternative planting policy.

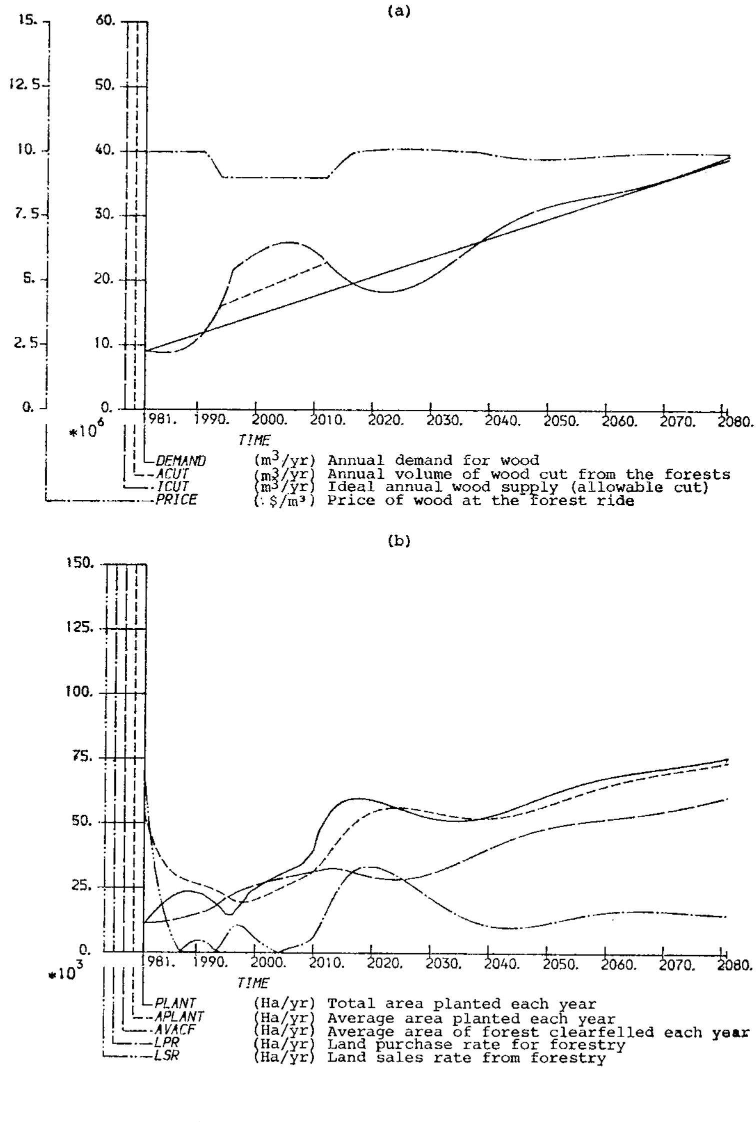

FIG. 7: *Forecasting error experiment — relative bias.*
(Prices in constant 1978 dollars)

(a) *Desired Rotation Age=37.5 years*

This policy experiment involves increasing the desired rotation age to 37.5 years, from 30 years in the Base Case.

Figure 8(a) indicates that the demand for wood is not being met by supply until the mid-1990s. However, from then onwards the allowable cut (ICUT) only slightly exceeds demand, compared with the large over-supply between 1990-2020 for the Base Case (Fig. 4 (a)). The price of wood at the forest ride (PRICE) remains relatively constant throughout the simulation run. This suggests that the behaviour of the N.Z. plantation forestry system would be more stable and better controlled with this policy.

(b) *Alternative Planting Policy*

This experiment illustrates the effects on system behaviour of an alternative source of information in the policy guidelines for the planting decision. Here it is assumed that the planting policy is calculated as the difference between the desired and actual stocked area of forests corrected over a period of time plus the average area planted each year. (Note that the Base Case included the average area clearfelled each year as the inertia term in the planting policy compared with this experiment which includes the average area planted each year). Figure 9 shows the graphical behaviour of the main variables for this experiment.

Figure 9 (a) indicates that the period of oversupply relative to demands lasts for 10 years longer than the Base Case (Fig. 4 (a)) and is much larger. Consequently, the effect of the longer period of oversupply is to cause prices to remain relatively low between 1990-2030. However, the higher planting rate (PLANT) during the 1980s (shown in Fig. 9 (b)) indicates that the employment situation is better than the Base Case.

