A Simulation of the Grain Producers' Decision Problem at Harvest

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A simulation model is employed to find the least cost way of dealing with the grain carryover during and after completion of harvesting that is caused by a difference between harvesting and trucking capabilities in the short run. The study may potentially aid the farmer in the face of legislative changes affecting wheat marketing, as well as technological changes in harvesting equipment. Results tend to indicate that temporary paddock storage may be more efficient than contract trucking in managing the carryover.

1. Introduction

Grain farmers face complex investment and operational decisions in establishing and modifying their grain harvesting, handling, storage and transport systems from paddock to central storage or end-user. In Australia, they have had to cope with rapid technological changes affecting the harvesting rate and are now faced with making major adjustments to central storage and marketing systems resulting from government policy and legislative changes.

Tthe Royal Commission on Grain Storage, Handling and Transport (1988) found that savings of about $10 per tonne could be achieved if producers and merchants were free to choose the means of distribution. The Commission recommended the removal of the sole-receival rights of the state bulk handling authorities and greater road transport competition. These recommendations were implemented in the 1988 Wheat Marketing Amendment Act, with commercial powers given to the Australian Wheat Board (AWB) to appoint the agents of its choice. Under the 1989 Wheat Marketing Act, the AWB's powers of acquisition in the domestic market were removed, thus largely completing the deregulation of this market (although its export trading monopoly continues to give it significant market power over competitors in the domestic market).

These changes have increased the marketing options available to farmers; a development which warrants additional research into their delivery strategy. Cost savings might be achieved by lowering costs of information about grain handling options to farmers. This should enable them to make faster adjustments to their grain handling systems and to get closer to the best system at any point in time. The rapid increase over the past twenty years in the farmer's harvesting capacity has been largely due to advancements in harvesting technology. Howard and Lawrence (1986) suggest that this change in technology has compressed the harvest period and emphasised peak load problems in delivering to central storages. Benson *et al* .(1987) note that these have been accentuated by the gap between harvesting hours and central depot receival hours per day.

Briggs and Johnston (1991) examine economic factors influencing grower decisions about on-farm grain storage and make several inferences of relevance to this study. They point out that while decisions about on-farm grain handling, storage and transport seemingly involve a large number of variables, many of which are uncertain, in reality the number of variables facing an individual grower at a particular point is far fewer. Most farmers make decisions about adjustments at the margin. Complete replacement of such systems is rarely cost-effective given the large capital component of such systems and the gap which invariably exists between the purchase price and the salvage value of such equipment. This, they argue, has two effects.

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Firstly, it makes the decision problem a lot simpler and they describe a step-by-step approach to analysis to make it even easier to grapple with. Secondly, it makes the decision problem facing an individual grower concerning on-farm grain handling quite personal and different from his or her neighbours. This second characteristic makes the problem ideally suited to the application of decision support systems such as simulation models and expert systems.

The purpose of this study is to take a single component of the farmers' grain handling decision problem, develop a simulation model of it and then show how this can be used by farm advisers and computer-equipped farmers to analyse best-bet strategies under the changed market circumstances now facing farmers. Models can then be developed of the other components of this decision problem and applied sequentially to study those aspects which apply to particular farmers in the manner proposed by Briggs and Johnston (1991). The particular decision problem analysed in this study is one that farmers often find themselves confronting at harvest; that is, how to handle a surplus generated by the gap between the farmer's harvesting capacity and the rate capacity of his or her own trucks. Two broad options considered here are contract trucking and temporary storage. The results appear to be applicable not only to the area from which the survey results were drawn to construct and apply the models but also to other areas. They indicate the importance of particular variables and the extent to which they could be ignored altogether or, alternatively, assumed constant for groups of farmers such as those delivering to a particular central depot or those harvesting particular grain types.

2. Theoretical Considerations

The decision problem described is quite complex, and is representative of the type of decision facing the farmer (a choice between two discrete options). If the environment surrounding the decision problem remains constant, farmers will adjust their strategies until the best alternative is found. This is achieved through trial and error and by observing the practices of surrounding farms. Under a changing decision environment, however, such experimentation is both costly to perform and far less effective. Under these conditions, simulation models become a useful aid to decision-making.

Simulation is most often used when it is not possible to experiment with the actual system, either because it is too complex, or because experimentation itself affects the system (Naylor 1971). Two types of simulation are used here. The first is deterministic simulation, where all parameters are "determined" and have no error term associated with them. The second is stochastic simulation, which is also known as Monte Carlo programming. With this technique some parameters are taken not to be known with any certainty, so that there is an error term attached to the parameter. When the simulation is conducted using stochastic variables, the outcome is not predictable because the variables which are not predetermined draw on probability distributions to derive their expected values.

