OPTIMAL DESIGN OF MULTIPART TARIFFS
FOR DAM WATER: THE COMET RIVER DAM
PROJECT

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INTRODUCTION

The following study aims to analyse the Central Queensland region and its need for water supply, investigate approaches to the pricing of water and subsequently optimally design a system of multipart tariffs for dam water. The approach used combines a mechanism design framework with inventory theory.

The model is then applied to Central Queensland where several Water Development Projects are being proposed, one of which is the Comet River Dam Project. The dam is being proposed to serve additional demand for water stemming from the expanding agricultural and coal mining production and surrounding this is a certain water pricing debate. The debate consists of differing opinions on the structure of water prices, particularly that of increasing the price of water.

A model is developed to discover the optimal tariff structure with Tariff 1 being a consumption charge and Tariff 2 based on a minimum charge and a consumption charge. The model considers the water authority selling to two agents, namely the farmer and the mine and involves concepts such as individual rationality and incentive compatibility.

1.1 Defining the Problem

Water pricing is currently a contentious issue especially with respect to the Queensland Government's proposal for the Comet River Dam Project. Reform in water pricing has been ongoing with many issues arising out of this process. These include issues such as full cost recovery, user pays, asset refurbishment, environmental concerns, microeconomic reform and many others. There are several approaches to the pricing of water and all involve differing opinions from different sources of literature. These include marginal cost pricing, average cost pricing, Ramsey pricing, full cost recovery, all of which possess inherent problems. Therefore this study aims to optimally design a system of multipart tariffs through the use of a mathematical model. The model is broadly based on the region of Central Queensland in order to address the water pricing issues arising from the Comet River Dam Proposal.

Future growth and prosperity in this region will depend on the availability of adequate reliable water supplies. Water supplies for the expanding mining and agricultural industries have been virtually unavailable and there have been difficulties with securing priority domestic supplies to townships. Cost-effective and flexible policy instruments should be implemented, such as improved valuation, pricing and incentive mechanisms.

Section 2 aims to 'set the scene' by providing an overview of the main industries in the surrounding region and the current and future need for increased water supply and efficiency. The main rural industries in the region include cotton, peanuts, table grapes and citrus trees. Subsequently section three aims to provide the theoretical foundation of the formulated model.
leading to the technical development and application of the model to the Central Queensland region. The two sources of literature that provide the framework of the model, inventory theory and mechanism design, are discussed from which the optimisation procedure progresses. The decision problems of the farmer, mine and water authority are worked through in section 4, resulting in three optimal utility equations which are used to obtain results from the region. The results of the model are presented in section 5, providing the optimal utilities of the groups involved which are obtained by a random number generator. An analysis of stochastic dominance, incentive compatibility and individual rationality is conducted through the plotting of cumulative distribution functions. Finally, section 6 draws the main concepts together.

2 PRIMARY INDUSTRIES IN CENTRAL QUEENSLAND
The region of Central Queensland supports many agricultural industries as well as the prominent coal mining industry. For increased production in these sectors, increased water supply coupled with an increase in the efficiency of water use is required. The main agricultural industries in this region are citrus, cotton, table grapes and peanuts. The characteristics of the major agricultural industries in Central Queensland are summarised in Table 1. It is observed that cotton production is by far the dominant rural industry in terms of its value as it contributed $68M to the Central Queensland economy in 1993 (Queensland Department of Primary Industries, 1996).

Irrigation is essential for citrus crops which require the highest level of water usage. Citrus crops also contribute significantly to the economy and therefore should be supported through the supply of increased water.1

<table>
<thead>
<tr>
<th>CROP</th>
<th>VALUE (1993 $M)</th>
<th>WATER USAGE (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CITRUS</td>
<td>10</td>
<td>8.7-10</td>
</tr>
<tr>
<td>COTTON</td>
<td>68</td>
<td>7</td>
</tr>
<tr>
<td>GRAPES</td>
<td>3.5</td>
<td>6-8</td>
</tr>
<tr>
<td>PEANUTS</td>
<td>5.6</td>
<td>4-7</td>
</tr>
</tbody>
</table>

Source: QDPI Information Sheets, 1996

The gross margin for dryland cotton is estimated at $204 per hectare and irrigated cotton at $1 666 per hectare (QDPI, 1996).

