# *Dynamics of Optimal Interactions between Pasture Production and Milk Yields of Australian Dairy Farms*

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## ABSTRACT

Deregulation of the Australian dairy industry could effect the utilization of resources by milk producers. In this study we examine the feed input mix dairy producers use, both pastures and supplements, prior to and after deregulation. We are particularly interested in the interaction of pasture utilization and farm profitability.


Key words; dairy production, pasture utilization, deregulation.

**Introduction**

Regulation of the Australian dairy industry is currently under review by both the state and federal governments with the aim of reducing government intervention in dairy production. The federal government is looking to remove some of the dairy marketing regulations under it's control to comply with the outcome of the Uruguay Round of the GATT and the recommendations of National Competition Policy contained in the Hilmer Report (Hayman; McQueen). Given these federal pressures, state governments are also considering deregulating the parts of the industry under state control. In New South Wales (NSW), the state government regulates the price of market milk, that milk used for human consumption, and maintains a quota scheme on the amount of market milk individual dairy producers can supply (Tozer 1993). There is no constraint on total supply of milk, just on the supply of market milk.

One aspect of deregulation that is particularly worrying producers in NSW is the proposal to phase-out the price premium for market milk and remove the supply quota for market milk (Hayman). With the removal of the price premium producers believe that they will not be able to remain in the industry given current production practices. The typical production method of Australian dairy producers is pasture-based grazing with concentrates or grains being fed to supplement the dietary requirements of the cows or improve milk productivity (ABARE; ADC). These dietary supplements can be relatively expensive with respect to the expected increase in milk production (Tozer 1997) and the price of milk in some periods over the production year.

Producers who wish to remain in the industry may have to seek ways to reduce the costs of production. One way to reduce the costs of production is to adopt a low-input production method. Australian producers are already using a pasture-based production method, with some supplementary feeds, therefore to reduce costs they may have to use a fully pasture-based milk production method. Low-input dairy production is a method where producers alter their management practices to avoid periods of relatively high cost inputs.

The study of low-input dairy production requires an extension to the pasture modeling found in the literature. Previous pasture modeling efforts have focused on rangeland stocking operations. These studies assume ranchers stock cattle on rangeland to gain some desired weight per head over the growing season (Torrell, Lyon and Godfrey; Karp and Pope; Huffaker and Wilen). In contrast, we are interested in the interactions between pasture productivity and milk yield in an intensive-grazing situation. This also differs from previous dairy supply research, which has assumed that milk producers have access to an infinite supply of purchased feed (Chavas and Klemme; Howard and Shumway; Gao, Spreen and DeLorenzo; LaFrance and Gorter). In a pasture-based dairy system there is not an infinite amount of pasture available due to the biological processes of the plant components within the system.

In modeling a fully pasture-based dairy systems, we develop a novel milk production function that incorporates all the biological systems of a dairy farm into one equation describing milk production as the excess of energy supplied by pasture over that demanded for all of the herd's non-lactating physiological demands. This function is incorporated into an optimal control model of a case study of a representative milk producer to characterize the dynamics of low-input pasture-based milk production. The model, solved as an empirical non-linear programming problem (Howitt), will be used to examine the profitability of low-input dairying and to determine the producer's optimal response to a number of deregulation scenarios. The deregulation scenarios of interest are full deregulation and partial deregulation. The sensitivity of the system to changes in the price of milk will be tested, as will several herd and pasture management options, to determine the economic stability of low-input dairying with respect to changes in the biological processes of the system.

**Optimal Control Model**

The dairyman's problem is to maximize the flow of revenues generated within the dairy system:

$$(1)\ \underset{\mathbf{S}}{Max}\ NPV = \sum_{t=1}^{T} \sum_{m=1}^{12} b(t,m)\{p_{I,m}[\mathbf{S,H,E}] + p_{L,m}[\mathbf{H}] - C_{E,m}[\mathbf{S,H}] - C_{P,t}\}$$

Subject to

(2) $\mathbf{H}_m - \mathbf{H}_{m-1} = f(\mathbf{H}_{m-k})$ $\qquad$ k = 0,…,11.