Expected utility theory indicates how to select the best plan given utility maximisation, but this requires a known utility function. This could be obtained using gaming theory, as outlined in Anderson *et al*.(1977), but then the plan would be producer specific, and would not be as useful for broader recommendations. Even when advising individual grain producers using the model developed here, to obtain utility functions for each grower would considerably increase the time, cost and difficulties of such advice. Knowledge of the utility function is avoided by making two broad generalisations about the decision maker's preference relating to risk, corresponding to the first and second stochastically dominant principles. The first is that the producer prefers more income to less and the second that the producer prefers lower to higher risk. These generalisations have intuitive appeal. Anderson *et al* .(1977) give a clear derivation of these principles. Stochastic dominance is used in this study to select best-bet strategies.

3. Simulation Models, Data and Procedures

The basic assumptions for all of the models are outlined below. The farmer has a quantity of grain (wheat) to harvest. This is assumed to be known at the time of harvest. In a long-run analysis, this would have to be a stochastic variable; that is, he or she has to take yield variations into account. This grain can be harvested at a rate of R tonnes/hour. The length of daily harvest is H hours and thus the daily harvesting rate is RH tonnes/day. The farmer has a truck capacity of A tonnes. He or she can make N trips to the central depot in a day so that the daily trucking rate is NA tonnes/day. The condition must hold that RH > NA; that is, daily harvest capacity must be more than trucking capability.

The farmer also wishes to store a certain quantity of grain for later use - whether for feed, seed, or for sale - this grain is stored in centralized permanent on-farm storage. It is assumed that existing trucks carry this, since it is only a short distance and it is on the farm, which enables the use of unregistered trucks. This does not detract from the trucking capacity NA described above. It is also assumed that this permanent storage is not used as buffer storage. Thus the *sink* (B) required daily is B = RH-NA-Sday, where Sday = the amount stored in permanent farm storage each day.

There are three versions of the basic model. Model 1 uses constant daily harvesting and trucking rates. Since all parameters are known with certainty, this is a deterministic model. The main use of this model is to clarify reasoning and to provide a base for other models. The result is a discrete, corner solution showing either contract trucking or temporary storage to be superior. Figure 1 displays a diagrammatic representation of this model. An important feature of this figure is that the daily rates of harvest, storage and transport can be summed to depict total harvest period requirements.

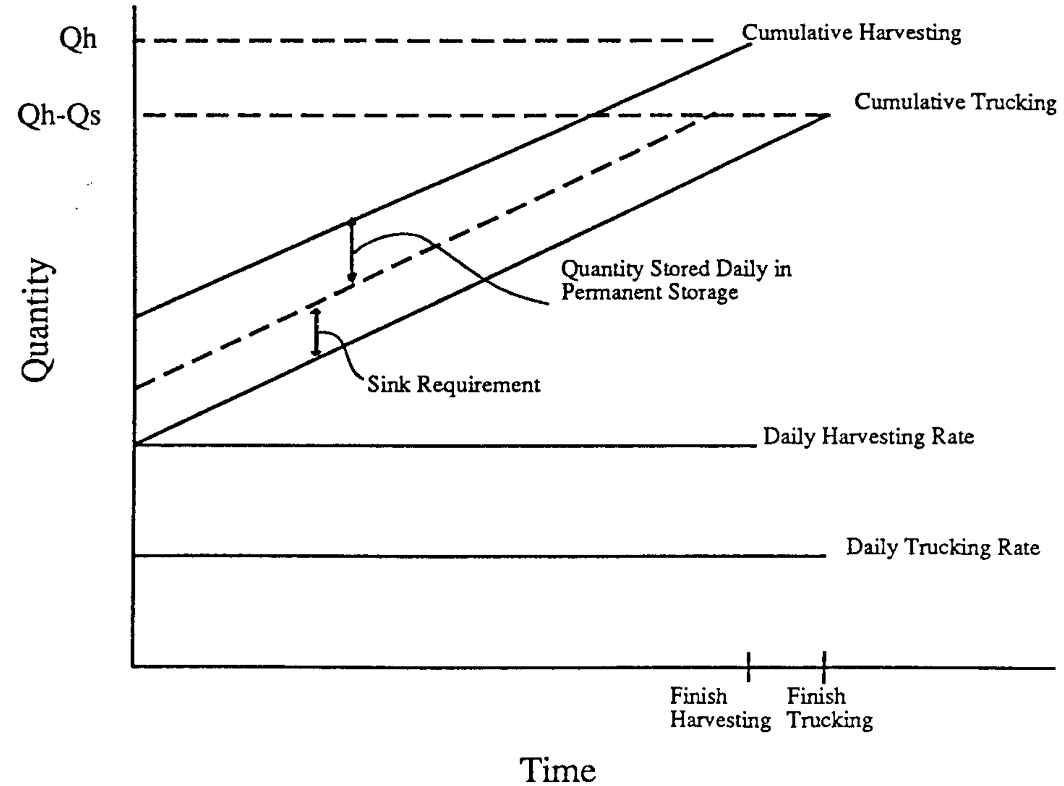
Model 2 is a deterministic model like the first, but it accounts for the opportunity cost of interest foregone on grain stored on farm and also for potentially differing wage rates of truck drivers during and post harvest. Again a corner solution will be reached but the changes make this model more realistic. Farmers are not paid for their grain until it is delivered and as Benson *et al* .(1987) suggest, for longer term storage, the interest foregone is one of the largest components of their total on-farm storage costs. Whan (1969) also argues that this may explain why many farmers were prepared to tie up trucks in queues for weeks on end in the 1967 to 1969 period. It is therefore of interest to know what importance should be attached to it in short-term decision making. Clearly, it increases the attractiveness of contract trucking to some degree. Post harvest casual labour rates and the opportunity cost of permanent farm labour are often significantly lower than during harvest.