1 Central Queensland has a competitive advantage in that citrus fruits ripen one to two weeks before other areas thus creating a price advantage in domestic and export markets (Queensland Department of Primary Industries, 1996).
Dryland cotton relies on rainfall whilst irrigated cotton requires approximately 7 megalitres per hectare annually (QDPI, 1996). Water usage will increase however, if irrigation systems are inefficient.

The table grape industry represents a strong industry in Central Queensland where the gross margin per hectare is approximately $18,708 per hectare (QDPI, 1996). Irrigation is once again essential for the growing of table grapes and is especially critical in the flower and fruit development phase which is September to December. Central Queensland's contribution to Australia's peanut production was valued at $5.6 million in 1993 with the gross margin for irrigated peanuts being estimated at $988 per hectare (QDPI, 1996). According to QDPI figures, it is not feasible to grow dryland peanuts in Central Queensland thus highlighting the requirement of continued water supply. (QDPI, 1996).

Other crops grown in the region are wheat, sorghum, soybeans and mungbeans, all requiring different usages of water and returning different prices per tonne. Table 2 highlights these characteristics.

<table>
<thead>
<tr>
<th>CROP</th>
<th>PRICE/t (1996)</th>
<th>WATER USAGE(ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUNFLOWER</td>
<td>$318</td>
<td>4</td>
</tr>
<tr>
<td>SOYBEANS</td>
<td>$400</td>
<td>6</td>
</tr>
<tr>
<td>BARLEY</td>
<td>$155</td>
<td>4</td>
</tr>
<tr>
<td>MUNGBEANS</td>
<td>$450</td>
<td>4</td>
</tr>
<tr>
<td>WHEAT</td>
<td>$180</td>
<td>5</td>
</tr>
</tbody>
</table>

Source: Spackman, 1996, p2

Central Queensland not only consists of agricultural industries but a well established and growing coal mining industry. Coal mining contributes significantly to the Central Queensland economy. The main coal mines in the area which may benefit from the construction of the dam include South Blackwater, Blackwater, Curragh and Gordonstone. Table 3 shows the annual production of these mines as well as their annual usage of water.
Blackwater mine draws from the Mackenzie River which is fed by the Nogoa River, the mine would benefit indirectly due to a larger level of security of water supply. As the supply of water from rivers is not considered in the model, Blackwater is not used as an example. Curragh, one of the larger mines, draws from the Bedford Weir as well as having on-site retention dams and uses approximately 3400ML of water annually. Management of the mine is aiming to reduce this amount and increase recycling due to the increasing environmental pressure and need for water efficiency. It is considered by management that the construction of the Comet Dam will improve water supply and provide a '100% guarantee.' (Thompson, 1996, Personal Communication) Therefore Curragh mine is used in the model as its characteristics are the most suitable.

2.1 Water Development Projects in Central Queensland

Major investment in water infrastructure in recent years has been directed towards upgrading existing facilities, improving the reliability of supply and extending the geographic area which has access to supply. In order to address the needs of particular industries and regions, specific projects have been developed including the Fitzroy Basin Water Infrastructure Project (Queensland Government, 1995).

The former government endorsed in principle a $500 million Fitzroy Water Infrastructure Development Strategy which was developed in response to the fact that one of the major factors impeding the future growth of this region was the lack of new water storage and transmission infrastructure (Queensland Government, 1995). One of the aims of the Fitzroy Water Infrastructure is to improve reliability of supply from the Fairbairn Dam thus a new 1.3 million megalitre (ML) Dam on the Comet River at a cost of $235M has been proposed (Queensland Government, 1995). The dam is projected to be approximately the same size as Wivenhoe Dam and will yield an additional 550,000 ML water per annum with a high level of reliability and an additional 90,000 ML of water at the present level of reliability. The new dam will open up some 20,000ha of irrigated land for agriculture and enable present water resources to be managed more effectively by having some

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Table 3 - Central Queensland Mines - Annual Production and Water Usage

<table>
<thead>
<tr>
<th>COAL MINE</th>
<th>PRODUCTION (Mt)</th>
<th>WATER USAGE (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLACKWATER</td>
<td>2.8</td>
<td>2471</td>
</tr>
<tr>
<td>CURRAGH</td>
<td>4.9</td>
<td>3414</td>
</tr>
<tr>
<td>SOUTH BLACKWATER</td>
<td>1.1</td>
<td>201</td>
</tr>
<tr>
<td>GORDONSTONE</td>
<td>3.5</td>
<td>1078</td>
</tr>
</tbody>
</table>

Source: MINMET Australia, 1996
established users draw water from the new dam thereby alleviating pressure on the existing catchment (Queensland Government, 1995).

