The University of Western Australia

AGRICULTURAL ECONOMICS

SCHOOL OF AGRICULTURE

Nedlands, Western Australia 6009

THE LONG TERM PEAK LOAD PROBLEM IN GRAIN STORAGE: AN EMPIRICAL ANALYSIS

D BRENNAN AND R K LINDNER

Agricultural Economics
Discussion Paper 9/89

Contributed Paper presented to the Thirty-Third Annual Conference of the Australian Agricultural Economics Society, Lincoln College, Christchurch, New Zealand, 7-9 February 1989.

The authors are grateful to the Wheat Research Committee of Western Australia for financial support for this project.

THE LONG TERM PEAK LOAD PROBLEM IN GRAIN STORAGE: AN EMPIRICAL ANALYSIS

Abstract

The cost of investing in grain storage capacity at country receival points depends on the technology used (level of capital intensity) as well as annual variation in the volume of grain produced. Peak load pricing theory, which was originally formulated to examine investment problems for public utility industries who face a fluctuating and uncertain demand, was applied to the grain storage problem. A cost minimization investment model is outlined which examines the problem of choosing the optimal combination of technology types, and the total level of storage to meet a fluctuating demand for storage.

An examination of the marginal costs of grain storage reveals that the demand for storage should generally be met by using permanent horizontal storage technology to satisfy most demand, while using bunker storage to satisfy the peak demand arising from bumper harvests. This is in contrast to the widespread use of vertical storage in some states, particularly South Australia. It is revealed that the capital costs of vertical storage are far too high to justify investment for the long term storage of grain.

An examination of actual investment levels in Western Australia revealed a generally high level of overinvestment, with some sites having twice as much storage as they should have had. A second major finding was that many sites appeared to be too small to justify the high fixed costs associated with investment in permanent storage facilities.

Introduction

Recent studies have highlighted many inefficiencies in the grain storage, handling and transport industry (Royal Commission into Grain Handling and Storage (RCGH) (1988), Blyth, Noble and Mayers (1987), Kerin (1985)). However, these studies have focused mainly on spatial issues concerning the level of centralisation of handling facilities and intermodal competition, and have paid little attention to the optimal mix of technologies at receival points, or the total level of storage that should be available to cope with a fluctuating annual harvests. This paper applies a theoretical model which was presented at last year's conference to examine the optimal level and mix of storage technologies. After outlining the basic features of the model and discussing the various grain storage technologies and costs, the efficient combination of storage types is identified. Our optimal criteria are then compared with the actual level of storage at a number of sites in Western Australia, and the inefficiencies of the current system are highlighted.

The Theoretical Model

The grain storage investment problem is like an optimal inventory problem in which there is a trade off between the cost of providing extra storage which may not be needed with the cost of not having enough storage in a year of high production. It is also similar to the peak load problems faced in public utilities - where the cost of not having enough storage is like the loss in consumer surplus associated with not having enough capacity to meet all demand. We present a model which was based on a modified version of Crew and Kleindorfer's investment model for public utilities with diverse technology and fluctuating demand (Crew and Kleindorfer 1976) .

The model examines the optimal amount and type of storage that should be constructed at a site. In the simple version of the model it is assumed that all of the grain that is harvested is stored in the country, apart from some grain that might be shifted to the port as an emergency option. This is an oversimplification as number of sites handle a volume of grain that is larger than the physical storage capacity, with a substantial railing out programme during the harvest period. Nevertheless, it is a reasonable assumption for most sites, because the rail system could not shift the grain to the port during the 6 week harvest period, without requiring grossly uneconomic extra capacity.Consequently, the assumption that there is an upper bound of unity on the turnover of grain (grain received/storage capacity) is valid for most country sites.

The investment model aims to minimise the expected cost of storing grain, where the demand for grain storage is defined by the fluctuating annual production level, and the costs of storage include the marginal costs of capital (B_i), marginal operating costs (b_i) as well as a failure cost, which is a function of the level of excess demand. There is a choice of technologies available, which are characterised by an inverse relationship between capital and operating costs. Hence there is a trade off between investing in capital intensive technology, and investing in technology that has low capital costs but high operating costs. While the capital intensive technology may cost much less where demand is certain, the trade off becomes increasingly important as expected utilisation decreases, so that the labour intensive storage is better for dealing with the extra demand created in peak harvest years.

A detailed explanation of the model is given in Brennan and Lindner (1988), but the the basic results for the most simple assumptions (constant marginal and average costs) can be demonstrated diagrammatically. We distinguish between capital intensive (permanent) and labour intensive (temporary) storage by the subscripts p and t, while failure of storage capacity to cater for storage demand in a given year is denoted by the subscript f. The expected use of a *marginal* unit of storage (ie. the probability that demand for storage is greater than or equal to that level of storage capacity) is denoted by the cumulative density function $\Phi(K^*) = \int_{K^*}^{\infty} \phi(q_i)dq$.

of the marginal unit and is a function of utilization $(B_i + \Phi(K^*)b_i)$. Utilization is shown on the horizontal axis and is equal to 1 at the left hand side of the figure, and as we move across the figure, it reduces to zero. Note that utilization is inversely related to the total amount of storage, and if we had knowledge of the production c.d.f we could draw the same diagram mapped onto a horizontal axis showing marginal expected costs as a function of increasing capacity.

