REVIEW OF MARKETING AND AGRICULTURAL ECONOMICS
Vol. 45, Nos 1 and 2 (*March* and *June* 1977)

THE ECONOMIC IMPACT OF FREE LYSINE ON THE PROTEIN FEEDS INDUSTRY IN N.S.W.*

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Free lysine, an amino acid produced industrially by microbial fermentation, is becoming increasingly important in intensive livestock production. Estimates are made of the economic impact of its wider use. The economic impact of doubling the current utilization rate of free lysine in pig production is also investigated. It is shown that the use of free lysine as a replacement for protein concentrates is marginally profitable at current utilization rates and prices. However, if experimental techniques of doubling free lysine utilization rates are adopted by the industry, the use of free lysine could lower costs of pig diets and substantially replace high lysine protein concentrates in pig diets.

1. INTRODUCTION

The pig and poultry industries are the major intensive livestock industries in N.S.W., and are the major users of concentrate feeds. Intensive livestock production requires two major types of concentrate feeds, namely energy and protein. Energy feeds are most commonly the cereals (for example, wheat, barley, oats, sorghum, maize) and, to a lesser extent, other feeds such as bran, pollard and tallow.

In addition to supplying energy, the cereal base of a diet also supplies approximately half the crude protein (CP) requirements of pigs (16.5–18 per cent CP for porker pigs). The remainder is supplied by protein concentrates. These concentrates vary between 20–80 per cent CP and can be divided into two broad quality groups based on their balance of amino acids. The high quality concentrates such as fishmeal, soybean meal and skim milk powder are suitable for human, as well as intensive livestock, consumption. Lower quality protein concentrates are generally unsuitable for human consumption and include the meals derived from cottonseed, rapeseed, linseed, peanuts, sunflowerseed, safflowerseed and copra, and meals derived as animal by-products such as meat meal and bloodmeal.

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* Comments by Jeff Davis, Sid Durbin and an anonymous referee have materially improved various sections of this paper.

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Of the amino acids constituting protein, lysine[1] is the most important since it is normally the first and major limiting amino acid in cereal-based diets[2]. The available lysine requirement of growing pigs is approximately 0.8 per cent of diet. Cereals normally contain 0.2–0.4 per cent available lysine, and protein concentrates vary from 0.5 per cent available lysine (safflower meal 20 per cent CP) to 5.7 per cent available lysine (fishmeal 65 per cent CP).

The energy, crude protein and available lysine contents of feeds commonly used in the intensive livestock industries of N.S.W. are shown in Table 1.

TABLE 1: *Average Composition of Common Feedstuffs for Intensive Livestock*

Feed	Digestible energy (Mcal/kg)	Crude protein (per cent)	Available lysine (per cent)
Wheat	3.53	12.5	0.36
Barley	3.09	11.7	0.40
Sorghum	3.44	10.6	0.21
Maize	3.53	10.6	0.26
Fishmeal	2.99	67.0	5.74
Meat-and-bone meal	2.95	54.9	2.47
Soybean meal (expeller)	3.48	43.7	2.65
Cottonseed meal	3.13	39.7	1.61
Sunflower meal (expeller)	3.12	36.8	1.30
Peanut meal	3.48	46.7	1.61
Linseed meal	3.40	34.0	1.34
Safflower meal (dehulled)	2.89	41.2	1.05
Rapeseed meal	2.80	35.0	1.91

Source: After Todd and Luttrell [9].

Recent advances have been made in developing industrial processes for producing amino acids. Methionine and lysine have now been commercially available for several years. The major problem with the use of free lysine is that, under the restrictive feeding regimes normally practised to produce carcases of high lean content, up to half of the free lysine may be wasted. This occurs because free lysine, being soluble, is digested and absorbed more rapidly than the protein-bound amino acids.

[1] The following conventions are adopted in referring to the amino acid lysine—(i) the generic name "lysine" is used to refer non-specifically to the amino acid; (ii) "feed lysine" is used to refer to the lysine content of naturally occurring feedstuffs; (iii) "free lysine" is used to refer to the industrial product L-lysine monohydrochloride (98 per cent feed grade) produced by microbial fermentation which contains 80 per cent by weight of the amino acid, lysine; and (iv) "available lysine" refers to the amount of the amino acid in feedstuffs which intensive livestock can actually absorb and utilize.

[2] In the linear programming model of pig diets developed below, lysine is taken to be the only limiting amino acid since, with wheat-based diets and crude protein constrained to 16.5–20 per cent of the diet, there is no evidence that any other amino acid becomes limiting [6].

As amino acids cannot be stored in the pig, up to half the free lysine may be broken down and excreted. This problem can be avoided by more frequent feeding (e.g., at three-hourly intervals) thereby ensuring a more even flow of food through the digestive system [2, 3].