The town of Comet is located approximately halfway between Blackwater and Emerald. Four potential sites have been chosen for the dam along the Comet River, which runs south to Rolleston. The preferred site is located 125 kilometres upstream of the Mackenzie River junction. If the dam is constructed at this site the township of Rolleston is expected to flood, thus requiring the town to be relocated at a cost of approximately ten million dollars (Jeffrey, April 1996).

2.2 Policy: The Queensland Case
Water pricing has played a significant part in dam discussions with some producers expressing concern over the equity of a user pays system. A policy favoured by some is a uniform pricing scheme whereby water would be initially offered at a flat rate price and then adjusted over time in accordance with external influencing factors (Jeffrey, March 1996). There are obvious economic benefits in some averaging of prices to broad groups of consumers because of costs of administering prices and the practical problems in discovering the costs of supply to individual customers (Watson, 1995). Coase analysed the effects of uniform pricing by public utilities and stated that 'a uniform pricing system results in some consumers being charged more and some less then the costs of supply therefore some consumers who would be willing to pay the costs of supplying them do not in fact receive a supply' (Coase, 1947, p.149). In the case of the proposed Comet Dam where it is most likely to be supplying to producers and minesites, it is possible that the mine is actually willing to pay more for the supply of water as it has a better capacity to do so compared to the farmers.

It is important to realise that the history, politics, water prices, pricing practices and technical aspects of irrigation are extremely different in each of the Australian States. The role of the Commonwealth in formulating irrigation policy is increasing and in recent years the Council of Australian Governments has also played a major role. The general emphasis of policy has now moved towards higher prices and this has been due to concern with economic efficiency, environmental concerns and the desire of governments for increased revenue. Watson (1995), makes the point that current policies for the pricing of water are not based on sound economic principles.

In previous years, governments held a more relaxed attitude towards water prices due to irrigation being largely justified by non-economic objectives which no longer carry the same support from political circles. Present policies are largely based on arguments about efficiency of resource allocation. Changing community attitudes towards water prices are also motivated by increasing concerns with the environmental effects of irrigation. Watson argues that, "in effect, the environment
has become a stalking horse to rationalise recovering more of the costs involved with the irrigation system by increased water prices." (Watson, 1995, p. 16).

Watson also argues that with respect to increasing government revenue, governments are naturally far more inclined to respond favourably to political pressure that increases its revenues rather than their outlays. He highlights that the environmental and revenue objectives for higher water prices are at cross purposes. This can be explained by considering the price elasticity of demand which measures the responsiveness of consumption to price changes. "If water use by irrigators is sensitive to water prices, then higher prices will reduce water consumption, with possible environmental benefits and certain reduction in revenue. Further, if demand is very elastic, the target of cost recovery is unobtainable." (Watson, 1995) As optimal cost recovery is the main concern of this paper, demand is assumed to be inelastic.

The primary instrument used to allocate and manage water resources in Queensland is a licence issued under the Water Resources Act. This procedure is designed to ensure orderly access to water, protect riparian rights and to minimise the conflict between competing users. Government decisions in the past have been based on the perceived regional and social benefits from water resource developments and also that the State would fund the capital costs of irrigation schemes. Under present policy, full cost recovery including a return on capital is targeted for all industrial, mining and bulk urban customers.

The level of charging has typically been lower for farmers compared to water users in other sectors. That is, reduced water charges are often used by the Government to assist farmers facing adverse conditions of a cyclical or seasonal type (Queensland Government, 1993).