Model 3 is a stochastic simulation. It accounts for uncertainty in both the harvest rate and the quantity trucked each day. The uncertainty in harvest rate arises from a change in the number of hours worked in a day, and the uncertainty in trucking capacity reflects a change in the number of trips. Each scenario of the model reflects one possibility of the system; that is, each has different quantities harvested and trucked each day. Further, different solutions are generated. If a large number of scenarios are simulated, then the least-cost option can be found by using stochastic principles.

Basic data were drawn from a survey of grain producers in the Grong Grong area in New South Wales documented in Benson *et al* .(1987). Table 1 summarises the physical parameters, their basic values and the range over which they were varied in the sensitivity analysis or stochastic simulation. Table 2 displays the cost data used in the simulations. Trucking costs were taken from Rish and McClintock (1989) who synthesised the cost for each of seven categories of truck utilised by surveyed Grong Grong farmers. They estimated depreciation and interest costs using a modified declining balance model consistent with the literature on true economic depreciation. This model provided the closest fit to a large sample of second hand truck values. A real interest rate of 7 per cent was used. Storage costs were taken from Benson *et al* .(1987) who used a conceptually identical approach to that used by Rish and McClintock in estimating capital costs.

There are three important parameters in this study: daily harvesting rate, daily trucking capacity and the quantity to be stored. The maximum (likely) work rate during harvest is an exogenous variable. Harvesting rate (tonnes/hour or hectares/hour) is a function of header size, capacity, speed and yield, and, assuming a reasonably constant yield and driving speed, will not change over the harvest period (Whan and Hammer 1985). Thus, daily

