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Economics of grain accumulation for ethanol production: an Australian regional case study

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Economics of grain accumulation for ethanol production: an Australian regional case study

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Abstract

Ethanol production is increasingly commonplace in many grain producing regions. This paper uses the grain producing region of Western Australia as a case study to illustrate how the location and size of an ethanol plant affects its grain accumulation costs. Specifically, this study examines how price variability of various wheat grades, combined with spatial and temporal variability in production of those grades affects the costs of grain accumulation for ethanol production. These costs are the main component of a plant's operating costs so lessening these costs can offer a comparative advantage for a plant owner. Logistics models based on mathematical programming were constructed to depict a range of plant sizes and locations for ethanol production. The key findings from analysis of the models' output are that, in some cases, large cost savings in grain accumulation costs are possible through locating ethanol plants at a sub-set of southern locations in the Albany, Kwinana and Esperance grain receival zones of Western Australia. The southern inland site of Newdegate, in particular, offers the greatest potential savings in costs of grain accumulation, displaying the lowest certainty equivalent of these costs when compared to all other locations. At all locations, small to medium-sized plants offer advantages of lower and less variable costs of grain accumulation.

Keywords: ethanol, mathematical programming, logistics, wheat, grain quality

1. Introduction

Large increases in crude oil prices since mid-2004, combined with policy incentives and uncertainty over future rises in petrol prices have stimulated investment in many countries in the production of biofuels, such as ethanol (Biofuels Taskforce, 2005; Wilkins & Hancock, 2006). The International Energy Agency predicts ethanol's share of the world's gasoline use will be 10 per cent by 2025, rising to 30 per cent by 2050 (Whittington, 2006). In Australia, CSIRO (2003) estimate a rise in ethanol production from 60 million litres to 115 million litres (ML) between 2003 and 2010. In Western Australia (WA), construction of a 160 ML ethanol plant based at Kwinana was announced in 2006 (BP, 2006).

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Several factors will affect the viability of ethanol production in Western Australia, including the relative commercial attractiveness of ethanol as a fuel, the degree of consumer confidence in fuels that include ethanol, the cost of plant feedstock used by ethanol plants, the value of government assistance and subsidies (Nalley & Hudson, 2003) and the size of the domestic markets for ethanol and distillers grain, the latter being a by-product of ethanol production (Wilkins & Hancock, 2006). The cost of feedstock (e.g. wheat) is particularly important, as it represents between 70 to 75 per cent of an Australian dry mill ethanol plant's operating costs (Klein *et al*, 2005; DAFWA, 2006a). Hence, feedstock accumulation costs and the ability to minimise these costs can have a large impact on plant operating costs, thereby affecting the economic feasibility of constructing and operating ethanol plants (Dobbs *et al.*, 1984).

In the case of ethanol production based on wheat, grain transportation costs (Brennan, 1990) and the availability of cheaper grades of wheat (general purpose and feed grades) will affect costs of grain accumulation, the main cost of ethanol production. Hence, the economic feasibility of ethanol production is likely to be influenced, in large part, by an ethanol producer's ability to minimise grain transport costs (Dobbs *et al.*, 1984) and to purchase sufficient volumes of cheaper grades of wheat. This issue of the cost of grain accumulation is explored in this paper. This paper shows how temporal grain price variability and temporal and spatial grain production variability affect the grain accumulation costs for ethanol production based on wheat grown in the agricultural region of Western Australia.

Spatial and temporal variability in the availability of cheaper grades of wheat presents logistical problems and opportunities for grain accumulation to lessen variability in production costs (Nalley & Hudson, 2003; Short & Dickson, 2004). Typically ethanol plants are located near a reliable supply of wheat, so that ethanol production is not compromised by difficulties in accessing grain, causing additional storage and transport costs (Short & Dickson, 2004). Ideally, ethanol plants are located near both the source of grain and the market for ethanol and distillers grain, allowing the transport costs of a plant's main inputs and outputs to be reduced (Dobbs *et al.*, 1984). In Western Australia 90 percent of wheat produced is transported by trains and trucks from Cooperative Bulk Handling (CBH) receival points to port for export, with freight costs in 2005/06 ranging from approximately $4 to $21 per tonne from receival points to port (CBH, 2006). It is expected that significant cost reductions are likely to be achieved if ethanol plants are located at regional locations close to the source of grain rather than at port, as the logistics and therefore costs involved in grain transport and storage would be cheaper (Richard-Molard & Wrigley, 2004). Dry mill ethanol plants located inland or near a primary source of wheat are likely to have lower grain accumulation costs than plants at port, due to reduced transport costs.

While plant location is important to lessening costs of grain accumulation, the production capacity or size of an ethanol plant also affects a plant's ability to achieve economies of scale. Ultimately, diseconomies of scale can apply (Gallagher, Brubaker & Shapouri, 2005) partly because plants that require large grain throughputs are forced to purchase either higher-priced grades of wheat from nearby receival points or transport cheaper grades from even more distant receival points, or invest more in long-term grain storage (Wight, 1982). Also economies of scale is affected by the variability in grain supply; both variability in grain quantity and quality (Tiffany & Eidman, 2003).

In this paper the twin issues of plant location and plant size and their associated costs of grain accumulation are examined for the study region of the wheat-growing districts of Western Australia. The paper's purpose is to identify the extent of differences in grain accumulation costs associated with plant location and plant size in the study region. The paper is structured as follows. The next two sections describe the mathematical programming models of grain logistics and their data sources. Section four presents the modelling results and comparative analysis. Section five is a discussion of results and the paper then ends with a set of conclusions.