This paper examines the likely economic impact of both the increased use of free lysine, and of current research aimed at increasing its utilization rate. Since much consumed feed does not enter recorded statistics, analytic investigations of the concentrate feed market are of limited usefulness (see below), and intensive livestock have similar though not identical feed requirements, the impact of wider and more efficient free lysine use is investigated via synthesized feed supply curves based on the feed requirements for grower pigs. Although an accurate assessment of the consequences of free lysine use cannot be established by this procedure, sufficiently good estimates of potential benefits can be made to indicate the kind of market changes that are likely to follow the wider and more efficient use of free lysine.

2 PRODUCER USE OF FREE LYSINE FOR PIGS

Co-ordinated demonstrations[3] throughout N.S.W. have shown the general production superiority of a 90 per cent wheat/10 per cent meat meal/0.3 per cent free lysine pig diet over the traditional 80 per cent wheat/20 per cent meat meal pig diet on once-a-day feeding—i.e., even though the pig's utilization rate of free lysine may have been only 50 per cent. The economic usage of free lysine depends upon (a) the relative prices of energy and protein concentrates, and (b) the costs of using lysine, including feed-mixing costs and the costs of more frequent feeding if a higher rate of utilization of free lysine is desired.

2.1 Costs of Using Free Lysine

Since many pig producers mix their own feeds, the use of free lysine only marginally affects feed preparation costs. Additional care must be taken with mixing to ensure thorough blending of the small quantities (0.3 per cent by weight) of free lysine used, but this should not increase mixing costs.

In aiming for high utilization of free lysine it is necessary to feed frequently. In small, low capital cost pig enterprises, labour costs prohibit the use of frequent feeding. In a regime where pigs are fed *ad lib.*, the pig is allowed to regulate its own intake of food, thereby maintaining an even rate of food passage through the digestive system; however, in the later stages of production, it may become necessary to feed restrictively in order to prevent over-fatness. Under such a system, the costs of feeding need not have to be increased to improve free lysine utilization in the earlier growth stages (up to porker weight).

[3] Monthly and annual reports 1975–76 of District Livestock Officers (Pigs), Department of Agriculture, N.S.W.

Where pigs are intensively housed and fed mechanically under manual control, the costs of increasing free lysine utilization by frequent feeding are those costs resulting from making the feeding system fully automated—i.e., of introducing controls into the system which enable the automatic feeding of pigs at prescribed times. The capital costs of conversion for a commercial piggery have been estimated at less than $500.[4]

2.2. Benefits of Using Free Lysine

There are two main potential uses of free lysine:

(i) In conjunction with low quality protein concentrates. Free lysine allows combinations of energy and protein feeds otherwise unsatisfactory for pig feed—e.g., sorghum-sunflower meal combinations.

(ii) As a potential replacer of protein concentrates *per se*. Lysine is sufficiently limiting in some cereal-based diets that up to half of the protein concentrate is needed purely to supply lysine, all other amino acids being in excess. It is possible to supply this lysine deficiency by a free lysine supplement, thereby considerably reducing the need for high lysine feedstuffs. In fact, with high protein wheat, it is possible to completely replace the protein concentrate with free lysine and obtain satisfactory pig performance [6].

As a result of the above two factors, free lysine has the following potential benefits to the pig industry:

(a) There is a greater flexibility in feed formulation as a result of the wider range of feeds that are available. This is particularly important in Australia, as there is a wide variety of lower quality protein concentrates available.

(b) The dependence of the pig industry on the supply of high quality protein concentrates is reduced. These concentrates, mainly imported and generally expensive (especially soybean meal and fishmeal), are also sought by the poultry industry and are directly used in human nutrition.

In general, least-cost feedmixes are best derived by linear programming. However, since pig diets frequently approximate an 80 per cent grain/20 per cent protein concentrate formulation, the following rule of thumb can be applied to the farm situation where a low quality protein concentrate plus free lysine is substituted for a high quality protein concentrate where the percentage of each protein concentrate by weight is constant.

This farm-level decision rule is to use a lower quality protein source (cereal, oilseed meals other than soybean, meat meal) plus free lysine when

$$P_H > P_O + kP_L$$

[4] For a unit up to 4 000 group-penned grower pigs, the following estimated capital outlay is required to convert manually controlled automatic feeders to completely automatic operation. Approximate costs are shown in parentheses: Time clock ($60); relay switch ($25); activator (geared motor or solenoid) ($120); installation ($120).

where P_H is the price/tonne of a high quality protein concentrate; P_O is the price/tonne of the lower quality protein concentrate; P_L is the price/kg of free lysine, and k is the number of kilograms of free lysine required to bring the lower quality concentrate up to the available lysine status of the higher quality concentrate. Values for k with respect to soybean meal of the five common low quality oilseed meals and meat meal are given in Table 2.

TABLE 2: Free Lysine Supplement (kg/tonne) Required to Equalize Available Lysine Status of Low Protein Oilseed Meals with Soybean Meal

	Free lysine utilization rate	
	50 per cent	100 per cent
Safflower meal	32.0	16.0
Sunflower meal	27.0	13.5
Rapeseed meal	14.8	7.4
Linseed meal	26.2	13.1
Cottonseed meal..	20.8	10.4
Meat-and-bone meal	3.6	1.8

Source: Derived from Table 1.