Figure 1: The Basic Model



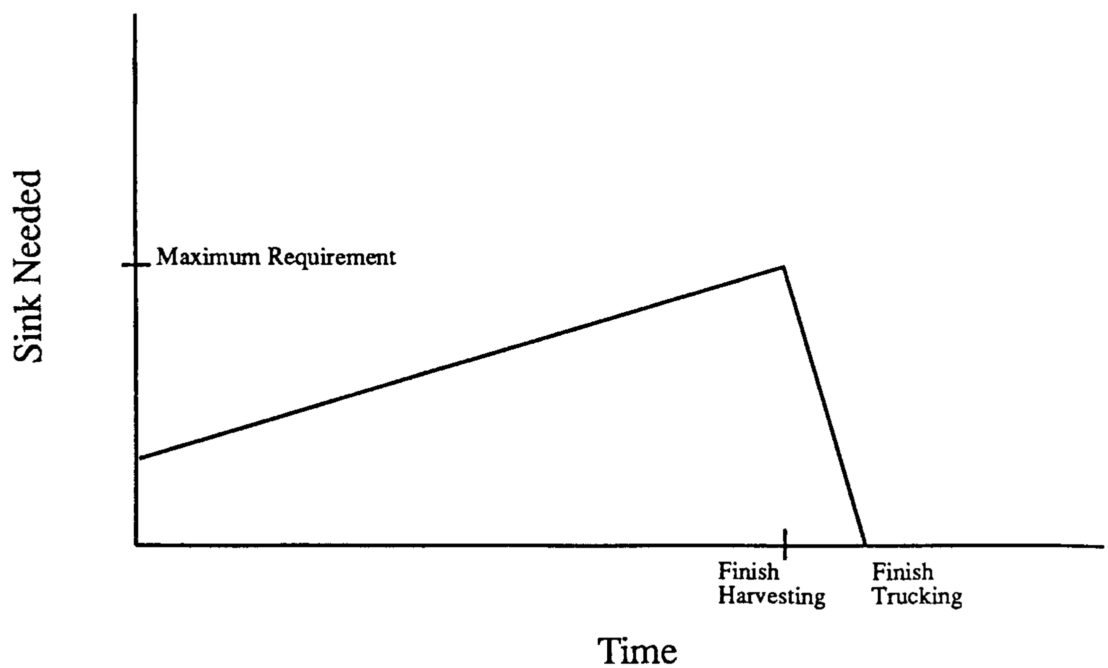


Table 1: Physical Parameters, their Basic Values and the Range of the Sensitivity Analysis

Parameter	Explanation of Parameter	Value	Range for Sensitivity Analysis
Quantity to be harvested	Average production of wheat as given in the survey	868 tonnes	500 - 1100
Rate of harvest	Specification depends on the choice of header. Value based on average survey capacity x 2 tonnes/ha	11 tonnes/hour	8 - 14
Length of harvesting period per day			Stochastic simulation
Maximum number of harvesting hours/day	From survey: 11 am - 9pm	10 hours	
Quantity to be stored	Amounts needed for feed, seed and later sale will affect quantity to be stored	100 tonnes	50 - 250
Truck capacity	The mean load size that can be carried by the farmers' trucks	20 tonnes	15 - 25
Number of trips to central depot		3 trips	3 - 7
Variance of the average number of trips	Not statistically derived	3	Stochastic simulation
Distance from central depot		18.1 km	10 - 30
Capacity of temporary paddock storage		18.6 tonnes	
Water Rate	Peak-Transport Workers' Union Non-Peak Station hand's wage	$8.30/hr $5.95/hr	
Interest rate	Government bond rate	13%	10 - 20%
Value of grain		$100/tonne	80 - 140

Table 2: Cost Data Used in the Simulations[a]

Cost of Storage

Temporary Paddock Storage

a) Fixed Costs

	Depreciation	Interest on Capital	Insurance
	43.30	65.74	4.42

b) Variable Costs

	Repairs and maintenance	Unloading costs
	1.06	0.37

Permanent Farm Storage

a) Fixed Costs

	Depreciation	Interest on Capital	Insurance
	105.53	65.74	4.42

b) Variable Costs

	Repairs and maintenance	Insect Control
	1.06	0.77

Cost of Trucking

a) Fixed Costs of Farmer Owned Trucks

Truck 1	Depreciation (at 10 years)	Registration	Insurance
	3825.00	753.70	163.30
Truck 2	Depreciation (at 20 years)	Registration	
	3825.00	753.70	

b) Variable Costs

Truck 1	Fuel	Tyres	Repairs and Maintenance
	0.132/km	0.041	0.161
Truck 2	Fuel	Tyres	Repairs and Maintenance
	0.308/km	0.028	0.139

Contract Carting Rates

$7.50/km/tonne and 11¢/km/tonne for every k > 17~ two way trip distance to central depot.

[a] All cost figures are in dollars

harvesting rate (tonnes/day) is affected only by hours worked, which is an endogenous variable. This, in turn, is a function of certain state variables such as weather, breakdowns and labour availability.

Rain is the most obvious factor that determines daily hours of harvest. But temperature, in terms of its effect on daily decisions, is a more crucial constraint.It is likely to rain on only two days in any three-week period, whereas the daily drop in temperature after sunset means that the straw becomes very "tough" to strip. This makes it difficult for the header to work effectively. Once the temperature reaches about 10 degrees Celsius, which generally occurs in the Grong Grong region at about 9 pm, the harvest stops altogether.

If it is a hot night and labour is available, the harvest could continue beyond 9 pm. However, there are other factors to consider. Once it is past the time when the central depot is shut, harvesting usually continues only until trucks and buffer storage are full. The wheat is then carted the next morning, as the harvester would not begin until about 11 am, when it is both hot and dry enough.