2. Models

To explore how ethanol plant location and plant size affect the cost of accumulating wheat for ethanol production in Western Australia, mathematical programming (MP) grain logistics models were constructed. Eight possible sites for ethanol plants were examined and their least costs of grain accumulation over a 9 year period were identified using MP modelling. MP models of least-cost grain accumulation at each site were created in Microsoft Excel© and solved using 'What's Best'©, an add-in software for Excel©. Solving the MP models generated optimal cost and logistic solutions to the problem of minimizing grain accumulation costs.

Each MP model had a non-linear cost function as its objective function, subject to relevant constraints and resource availabilities. All models included input costs and resource availabilities. Sensitivity analysis of key parameter values (e.g. transport costs) allowed a range of results to be generated to test the robustness of the findings.

The objective function of each model was to minimise the total cost, in present value terms, of purchasing and transporting set quantities of grain involving some combination of Australian Standard White (ASW), Australian General Purpose (AGP) and Feed grade wheat each year from CBH receival points, over the nine year period from 1997 to 2005. The set tonnages considered ranged from 75 000 to 575 000 tonnes, and three levels are highlighted in the presentation of findings; required tonnages of 125 000, 275 000 and 575 000 tonnes. These three tonnages correspond to three plant sizes (small, medium and large) that typically produce 45 ML, 90 ML and 207 ML per annum of ethanol respectively.

Mathematically, the objective function for a plant of size, C, at location, L, is to minimise the total cost of grain accumulation, E_{CL} such that:

$$E_{CL} = \sum_{y=1}^{9} \sum_{r=1}^{n} \sum_{q=1}^{3} (P_{yrq} + T_{yrq}) / (1+d)^{y} \quad (1)$$

and where:

E_{CL} is the present value of total expenditure over a nine year period of accumulating C tonnes of grain each year at location L.

P_{yrq} is the price per tonne of wheat delivered to location L from receival point r in year y when the wheat is of quality or grade q.

and there are n receival points,

y_{max} is 9 (i.e., 9 years) and there are 3 grades or qualities of wheat (AGP, Feed and ASW) likely to be purchased by the ethanol plant (i.e. q_{max} = 3). Note in some models considered in this paper, especially those for large inland plants, q_{max} = 4 as Australian Premium White (APW) wheat also needs to be bought in the poorest seasons, when wheat production is much reduced, to satisfy the plant's throughput requirements,

d is the discount rate set at 7 per cent.

and where equation (1) is subject to the following constraints:

Plant capacity (tonnes/year) (C)

$$\sum_{r=1}^{n} \sum_{q=1}^{3} Q_{qr} \geq C_{Ly} \quad \text{for each y = 1,2,....,9} \quad (2)$$

where Q_{qr} is the purchased quantity of grain of grade q at receival point r in year y and,

C_{Ly} is the required throughput of grain for the ethanol plant each year at location L.

Grain availability (tonnes/year) (A)

$$Q_{yrq} \leq A_{yrq} \quad (3)$$

where:

Q_{yrq} is the quantity of grain of grade q purchased from receival point r in year y, and

A_{yrq} is the quantity of grain of grade q available at receival point r in year y;

and the required non-negativity constraints are:

$P_{yrq} \geq 0$
$Q_{yrq} \geq 0$
$T_{yrq} \geq 0$

where:

T_{yrq} is the cost per tonne of transporting grain of grade or quality q to the ethanol plant from receival point r in year y, and

P_{yrq} is the price per tonne of grain of grade or quality q at receival point r in year y.

In constructing the models several assumptions are invoked, including:

1. Ethanol producers have knowledge of:
   (i) grain availability at each CBH receival point by grade and tonnage
   (ii) price of each grade of wheat which is assumed fixed within each financial year, although varying across financial years.

2. The historically observed prices for ASW, AGP and Feed grade wheats typify the prices likely to be paid for grain accumulation by any ethanol producer that establishes a plant based on wheat in Western Australia's agricultural region. This is a bold assumption particularly for large ethanol plants in some locations and in some years, particularly when grain production is poor and there is enhanced competition between ethanol producers, intensive livestock producers, feed grain exporters and farmers seeking additional feedgrains for their stock. The presence of a very large ethanol plant at some locations, in some years, almost certainly is likely to increase the price received by farmers for their ASW, AGP and Feed grade wheats. However, as Western Australia typically exports around 90 per cent of its wheat production (DAFWA, 2006b) with the export market being the predominate market even in poor years, the principal requirement for an ethanol producer will be to at least match the FOB export price of wheat. This will be the lower bound on prices paid by ethanol producers.

3. Estimated transport costs from CBH receival points to regional ethanol plant locations are based on grain being transported by rail or road routes which minimise the distance wheat is transported.

4. If ASW, AGP or Feed wheat resources are exhausted or only available from distant expensive receival points then APW wheat is purchased, to fulfil grain requirements so the ethanol plant can

always run at maximum capacity. Note, this requires the model in equation (1) to be amended with a fourth class of wheat that rarely is purchased.

Eight plant locations are considered in this analysis. These sites were the ports of Kwinana, Geraldton, Esperance and Albany and the inland locations of Avon, Broomehill, Corrigin and Newdegate (Figure 1). The ports are often viewed as likely sites for ethanol plants as the majority of Western Australia's wheat crop is exported and therefore flows through these ports.