Up to 1988, the accepted policy was for the acceptance of the partial recovery of direct operating costs. Refurbishments have traditionally been regarded as part of overheads or funded as capital outlays instead of being regarded as an expense relevant to and recoverable from local operations. Following the Cabinet approval in April 1990 of a policy that all new allocations would incur a capital charge, a more commercial approach has been adopted for recent and future developments. The current pricing policy for Queensland water supplies varies according to categories of water services and between separate water supply schemes. Irrigators receive a nominal allocation and generally pay a minimum charge equivalent to the cost of 75% of this allocation regardless of use. An announced allocation at a fixed proportion of nominal allocation is determined on the basis of available supplies and excess charges apply if more than the announced allocation is used (Bevin, 1993).
3 APPROACHES TO PUBLIC UTILITY PRICING

Watson (1995) discusses two general approaches to the economic problem of public utility pricing and that is of Harold Hotelling and Coase. Hotelling argued that prices should be set at marginal cost with the deficiency in revenue being made up through government subsidy. However, Coase had concerns with this reasoning and highlighted two main problems; (1) That taxation revenue is needed to finance the subsidy and (2) Public utilities are continuously dependent on government subvention. He argued that multi-part tariffs with short-run marginal cost pricing would lead to the most optimal outcome in terms of economic efficiency (Watson, 1995). Therefore a multipart tariff is designed in this study to determine its effects on the consumers and the water authority.

3.1 Multiple-part Tariffs

Tariff structures define how charges are distributed between different customers, influence decisions made by both users and scheme managers and provide incentives to use water efficiently. There are two types of costs that can be identified in the operation of water supply schemes. They are fixed costs (which result from just maintaining the system even when no water is used) and variable costs (costs which are incurred only when water is consumed).

The costs associated with delivering the next unit of water are marginal costs and in the short run, marginal costs include mainly variable costs of delivery within the capacity of the facilities. However, substantial capital investment may be required in the long run and these costs also represent marginal costs. Appendix 1 shows the different tariff options that are available. Option A is an example of a tariff structure based only on marginal costs, whilst options B, C and D are three different examples of multi-part tariffs. (Queensland Government, 1993).

Two-part tariffs are well-known mechanisms used to improve the efficiency of public utility pricing when average costs are decreasing. With a two-part tariff structure, a price less than average cost may be charged and the balance of total cost may be covered by levying from each consumer a licence fee which is not based on the amount consumed. However the problem which exists with the two-part tariff is how much less than average cost should price be. Apart from the administrative costs associated with two-part tariffs, it is generally agreed upon that they guarantee efficiency superior to that of uniform pricing. (Ng and Weisser, 1974). Ng suggests that a two-part pricing technique (a fixed charge plus a unit price) particularly in the case of water is a superior method. Due to some water consumption being essential for all users and substitutes are almost non-existent, a moderate fixed charge to account for the required amount in excess of marginal cost (MC) can be introduced along with MC-pricing without driving out any consumers. The use of a two-part tariff may also be a politically acceptable
method to approximate the efficient optimal price cycles. Thus a low unit-price with a substantial fixed charge may be used when capacity is abundant relative to demand. The fixed charge can be reduced or even waived completely as the unit price is increased to restrain demand when demand is high relative to capacity. (Ng, 1987).

An important conclusion that Coase (cited in Watson, 1995) made was that multi-part pricing provides an alternative solution to the dilemma of setting prices in situations with decreasing costs. Freebairn (cited in Watson, 1995) also supports this notion of multi-part pricing and points out that an advantage of multi-part pricing is that the revenue of a public utility is more stable and that moving to a system of purely use-based charges would have destabilising effects on the revenues of farmers and utilities alike. The effect of both approaches is discovered in this study by designing tariffs pertaining to each type of structure.

4 A MODEL OF MULTIPLE-PART PRICING OF DAM WATER WITH STORAGE COSTS

In designing the system of tariffs, literature from mechanism design and inventory theory were used. Inventory theory provides the basis of determining the cost function for the water authority to supply water which is incorporated into the mechanism design framework. The discussion on mechanism design briefly describes the characteristics of incentive compatibility and individual rationality. After providing the theoretical foundation, the model is developed through a series of steps resulting in the optimal utility functions for both tariff structures.