3. EFFECT OF FREE LYSINE USE ON PROTEIN FEEDS MARKET

3.1. METHOD

There is little quantitative work related to the economic organization of the feed markets for Australia's intensive livestock industries. The Australian grains [10] and stock feeds [1] industries have been investigated. Some work relating to protein concentrates in Queensland [7] and N.S.W. [4] has also been published. However, there appear to be no satisfactory empirical estimates of the characteristics of demand or supply of feed for the intensive livestock industries.

In order to examine the impact of changed free lysine use on the market for protein concentrates, industry marginal cost curves for a least-cost feedmix were synthesized using monthly data in a linear programming model. Such marginal cost curves approximate short-run industry supply curves. These short-run supply curves are then used to estimate the efficiency gains that could accrue from the widespread use of free lysine at currently achieved utilization rates. Efficiency gains resulting from research into improving the utilization of free lysine are also estimated.

Because data on the stock feeds industry is so sparse, major simplifying assumptions have had to be made.

(i) The economic benefits from free lysine use are estimated in a partial equilibrium context using estimated short-run industry supply curves and historical feed prices. Without a detailed analysis of the entire Australian feeds industry, beyond the scope of the present study, this major simplifying assumption is unavoidable.

(ii) Although stock feeds are directed into two distinct but related industries, there are no available statistics on which differentiation between feed used by the pig and poultry industries can be made. Since dietary requirements of pigs and poultry are similar, though by no means identical, a second major simplifying assumption is made that grower pig diets represent diets for all intensive livestock.

The short-run marginal cost curve for a nutritionally adequate diet ("feedmix") was synthesized using linear programming (LP). An LP matrix (see Table 3) was constructed based on grower pig diets. Least-cost solutions to the LP diet for a range of feedmix levels 5 000, 10 000, . . ., 70 000 tonnes were used to determine marginal cost curves for feedmix.

Features of the linear programming model are:

(a) Least-cost solutions for feedmix use wheat as the primary energy source, and a range of protein concentrates. Wheat was chosen as the primary energy source because it is the most widely used cereal in the intensive livestock industries and because, in conjunction with the crude protein constraint in the LP matrix, lysine is the only limiting amino acid [6].

(b) Feed prices, taken from earlier [4] and current work [8; June 1976], were used to specify two known vectors of feed prices, and thus two basic estimates of industry short-run supply curves were made. While there are obviously an infinite variety of feed price vectors, it was felt that vectors from two different temporal market situations for protein concentrates would adequately specify the range of benefits resulting from free lysine use.

(c) Biological constraints for energy, crude protein and available lysine were based on conventional pig nutrition. Fishmeal, cottonseed meal and rapeseed meal were restricted to a maximum of 10 per cent of diet because of problems of taint, gossypol and goitrogenic properties, respectively. These constraints are shown in their conventional form for least-cost diets in Table 3; the programme converted these constraints to physical units during solution to maintain compatibility with constraints on the physical availability of feeds.

(d) The maximum quantity of each protein feed which could enter the sequence of solutions to the least-cost problems was constrained to be the average monthly availability of protein concentrates in 1971–72 (calculated from [4]). This average monthly availability of protein concentrates implies a maximum feedmix level of 60 000 tonnes per month. Since the use of free lysine economizes on the use of protein concentrates, monthly feedmix levels were extended to 70 000 tonnes whenever free lysine was used.

TABLE 3: Basic Linear Programming Formulation of Least-Cost Diet

	Wheat	Fish-meal	Blood-meal	Meat meal (>50 per cent CP)	Meat meal (<50 per cent CP)	Soybean meal	Cotton-seed meal	Sun-flower meal	Linseed meal	Rapeseed meal	Safflower meal	Free lysine	‡Constraint and right hand side
Objective function—													
($/tonne)—1971–72	49.8	142.1	127.8	86.8	78.2	116.2	76.0	82.0	80.0	50.0	92.5	3 500	..
—June 1976	99.0	385.0	343.0	150.0	126.0	218.0	140.0	116.0	116.0	200*	101.0	3 500	..
Digestible energy (Mcal/kg)	3.53	2.99	2.68	2.95	2.87	3.40	3.13	3.12	3.40	2.80	2.89	..	{ GT: 3.00n** LT: 3.50n
Crude protein (per cent)	12.5	67.0	82.3	54.9	45.0	46.0	39.7	36.8	34.0	35.0	41.2	..	{ GT: 16.5n LT: 18.0n
Available lysine (per cent)	0.36	5.74	4.62	2.47	2.13	2.84	1.61	1.3	1.34	1.91	1.05	80†	GT: 0.8n
Fishmeal	..	1	..	..	..	..	..	..	..	..	..	..	LT: 0.1n
Cottonseed meal	..	..	..	..	..	..	1	..	..	..	..	..	LT: 0.1n
Rapeseed meal	..	..	..	..	..	..	..	..	..	1	..	..	LT: 0.1n
Bulk	1	1	1	1	1	1	1	1	1	1	1	1	EQ: 1n
Availability (tonnes)—													
Fishmeal	..	1	..	..	..	..	..	..	..	..	..	..	LT: 964
Bloodmeal	..	..	1	..	..	..	..	..	..	..	..	..	LT: 276
Meat meal (>50 per cent CP)	..	..	..	1	..	..	..	..	..	..	..	..	LT: 5 193
Meat meal (<50 per cent CP)	..	..	..	..	1	..	..	..	..	..	..	..	LT: 2 405
Soybean meal	..	..	..	..	..	1	..	..	..	..	..	..	LT: 701
Cottonseed meal	..	..	..	..	..	..	1	..	..	..	..	..	LT: 1 618
Sunflower meal	..	..	..	..	..	..	..	1	..	..	..	..	LT: 2 074
Linseed meal	..	..	..	..	..	..	..	..	1	..	..	..	LT: 194
Rapeseed meal	..	..	..	..	..	..	..	..	..	1	..	..	LT: 593
Safflower meal	..	..	..	..	..	..	..	..	..	..	1	..	LT: 239