(Figure 1 about here)

The process for selecting the locations for the inland ethanol plants was based on scoring the CBH receival points within each port zone according to the following selection criteria. The first criterion for a regional plant location was that the regional location needed to have a high average of AGP and Feed grade wheat receivals compared to other receival points in the same port zone. Secondly, the regional location needed to display low temporal variation in the receivals of AGP and Feed grade wheat. Thirdly, the location needed to be on a railway line and preferably be a CBH primary receival point or be in close proximity to a primary receival point, to ensure storage facilities were available and there was a capability to receive and distribute large throughputs of wheat. Fourthly, surrounding receival points needed also to have high average receivals and low temporal variation of AGP and Feed grade wheat receivals. Finally, locations preferably needed to be near a port or areas with intensive livestock operations, to enable ethanol producers to minimise the transportation of ethanol or distillers grain to market. Applying these selection criteria led to the selection of the following four inland sites: Avon, Broomehill, Corrigin and Newdegate. Avon and Corrigin are receival points in the Kwinana port zone and Broomehill and Newdegate are in the Albany port zone. While regional models were considered for the Geraldton and Esperance port zones, possibly better regional locations were in the Kwinana and Albany port zones due to their high average receivals and low temporal variation in receivals of AGP and Feed grade wheat, and their proximity to the metropolitan ethanol market and industries with intensive livestock production that could purchase the distillers grain by-product of ethanol production.

3. Data

3.1. Wheat grades, receivals and prices

Confidential data sets were provided for this research by the Australian Wheat Board (AWB) and CBH, but due to the commercial value of these data sets confidentiality agreements require the raw data to remain confidential. The AWB data set provided detailed information on the tonnages received of ASW, AGP and Feed grade wheat at each CBH receival point on a season basis from 1997/98 to 2005/06. CBH provided data on freight costs, estimates of the distance between receival points and grain assessment and receival fees and charges for 1997/98 to 2005/06. Data provided by AWB, CBH and other price information published in the Department of Agriculture and Food's *Farm Budget Guides* from 1997 to 2005, was used in deriving silo return wheat prices, based on the AWB free-on-board pool prices. The pricing components of the derivation are outlined in Appendix one. The pool prices for the various wheat grades, ASW, AGP and Feed grade are listed in Table 1. The pricing model assumed is the same as found by Gallagher, Wisner & Brubacker (2005) for the pricing of corm supplied to ethanol plants in Iowa, namely that the silo return price increases nearer to each ethanol plant. There is no uniform price paid across the range of silos.

(Table 1 about here)

3.2 Transport costs

For the Kwinana, Geraldton, Albany and Esperance port models actual historical freight rates were provided by CBH and were used in the models. These freight rates show the cost of transporting each tonne of wheat of any grade from each CBH receival point to each port for the period 1997 to 2005. For the regional models however, an estimated freight rate per kilometre was used. To calculate this, the average freight rate from each receival point to port for the nine year period was determined. This average transport cost ($ per tonne) for each receival point was then divided by the estimated distance (kilometres) from the receival point to port to give a $ per tonne per kilometre figure. Although there are published freight rates for receival point to port flows, actual freight rates for inland flows (i.e. receival point to an inland ethanol plant) would need to be negotiated between ethanol producers, CBH and railway groups. However the method used to estimate freight rates is a reasonable approximation of the likely freight charge. According to CBH this method was likely to generate accurate estimates of the likely cost of inland grain transport. The average of the $ per tonne per kilometre figure for each port zone was then used as the standard freight rate for the four regional models (Table 2), as there was little variation in the freight rates over the nine year period up until 2004/5.

(Table 2 about here)

3.3 Grain requirements and plant size

Based on information from Australian Ethanol Limited and from data on the production capacity of ethanol plants in the United States of America (USA), ethanol plants can be classed into three sizes. These are plants producing 45, 90 and approximately 207 ML of ethanol per year. These sized plants are considered small, medium and large in terms of ethanol production capacity sizes in both the USA and the growing Australian ethanol industry. Using the conversion factor of 360 litres of ethanol from each tonne of wheat (Wilkins & Hancock, 2006; Whittington, 2006; Kim *et al*, 2003) the grain requirements of a small, medium or large sized ethanol plants are 125 000, 275 000 and 575 000 tonnes of wheat per year respectively, for maximum production capacity. Although a wide range of throughput was used in the models to compare the effect of plant size on the cost of accumulating grain these three plant sizes are highlighted in the presentation and discussion of results as they represent commonly held views as to what constitutes small, medium or large plants.

4. Results and Discussion

4.1 Low cost sites for grain accumulation

Modelling results identify the port locations of Geraldton and Kwinana are relatively expensive sites of grain accumulation for ethanol production compared to all other sites (Figure 2). By contrast the port of Esperance and the inland location of Newdegate are the lowest cost sites for grain accumulation for small and medium-sized ethanol plants, the latter site being the lowest cost site for grain accumulation across all grain throughputs, even those for large ethanol plants. In general, it is the southerly and inland locations that offer the best prospects for lower costs of grain accumulation. Principally this is due to the inland and southerly regions being the main consistent sources of feed, AGP and ASW grades of wheat.

(Figure 2 about here)

As the amount of wheat required to be purchased annually increases so does the unit cost of accumulation. This is due to nearby stocks of cheaper wheat grades being exhausted, causing the ethanol plant to then use either more expensive nearby grades of wheat and/or transport additional stocks of cheaper grades of wheat from more distant locations. All sites, except Esperance, exhibit a similar gradual rise in the unit cost of grain accumulation. The steep rate of rise for Esperance is due to the fact that once local supplies of cheaper grades are exhausted then grain often needs to be transported long distances to satisfy throughput requirements.