(3) $\mathbf{E}_m - \mathbf{E}_{m-1} = f(\mathbf{E}_{m-1}, \mathbf{S}_{m-1})$

$\mathbf{E}_0 = \mathbf{E}_x$

$\mathbf{H}_0 = \mathbf{H}$

The discount rate, b(t,m), is a function of both t and m, as we have monthly, m, operations nested within an annual, t, revenue function. $\pi_{I,m}[\mathbf{S,H,E}]$ is the net revenue from milk production, which is a function of the stocking rate control variable, **S** (hd/ha), the herd size state variable, **H**, measured in head, and the total pasture energy state variable, **E**. $\pi_{L,m}[\mathbf{H}]$ is the net revenue from livestock trading activities which is purely a function of the state variable, **H**. $C_{E,m}[\mathbf{S,H}]$ is the cost function for the supply of supplemental energy. The costs of pasture sowing and maintenance, $C_{P,t}$,are assumed to be an annual cost for each pasture type as the farmer sows pasture once a year rather than monthly. $E_{x,0}$ and $H_0$ are initial stocks of each pasture's energy and the dairy herd, respectively.

Equation 2 is the equation of motion for the total herd size state variable. In this study there are two measures of stock numbers, one is **H** and the other is **S**. **S** measures the number of cows that can be carried on pastures alone, whereas **H** measures the total number of cows the dairy farm has on any type of feed whether it is pasture or supplements. By multiplying **S** by the area of the farm and subtracting this from **H** we can determine the number of cows on supplements. The third equation represents the equation of motion for the pasture energy state variable, $\mathbf{E}_m$. Pasture energy equation is a function of itself and a lag of the control variable, $\mathbf{S}_{m-1}$.

*Herd dynamics*

The herd dynamics are a quadratic form of the Leslie matrix similar to that used in Chavas and Klemme, but is a stage class population as defined in Getz and Haight. The culling and death rate parameters, $\delta_{j,c}$ and $\delta_{j,d}$, vary between age classes, j, and the calving rate, $\alpha_c$, is constant across classes. The milking herd size at month m is:

$$(4)\ \mathbf{H} = \sum_{j=2}^{5} \sum_{k=12}^{23} (1 - d_{j,c} - d_{j,d}) H_{j-1,m-k}$$

Where $H_{j-1,m-k}$ is the number of cows in age class j-1 that calved k periods previous to m, the number of calves and replacement heifers is derived in a similar manner

Livestock revenue, $\pi_{L,m}$, is generated from the number of cows culled, bull calves born, and the proportion of heifer calves deemed to have undesirable physical or genetic characteristics, which can be derived directly from the parameters of the model. The price of cow beef ($P_b$) is a non-homogeneous first-order difference equation, prices for bull ($P_{bc}$) and surplus heifer calves ($P_{hc}$) were based on the expected slaughter value of these animals (Tozer 1998). The profits from culling cows, depends on the weight of the cull cows, and the number of culls from these classes, which depends on the culling parameter $\delta_{(j,c)}$.

*Energy demand*

The demand for energy by an individual cow is contingent upon the physiological condition and the physical size of the cow. Total energy demand by a cow can be seperated into four physiological demands, maintenance, lactation, weight change and fetal growth, and the amount of energy required to satisfy each of these demands will depend on the time since the cow last calved. In a year-round calving dairy herd it would be reasonable to assume that there would be cows in one of three groups requiring different combinations of the four demands. The first group is made up of cows that are lactating and non-pregnant cows requiring energy for maintenance, lactation and weight change. The second group consists of cows that are lactating and pregnant, which have the same energy demands as the first group plus energy for fetal growth. The final group is cows that are dry and pregnant and these cows demand energy for maintenance, non-fetal weight change and fetal growth.

From equation 4 we can see that the milking herd will be made up of cows in one of the three physiological stages discussed above. Therefore, we can show that energy demand for the cows in each stage is a summation of the number of cows in each stage multiplied by the energy demand for the particular physiological condition. If we sum the energy demands multiplied by the number of cows in each class and collect like terms, we can show that total energy demanded by the whole milking herd is:

$$(6)\ E_{D,m} = \eta_{NP,m} + \eta_{PL,m} + \eta_{PD,m} + \alpha_c \sum_{j=2}^{5} \sum_{k=0}^{9} \tau L_{j,m-k} H_{j,m-k}$$