Any change in the number of harvesting hours is usually due to machinery breakdown or rain. If rain is forecast, longer hours may be worked beforehand but the above constraints (temperature and storage capacity) inhibit this possibility. There is not much scope for change above the normal rate, but there may be quite a bit below the normal rate. A fairly high probability exists that little or no work would be achieved on a day on which there is breakdown, rain etc. There is a high probability of working close to the maximum rate, but less chance of working, say, for a few hours in a day. This distribution is complex and is shaped like a truncated bimodal distribution (Burrows and MacMillan 1981). However, for simplicity it is modelled using a uniform or rectangular distribution.

Daily trucking capacity is calculated using load size multiplied by the number of trips made to the central depot on that day. The volume of wheat carried each time is modelled not to change very much during harvest, as the farmer generally fills the truck to capacity. The number of trips which determines daily trucking capacity is a function of "turnaround time", which involves the distance to the central depot, the speed at which the truck is driven, receival traits of the silo (time spent sampling, weighing and unloading), and queuing time at receival point.

On a daily basis queuing is the most variable factor. It was the one factor not adequately covered in the survey of Grong Grong producers. However, Quiggin (1990) has covered this topic in depth. The approach taken in this study is to use the change in the number of trips as an approximation of changes in trucking capacity due to queuing. Different queuing times at different stages of the day are ignored. The justification for this is that queuing is to be considered on a daily basis.

The number of trips has been assumed to be normally distributed. Cassidy *et al* .(1970) argue that it would be better to use a triangular distribution when dealing with an unknown variable: minimum, maximum and most likely value. This is in comparison to a normal distribution which requires a mean and a variance. The normal distribution was chosen because the number of trips was assumed to be fairly symmetrical about its mean, and because triangular distributions fit skewed data more accurately. There was an additional problem associated with assigning probabilities to minimum and maximum values, and also to determining these values, because they change daily.

The quantity of wheat stored for later purposes is the amount that the farmer envisages is required for seed, feed and later sale. It is an exogenous variable because it is decided before harvest begins. This grain, which is stored in centralised, permanent on-farm storage, is distinguished from that which is stored temporarily. Permanent storage is centralised at one, or possibly two, locations and generally is not too far from sheds and houses. Paddock storage, in contrast, is small and mobile. It must be small so that headers can unload into it. Grain is only stored for a short period of time. Costs of loading into and unloading out of the storage have been included as part of the variable costs.

Contract trucking has three aspects that are relevant to this study: availability, costs and risk. It is assumed that there is little problem with obtaining contract services. A pool of vehicles and contractors can be drawn upon in most seasons and districts in eastern Australia because individual harvest periods rarely coincide. The risk in using contract services is a delay in arrival, and if this in turn delays the harvest, penalty costs should apply. Variations in rates occur between seasons which presumably are largely due to variations in the quantity of grain to be transported and hence the demand for these services. They also occur within the harvesting period due to a range of factors affecting demand.

4. Empirical Results

The basic results gained from the deterministic models show that temporary paddock storage may be the most efficient option (see Table 3). The total costs of using temporary storage (including costs associated with using the farmer owned truck fleet) and contract trucking were $7,044 and $7,380 respectively. The effect of including opportunity costs of capital and labour for the second model did not change the general result. Lowering the wage rate after harvest decreased costs associated with trucking by $94, while the cost of interest foregone was $49. In contrast to the conclusion of Benson *et al*.(1987) on the importance of the interest earnings foregone, the costs in the current study accounted for only 3.3 per cent of the cost of temporary storage. A sensitivity analysis was conducted on the major parameters, with the ranges over which the parameters were manipulated presented in Table 1. The analysis indicates that temporary storage is still the least cost option over all the ranges of values of the parameters used. This is important because it shows that the results may be applicable to different types of farms.

Different contributions of the opportunity costs of labour and capital derived from the sensitivity analysis indicate that only one variation caused the interest cost to be more important than the different driver's wage during peak and non-peak times, that being when production was 1100 tonnes. Varying the interest rate, the value of the grain, the volume of *sink* requirements, and the length of time in storage had a substantial impact on the interest cost. Changing the assumptions underlying the choice of labour did not change the optimal solution, but it did change the contribution to total cost. This was when the peak wage was taken to be the farmhand's wage and the non-peak wage was set equal to zero, assuming permanent farm labour would be idle after harvest and hence a zero opportunity cost after harvest would apply.

A break-even analysis was also undertaken to see how sensitive the major cost variables were; the intention being to demonstrate at which values contract trucking became more efficient. The results were sensitive to the fixed costs associated with using temporary storage and the quoted contract rate, but not very sensitive to the variable costs attached to using the storage.