An inventory control approach is used to determine a cost function to incorporate into a non-linear pricing model. The generalised inventory model, as shown below, is modified to reflect the specific situation for dam water. An inventory problem exists when it is required to stock physical goods or commodities in order to satisfy demand over a specified time horizon. The total cost of a general inventory model can be shown as follows:

\[ \text{Total inventory cost} = \]

\[ \text{Purchasing cost} + \text{setup cost} + \text{holding cost} + \text{shortage cost} \]

(Taha, 1982)

\[ \]

2 A Stackelberg game approach was attempted however a solution could not be found as it is a regulatory problem where the water authority is the leader trying to control the demand of the two types of consumers, the farmer and the mine. Therefore a Nash equilibrium is achieved instead.
There are many types of inventory models and the one that is adopted in this study is a static storage model. The cost function in this study ignores the purchasing, setup and shortage costs due to the requirement of significant estimation of these values as a result of the non-existence of the dam to date.

In contrast to the static model used in this study there have been a number of studies carried out using dynamic models by Prabhu (1965) and Moran (1954) and more recently by Abdel-Hameed and Nakhi (1995), Assmussen and Kella (1996) for representative examples. Therefore extensive work using an inventory control approach has been used, however this study differs in that this theory will be embedded within a mechanism design framework.

In the organisation of economic, political and social activity, institutions play a significant role. A central problem in the theory of institutions is the characterisation of outcomes which can be achieved by institutions which is the problem that the theory of mechanism design addresses. A basic principle of mechanism design with incomplete information is that any outcome which is a Bayesian Nash equilibrium outcome to a mechanism (institution) must satisfy an incentive compatibility condition.

Implementation theory seeks to characterise those outcomes which are unique equilibrium outcomes to mechanisms, and incentive compatibility is thus a necessary condition for implementation (Palfrey, 1987).

In the case of a dam, each agent, the farmer and the mine knows the amount of water required by their own type however not that of the other. Therefore, incentive compatibility exists if each agent receives the correct amount of water and thus the allocation of water is implementable.

Assume there are 3 agents and Ti denotes the set of possible types for agent i=1,2. A type for agent i, t_i specifies the preferences of i and also i's information about other agents. A is an arbitrary set of alternatives and U_i(t_i) the utility function of agent i if he is of type t_i E Ti. t_i is represented in the model by differences in technology and differences in market structures. Let T = T_1xT_2 x...xT_3 and let X = (x : T -> A) be the set of all allocations where an allocation is a function (x : T->A).

In this formulation, each agent is assumed to know his own type but not necessarily that of any other agent. The question remains whether there exists a mechanism which has x as its unique equilibrium outcome and if there exists such a mechanism, the allocation is said to be implementable (Palfrey, 1987).

After determining the total cost function using a simple inventory control approach, this is substituted into a mechanism design framework. The model considers two types of agents, in this case, the farmer and the mine, and is expanded to incorporate a case for a two-part tariff. The non-linear
pricin g method is an example of mechanism design which has evolved through the recent economic literature. It involves concepts such as individual rationality and incentive-compatibility, which represent constraints in the model. The individual rationality constraint or participation constraint occurs due to the requirement that the consumer must be willing to purchase. The incentive-compatibility constraint requires that the consumer consumes the bundle intended for his type (Fundryerg and Tirole, 1992). Therefore this study is adding to the existing work done on water pricing models by combining two sources of literature and analysing cases for two different tariff structures, which represents options A and B in Table 4.

Optimal utilities for the farmer and mine are sought and a profit maximisation for the water authority. Utility functions for the decision problems of the farmer and the mine are used where a 'utility function is simply a device for assigning numerical utility values to consequences in such a way that a decision maker should act to maximise subjective expected utility' (Anderson, Dillon and Hardaker, 1977).

4.1 The Farmer's Decision Problem

The farmer's profit function is developed in the following way. Firstly, the total amount of water used by the farmer is a function of the amount pumped from the dam, Q, and rainfall, r which is essentially f(Q, r). By using a power function

$$ F(Q, r) = k(Q + r)^p $$

the profit function can then be defined. However the structure for Tariff 1 must also be established and as this is simply a consumption charge it appears as follows

$$ T = c_Q r $$

where cf is the cost of water for the farmer and Qt is the amount of water received by the farmer.