4.5 *Summary of the Model Experiments*

Some numerical performance indices, for each of the model experiments described above, are summarised in Table 1. However, it is important to realise that there are probably many ways of measuring the performance of the "real" N.Z. plantation forestry system, perhaps reflecting different interest groups such as government, forestry managers, trade unions. Holling (1977: 248) emphasises this point: "there is no 'comprehensive' list of indicators and there are no 'right' set of indicators for any problem, ever."

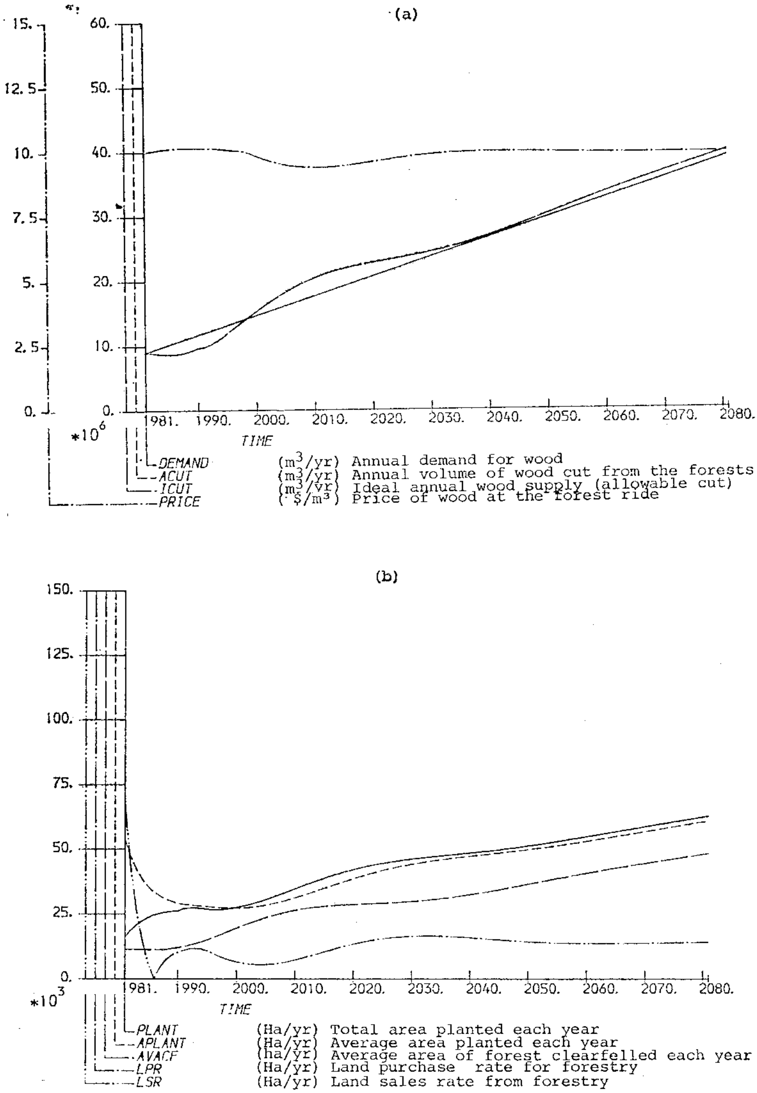

FIG. 8: *Policy experiment — desired rotation age = 37.5 years. (Prices in constant 1978 dollars)*