Significant changes in contract trucking rates do occur within and between harvest seasons for reasons outlined earlier. Thus, the appropriate fixed

Table 3: Results from the Deterministic Models[a]

	Cost of Trucking	Cost of Storage	Cost of Temporary Storage	Cost of Contract Trucking	Total Cost of Temporary Storage	Total Cost of Contract Trucking
Model 1	5,279	359	1,407	1,742	7,044	7,380
Model 2	5,185	359	1,456	1,742	7,000	7,286

[a] All cost figures are in dollars.

costs of temporary storage may well vary greatly between farmers depending on the likely frequency of use. For example, if the expected life of a bin were 10 years regardless of use, but the farmer only used it every second year, then its effective life would be only five years, and the depreciation expense should be increased accordingly. The break-even analysis indicates that if the depreciation rate were increased by $27 per tonne stored, or by just under 50 per cent of the base cost, then the use of contract trucking would be optimal. Finally, a change in the variable costs of storage could suggest a different running cost, such as if the bin required two people to operate (load/unload) it. The variable costs had to be nearly doubled to find the point at which it becomes more expensive to use temporary storage.

The costs of each option for Model 3 are shown in Table 4. Each scenario of the model gave one set of results, representing one possible state of the system. It should be noted that temporary paddock storage is cheaper virtually all of the time. However, given that there is one case where contract trucking is cheaper, the grain producer might be forgiven for being sceptical of the results when no reference is given to the likelihood of those results. Figure 2 shows that when the probabilities of the events are included (by sorting and plotting the results against the cumulative probability), temporary paddock storage is stochastically dominant over contract trucking.

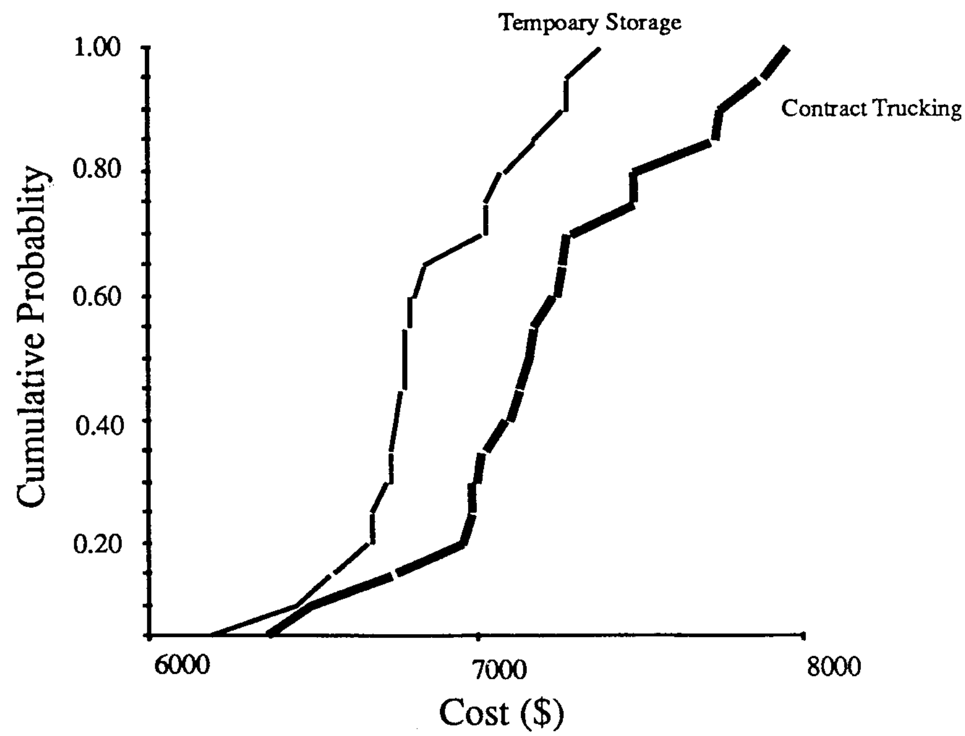
A comparison with the data obtained from the Grong Grong survey reveals that the model performs favourably for the harvesting conditions and costs applying at that time. In the survey, an average of 5.6 field bins were reported per farm, with three being semi-mobile field bins, as considered in the costing analysis. The others were mobile

Table 4: Results from the Stochastic Simulation[a]