The range in the costs of grain accumulation across the various sites and sizes of throughput requirement suggests that cost savings could be made through a careful siting of an appropriately sized ethanol plant. For example, a small plant at Newdegate or Esperance operating over the period 1997 to 2005 would have an estimated expenditure on grain accumulation of around $250M (in present value terms) compared to

$264M for an equivalent plant at Kwinana or Geraldton. Also, a medium sized plant at Newdegate would have a grain accumulation cost of $555M compared to around $600M at Kwinana or Geraldton.

4.2 Partitioning costs of grain accumulation

The cost curves in Figure 2 can be partitioned into transport and grain purchase components. A sub-set in Figure 3 illustrates how transport and grain purchase costs both increase as the throughput requirements of an ethanol plant increase. Larger ethanol plants require larger grain catchments and often require more expensive grades of wheat to be purchased.

(Figure 3 about here)

At most sites as the ethanol plant size increases then the increase in the unit cost of grain accumulation is mostly due to the need to purchase more expensive grades of wheat. This is due to the fact that in some seasons there are only limited quantities of feed and AGP wheat produced in many parts of the agricultural region in Western Australia. Accordingly, once these limited supplies of cheaper grades are utilised then more expensive grades must be purchased to satisfy throughput requirements. The price differentials between wheat grades in some seasons is large (see Table 1) so any requirement to purchase more expensive grades of wheat in order to meet throughput requirements in such seasons can quickly force up unit costs of grain accumulation.

4.3 Temporal variation in the costs of grain accumulation

At all locations and for all plants sizes there is marked temporal variation in the cost of grain accumulation, as illustrated in Figure 4. A small ethanol plant operating at Esperance for example, potentially would have been able to purchase grain at a unit cost of $117 per tonne in 1998/9 when seasonal conditions within the Esperance region caused downgrading to feed status of a large proportion of its wheat production. By contrast in 2002/3 seasonal conditions favoured wheat production with mostly higher grade ASW and APW wheat being produced in a year when wheat prices were historically high; so the unit cost of grain was far greater at $214 per tonne. Medium and large sizes of ethanol plants at Esperance display some of the highest coefficients of variation in grain accumulation. By contrast, for equivalent sized plants at the locations of Geraldton, Broomehill and Newdegate offer among the lowest coefficients of variation in grain accumulation costs.

(Figure 4 about here)

The range in prices of grain likely to be paid by ethanol producers at the various locations is no surprise, given the impact of seasonal and market forces on the prices of the various grades of wheat in Western Australia. The temporal variation in prices paid is likely to have considerable impact on the ethanol producers and is only likely to be slightly reduced through locating plants at sites with lower transport costs and with access to more reliably available larger volumes of cheaper grain. Forward pricing, hedging and storage mechanisms, not considered in this analysis, could further lessen the impacts of price volatility (Wilson *et al*, 2006). An ethanol producer who purchases grain at $210 per tonne or $120 per tonne has grain accumulation costs of 61 cents per litre of ethanol and 31 cents per litre of ethanol respectively. Accordingly, extended periods of very high grain prices can rapidly erode the viability of an ethanol plant.

As 90 percent of wheat grown in Western Australia is exported (DAFWA, 2006b) local ethanol producers are likely to be price takers in the grain market. With the price of wheat making up the majority of grain accumulation costs (DAFWA, 2006a) a large portion of an ethanol plant operator's costs are thus outside their control. Aside from forward pricing, hedging and storage mechanisms, ethanol producers can only lessen expected grain costs and their volatility through the careful siting and sizing of their ethanol plant. Results in this study show potentially commercially important differences in grain accumulation costs and cost volatility across various sizes and locations of ethanol plants. The range and volatility of grain accumulation costs can be re-expressed as certainty equivalents as in Table 3 that assumes a simple negative exponential utility function with a constant absolute risk aversion coefficient of 0.01.

(Table 3 about here)

Results in Table 3 show that Newdegate is a preferred site due to its low certainty equivalent across all sizes of ethanol plant. Other highly ranked sites, dependent on the size of the ethanol plant, are Broomehill, Esperance and Corrigin.

Aside from the temporal variation in grain accumulation costs, there is also spatial variability associated with grain purchases. Table 4 shows the number and range of grain receival sites that form part of the least-cost grain logistics for various ethanol plant sizes at various locations. As the size of an ethanol plant increases so does the mean number and range of receival points that need to be accessed. Variability in wheat production across seasons also means that for any size of ethanol plant a wide range of receival points need to be accessed to supply grain over any extended period.

(Table 4 about here)

Another aspect of temporal variation in grain accumulation costs concerns the impact on grain prices of an emerging ethanol industry. In practice the size and number of ethanol plants initially constructed are likely to influence the prices paid for the ASW, AGP and Feed grade wheats. The upward pressure on these prices attributable to an emerging ethanol industry, however, may stimulate farmers to grow more of these grades, thereby relieving some of the upward pressure on prices. Moreover, wheat breeders would have an increased incentive to develop new varieties of high yielding, high starch feed wheats that, through supply shifts, would also lessen the upward pressure on prices received for such grades of wheat. The unfolding of these shifts in demand and supply may add to price volatility and be one further ingredient in the temporal variation in grain accumulation costs for ethanol producers. The modelling in this paper overlooks this component of the temporal variation in grain accumulation costs.