where $\eta_{NP,m}$, $\eta_{PL,m}$ and $\eta_{PD,m}$ represent the non-lactation energy demands for each physiological class. $L_{j,m-k}$ is the milk yield per head of a cow in age class j that calved k periods ago and $\alpha_c H_{j,m-k}$ is the number of cows in each age class that calved k periods previously. Therefore, the last term in equation 6 represents the total milk yield at time m of the dairy system multiplied by the energy content of the milk produced, $\tau$. Now, if we let:

$$(7)\ Y_m = \alpha_c \sum_{j=2}^{n} \sum_{k=0}^{9} L_{j,m-k} H_{j,m-k}$$

and substitute this into equation 6 and rearrange we have:

$$(8)\ Y_m = (E_{D,m} - (\eta_{NP,m} + \eta_{PL,m} + \eta_{PD,m}))/\tau$$

This function demonstrates that milk production is the difference between total energy demanded and the energy required for non-lactation purposes weighted by the energy value of the milk produced. We can determine from the derivation of the milk production function that it is entirely a function of **H**.

*Energy Supply*

Dairy farmers have two sources of energy for their dairy herd, pastures and forages grown on-farm, or purchased supplements. In this study we are assuming the farmer grows two types of pastures and forages, two perennial pastures and two annual forage crops. The growth and consumption of forage and pasture energy by grazing animals can be shown to be a first order difference equation with respect to the energy of the pasture and the control variable **S** (Tozer 1998). Summing across all pastures and forages yields the pasture and forage energy state variable, **E**.

The second source of energy is concentrates or supplements, $E_{e,m}$, such as ready-mix feeds, hay or grain. The amount of concentrates required will depend on **H**, **S**, the area of the farm, A, and the energy content of the supplements in the diet of each cow ($X_e$):

(10) $E_{e,m} = (\mathbf{H}_m - \mathbf{S}_m A)X_e$

Now the total energy available in any one period is the amount of pasture energy produced plus the purchased supplements and the amount of conserved feed fed in m, weighted by $\vartheta$ to account for the reduction of energy due to the conservation process. Hence, total energy supplied in month m, $E_{S,m}$, is:

(11) $\mathrm{E}_{S,m}(\mathbf{E},\mathbf{S}) = \sum_{x=1}^{4} E_{x,m}A_x + E_{e,m} + JCE_m$

*The Milk Production Function*

If we assume that energy supplied equals energy demanded in period m, then we can substitute $E_{S,m}$ into equation 8 to yield a maximum milk production function, or the milk production frontier, such as that shown in equation 12;

(12) $Y_m = (E_m - (h_{NP,m} + h_{PL,m} + h_{PD,m}))/t$

This milk production frontier tells us the maximum amount of milk that could be produced if all the available feed is consumed. However, this is not usually the case in a grazing based operation as the farmer must limit the amount of pasture or forages fed to cows otherwise it is possible there will be insufficient feed available in m+1 or beyond, thus the total milk yield will be less than $Y_m$. The milk production function is an ideal summary of the biological processes of the dairy system as it incorporates all the biological information contained within the system. The pasture and energy systems are captured in the first term and the herd dynamics are captured within the second term, in brackets. From the definition of $E_{S,m}$ and $Y_m$ we can show that total milk production is a function of the control variable, $\mathbf{S}_m$, and $\mathbf{S}_{m-1}$, and various lags of the state variables **H** and **E**.

(13) $Y_m = Y_m(\mathbf{S}_m, \mathbf{S}_{m-1}, : \mathbf{E}_{m-1}\ \mathbf{H}_{m-k})$

From the biological components of the dairy system we have developed a model of milk production in terms of these processes. This milk production function can then be incorporated into the milk revenue function of equation 1.

**Results and Discussion**

The base case generated a net present value of $282,344, see Base in Figure 1. This base situation is a typical pasture management situation, where some forage is conserved and fed in periods of low pasture production and no purchased supplements are fed. The limiting factor to a higher NPV is the availability of energy in several months over the planning period. This limiting factor is governed by the growth rates of some of the pasture and forage types in the system. Any attempt to increase the herd size above the optimal level leads to at least one of the pastures collapsing into extinction, thus imposing additional costs to the farm income.