Model 3 Scenario	Cost of Trucking	Cost of Storage	Cost of Temporary Storage	Cost of Contract Trucking	Total Cost of Temporary Storage	Total Cost of Contract Trucking
1	6010	359	993	1540	7363	7909
2	5749	359	627	1159	6735	7267
3	6004	359	371	631	6734	6994
4	5856	359	815	1484	7029	7699
5	5923	359	166	86	6448	6368
6	6254	359	655	843	7268	7455
7	8545	359	630	1048	6834	7252
8	5928	359	457	744	6744	7031
9	5769	359	443	612	6571	6740
10	6263	359	455	610	7076	7231
11	5876	359	547	910	6782	7145
12	5632	359	683	1475	6673	7466
13	5573	359	867	1233	6799	7165
14	5725	359	601	1003	6685	7087
15	5739	359	695	838	6793	6936
16	6109	359	313	506	6781	6974
17	6165	359	736	1312	7260	7836
18	6108	359	547	645	7013	7112
19	5497	359	334	634	6190	6490
20	6059	359	748	1292	7165	7710

[a] All cost figures are in dollars.

Figure 2:Temporary Storage Versus Contract Trucking



"chaser" bins and stationary "mesh" bins. About 75 per cent of wheat was put through field bins. This includes grain put through chaser bins, which are used to take grain from the harvester to the truck to keep the harvester going.

However, 19 per cent of grain delivered to Grong Grong was delivered through contract vehicles. Whan (1969) offers two explanations for this observation. His survey shows that farmers tend to have a high discount rate at the end of the year because cash-flow problems are most common then. Secondly, he argues that rapid delivery in those years may have been an essential strategy to obtain a share of the central silo's capacity before it fills. This is important mainly for farmers who deliver to smaller silos, where little outloading occurs during harvest or where such outloading holds up farmers' deliveries.

A third possibility is that some farmers would also have faced the cost of additional investment in handling equipment, such as augers, in order to be able to effectively utilise the temporary storage option. As a special case, the optimal grain handling system for some farmers may involve the employment of contract harvesters supplying the equipment. One farm in the Grong Grong area had certainly adopted this strategy. To avoid costs of ownership in this way may be optimal, but the current study was not designed to investigate this problem - that involves capital budgeting, or an investment decision.

A fourth explanation is that at times during harvest when a surplus builds up on a particular farm between harvesting rate and the planned trucking capacity, additional temporary storages may be unprocurable.

The validity of the previous results hinges on the underlying assumptions of the model (Baker and Currie 1976). For example, it was implicitly assumed that enough labour was available to run the farm truck fleet. If that were not the case then a different trucking capacity would have to be used. There was no time limit imposed in the model on the period for which grain might be delivered by the trucks after harvest. If there was an artificial constraint, such as the silo closing (as identified in Whan 1969), then contract trucking might be desirable. Permanent storage was assumed not to have a buffer role because there are increased costs in using it (including additional transport costs), since permanent storage is generally not located at the harvest site. If a buffer role were envisaged for this type of storage, then a mini-spatial equilibrium problem would have to be designed.

The trucks in the fleet delivered alternate loads, and made an equal number of trips to the silo. This is quite common, but the main reason for suggesting this was to simplify programming. This assumption can be relaxed by changing truck capacity. Contract trucking, as a category, did not include hiring or borrowing a truck, which is clearly an option, even in the short term. Borrowing a truck would be best included as a change to the farm operated truck fleet, and a change to costs attached to trucking.

The model did not allow for a mix between contract trucking and storage, although some mix might be optimal in the farmer's delivery strategy. With a few modifications, an optimisation problem could be incorporated into the existing framework. A final limitation is that the model did not cater for variations in central depot opening hours. It was assumed that the silo would be open for 10 hours (from 8am to 6pm, which in fact approximates the actual opening hours).

5. Conclusion

The overriding conclusion emerging from the preceding analysis is that temporary paddock storage may be the most efficient way to deal with the *sink*. The inclusion of opportunity costs of labour and capital, and the inclusion of risk, did not change this general observation. The results are found to be quite robust for variations in the parameters of the type observed in Grong Grong and therefore applicable to a broad range of farms in that area. The validity of the model is therefore supported by the finding that the results are consistent with the responses from the Grong Grong grain growers' survey, where a high usage of field bins was recorded. The results may be of interest to central silo operators and government policy-makers, as the use of temporary storage decreases the peak load requirements for grain receival facilities, and may therefore influence broader commercial and policy objectives. However, the main use of this study will be as a base for applied research into more complex investment decisions such as the optimal mix of storage and contract services. This should lead to the development of computer software aimed at assisting farmers to make better operating and investment decisions about their grain harvesting, storage and transport systems. Such models could be used either by farmers directly or by farm advisers and consultants.