4.4 Implications for ethanol costs of production

Small, medium and large ethanol plants are likely to produce 45, 99 and 207 ML per year respectively. The costs of grain accumulation can be re-expressed in terms of cents per litre of ethanol. For example, at a site displaying comparatively low costs of grain accumulation, such as Newdegate, the mean nominal cost of ethanol production is estimated to be 43.7, 43.9 and 45.8 cents per litre for a small, medium and large plant respectively. By comparison, a higher cost site such as Geraldton has mean cost estimates of 46, 47.5 and 49.1 cents per litre respectively. DAFWA (2006a) and Rendell (2004) estimate that grain accumulation costs are generally around 70 per cent of the operating costs for an Australian ethanol plant. By comparison, Shapouri & Gallagher (2005) report grain accumulation costs are around 65 per cent of the operating costs for dry mill ethanol plants in the United States.

Although grain accumulation costs are less for small and medium plants compared to large plants, nonetheless economies of size advantages help offset the likely higher unit cost of grain for large plants. Size economies are known to be a feature of ethanol production (Gill *et al*, 2003; Gallagher, Brubaker & Shapouri, 2005) with labour and utility costs per litre of ethanol produced decreasing with increased plant size (Bruni, 1964; Gill *et al*, 2003; ICM, 2006). For example, Gallagher, Brubaker & Shapouri (2005) found an ethanol plant producing 295 million litres, compared to a smaller plant producing 182 million litres, had unit capital costs that were 4.8 cents per litre less, roughly equivalent to an annualised value of

1.2 cents per litre. Whether the reductions in the unit costs of capital, labour and utilities in aggregate are greater than the additional unit cost of grain accumulation as plant size increases is an empirical question, and is likely to be case specific. Australia, for example, is known to have higher unit costs of ethanol plant construction compared to the United States (Anderton 2006). The costs of grain accumulation reported in this study suggest that small plants compared to large plants offer reduced grain accumulation costs of between 2 to 3 cents per litre.

Ultimately the most profitable plant size will be determined by several factors including the size of the ethanol market and the market for by-products, the cost of capital, returns to size and grain costs and grain availability (Besanko *et al.*, 2000). As Eidman (2006) comments :

> 'Producing ethanol is a commodity business with wide swings in profitability, dependent largely on the price of the feedstock (primarily corn and grain sorghum), the price of ethanol, and the cost of the fuel used in the plant.' (p.4)

One of the advantages of some the inland locations for ethanol plants, such as Broomehill, Newdegate and Avon and for the port location of Esperance, is the proximity of markets for wet or dry distillers grain. At or near these locations are either feed-lot businesses or animal enterprises that are ready markets for the distillers grain. Profitable markets for distillers grains boost the profitability of ethanol production (Agriculture and Agri-Food Canada, 2003; Shurson, 2005; Tiffany & Eidman, 2005). Wet distillers grain has a shelf life of 4-5 days and involves the transport of 70 per cent water by weight of product. By contrast dry distillers grain has a 12 month shelf life but uses large amounts of energy in grain drying (Rendell, 2004).

4.5 Modelling starch

A desirable refinement of the modelling would be to include not only the price of each grade of wheat but also their likely starch content, as it is the starch that is the key resource for ethanol production. Unfortunately, we do not have access to any detailed historical data on grain quality by grade at each receival silo. Such data would allow the model to be based on purchases of starch rather than purchases of grain. However, some general observations about the starch content of wheats grown in Western Australia can be noted.

Over 40 per cent of Western Australia's wheat production displays a relatively high starch content principally due to its protein level being 10 per cent or less (DAFWA, 2005a; Wilkins & Hancock, 2006), making this wheat potentially well-suited to ethanol production. There is an inverse relationship between protein and starch in wheat (Kim *et al*, 2003). The low protein (or higher starch) wheat grown in Western Australia is mostly the AGP and ASW grades and these grades are grown mostly in the southern and central western regions of the wheatbelt. These regions typically experience higher rainfall and a longer growing seasons (DAWA, 2000), with weather conditions causing wheat to be downgraded to the AGP and Feed wheat classes. These regions lie mostly in the Kwinana, Albany and Esperance port zones. By contrast, the majority of the high protein (lower starch) wheat grades such as the Australian Prime Hard, Australian Hard and APW grades are produced in the areas of lower rainfall with a shorter growing season. These areas are predominately in the eastern, northern and north-eastern regions of the Kwinana port zone and the Geraldton port zone, or in the more fertile lower rainfall areas north of Esperance (DAWA, 2000). Accordingly, as suggested by the modelling in this paper, inland sites in the Kwinana, Albany and Esperance port zones (see Figure 1) that draw on Feed, AGP and ASW grades that are mostly grown in southern medium rainfall areas are lower cost sites for grain accumulation.

6. Conclusions

Many factors can affect the profitability of an ethanol plant. However, the cost and reliability of access to feedstock are particularly important as feedstock typically forms around 70 per cent of the operating costs of an ethanol plant. This paper uses logistics modelling to show how an ethanol producer can lessen their cost of grain accumulation by carefully selecting sites and production capacities. The agricultural region of Western Australia and ethanol production based on wheat are used as a case study.

This study identifies a sub-set of locations in Western Australia that may favour ethanol production. These places have access to reliable sources of wheat of appropriate quantities and qualities and often they are close to possible users of distillers grain, a by product of ethanol production. One location, Newdegate, is a least cost site (in terms of grain accumulation) across the range of plant sizes considered. Some other locations such as Broomehill, Esperance and Corrigin are also, in some circumstances, low cost sites for grain accumulation.