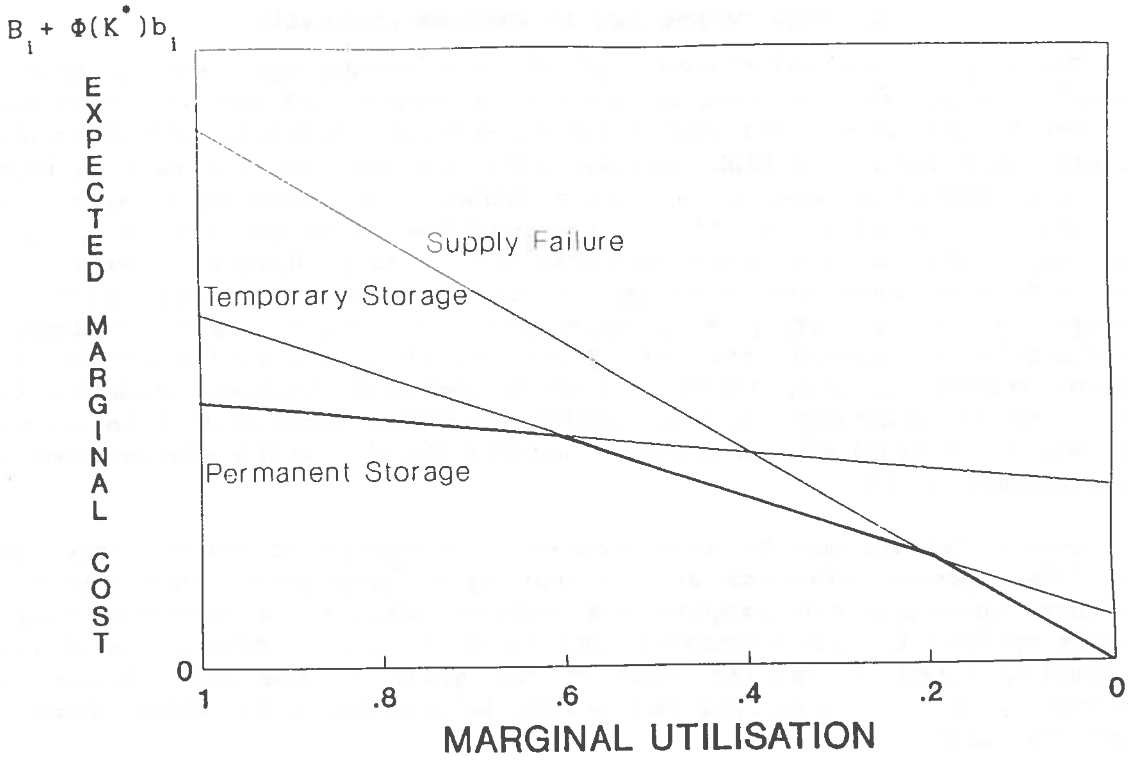

Figure 1: Efficiency Frontier

The nature of the trade off can best be seen by reference to the kinks in the diagram, which correspond to the first order conditions derived from the mathematical model (Brennan and Lindner 1988). These are:

> Invest in permanent (capital intensive) storage up to the point where ratio of the savings in capital costs and the extra operating costs associated with using temporary storage are just equal to the marginal utilization of capacity $(B_p - B_t)/(b_t - b_p) = \Phi(K_p)$[1].

---

[1] Note that if the left hand side of the equation is greater than one, the capital intensive storage type is not efficient, because this implies that its marginal cost at full utilisation is greater.
ie. if $(B_p - B_t)/(b_t - b_p) > 1$, then $B_p + b_p > B_t + b_t$, hence permanent storage is not efficient.

and similarly,

> Desist from further investment in storage at very low expected utilisation levels as it is cheaper to bear the high cost of infrequent failure. This condition is written $B_t/(b_f - b_t) = \Phi(K_p + K_t)$.

Storage Technology in Western Australia

There are four major types of storage technology used in Western Australia. They are (in order of decreasing capital intensity) - Vertical, Horizontal, CLS bunker and nonCLS bunker storage. Vertical and horizontal storage types both have high capital costs and are characterized by being totally closed structures with fixed machinery for inloading the grain and outloading onto rail. By its nature vertical storage has much lower operating costs, as the grain outloads via gravity. However, the capital cost of this storage type is higher. At the other extreme, there is bunker storage, which is simply a bitumen pad onto which grain is dumped, contained by corrugated iron walls. The inloading and outloading of this type of storage is very labour intensive and also involves covering the grain with PVC sheeting. A more capital intensive version of this storage has some fixed machinery (a Conveyor Loading System) which reduces some of the inloading costs.

Supply failure may be accommodated by a number of means - the long lead time between planting and harvesting a crop means that the bulk handling authority can prepare for supply failure in advance. Supply failure options include transport options such as providing extra storage at country sites by railing some of the grain to the port during the receival period or diverting deliveries to another site where there is space available.

However, transport options are limited by the capacity of the transport system in the peak period, and the consequent peak load costs. An alternative method of meeting supply failure involves the construction of additional bunker storage prior to harvest in an emergency year. We call this supply failure option 'emergency storage' in the following analysis.

Costs of Storage Options

Capital Costs

Work by the Royal Commission indicates that there are declining average construction costs associated with constructing permanent storage facilities (RCGH 1988). From this work we can derive marginal and fixed costs of construction of vertical and horizontal storage. Marginal costs are amortized to reflect an annual value, and fixed annual maintenance costs are added. In order to take account of the effect of segregation, capital costs are scaled up to reflect the cost of an effective unit of storage capacity, by 5% for vertical storage (Kerin 1985) and 15% for horizontal storages (Co-operative Bulk Handling Ltd. (CBH) 1988). Costs are shown in Table 1. There is no evidence on the shape of the construction cost of bunker storage, but we assume that average costs approximate marginal costs, apart from the fixed costs associated with constructing the conveyor system, in the case of CLS bunker storage.

TABLE 1: CAPITAL COSTS OF STORAGE $/tonne

	Marginal Cost	Fixed Cost
vertical	4.936	51230
horizontal	2.307	38320
cls bunker	2.003	3610
noncls bunker	1.441	0

Operating Costs

While the RCGH work indicated that grain receival points may have declining average operating costs, cost curves for different storage types were not examined. Kerin also provides evidence on declining average operating costs, but noted that it was mainly due to the fixed costs associated with opening a facility. As we don't have any information on marginal costs it is necessary to use average operating costs. Despite the observed shape of average cost curves in recent literature, the error associated with using average costs to represent marginal costs is reduced because many of the fixed costs associated with opening a site (weighing, sampling) do not depend on storage type, and are assessed independently in our data. Costs are based on those presented in CBH's submission to the RCGH. In addition, an extra cost of queuing is added to the cost of inloading into nonCLS bunker storage, to allow for the effect of the slower rate of inloading grain into this storage type. The outloading of grain from bunker storages onto rail generally makes use of the machinery attached to permanent storages, so the costs of using bunker storages are higher where there are no permanent storages at the site, as slow portable elevators must be used. Operating costs are shown in Table 2.