The receival rate characteristics of the central storages, harvest weather patterns and the farm characteristics in the Grong Grong district are found to be important in this model and appear to be fairly typical of the central and southern New South Wales and Victorian wheat belts. Mobile paddock bins are also a fairly standardised product with a strong competitive market and reasonably uniform price. The same applies even more to contract trucking. Thus, for grain producers in these regions confronting a problem of harvesting rates exceeding daily trucking capacity, additional temporary paddock storage is likely to be a better option than contract trucking. Possible reasons for this may be that farmers do not want to reduce harvesting rates because of expected grain losses (quality and quantity), or are unable to invest in another truck, or are unable to borrow a truck, or have the auger capacity to handle additional temporary storage or are unable to buy suitable temporary paddock storage. Does this conclusion hold true under the recent changes in central storage, handling, transport and marketing of grain in Australia? The answer is most likely yes but what is unclear is the impact these changes have had on the receival rate capacity of central storages and hence the trucking rate capacity of individual farms.

Closure of some central silos seems probable, which means some producers may have to look for alternative delivery sites. This is likely to have a marked effect on actual trucking capability, and may increase the need for either buffer storage or contract services. With rationalisation of the receival system, the franchising or leasing to local operators of some central silos has been proposed. This may result in increased central silo opening hours and possibly an increase in "warehousing" of grain. These factors tend to reduce the need for on-farm storage requirements. On the other hand, there may be an increase in futures contracts (temporal allocation of product), and in direct sales to end-users, which is likely to increase the producer's need for on-farm grain storage capacity. The changes taking place in the central grain handling, storage and transport system indicate the need for decision support systems able to analyse investment decisions concerning farm trucking and storage capacity under uncertainty given new options concerning delivery destinations, distances and silo opening hours. The model developed in this study potentially constitutes a necessary component of any such system.

References

ANDERSON, J.R., DILLON, J.L. and HARDAKER, J.B. (1977), *Agricultural Decision Analysis*, Iowa State University Press, Ames, Iowa.

BAKER, C.H. and CURRIE, R.B. (1976), "Structure of agricultural simulators: a philosophical view", *Agricultural Systems* 1 (3), 201-16.

BENSON, R., ESPINAS, V., ANDREWS, A., JOHNSTON, J., PRICE, D. and SMALL, A. (1987), On Farm Grain Storage from a Policy Perspective: Models, Costs and Utilization, Contributed Paper presented at the 31st Annual Conference of the Australian Agricultural Economics Society held at the University of Adelaide, 9-12 February.

BRIGGS, D. and JOHNSTON, J. (1991), Economic Issues Influencing Grower Decisions about Farm Grain Storage, Paper presented at the Farm Grain Storage Workshop held at the University of Queensland, July.

BURROWS, J.L. and MACMILLAN, R.H. (1981), *A Computer Simulation of the Selection and Management of Wheat Harvesting Machinery*, Agricultural Engineering Report No. 57/81, University of Melbourne Press.

CASSIDY, P.A., RODGERS, J.L. and MCCARTHY, W.O. (1970), "A simulation approach to risk assessment in investment analysis", *Review of Marketing and Agricultural Economics* 38 (1), 3-24.

DEPARTMENT OF AGRICULTURE NEW SOUTH WALES (1987), "Grain contaminant control and on-farm storage", *Submission to the Royal Commission into Grain Storage, Handling and Transport*, Division of Marketing and Economic Services, Department of Agriculture, New South Wales, Sydney.

HOWARD, P. and LAWRENCE, M. (1986), "Australian grain storage capacity", *Quarterly Review of the Rural Economy* 8(4), 330-4.

NAYLOR, T.H. (1971), *Computer Simulation Experiments with Models of Economic Systems*, John Wiley and Sons, New York.

QUIGGIN, J. (1990), "Peak-load pricing and on-farm storage in the Australian grain handling system", *Australian Journal of Agricultural Economics* 34(3), 263-279.

RISH, B. and McCLINTOCK, D. (1989), *The Economics of Farm Grain Transportation*, Research Workpaper Series, NSW Agriculture and Fisheries, Division of Rural and Resource Economics, Sydney.

ROYAL COMMISSION ON GRAIN STORAGE, HANDLING AND TRANSPORT (1988), *Volume One: Report*, Australian Government Publishing Service, Canberra.

WHAN, I.F. (1969), The Economics of Road Transporting Wheat from the Farm to Government Storage and the Reasons for Adopting a Particular Delivery Strategy, Unpublished B. Ag. Ec. Thesis, University of New England, Armidale.

WHAN, I.F. and HAMMER, G.L. (1985), "The cost of delay in harvesting wheat", *Review of Marketing and Agricultural Economics* 53 (1), 14-24.