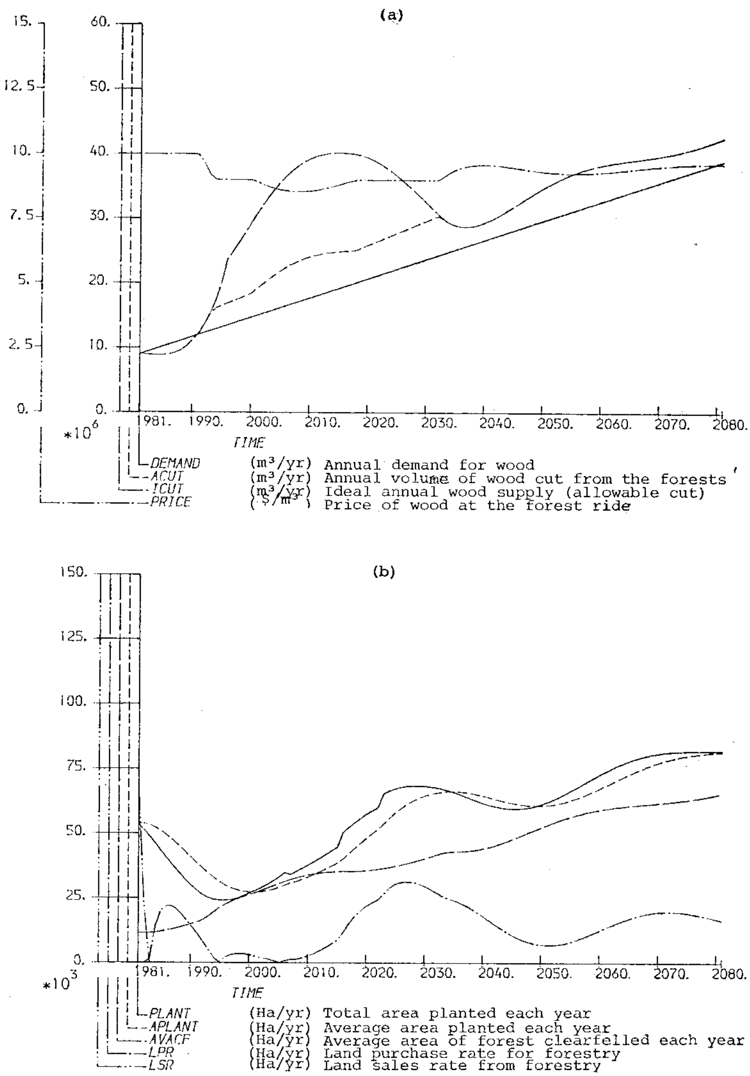

FIG. 9: *Policy experiment — alternative planting policy (Prices in constant 1978 dollars)*

TABLE 1: SELECTED RESULTS OF THE MODEL EXPERIMENTS*

Figure Experiment	*Cumulative Wood Removals Index* *CWRIX*	*Cumulative Profit Index* *CPROFIX*	*Unit Net Cash Flow Index* *UNCFIX*	*Resource Control Penalty Index* *RCPIX*	*Employment Loss Penalty Index* *EMLPIX*
4 Base Case (medium demand scenario)	100.0	100.0	100.0	100.0	100.0
5 Low demand scenario	61.8	59.6	107.7	297.8	172.2
6 High demand scenario	138.8	140.7	96.7	21.8	38.6
7 Demand forecasting error-relative bias	96.5	99.3	103.0	105.8	103.4
8 Desired rotation age=37.5 years	97.4	129.5	122.1	7.7	94.1
9 Alternative planting policy	110.0	92.4	81.0	457.1	54.6

*An increase in CWRIX, CPROFIX and UNCFIX, and a decrease in RCPIX and EMLPIX indicate an improvement in system performance, compared with the Base Case.

A method of calculating performance indices to reflect the balance between avoiding undesirable dynamic behaviour of some variables during the simulation run, while rewarding the attainment of attractive states for others at the end of a simulation, has been developed to supplement the analysis of the graphical output indicators of performance (Coyle, 1978). Based on that approach, the following performance indices have been calculated (Cavana, 1983: 257-69) for the purposes of comparing these experiments:

(1) The cumulative wood removals index provides an indicator of the total volume of wood removed from the forests during the simulation run. This is also a fair indicator of the total level of employment and forestry activity generated by the system.

(2) The cumulative profit index is based on the accumulated annual profits and it provides an indicator of the financial or economic performance of the system.

(3) The unit net cash flow index provides another measure of the financial performance of the system. This index is derived as an average over the simulation run, of the cumulative net cash flow divided by the cumulative volume of wood removed from the forests.