By feeding supplements to a proportion of the milking herd the NPV increases by $35000, MM100 in Figure 1. The increase in NPV of the supplemental feeding case is limited by the available capacity of the dairy farm to handle a larger number of cows on feed. The sensitivity of the model to changes in the price of manufacturing milk is also shown in Figure 1. From this figure we can see that a 10 per cent reduction in the price of manufacturing milk (MM90) leads to a 2.5 per cent fall in the NPV of the dairy operation, which can be directly attributed to the price fall as the stocking rate remains constant. A further 10 per cent reduction leads to an 82 per cent fall in the NPV from the base situation, MM80. This drop is due to a large fall in stock numbers as well as the reduction in income caused by the price reduction. At this level of production, economics rather than biology is limiting the system, as it is not economically feasible to increase the herd size even thought there is sufficient feed for a larger herd than there is in this case.

In the polar case where cows are fed entirely on pasture and no feed is conserved, the biology of the system is the binding factor as the lowest monthly amount of energy produced over the planning period limits the size of the herd. From Figure 1 we can see that the NPV for the two pasture-fed cases, P0 and P60, are relatively low, and would indicate an operation that is not able to support the lifestyle of the dairy farmer's family. An increase of $54022 occurs when the farmer receives the higher pooled price for milk (P60) rather than the lower manufacturing price (P0), however, this still represents a situation where the farmer's gross income each year is approximately $7000.

In the situation where the farmer receives the manufacturing milk price-only and conserves feed, C0, there is an increase of $6725, or 35 per cent, from P0. This small response is due to the low marginal revenue, the price of manufacturing milk, limiting the size of the dairy herd on pasture. When the manufacturing price-only is received for milk it is not economically feasible to feed the types of supplements used in this model.

If we alter the growth rates of one of the forage types we would expect some change in the objective function value, however the size of this change will be again controlled by the biological processes in the system. An increase of 10 per cent in the growth rate of alfalfa in every period, L+ in Figure 1, which could be the result of increased fertilizer use or a higher yielding variety, leads to a small, approximately $11000 or 4 per cent increase in the NPV of the system. This relatively small increase is due to the constraints imposed on the herd size by the three other forage types, particularly the alfalfa, ryegrass and white clover pasture. An alternative interpretation of this response is that at the optimal point of the base situation one of the pastures is limiting, and it appears as though the alfalfa pasture is constraining the herd size, however, as we increase the growth rate of alfalfa another constraint is met and that is the availability of the mixed perennial pasture throughout the planning period.

This type of result is consistent with von Leibig's Law of the Minimum. Von Liebig's Law proposes that yield responses are limited by the availability of an essential component and that it is not possible to substitute one component for another (Waggonner and Norvell). Many of the studies of the Law of the Minimum have been in agronomic analyses of yield responses to fertilizer applications. In an analagous situation we suggest that low-input dairying and the milk yield from these production systems can be studied as case of the Law of the Minimum, where the limiting components are the "nutrients" of the system, or the pasture and forage energy. A point of clarification of the interpretation of the law, we can substitute one forage for another in the diet of the dairy herd, but we cannot substitute the growth of one forage for the growth of another.

A similar interpretation for the response to a reduction in the alfalfa growth rate can be made to that of an increase in the growth rate. Once again, at the optimal point in the base situation we are constrained by the total amount of energy available in particular months. If we reduce the availability of one of the essential components of the system, alfalfa, then again we would be constrained by the most limiting resource, which on the response to a reduction in growth rate, appears to be alfalfa. At the optimal point we could assume by the response to an increase in the growth rate that alfalfa was the binding variable as an increase in the growth rate of a variable in surplus would not change the objective function. Therefore, a reduction in a binding variable would lead to an equal or maybe relatively higher decline in the objective function value which occurs with the reduction in the alfalfa growth rate. This is the reaction of this model, a 10 per cent reduction in the growth rate of alfalfa, L- in Figure 1, leads to a fall of $59000 or 21 per cent in the NPV of the dairy.