Grain accumulation costs increase with plant size, independent of site and the logistics become more involved with more receival points required to be sources of grain. Large plant sizes are exposed to more expensive grain accumulation costs in years when relatively small volumes of cheaper grades of wheat are produced. In these years more expensive grades of local wheat need to be purchased and more distant supplies of cheaper grades need to be purchased. Across all plant sizes, volatility in grain accumulation costs and different logistics patterns across years are a feature of ethanol production in the study region, due to seasonal conditions that affect the quantity and quality of grain produced, as well as due to price volatility on wheat export markets.

This study highlights potential cost savings in grain accumulation costs derived by judicious siting and sizing of an ethanol plant and shows how these costs are linked to plant size. However, although grain accumulation costs are a major consideration in the investment decision regarding the size and siting of an ethanol plant, there are several other important cost and revenue considerations that impinge on the investment decision. These are factors not considered in this study but include such items as the cost of capital, economies of size advantages, policy settings for bioenergy, cost of utilities, consumer demand for ethanol blends and markets for by-products.

Table 1: AWB Total Pool Return (Free-On-Board) prices for Australian Premium White (APW), Australian Standard White (ASW), Australian General Purpose (AGP) and Feed grade wheat for 1995 to 2005 ($/tonne)

	Wheat Grade			
	APW	ASW	AGP	FEED
1995/96	254	249	239	219
1996/97	205	200	192	168
1997/98	198	193	179	163
1998/99	190	185	168	129
1999/00	192	190	173	153
2000/01	234	226	220	185
2001/02	259	248	235	189
2002/03	258	245	242	238
2003/04	233	220	218	205
2004/05	197	192	190	177
2005/06	189	170	165	158
Mean	219	211	202	180
St Dev	29.17	28.17	29.63	31.52

Table 2: Mean and standard deviation of the estimated transport cost used in the models to calculate the cost of grain transportation from regional CBH receival points to inland plant locations ($ per tonne per km)

Port Zone	Mean	St Dev
Kwinana	0.05695	0.006
Albany	0.05833	0.0056

Table 3: Certainty equivalents of the nominal cost of grain accumulation over the period 1997/8 to 2005/6 ($/tonne) for ethanol plants of various sizes at different locations, sorted by the certainty equivalent[a]

Small plant	Site	Newdegate	Esperance	Broomehill	Corrigin	Kwinana	Geraldton
	($/t)	153.8	154.6	155.4	159.6	161.6	162.9
Medium plant	Site	Newdegate	Broomehill	Esperance	Corrigin	Kwinana	Geraldton
	($/t)	155.4	160.7	161.6	163.2	166.8	168.2
Large plant	Site	Newdegate	Broomehill	Corrigin	Esperance	Kwinana	Geraldton
	($/t)	161.6	166.5	167.0	169.3	171.4	173.7

[a] based on a negative exponential utility function with a constant absolute risk aversion coefficient of 0.01.

Table 4: The number of receival points forming part of least-cost grain logistics for different sizes of ethanol plants at various locations: for the period 1997/8 to 2004/5.

		Kwinana			Broomehill			Newdegate		
		Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
No. of	Mean	20.8	31.8	46.9	19.6	31.7	38.2	16.8	23.8	37.0
receival	Min	6	16	26	7	14	16	7	13	25
points	Max	52	62	71	32	48	50	33	44	53