The marginal cost of supply failure is likely to be an increasing function of the level of excess demand, because of the limited availability of low cost options (such as diverting to a neighbouring site) and the effect of peak transport costs. For simplicity we represent the cost of supply failure as the cost of building extra storages in a peak year but it should be noted that this is likely to overestimate the average cost of supply failure, because of the availability of transport alternatives, and the fact that emergency storage can be pulled apart and used at another site in another year, reducing effective capital costs. Consequently, our results will err on the side of *overestimating* total optimal investment.

TABLE 2: OPERATING COSTS OF GRAIN STORAGE $/tonne

Vertical	.996
Horizontal	1.400
CLS Bunker	3.332
NonCLS Bunker	5.012
Supply Failure	14.012

+ penalty of $1.011/t for outloading CLS and nonCLS bunker storages if there are no permanent storages at the site.

Efficient Storage Types

It can be seen that the options available satisfy the conditions of inversely related capital and operating costs. However, not all storage technologies are efficient options, as shown by the efficiency frontier in Figure 2.

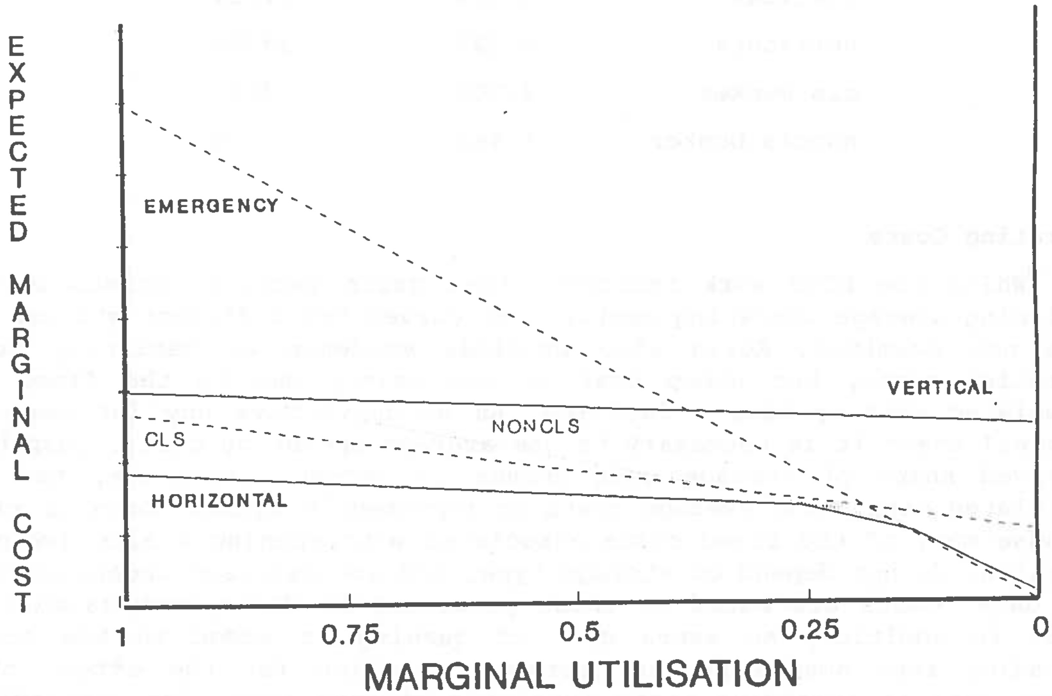

Figure 2: Efficiency Frontier Showing Least Cost Combination of Storage Types

Vertical Storage

The efficiency frontier shows that the storage marginal cost line for vertical storage always lies above the other lines, indicating that it not an efficient option. However, it is possible that vertical storage (because of its faster outloading rate) might achieve cost savings in railing the grain, making it relatively more efficient when compared to the other storage types. From work done by the RCGH on the effect of different outloading rates it appears that the difference in rail costs for grain that is railed from vertical storage facilities and other storage types might be as high as as $1/tonne[2]. However, even after accounting for a penalty associated with using horizontal storages, the ratio of the difference in capital and operating costs is equal to 1.75. This implies that vertical storage is an inefficient technology for a once a year operation.

Note though that while vertical storage is not efficient when considered solely as a storage option, its relatively low operating costs mean that,it may be the best alternative where high handling to capacity ratios are achievable. In last year's conference paper we developed the following efficiency criteria for investment where a high handling to capacity ratio α was possible:

---

[2]This figure reflects the cost differences between inloading rates of 100 and 500t/hr.

$$(B_v - B_h)/(b_h - b_v) \leq \alpha\Phi(\alpha K_v)$$

This implies that a turnover level of at least 1.75 would be necessary to justify investment in vertical storage if storage were to be fully utilised. certain. However, because of the variability of production, a higher turnover level will be necessary to justify vertical storage[3]. For example, investment in vertical storage to meet all production in 50% of years would require a turnover level at least 3.2. Obviously, this turnover level would be impossible to apply across all sites because of the high peak load costs it would impose on the transport industry. This indicates that vertical storage is not an efficient option as a country storage alternative, although it may be an efficient alternative at subterminals or high throughput sites.

Horizontal Storage

It can be seen from the efficiency frontier that horizontal storage is an efficient option and should be used to meet the majority of storage demand. If provided at an optimal level, it should satisfy all demand in 7 out of 10 years. This result is independent of the variance of production at a site, which means that the optimal storage capacity will be relatively larger (and average costs will be higher) at those sites where production is more variable - this is because it is marginal costs not average costs, that determines optimal investment criteria, and a minimisation of marginal costs ensures a minimisation of total and average costs.