NOTES: * Assumed figure. No quote available.

** n = 5 000, 10 000, . . ., 70 000 tonnes. Table above feed availability converted to physical units for solution.

† 100 per cent utilization rate; 40 for 50 per cent utilization rate.

‡ GT: greater than; LT: less than; EQ: equal to.

3.2 Results for Conventional Feedstuffs

The sequence of least-cost problems was solved for average 1971–72 prices without free lysine being available. The protein concentrates constituting the least-cost feedmix at each iteration are shown in Table 4. The feedmix marginal cost curve is shown in Figure 1 (curve 1).

An infeasibility problem occurred above 20 000 tonnes of feedmix caused by an inconsistency between the maximum CP level permitted and the minimum available lysine constraint. The solution adopted to remove infeasibility was to relax the CP constraint above biologically desirable levels; the maximum CP level was increased from 18 per cent to 20 per cent. A further infeasibility occurred above 60 000 tonnes of feedmix since the protein feeds could not deliver sufficient available lysine. Least-cost solutions were only derived above 60 000 tonnes of feedmix where free lysine was used as a feed source.

3.3 Feedmixes Using Conventional Feedstuffs together with Free Lysine

3.3.1 Results of Incorporating Free Lysine at 1971–72 Feed Prices

Free lysine was introduced into the linear programming model as an additional activity vector. Its impact was examined at currently-achieved utilization rates of free lysine (approximately 50 per cent) and at the maximum potential utilization rate (100 per cent). At 1971–72 feed prices, free lysine did not enter the least-cost feedmix up to 70 000 tonnes of feedmix at the relaxed CP constraint (16.5–20 per cent CP). When CP was constrained to biologically desirable levels (16.5–18 per cent) at 1971–72 prices, free lysine (100 per cent availability) entered the sequence of solutions for feedmix at 20 000 tonnes. The effect of free lysine on feedmix marginal costs for both protein constraints is shown in Figure 1 (curves 2 and 3).

3.3.2 Results of Incorporating Free Lysine at June 1976 Feed Prices

The effect of incorporating free lysine in the feed supply at June 1976 prices [8] was examined although the availability of protein concentrates was not known. The average monthly availability of each protein concentrate in 1976 was assumed to be identical to that of 1971–72. Protein concentrate prices at June 1976 are shown in Table 3.

Feedmix marginal costs curves are shown in Figure 1 for the following situations: (i) no free lysine in least-cost diet; (ii) free lysine at 50 per cent utilization rate; and (iii) free lysine at 100 per cent utilization. At the relaxed CP levels (16.5–20 per cent) there was no effect of introducing free lysine at $3,500/tonne when it was only 50 per cent utilized. At 100 per cent utilization, however, free lysine entered the least-cost feedmix after cottonseed meal (at 45 000 tonnes of feedmix). At 70 000 tonnes of feedmix, free lysine substituted for soybean meal, bloodmeal, rapeseed meal and fishmeal.

*TABLE 4: Protein Concentrates in Least-Cost Diet at Various Levels of Feedmix**

Feedmix ('000 tonnes)	Average cost ($/tonne)	Marginal cost ($/tonne)	Protein concentrates in optimal solution (tonnes)							
			Meat meal (< 50 per cent CP)	Rapeseed meal	Fishmeal	Meat meal (> 50 per cent CP)	Bloodmeal	Cotton-meal	Soybean meal	Linseed meal
5	54.4	54.4	500	..	..	..	..	..	..	..
10	55.4	56.4	1 962	598	..	..	..	..	..	..
15	56.0	57.2	2 405	598	263	..	..	..	..	..
20	56.3	57.3	2 405	598	672	..	..	..	..	..
25	56.5	57.4	2 405	598	964	299	..	..	..	..
30	56.7	57.5	2 405	598	964	1 341	..	..	..	..
35	56.8	57.5	2 405	598	964	2 384	..	..	..	..
40	56.9	57.5	2 405	598	964	3 427	..	..	..	..
45	57.0	57.5	2 405	598	964	4 469	..	..	..	..
50	57.0	57.6	2 405	598	964	5 193	157	..	..	..
55	57.2	58.8	2 405	598	964	5 193	276	1 357	..	..
60	57.5	61.3	2 405	598	964	5 193	276	1 618	701	139

NOTE: * Crude protein constraint—16.5–18 per cent CP: 5–20 000 tonnes feedmix.
16.5–20 per cent CP: 27–60 000 tonnes feedmix.