Thus the profit function for the farmer is shown as

$$ Pr = p[f(Q + r) - c_f]Qf for a = 1 $$

where p is the price received by the farmer for a specific commodity and k, is a scalar value. If the log is taken of this function then a utility form is found as shown below.

$$ U_f = \ln[pf(Q + r) - c_f]Qf$$
By differentiating this equation with respect to $Q_t$, it is hoped that a solution for $Q_t$ is found.

$$\frac{dU_f}{dQ_t} = \frac{(pk_t-c_t)}{[pk_t(q_t+r) - (c_t)]}$$

However a solution for $Q_t$ is not found, although a solution for $c_t$ is found to be

$$c_t = pk_t$$

which can be interpreted as the willingness to pay or where marginal cost is equal to marginal revenue for the farmer.

4.2 Mine's Decision Problem

The mine's decision problem is formulated in a similar manner with only slight variations. The amount of water consumed by the mine is $Q_t$ where

$$g(q_t) = \alpha Q_t^\beta$$

where beta equals one and $k_t$ is a scalar value. The structure for Tariff 1 is based on a consumption charge where

$$T_g = \alpha Q_t$$

The price received for the mine's commodity assumes monopolistic competition and is shown as

$$p = a \cdot b Q_t \cdot z$$

where $a$ is a constant determined by the price received by the Curragh mine for coal, $z$ is a constant determined by the effect of other mine's production on the price and $b$ is a coefficient. The computation of these values are detailed in Appendix 3. After defining these variables the profit function for the mine is established where

$$\Pi_g = (a \cdot b Q_t \cdot z) - c_0 Q_t - c_t Q_t$$

The profit function is transformed into a utility function by taking the log form such that

$$U_g = \ln[(a \cdot b Q_t \cdot z) - c_0 Q_t - c_t Q_t]$$

By differentiating with respect to $Q_t$ the following result is obtained.
Solutions for \( Q_1 \) and \( C_1 \) are calculated and shown in the following equations.

\[
Q_1 = \frac{1}{2} \frac{(-k_0 a + k_0 z + c_0)}{b k a}
\]

and

\[
c_1 = -2 b k_0 Q_1 + k_0 a - k_0 z
\]

These solutions are used to determine optimal utility functions for the farmer and the mine.

4.3 The Water Authorities Decision Problem

The decision problem of the water authority consists of an objective function which is set in a mechanism design framework such that

\[
EU = P f (c_0 Q_f - C_f) + P m (c_0 Q_m - C_m)
\]

where \( C_f \) and \( C_m \) are functions of \( Q_f \) and \( Q_m \) respectively, shown as

\[
C_f(Q_f) = \frac{1}{2} \frac{(r^2 c_t)}{Q_f + Q_m} + c_0 Q_f
\]

and

\[
C_m(Q_m) = \frac{1}{2} \frac{(r^2 c_t)}{Q_f + Q_m} + c_0 Q_m
\]

\( C_f \) and \( C_m \) are the costs incurred by the water authority of supplying to the farmer and mine and the functions are adapted from storage or inventory theory whereby rainfall is used as a proxy variable for \( r \) and is assumed to be the inflow whilst \( Q_f \) and \( Q_m \) represents the outflow of water. An average is taken to smooth out extreme seasonal differences in rainfall. An opportunity cost is also included to account for the returns foregone by storing water. This is established by taking the capital cost of the water stored in the dam and using the current rate of interest for investment. The value \( c_t \) is the variable cost of delivering water to the consumers which in this study is assumed to be zero. \( C_f \) and \( C_m \) are then substituted into the objective function of the water authority whereby
\[ EU = P_I[(c_Q - \frac{r^2c_I}{2(Q+Q'_I)}) - c_Q] + P_{in}(c_{Q'_I} - \frac{r^2c_I}{2(Q+Q'_I)}) - c_{Q'_I} \]

The water authorities objective function can be differentiated with respect to \( Q_i \) and \( Q'_i \) in order to obtain optimal results for \( c_i \) and \( c'_i \). Differentiating with respect to \( Q_i \), gives

\[ \frac{dEU}{dQ_i} = P_I(c'_i + \frac{r^2c_I}{2(Q+Q'_I)}) - c'_i - \frac{P_{in}r^2c_I}{2(Q+Q'_I)} \]

and solving for the optimum \( c'_i \), gives

\[ c'_i = \frac{[\frac{1}{2}(P_Ir^2c_I) - P_I(c'_i + \frac{1}{2}(P_{in}r^2c_i))]}{P_I} \]