CLS storage

An examination of the efficiency frontier shown in Figure 2 reveals that CLS bunker storage is not an efficient option.

However, it should be noted that where the demand for storage is low and required capacity is small, fixed costs of horizontal storage may mean that average costs are higher than the average costs of CLS bunker storage which is the the second cheapest option at full utilization. This situation may arise where receival points are very small, or where there is a need to expand the capacity of an existing receival point to meet increases in demand.

Noncls and Mobile storage

According to the costs shown in Tables 1 and 2, and the efficiency frontier represented in Figure 2, then both nonCLS and Emergency storage are part of the efficient set. Long term investment in nonCLS bunker storage is considered a better option than emergency storage at utilisation rates larger than 15%. At lower expected utilisation rates the bulk handling authority is better off waiting until it knows there will be excess demand and constructing bunker storage before the season opens.

Before discussing the analysis of Western Australia sites, the effect of fixed costs on the optimal investment criteria are discussed.

---

[3]This is intuitively obvious, as the right hand side of the equation still describes the expected annual utilization of storage. If demand were certain, this would be reduced to α, or the number of times a unit of storage was used during the year, consistent with the early deterministic models of peak load pricing under diverse technology (Eg. Wenders 1976).

Effect of Fixed Costs

Where optimal capacity is small, average costs of permanent facilities become high due to the fixed cost of investment. At small capacity levels, it is possible that marginal conditions are no longer sufficient, as the average costs of the less capital intensive facilities may be lower than those of permanent facilities. However, while high fixed costs make permanent facilities appear costly at low capacity levels, there is an additional cost associated with using bunker storages when there are no permanent facilities at the site, because the outloading rate is slowed. Figure 3 shows a comparison of the expected average costs of investing in horizontal storage with those of investing in CLS bunker storage at a range of mean receivals. The effect of fixed costs imply sharply declining average costs for horizontal storage facilities, and the high average costs at small capacity levels mean that it is cheaper to use temporary facilities (CLS bunker storage) when expected receivals are lower than 14000t. However, judging from the sharply declining average costs, as well as the high fixed costs of setting up a site it is obvious that the real issue might be whether or not receival points of such low sizes are justified. The issue of the optimal location and size of receival zones is beyond the scope of this analysis.

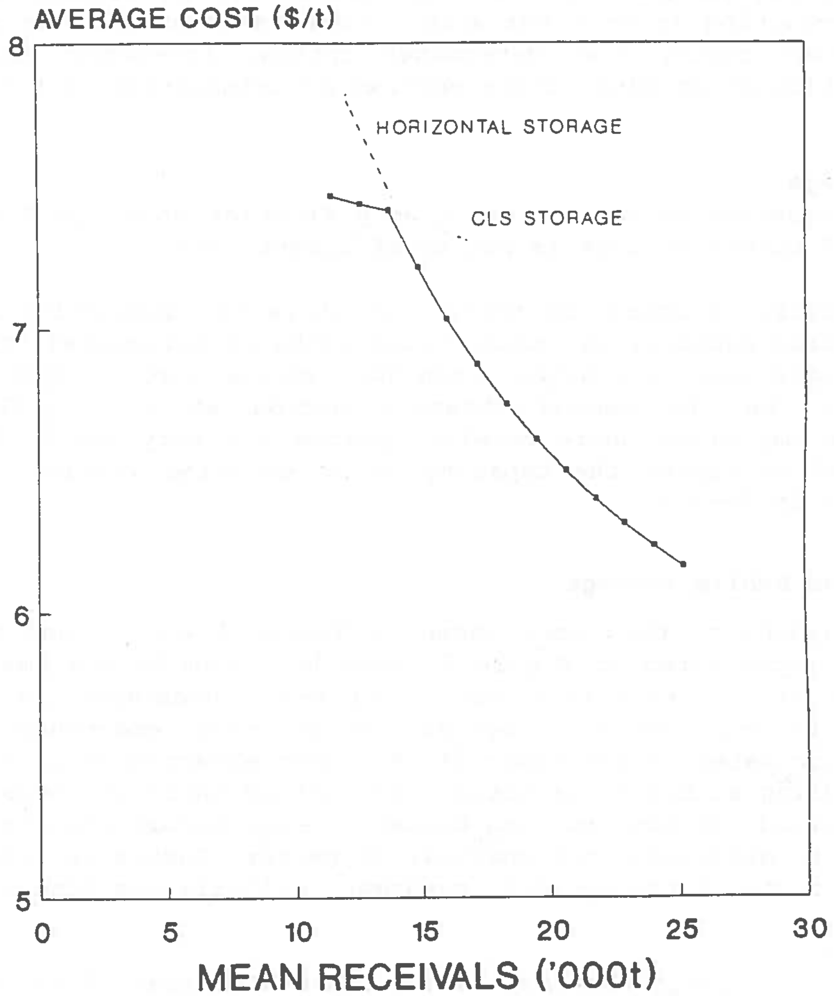

Figure 3: Average Costs of Grain Storage

Investment under Production Growth

The use of bunker storage (as an alternative to constructing an additional horizontal storage facility) to meet small capacity increases due to demand growth is relatively more attractive as there is no penalty associated with outloading bunker storage, as there already exists one permanent storage at the site.

We calculate that an additional horizontal storage shouldn't be constructed at a site we unless capacity expansion requirements to meet demand increases are in excess of 30000t. Consequently our static analysis, which ignores the effect of demand growth in the WA grain growing industry may overestimate the optimal level of permanent storage, that would have occurred in a dynamic environment. The effect of demand growth on our results is discussed later.

A Comparison of Actual Storage levels

The following analysis looks at the optimal levels and mix of storages from a static sense, and compares them to the actual capacity of storage at selected sites in Western Australia. The efficiency costs, levels of over or under investment are all measured relative to the static optimal case.