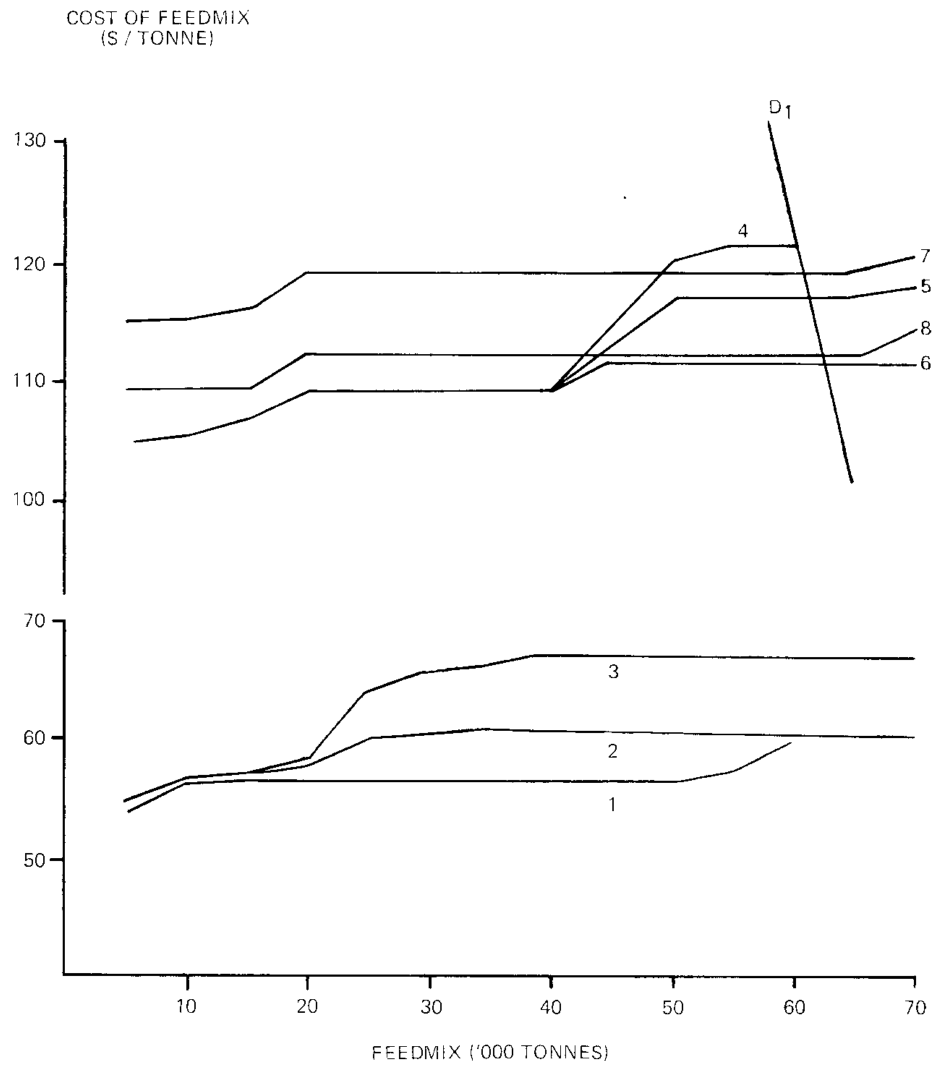

FIGURE 1. *Marginal Cost Curves For Feedmix*

KEY TO CURVE NUMBERS

FEED PRICE (YEAR)	FREE LYSINE PRICE ($/TONNE)	LYSINE UTILIZATION RATE (%)	CRUDE PROTEIN 16.5-20%	CONSTRAINT 16.5-18%
1971/72	NO FREE LYSINE IN DIET		1	, ,
	3500	50	1	3
	3500	100	1	2
1976	NO FREE LYSINE IN DIET		4	, ,
	3500	50	4	7
	3500	100	5	8
	2500	50	4	, ,
	2500	100	6	, ,

When free lysine is purchased in bulk, considerable price discounts are possible. For example, free lysine was obtained in mid-1976 by a buying group of northern N.S.W. pig producers at $2,500/tonne.[5] The effect of this lower free lysine price was to just bring free lysine into the diet at 50 per cent utilization (replacing rapeseed meal). At a free lysine utilization rate of 100 per cent, free lysine substituted for cottonseed meal at 40 000 tonnes of feedmix. Free lysine substituted for cottonseed meal, soybean meal, bloodmeal, rapeseed meal and fishmeal at 70 000 tonnes of feedmix.