Solving for the optimum \( c'_i \) can be similarly shown by differentiating with respect to \( Q'_i \) such that

\[ \frac{dEU}{dQ'_i} = P_{in}(c'_i + \frac{r^2c_I}{2(Q+Q'_I)}) - c'_i - \frac{P_Ir^2c_I}{2(Q+Q'_I)} \]

and solving for the optimum \( c'_i \), gives

\[ c'_i = \frac{[\frac{1}{2}(P_Ir^2c_I) - P_{in}(c'_i + \frac{1}{2}(P_{in}r^2c_i))]}{P_{in}} \]

After considering the decision problems for each party the optimal utilities for the farmer and mine can be determined as well as the optimal profit for the water authority by substituting \( c'_i \) and \( c'_i \) into the relevant equations.

The optimal utilities \( U_{f, opt} \), \( U_{m, opt} \) and optimal profit for the water authority, \( U_{w, opt} \) are shown to be as follows.

\[ U_{f, opt} = \ln[p_I(Q+Q'_I)+\frac{r^2c_I}{2(Q+Q'_I)} - c'_I] \]

where the farmer is now receiving an amount of water with certainty where \( P_I = 1 \) and \( P_{in} = 0 \).

At \( P_I = 1 \) and \( P_{in} = 0 \) the mine now receives an amount of water with certainty receiving the following utility.
The optimal profit of the water authority, at \( \Pi_t = 1 \) and \( \Pi_n = 1 \) is found to be

\[
U_{o,\text{opt}} \ln\left(\frac{1}{2} \frac{r^2 c_l}{(Q_l + Q_t)^2} + c_d \right) \cdot Q_t
\]

4.4 Procedure for Tariff 2
The same optimising procedure is used to determine optimal utilities for the two-part tariff. The structure consists of a minimum charge based on a percent of allocation with a consumption charge added for use over the allocation. That is where

\[
T_t = c_l Q_t + c_{\text{min}}
\]

and

\[
T_i = c_t Q_t + c_{\text{min}}
\]

where \( c_{\text{min}} \) and \( c_{\text{min}} \) are the minimum charges. By following the same optimising procedure the optimal utilities are found to be

\[
U_{t, \text{opt}} \ln\left(\frac{pk}{2} (Q_r + r) - c_{\text{min}} + \frac{1}{2} \frac{r^2 c_l}{(Q_r + Q_t)^2} \cdot c_d \right) Q_t
\]

\[
U_{t, \text{opt}} \ln\left(\frac{1}{2} \frac{r^2 c_l}{(Q_r + Q_t)^2} + c_d \right) \cdot Q_t
\]

5 EMPIRICAL ANALYSIS
Empirical data was used to parametrize the model and these are based on the production statistics of the region as well as several assumptions which are explained in the following sections.

Rainfall data is used as a random number generator to obtain simulations for the above optimised functions. Annual rainfall
data from the region is used from the years 1885 to 1994. By taking the first differences the distribution was found to be stationary.

The amount of water consumed by the farmer are based on informed estimates of the region taken from recent QDPI publications. $Q_i$ is determined by assuming that 200ha of cotton using 7ML per hectare requires 1400ML per year. A sensitivity analysis is carried out by using different crops, such as peanuts and wheat with different annual usages of water and this is shown in Appendix 3. $Q_i$ is based on the Curragh coal mine, one of the main coal mines in Central Queensland. Through personal communication with the environmental manager, it was established that approximately 3400ML of water is used annually. The model assumes that the level of the dam is only affected by rainfall and not riverflow.

The price of agricultural commodities ($P_a$) in the region is determined by local production figures with the standard assumption being that 200 hectares of cotton with a yield of 7.5 bales per hectare at $500 per bale amounts to $750,000 (Spackman, 1996). The same approach is used when using different crops.

The price of coal ($P_c$) is assumed to be based on a market structure of monopolistic competition whereby the constants $a$ and $z$ and the coefficient $b$ are computed through a simple regression. Appendix 2 shows the computation of the values obtained.

The scalar values of $k_1$ and $k_2$ are chosen arbitrarily to be 2 and 4 respectively.

The opportunity cost is determined by the values $c$ and $i$ where $c$ is the capital cost of water held in the dam and $i$ is the current interest rate. The capital cost of the water is valued at $10.35/ML which is the price charged under the Emerald Irrigation Scheme and $i$ is assumed to be ten percent. A sensitivity analysis is carried out on these variables to show the impact of a change on the water authority. The cost of delivery is assumed to be zero in this study.