One of the difficulties in comparing the model to the actual storage levels in Western Australia is dealing with the railing of grain during harvest. There is some scope for hauling grain out during the harvest period, and this has two effects on our model. Firstly, there are a number of sites that use rail in most years, and the turnover of grain through the receival point is greater than one. Secondly, the ability to use rail to shift grain during the harvest period at those sites experiencing a peak demand year lowers the cost of 'supply failure'. The inclusion of rail in our model cannot be done simply, it requires spatial considerations about the optimal allocation of rail capacity to different sites (which will increase turnover at some sites and could lead to justification of vertical storage at a few sites). It also requires an examination of the use of rail in meeting supply failure, and the correlation between supply failure at different sites.

In view of these problems, this analysis is restricted to those sites which have historically not used rail in the receival period because the assumptions about turnover being restricted to one and the high supply failure cost are reasonable. Consequently, 80 out of a total 190 sites were chosen for an analysis of the efficiency of past decision making procedures.

Measuring Production Variation

The interpretation of historical data to infer future variability in grain deliveries is made more difficult due to increases in acreage levels over time as a result to new land clearance, as well as the effect of policies which have resulted in changes in the spatial distribution of receivals over time. Because of these problems, we adopted a more pragmatic approach to estimating production variation, based on simulating a distribution for deliveries at a given site by multiplying an historical yield distribution with a function that represented expected acreage variation. Because of limited potential for new land clearance, it was thought that recent acreage levels would be more indicative of future production. The variation in acreage was simulated by assuming that price varied by about 20% (Sarris and Freebairn 1983), and that own price supply elasticity was about .6 (Hall and Menz 1985, Myers 1982). These distributions were thought to be the best available estimates of likely future production variation.

Optimal Investment Levels as a Proportion of Mean Production

When applying our investment rules to our distribution functions, it was found that total optimal storage (defined by the point .85 on the production c.d.f) was about 1.25 to 1.45 times the mean production level, depending on the variance at a particular site.

Efficiency Costs in Western Australia

Figure 4 shows the number of sites having excess and deficient total storage, as well as the combination of storage types. Of the 30% of sites classed as having too much permanent storage, half the sites proved too be so small that *no* construction of permanent storage should have taken place. Deficiencies in permanent storage were more common, and were observed at 70% of sites. However, deficiencies in permanent storage were more than made up for by bunker storage investment in many cases. *At least* 70% of the sites examined had too much total storage although the actual level of over investment may be larger as we have overestimated supply failure costs. The volume of over-investment was generally larger than the volume of under investment when measured as a % of the optimal, see Table 3, and costs of over investment were higher, with average efficiency costs being $1.59/t (about 20% higher than optimal). There was a large degree of variation in the size of efficiency costs (the difference between actual and optimal costs, in $/t), Figure 5 shows efficiency costs plotted against the total level of over investment. With the exception of 6 sites, a general linear trend can be seen between efficiency costs and the level of over investment. Those sites that have twice as much storage as they need have an expected efficiency cost of about $3/t, which is about 50% higher than the optimal cost. The six sites that lie outside the trend showing much higher efficiency costs are those sites that have vertical storage, which is inefficient where turnover is restricted to one. The average efficiency cost of those sites having vertical storage was about $5.33/t. This is nearly double what the costs should be.

However, apart from the sites having vertical storage, the efficiency costs are largely explained by the total level of over investment. Differences in the mix of permanent and bunker storage can explain deviations about the trend line, but are not very significant.

TABLE 3: AVERAGE EFFICIENCY COSTS IN WESTERN AUSTRALIA

AVERAGE EFFICIENCY COSTS:	those with too much storage	$1.59/t
	those with not enough storage	$ .76/t

AVERAGE % CAPACITY DIFFERENCE BETWEEN ACTUAL AND OPTIMAL:

over investment	33%
under investment	19%

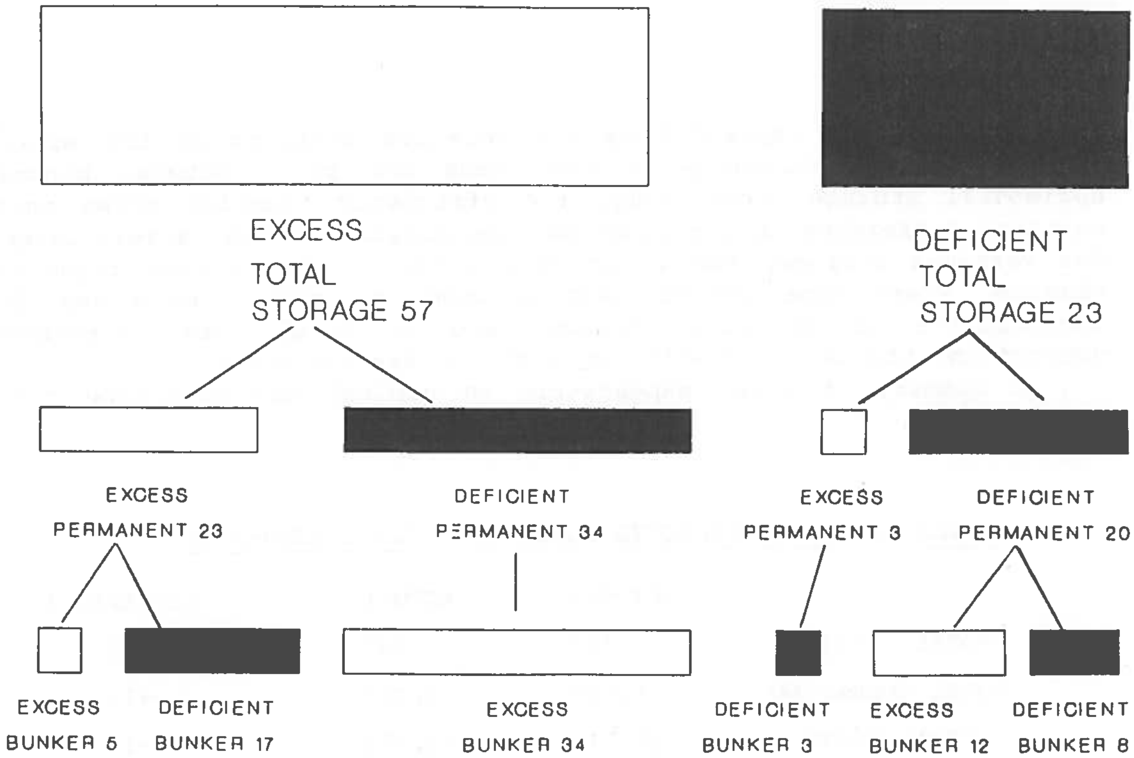

Figure 4: Number of Sites Having Excess / Deficient Storage

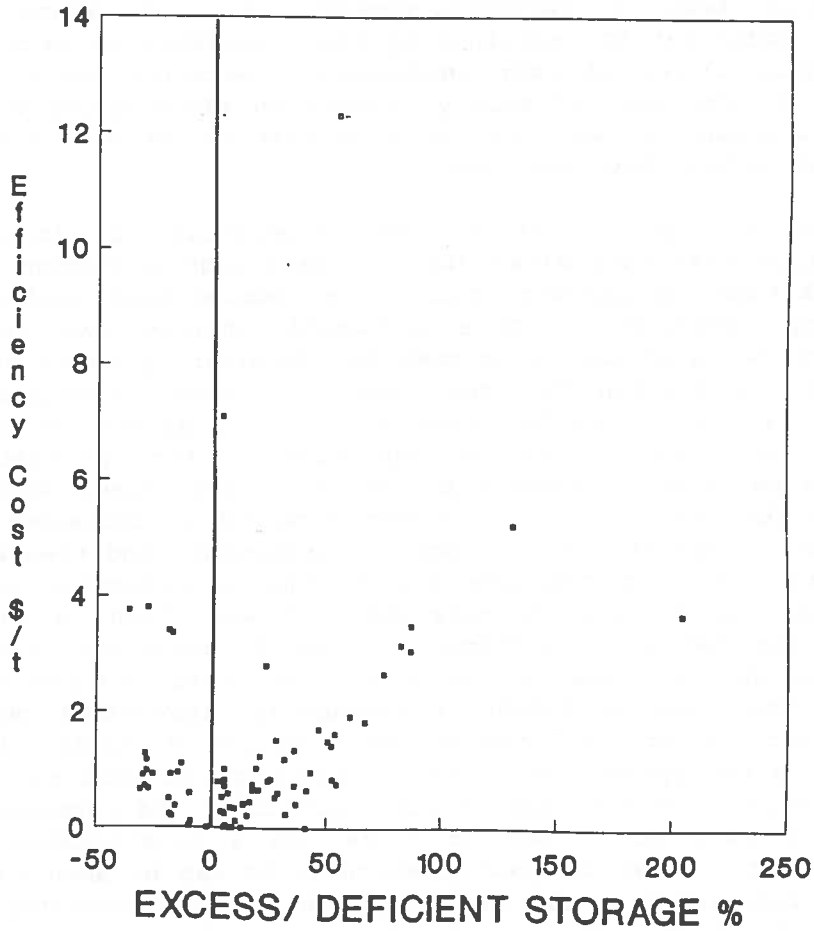

Figure 5: Efficiency Costs as a Function of Total Overinvestment

This fact can be explained by the relative flatness of the efficiency frontier in the vicinity of the trade off point between bunker and horizontal storage. Conversely, the efficiency frontier shows that the vertical difference in the lines showing marginal costs is very large for vertical storage, and it is also large at the extreme right of the diagram, where expected utilization tends to zero. These explain the significance of vertical storage, and of total over investment in determining the level of efficiency at the various sites.

A summary of total expenditure on capital and operating costs is shown in table 4.

TABLE 4: TOTAL EXPECTED COSTS OF SITES EXAMINED ($ '000)

	OPTIMAL	ACTUAL	% DIFFERENCE
TOTAL CAPITAL	8,193	9,493	+15
TOTAL OPERATING	4,025	4,459	+10
TOTAL COSTS	12,218	13,952	+14

It can be seen that at an aggregate level, the total expenditure on both capital and variable items was larger than it should have been. This is because there was excessive expenditure on the wrong technology, high capital costs can be explained by the occurrence of vertical storage and the general level of over investment. Operating costs are also higher because of the cost of supply failure on those sites which didn't have enough storage, as well as the high cost of using bunker storage where permanent should have been used.

The evidence of capital over expenditure is in contrast to the observation that many sites didn't have enough permanent storage. Indeed, the bulk handling industry could have reduced both capital and operating costs by investing in more permanent storage and following a more efficient decision making process for determining total storage levels. A possible explanation for the level of under investment in permanent storage is that there has been significant growth in demand since the storages were constructed. In many sites in Western Australia, there is only one permanent storage type, which in some cases were constructed as early as the 1970's. There have been substantial increases in receivals at many sites since the 1970's, due to increasing land clearance, as well as increasing cropping capacity due to the introduction of legume crops, which can replace pasture rotations. It was shown in the discussion on fixed costs that it is difficult to justify construction of an additional permanent storage, due to the high fixed cost, unless demand increases were in the order of 30000t. Consequently, investment decisions made in the dynamic growth environment may include a higher level of bunker storage in the optimal set, due to expanding production. Historical data on receivals since the time of construction of the permanent facility at a site were examined to see if there was a relationship between demand growth and the level of over investment. As can be seen in Figure 6 there is some relationship, but demand growth doesn't consistently explain the observed level of under or over investment in permanent storage at many sites. Another explanation for the diversity of the results is that the expectations of decision makers may have varied at the time of investment.