With tightly constrained CP levels (*viz.* 16.5–18 per cent CP), marginal costs of feedmix are significantly greater than for all other diets at low levels of feedmix (curves 7 and 8). However, at greater amounts of feedmix, marginal costs are substantially reduced, particularly if the maximum utilization rate of free lysine is achieved.

4 ECONOMIC CONSEQUENCES OF FREE LYSINE USE AND INCREASED UTILIZATION RATES

As well as being a satisfactory biological substitute for conventional high-lysine protein concentrates, free lysine has been shown to be a satisfactory economic substitute at historical price levels and current levels of use (*circa* 60 000 tonnes). Although free lysine costing $3,500/tonne used at current utilization rates (50 per cent) does not economically substitute for conventional protein concentrates for a feedmix 16.5–20 per cent CP, at 100 per cent utilization in the same circumstances free lysine reduces the marginal cost of feedmix by approximately $5/tonne. If free lysine could be obtained at $2,500/tonne, its 100 per cent utilization for a 16.5–20 per cent CP feedmix would reduce current feedmix marginal costs by $10/tonne. Where CP is constrained to the biologically desirable levels of 16.5–18 per cent of feedmix, free lysine at 50 per cent utilization costing $3,500/tonne reduces feedmix marginal costs by approximately $3/tonne compared to a feedmix with 16.5–20 per cent CP and no free lysine; 100 per cent utilization further reduces feedmix marginal costs by approximately $7/tonne.

There are three economic consequences of these changes in industry marginal costs of feedmix—*viz.* efficiency gains, changes in consumer surplus, and changes in the prices of protein feeds. Ideally, the impact of these changes could be traced in a generalized (e.g., quadratic programming) model of the feed industry. However, such a model is currently impossible to build because of a lack of information about supply and demand characteristics for protein feeds [4].

In section 4.1 a partial equilibrium model is used to estimate the efficiency gains and changes in consumer surplus which result from the use of free lysine. Estimates of the maximum potential change in each protein concentrate price are made in section 4.2. From these estimates of

[5] Hassab, P., District Livestock Officer (Pigs), N.S.W. Department of Agriculture, Gunnedah. Personal communication.

maximum potential changes in prices, a general knowledge of the industry enables predictions to be made as to the consequences of the interactions of these potential changes.

4.1 Efficiency Gains and Changes in Consumer Surplus

The size of efficiency gains resulting from the use of free lysine is dependent upon the prices of feeds (including that of free lysine) upon which the analysis is based. The partial equilibrium efficiency gains, at constant prices and availabilities of concentrates, can be calculated from the difference between those marginal cost curves in Figure 1 for which free lysine is not, and is, used. Alternatively, the efficiency gains can be determined as the decline in the average cost of feedmix resulting from the use of free lysine times total consumption.

Compared with a feedmix at 1976 prices in which free lysine is not used, free lysine at 100 per cent utilization results in a decrease in feedmix costs per 60 000 tonnes of feed of $66,000/month and $156,000/month for free lysine costing $3,500/tonne and $2,500/tonne respectively.

These values may understate the efficiency gains to be made from free lysine use. There is the potential for producers of those concentrates entering the linear programming solutions at low quantities of feedmix to increase their prices to consumers so that the marginal cost of all feedmix is identical. The high correlations of prices of protein concentrates (see Table 5) suggest that producers of protein concentrates are keenly aware of the value of these feeds.

If the various least-cost feedmixes determined by linear programming are, in fact, homogeneous it could be expected that the industry short-run marginal cost curves of feedmix are horizontal, even though as estimated they tend to have a positive slope. In this case, the potential efficiency gains arising from the use of free lysine are determined by the product of the fall in marginal cost of feedmix and the quantity of feedmix consumed. In the case where feedmix costs are determined by the marginal cost of feedmix at, say, 60 000 tonnes of feedmix, the efficiency gains at 1976 prices resulting from the use of free lysine at 100 per cent utilization are $276,000/month (free lysine price $3,500/tonne) and $606,000/month (free lysine price $2,500/tonne).

Although the use of free lysine with a tight CP constraint (16.5–18 per cent CP) reduces the marginal cost of feedmix considerably, infra-marginal feedmix costs are high because of the high use of free lysine at lower levels of feedmix. Thus while marginal costs of using free lysine at 60 000 tonnes of feed are lower than without free lysine, there are no aggregate efficiency gains resulting from its use. However, it should be noted that, even if no gains in efficiency over conventional diets arise from the use of free lysine, the increase in free lysine utilization rate from 50 per cent to 100 per cent results in efficiency gains of $420,000/month with a 16.5–18 per cent CP constraint and a free lysine price of $3,500/tonne.