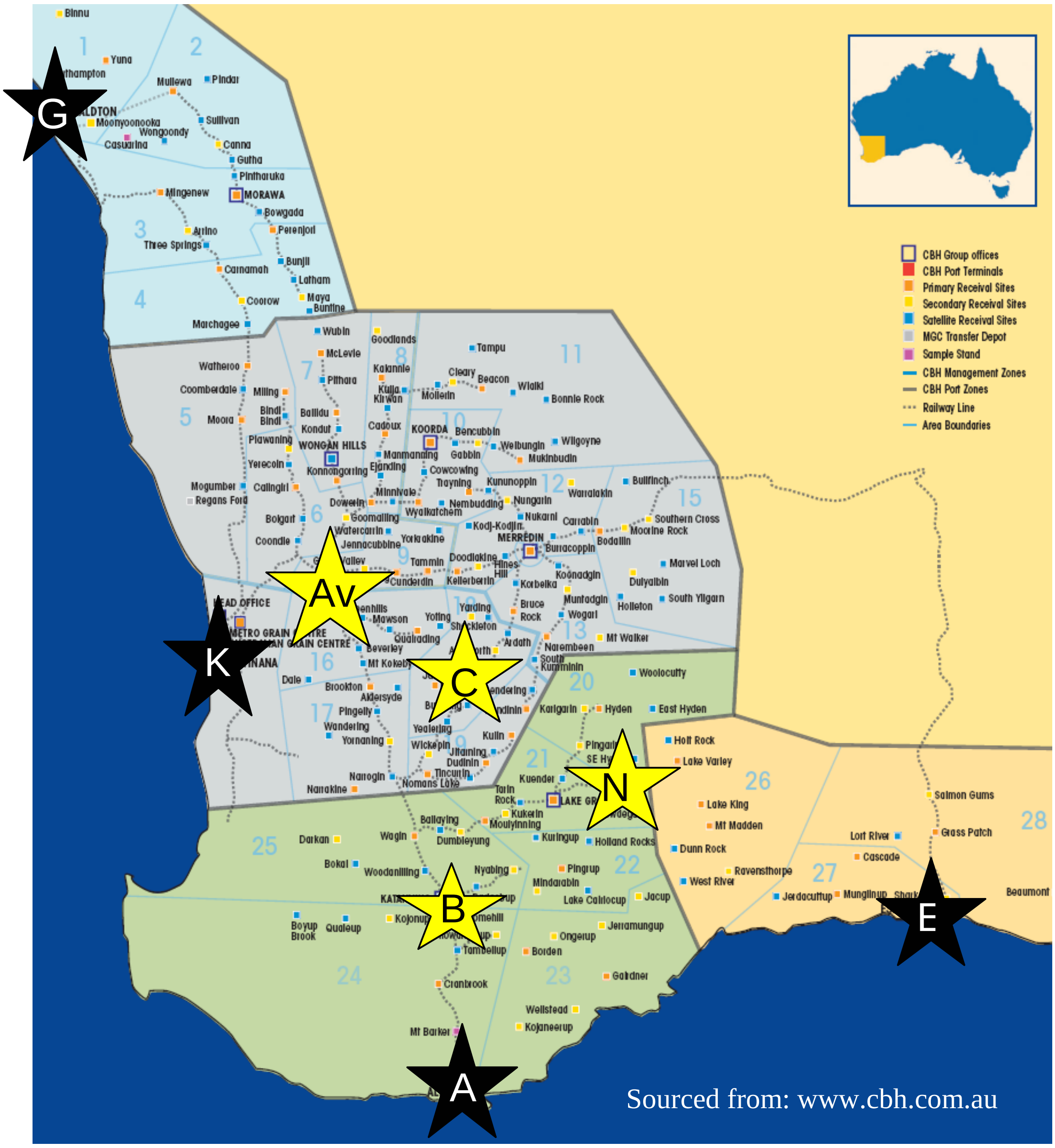

Figure 1: Map of sites for ethanol plant locations, port zones and CBH silos or receival points, where;

★ are port locations of Kwinana (K), Albany (A), Geraldton (G) and Esperance (E)

☆ are inland locations of Avon (Av), Broomehill (B), Corrigin (C) and Newdegate(N)

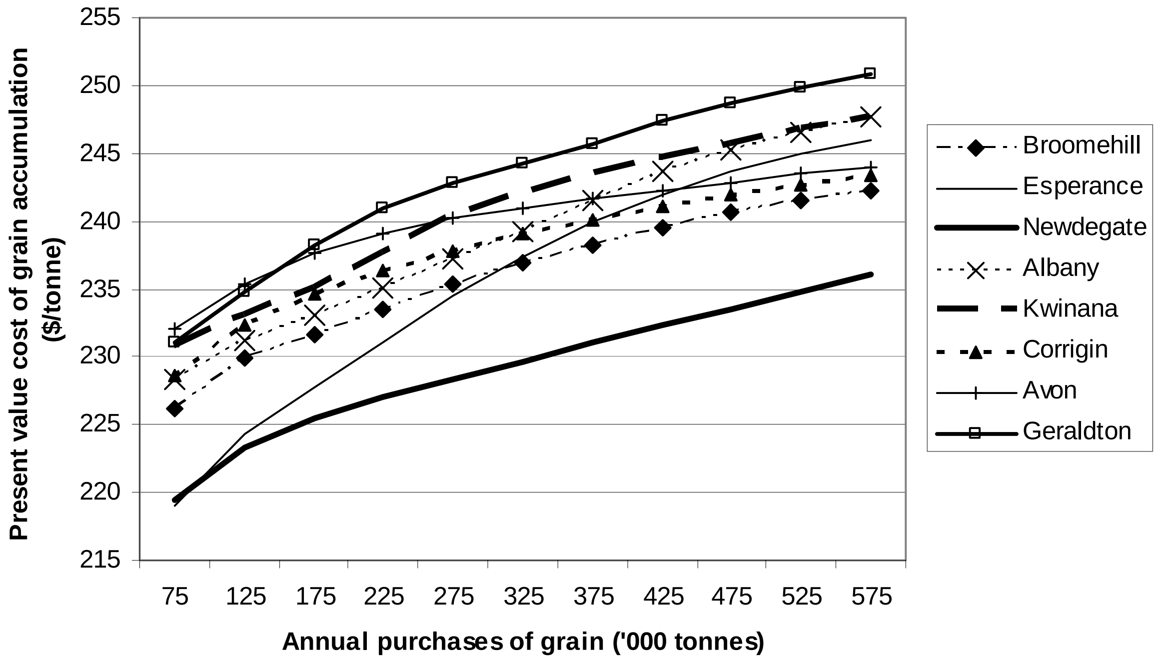

Figure 2: Cost functions for wheat accumulation for ethanol production at 8 sites in Western Australia ($/tonne of wheat, expressed in present value 2006 dollar terms)