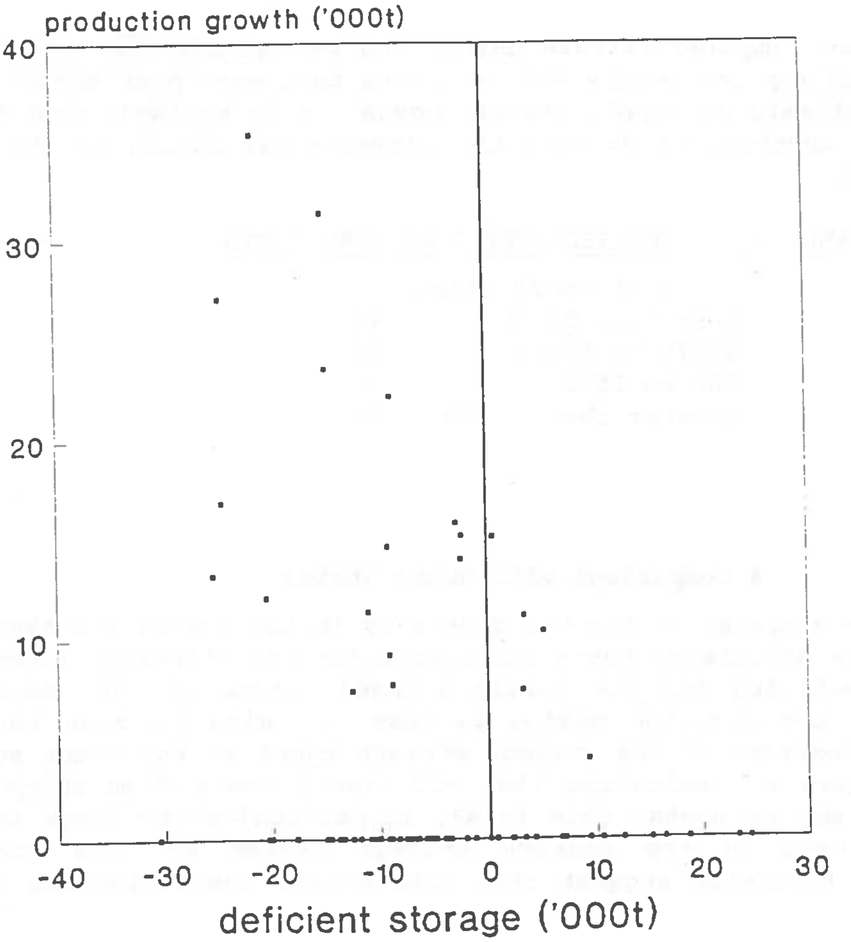

Figure 6: Deficiencies in Permanent Storage Compared to Production Growth that Occured Since Construction of Original Storage

A possible explanation for the observed level of over investment in total storage might be that the CBH expect further growth in production over future years. For this explanation to be valid, there also would need to be over investment in the technologies that have high fixed costs. On the contrary, the actual large levels of over-investment were in the form of bunker storage. An alternative explanation for the apparent level of over investment in WA might be that decisions makers perceive the costs of supply failure to be higher than shown here. By examining the actual investment levels we can derive estimates of an *implied* supply failure cost.

As shown in an earlier section, the investment decision for long term storage capacity continues until the marginal utilisation of the last unit of storage is equal to

$$B_{nc}/(b_f - b_{nc}) = \Phi(K_{total})$$

By rearrangement, we can calculate implied failure costs to be

$$b_f = [B_{nc} + b_{nc}\Phi(K_{total})]/\Phi(K_{total})$$

Table 5 shows implied failure costs, and we can see that more than half the sites had implied supply failure costs that were much higher than any reasonable estimate of supply failure costs. It is unlikely that these high values have anything to do with the grower's evaluation of the cost of supply failure.

TABLE 5: IMPLIED SUPPLY FAILURE COSTS

	% of total sites
less than $20/t	43
$20/t to $50/t	22
$50 to $500/t	11
greater than $500/t	16

A Comparison with Other States

One possible explanation for the diversity in the levels and types of investment and the efficiency costs calculated for the different sites, is the lack of competition and the serviced based nature of the industry. Inconsistency in the decision making process can also be seen between States. The combinations of the various storage types in the other states are shown in Figure 6, indicating that efficiency costs from suboptimal mixes of storage may be higher than in WA. In particular the large amount of vertical storage in the country storage system of some states, especially South Australia suggest that substantial inefficiencies occur in those states.

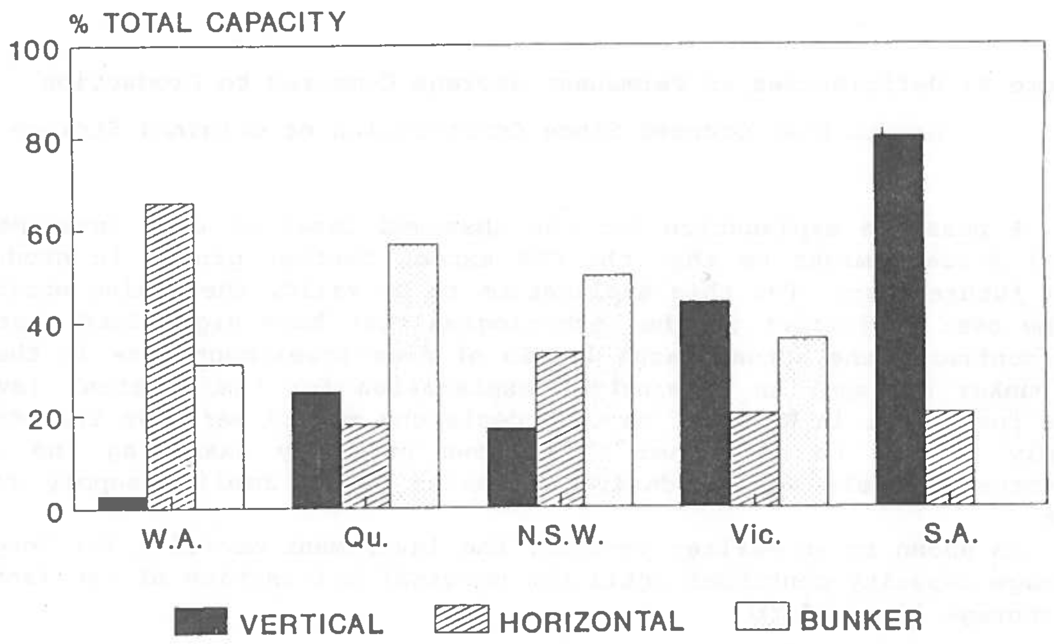

Figure 7: Mix of Storage Types in the Country Storage Systems of Various States

Moreover, while the aggregate figures indicate that WA may have the highest amount of over-investment in terms of total volume (Figure 7), sub optimal mixes of storage types may indicate a larger degree of over expenditure has occurred in the construction of country storage facilities in other states.