TABLE 5: Correlation Coefficients of Protein Concentrate Prices

Meat meal 50 per cent CP . .	1.00	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Meat-and-bone meal 45 per cent CP	.99	1.00	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Bloodmeal 80 per cent CP . .	.90	.89	1.00	. .	. .	. .	. .	. .	. .	. .	. .	. .
Fishmeal 65 per cent CP . .	.85	.84	.82	1.00	. .	. .	. .	. .	. .	. .	. .	. .
Fishmeal 50 per cent CP . .	.85	.85	.72	.93	1.00	. .	. .	. .	. .	. .	. .	. .
Soybean meal 45 per cent CP	.85	.85	.79	.85	.80	1.00	. .	. .	. .	. .	. .	. .
Safflower meal 22 per cent CP	.66	.66	.77	.77	.59	.85	1.00	. .	. .	. .	. .	. .
Sunflower meal 32 per cent CP	.84	.87	.82	.90	.84	.88	.84	1.00	. .	. .	. .	. .
Sunflower meal 40 per cent CP	.71	.71	.72	.83	.72	.87	.90	.92	1.00	. .	. .	. .
Linseed meal 32 per cent CP	.81	.82	.64	.76	.74	.88	.65	.75	.68	1.00	. .	. .
Cottonseed meal 40 per cent CP	.83	.84	.61	.80	.91	.78	.48	.76	.66	.80	1.00	. .
Free lysine (98 per cent feed grade)	.52	.53	.35	.33	.54	.49	.22	.41	.26	.52	.63	1.00

Source: Protein feed price series taken from "Ingredient retail prices for the Metropolitan area" (N.S.W. Department of Agriculture, Poultry Research Station, Seven Hills. October, 1974–September, 1976).

Efficiency gains which flow from the use of free lysine are highly dependent upon the free lysine price. Since it is a feedstuff wholly imported by only one or two firms, efficiency gains could easily be eliminated by a rise in the free lysine price. Possible changes in free lysine price are examined in section 4.2.

The demand for protein concentrates in the short term is substantially governed by the number of intensive livestock being fed. Thus the short-run elasticity of demand for intensive livestock feedmix is likely to be quite low—in Figure 1, the straight line demand curve D_1 has an elasticity of -0.5 at 60 000 tonnes of feedmix. Using a Marshallian partial equilibrium surplus argument in Figure 1, it is obvious that, with demand curve D_1, the short-run increase in consumer surplus as a result of the increased utilization of free lysine, is quite small. The maximum increase in consumer surplus at 1976 feedmix prices is of the order of \$3,000/month for free lysine at \$3,500/tonne; the maximum increase in consumer surplus for free lysine at \$2,500/tonne is approximately \$12,000/month. Since the average monthly value of 60 000 tonnes of feedmix at 1976 prices is approximately \$6.5 million, such short-run changes in consumer surplus are quite insignificant.

Even if medium-term changes in consumer surplus are considered, this conclusion is little varied. Gruen *et al.* put the demand elasticity for pigmeat at -2.19 (5; p. 4–51). Since the derived demand for feedmix is likely to be less elastic than that for pigmeat, the former is unlikely to exceed -2.0. At this elasticity, the gain in consumer surplus from the most substantial fall in marginal cost flowing from free lysine use illustrated in Figure 1, is only \$49,000/month, still insignificant when compared to the monthly value of 60 000 tonnes of feedmix.

4.2 Dynamic Effects of Free Lysine Use—Appropriation of Efficiency Gains

4.2.1 Potential Effects on Prices of High Lysine Protein Concentrates

An examination of least-cost solutions at 70 000 tonnes of feedmix shows the amount by which the prices of feeds not currently in the basis would have to fall in order for them to marginally substitute with basic feeds. The percentage fall in price required for each of the non-basic feeds to enter the basis one at a time is shown in Table 6.

As revealed in Table 6 the inclusion of large amounts of free lysine (*circa* 110 tonnes/month) costing \$3,500/tonne into feedmix for the intensive livestock industry implies potential price falls for fishmeal, bloodmeal and soybean meal of up to 14.6 per cent, 18.1 per cent and 6.0 per cent respectively. At a free lysine price of \$2,500/tonne, the potential price falls would be substantially greater—32.2 per cent, 33.7 per cent and 20.3 per cent respectively.

The degree to which prices of non-basic feeds would actually fall would probably be less than this since prices of all non-included concentrates would fall to permit all available protein concentrates to enter the least-

TABLE 6: Minimum Percentage Fall in 1976 Concentrate Price to Cause Change in Least-Cost Basis at 70 000 Tonnes of Feedmix

Free lysine price ($/tonne)	Fishmeal	Bloodmeal	Soybean meal	Cottonseed meal
3,500	14.6	18.1	6.0	. .
2,500	32.2	33.7	20.3	2.4

cost solution. The increased use cf free lysine could be expected to result in losses to sellers of fishmeal, soybean meal and bloodmeal. Since the bulk of the former two concentrates are imported, and hence their prices are determined internationally, increased free lysine use could be expected to significantly reduce imports of these feeds rather than be reflected in actual price falls, unless high profits are being made through importing cartels or monopolies. The fall in price of locally produced soybean meal, fishmeal and bloodmeal would be reflected in lower prices paid to Australian soybean growers and fishmeal processors; and a diversion of blood to meatmeal manufacture.