(4) The resource control penalty index is an indicator of managerial performance in matching supply to demand. This index penalises large differences between the supply of wood offered by managers based on the state of the forests, and the volume of wood demanded by the markets. The forests themselves act as a buffer stock and no great penalties are incurred if trees are cut a little before or after the desirable age. There is, therefore, no need to penalise small differences between supply and demand so the penalty function only comes into play if they differ by more than an arbitrary chosen value of 10%.

(5) The employment loss penalty index reflects the social objective that a decline in the level of employment in forestry is undesirable, particularly in the present circumstances of relatively high unemployment in N.Z. This index penalises downward changes in the planting rate compared with an average trend. If the planting rate remains constant or increases then no penalty will be incurred, because it is assumed that there will be no employment loss.

In Table 1 it can be seen that the values of these performances indices are set equal to 100 for the Base Case, as this provides a frame of reference for comparing the other model experiments.

For the experiment with the high demand scenario, the cumulative wood removals index and the cumulative profit index increase significantly and the resource control penalty index and the employment loss penalty index decrease noticeably. This indicates a substantial improvement in the performance of the system compared with the Base Case.

Conversely, the changes in the performance indices in Table 1 indicate that the system performs worse than the Base Case if the low demand scenario is the exogenous input into the model.

Table 1 indicates that the demand forecasting error experiment, with relative bias, does not significantly alter the overall performance of the system, since there is little change in the performance indices. However, the graphical results of this experiment have indicated how forecasting errors can cause instability in the behaviour of the system over time (see Fig. 7).

The policy experiment involving an increase in the desired rotation age to 37.5 years results in a better financial performance for the system as indicated by the increases in the cumulative profit index and the unit net cash flow index. Also, from a resource control point of view, the system's performance is substantially better with this policy as indicated by the drop in the resource control penalty index. Since the employment situation is not significantly affected with this policy (*i.e.,* there is only a slight change in EMLPIX and CWRIX in Table 1), then it is concluded that the overall performance of the N.Z. plantation forestry system could improve if the rotation periods are extended to 35-40 years, compared with the currently planned rotations of 25-30 years for radiata pine. This indicates that product diversification by planting different species with longer rotations may be beneficial to system performance.

The policy experiment involving the alternative planting policy suggests that the financial performance of the system could be significantly worse than the Base Case. This is indicated by the drop in the cumulative profit index and the unit net cash flow index in Table 1. Also, because of the longer period of oversupply from 1990-2030 (see Fig. 9 (a)), this causes a large increase in the resource control penalty index which indicates a considerable reduction in managerial efficiency. However, the significant drop in the employment loss penalty index and the increase in the cumulative wood removals index indicates that the general level of employment and activity in forestry would be higher with the alternative planting policy.

5. CONCLUSIONS

This paper has discussed a highly aggregated system dynamics model which has been developed to assist in the analysis and design of forest policies for managing N.Z.'s plantation forestry system. The model provides an example of an aggregated "macro" analysis of the way in which sequences of decisions, under the influence of broad policy guidelines, interact with exogenous events and the "basic physics" of a system to produce overall behaviour. Such an analysis is, we contend, useful as a framework for more detailed analyses of specific or localised decisions, perhaps using more "micro" tools such as discounted cash flow analysis.

The experiments presented here have emphasised the importance of the demand for wood on the performance of the system and they have demonstrated how forecasting errors can cause instability in the system's behaviour. The analysis with the alternative planting policies has highlighted the basic trade-offs that exist within forestry, between the socio-economic objective of maximum employment and the managerial objectives of maximum financial return and control over resources.

The policy experiment which involved an increase in the rotation length suggests that the overall performance of the N.Z. plantation forestry system could be improved if the rotation periods are extended to 35-40 years, compared with the currently planned rotations of 25-30 years for radiata pine. This indicates that product diversification by planting different species with longer rotations may be beneficial to system performance.

Finally, it is suggested that one of the most useful ways of further developing the model described in this paper, is by collaboration with policy makers and managers in the "real" N.Z. plantation forestry system. For example, the model could be disaggregated by species and silvicultural method to search for further improvements to system performance, a wood processing sector could be added to assist in the analysis of industrial development strategies, or the market sector could be extended so that policies which influence the demand for wood can be evaluated.

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