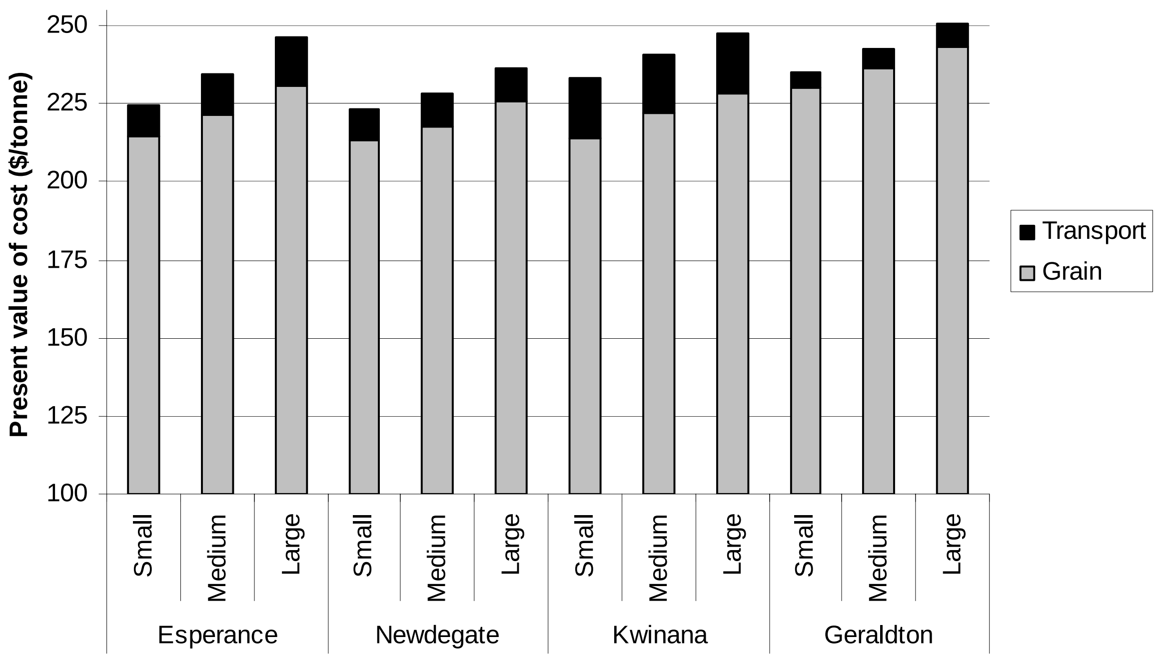

Figure 3: Cost components of grain accumulation for ethanol plants of different sizes at various locations (transport and grain purchase expressed as $/tonne of wheat in present value 2006 dollar terms)

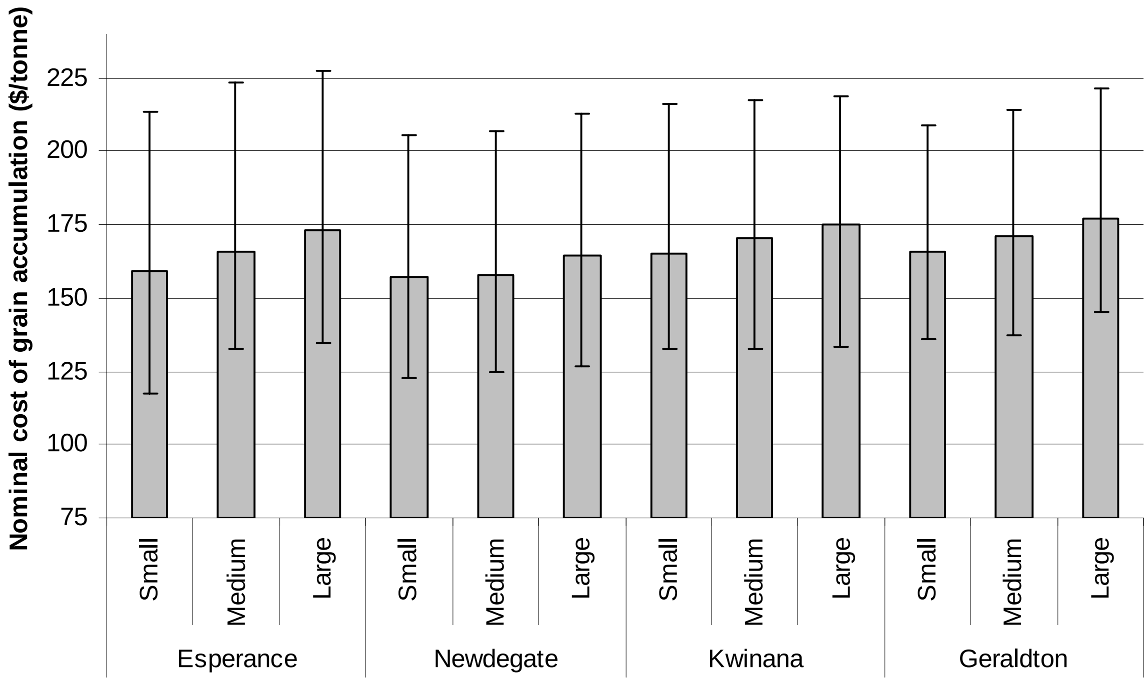

Figure 4: Cost of grain accumulation for ethanol plants of different sizes at various locations. (The thick grey bars are the mean nominal cost per tonne over the period 1997 to 2005 and thin lines depict the cost range)

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Appendix One

Wheat Pricing Terminology[a]

CIF (Cost Insurance Freight)

Landed price at the overseas destination (includes shipping and insurance costs)

↓ minus shipping and insurance costs (depends on destination)

FOB (Free on Board = Pool Return)

Price of wheat loaded on to the vessel ready to sail

↓ minus CBH export outturn costs plus port differentials and minus AWB Ltd finance (estimate related to borrowing to support pool payments at harvest and underwriting)

FIS (Free in Store)

↓ minus CBH receival and grain assessment costs

DPB (Delivered Port Basis)

Value of wheat delivered to port (i.e.Net Pool Return – CBH charge (plus or minus port allowances for wheat)

↓ minus freight to port

SILO RETURN

[a] Source: DAFWA (2005b) "Wheat Pricing Terminology", p. 56 Farm Weekly Budget Guide 2006