Increasing the milk productivity of the cows in the dairy herd imposes on the system extra demands for energy and other nutrients This increase in energy demands must be met by the pastures and forages of the farm, and we would expect that the increase in energy requirements would decrease energy availability, which in turn could lead to a lower stocking rate. By increasing the milk output of the dairy herd by 10 per cent, Mk+ in Figure 1, the NPV of the revenues of the system falls to $55057, a reduction of 80.5 per cent. This extremely large fall in revenue is due to the binding energy source, alfalfa. Using the same intuition here as in the previous case, any increase in energy demand will be limited by the availability of the most limiting resource, alfalfa, which in turn will be constrained by the growth rate of alfalfa. The crop cannot grow fast enough to sustain both the increase in energy demand of the higher producing cows and maintain a viable basis from which to successfully regenerate over the whole planning period.

Using the high cow productivity of the previous case and increasing the growth rate of alfalfa by 10 per cent, ML+ in Figure 1, the increase in NPV above that for Mk+ is marginal, approximately 2 per cent. This result is not surprising given the response to the increase in alfalfa growth rates discussed previously. The NPV increase is again constrained by the amount of energy available in particular months from the alfalfa, ryegrass and clover pasture. The pure alfalfa pasture is not binding, but the one of the other essential components of the system is limiting the increase in the NPV.

**Conclusions**

We have demonstrated three points in this paper. First, that profitable low-input dairying is possible in certain situations. The profitability of this type of dairying is dependent on the price of milk and providing that the milk price is relatively high after deregulation, pasture-based, low-input dairying could still be profitable in New South Wales. The second point is that the management of low-input dairy systems needs to consider all the components of the system before undertaking a change in one of the sub-systems. Thirdly, the bioeconomic model constructed for this study shows that it is possible to incorporate biological components into a supply model of a dairy system in a more structured method than has been previously attempted.

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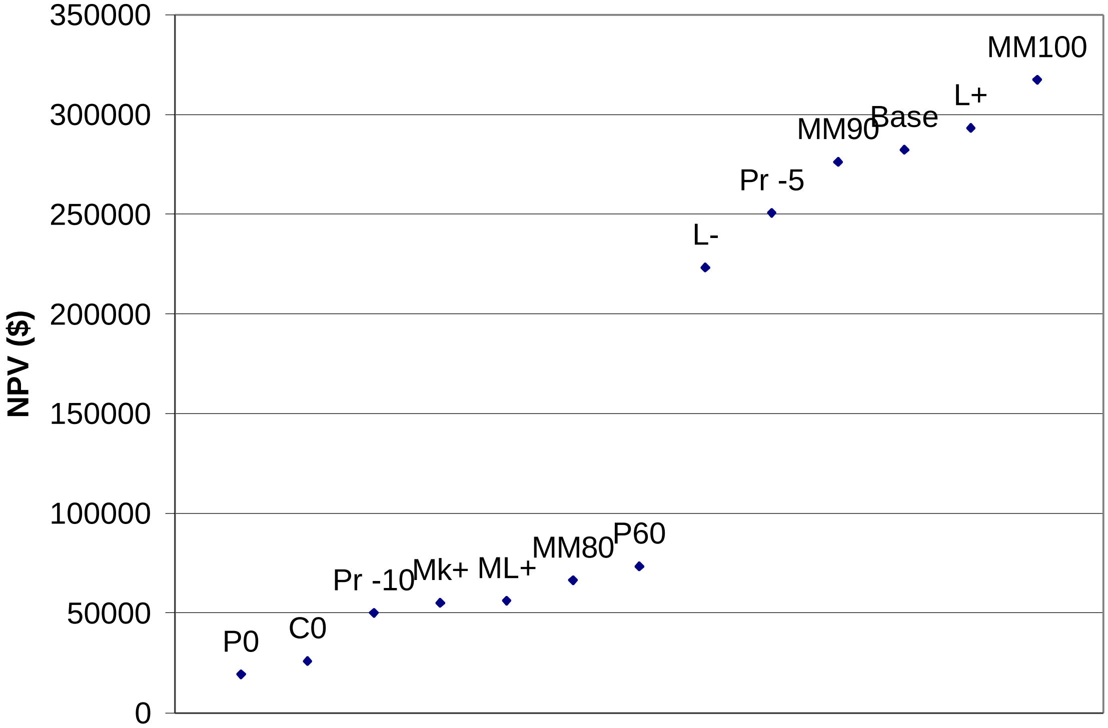


Figure 1. Net Present Value of Policy and Management Scenarios Tested