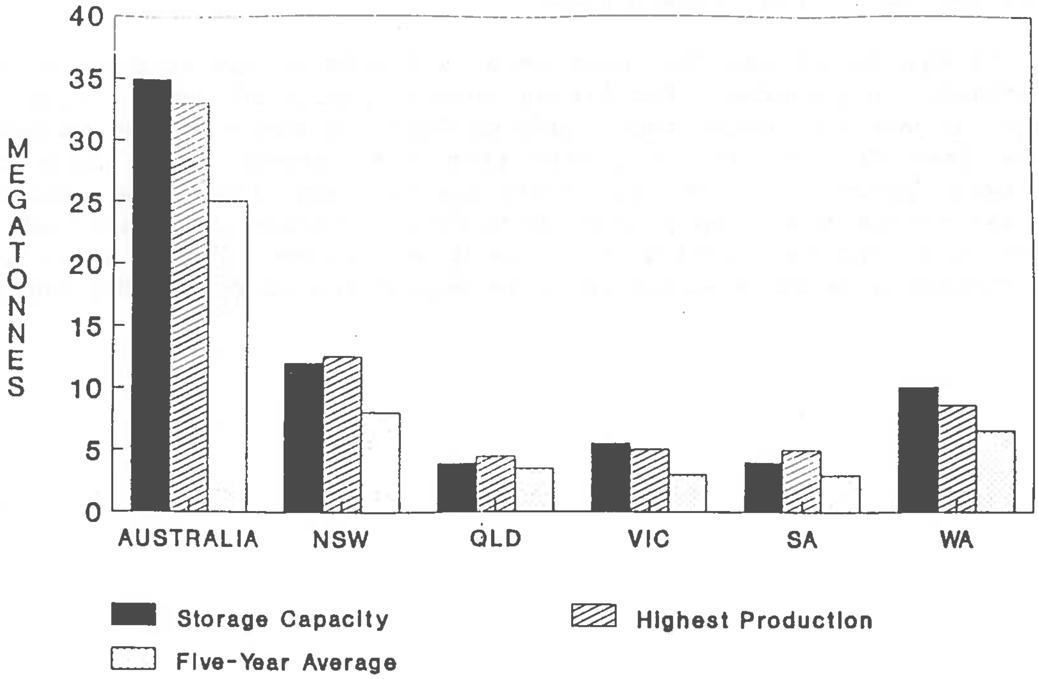

Figure 8: Grain Storage and Production

Conclusion

Examination of the efficiency frontier for grain storage reveals that only two storage types should be used, and these are horizontal and bunker storage. Horizontal storage should be provided so as to store all production in 7 out of 10 years. Vertical storage is not an efficient storage option, except in cases where it might fulfill a short term storage role such as at ports or subterminals where the turnover of grain storage is high.

While CLS bunker storage does not appear an efficient alternative, the high fixed costs of horizontal storage mean that CLS storage is a better alternative to constructing a horizontal storage facility where the required investment is small. In particular, investment in CLS bunker storage is an efficient means of providing extra storage where there have been significant increases in production at a site since the initial construction of permanent facilities.

An analysis of those sites in Western Australia that normally fulfill a storage role in the harvest season, revealed that the main cause of inefficiency was the unjustified construction of vertical storage facilities. Deviations from optimal horizontal storage did not have a very great effect on total efficiency costs, and it is possible that deviation from the long run optimal determined under our static analysis may have been warranted in a real world dynamic environment, because of the high average cost of constructing additional permanent structures to meet small demand increases. Apart from those few sites having vertical storage, the other main cause of efficiency costs seemed to be through over investment in the total amount of storage. The level of over investment was very large in many cases, and corresponded to infinitely large implied supply failure costs.

It was also found that mean receivals were so low at some sites, that investment in permanent facilities wasn't justified due to high average costs. It was also noted that, judging from the shape of the average costs curve (see Fig 3), it is likely that the current small size of some receival points in WA is inefficient, and that the gains from centralization will imply that horizontal storage is justified at all sites on a long term efficient perspective. However, the spatial issue of the optimal size of receival zones is beyond the scope of this analysis.

References:

Blyth M, Noble K and Mayers B (1987) "A Model of Grain Distribution in Eastern Australia" ABARE Discussion Paper 87.6 AGPS Canberra

Brennan, D and Lindner, R (1988) "The Long Term Peak Load Problem in Grain Storage" Contributed Paper at the 32nd Annual Conference of the Australian Agricultural Economics Society, LaTrobe University, Melbourne 9-11 February

Co-operative Bulk Handling (1987) Submission to the Royal Commission into Grain Handling and Storage

Crew, M and Kleindorfer, P (1976) "Peak Load Pricing with Diverse Technology" The Bell Journal of Economics 7(1) p207-231

Hall N and Menz K (1985) "Product Supply Elasticities for Australian Broadacre Industries - Estimated with a Programming Model" Review of Marketing and Agricultural Economics 53(1) p 6-13

Kerin, P (1985) "A Spatial Economic Analysis of the Eyre Peninsula Grain Handling and Transportation System" M Ec Thesis, University of Adelaide

Myers R (1982) "An Econometric Evaluation of Australian Wheat Pricing Policies" Agricultural Economics Bulletin 27Department of Agricultural Economics and Business Management, University of New England, Armidale

Royal Commission into Grain Handling and Storage (1988) Volumes Two and Three, Supporting Papers

Sarris A and Freebairn J (1983) Endogenous Price Policies and International Wheat Prices" American Journal of Agricultural Economics 63(2) p214-224

Wenders J (1976) "Peak Load Pricing in the Electrical Utility Industry" The Bell Journal of Economics 7(1) p232-241