4.2.2 Potential Effects on Prices of Low Lysine Protein Concentrates

In the preceding section it was shown that the wider and more efficient use of free lysine would lower the current value of high lysine protein concentrates (fishmeal, bloodmeal, soybean meal), and the maximum potential fall in each concentrate's value was calculated. The converse of a fall in the value of high lysine protein concentrates is an increase in the value of the lower lysine concentrates. Thus, a new price hierarchy would be established with the same degree of price correlation as shown in Table 5, but with a different series of relationships between feed prices.

The maximum potential price increase for each basic feed can be determined from the least-cost solution at a feedmix level of 70 000 tonnes. Although shadow prices can be used for determining potential price increases, a simple algebraic method[6] was used since the only operative

[6] For free lysine, F, another basic feed, C, and a non-basic feed, S, a marginal change in physical units of feed in the least-cost solution is represented by

$$\triangle F + \triangle C = \triangle S \quad \text{(i)}$$

and we wish to discover the maximum price of one feed with the other two prices constant. Thus, for P_F, P_C and P_S the respective feed prices we have

$$\triangle F.P_F + \triangle C.P_C = \triangle S.P_S \quad \text{(ii)}$$

or, say,

$$P_F = (\triangle S.\, P_S - \triangle C.\, P_C)/\triangle F \quad \text{(iii)}$$

The associated change in lysine, since available lysine is the only resource whose constraint is operative at the least-cost solution, is

$$\triangle F.L_F + \triangle C.L_C = \triangle S.L \quad \text{(iv)}$$

where L_F, L_C and L_S are available lysine levels in each feed, respectively. Let the marginal change in the least-cost solution be given by

$$\triangle S.L_S = 1 \quad \text{(v)}$$

Then, substituting (v) in (i) we have

$$\triangle F = (1 - \triangle S.L_C)/(L_F - L_C) \quad \text{(vi)}$$

and hence

$$P = (\triangle S(P_S - P_C)(L_F - L_C) + P(1 - \triangle S.L_C))/(1 - \triangle S.L_C)$$

resource constraint in the solution was available lysine. It can be shown that the upper limit on free lysine price P_F as a function of a non-basic feed S is given by

$$P_F = (\triangle S(P_S - P_C)(L_F - L_C) + P_C(1 - \triangle S.L_C))/(1 - \triangle S.L_C)$$

where P_S is the price of the non-basic feed, P_C is the cost of the cheapest feed in the least-cost solution; L_F, L_S, L_C are the proportions of available lysine in free lysine, the non-basic feed and the cheapest feed, respectively; and S is the reciprocal of L_S.

Similarly, a rearrangement of the equation can be used to determine the maximum increase in the price of other feeds in the least-cost solution. The maximum potential increase for each basic feed price relative to the non-basic feeds is shown in Table 7.

TABLE 7: *Minimum Percentage Increase in* 1976 *Prices of Feeds in Basis at* 70 000 *Tonnes of Feedmix to Cause Change in Basis*†

Basic feed*	Fishmeal	Bloodmeal	Soybean meal
Wheat	60.6	66.7	14.1
Meat meal (> 50 per cent CP) ..	65.3	68.7	34.7
Meat meal (< 50 per cent CP) ..	85.7	89.7	49.2
Cottonseed meal	50.7	55.0	18.6
Sunflower meal	71.6	75.9	31.0
Linseed meal	72.4	77.6	32.8
Safflower meal	86.1	92.1	40.6
Free lysine	23.7	33.1	12.0

NOTE:

† Free lysine 100 per cent utilization rate at $3,500 per tonne.

* The price comparison is between the substitution of 1 unit of available lysine in a non-basic feed, and a composite of a basic feed plus free lysine; in the case of free lysine, the comparison is between the non-basic feed and free lysine plus wheat.

A comparison of Tables 6 and 7 suggests that there could be considerable relative changes in concentrate prices following the wider and more efficient use of free lysine. Of particular interest is the fact that free lysine is wholly imported by one or two firms: hence the possibility exists for a large rise in the import price of free lysine.

5 CONCLUSION

Current research aimed at demonstrating the usefulness of free lysine use in pig diets and increasing utilization rates of free lysine can be expected to have significant economic effects. The potential effects include a cheapening of feed costs to the intensive livestock industries of up to $10/tonne of feedmix. Protein concentrates most affected by this change will be high lysine concentrates such as fishmeal, soybean meal and bloodmeal. Indeed, widespread use of free lysine may substantially reduce the amounts of fishmeal and soybean meal imported into Australia. Additionally, since the current marketing of free lysine in Australia is undertaken by a very small number of firms, the bulk of the efficiency gains that could arise from increased and more efficient free lysine use could be appropriated by sellers of free lysine through higher prices.

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