The minimum charge values are determined by the costs current under the Emerald Irrigation Scheme which are $10.35/ML for 75% of the allocation for the farm and $10.35/ML for 100% of the allocation for the mine (Bevin, 1993).

5.1 Results

In order to interpret the results an analysis has been conducted investigating stochastic efficiency, incentive compatibility, individual rationality and a sensitivity analysis on a selection of variables.

A stochastic efficiency analysis is conducted by constructing cumulative distribution functions (CDF) for each of the
utilities to determine which tariff scheme is dominant. In this analysis it was found that there was no effective difference between the tariff structures in terms of the utility of the farmer. However the mine experienced a slight decrease in utility as a result of the second tariff scheme. The two-part tariff yielded positive profits for the water authority whilst the consumption charge lead to negative returns. This is due to more of the costs incurred by the water authority being recovered through the higher price charged to consumers.

5.2 Incentive Compatibility
Incentive compatibility analyses whether each agent consumes the amount of water intended for his type. By substituting the value of $Q_e$ into the farmer's optimal utility function and $Q_t$ into the mine's optimal utility function the existence or non-existence of incentive compatibility is determined. If utility is greater with the other amount of water then there is no incentive compatibility. Figure 1 shows the outcome of substituting $Q_e$ into $Q_t$ such that $Q_t$ equals 3400 under Tariff 1.

![Probability vs Utility of Farmer](image)

--- $Q_e=1400$
--- $Q_t=3400$

*Figure 1: Incentive Compatibility of Farmer for Tariff 1*
It is observed that the utility of the farmer increases with \( Q_f = 3400 \) and thus incentive compatibility does not hold.

Similarly it is shown in Figure 2 that incentive compatibility does not hold under Tariff 2.

\[ \text{Figure 2: Incentive Compatibility of Farmer for Tariff 2} \]

When \( Q_f \) is substituted into the mine's optimal utility function, the utility for the mine decreases thus there exists incentive compatibility for the mine to obtain the right amount of water.
5.3 Individual Rationality
The individual rationality constraint arises due to the requirement that the consumer must be willing to purchase. That is, it needs to be individually rational for the farmer and the mine to purchase water and as the utilities under both schemes are positive then this requirement is satisfied. The water authority receives a negative return with a consumption charge only, therefore individual rationality is not established. This result suggests that it does not pay for the water authority to sell water. The farmer and mine under both tariff schemes, however, experience positive utilities. By implementing Tariff 2 the water authority yields positive profits due to a higher price being charged to consumers.

6 CONCLUSION
The model framework of mechanism design combined with inventory theory demonstrates that many simplifying assumptions were necessary. Individual rationality and incentive compatibility constraints were incorporated to determine the individual situation for each agent and the water authority. Individual rationality was found for the mine and farm, however was not established for the water authority under Tariff 1. Although individual rationality is not established, the result is still optimal. Tariff 2 however, resulted in positive utilities for all concerned which is due to the higher price. Thus it can be concluded that this tariff scheme is the most optimal.

It was also found that incentive compatibility existed for the mine however not for the farm which shows that the farm is deriving a higher utility from the amount of water that the mine receives. This indicates that the farmer has an incentive to 'lie' about the amount of water which he requires. The mine is receiving the optimal amount of water as it receives a lower utility when it receives the amount of water the farmer receives.

The sensitivity analysis conducted showed that the model is not very sensitive to changes in variables such as the interest rate, the capital cost of water and the minimum charge values however is sensitive to the input of different crop characteristics.

One of the major shortcomings of this project is that the dam does not presently exist, therefore details on its exact size, location and cost are not available. This lack of information may affect the data being used, for example, whether the fluctuations in the level of water is solely reliant on rainfall or on riverflow and rainfall. Another pitfall is the lack of knowledge about the demand functions for both the farm and the mine therefore they were assumed in this study to be price-independent and representative of the willingness to pay.

Central Queensland is experiencing significant expansion in its agricultural and mining industries which has lead to the
proposal for a dam on the Comet River to serve this additional demand. Other supply options include an inflatable crest on Bedfo.d and Bingeegang Weirs, damsites on Retreat Creek or private water harvesting from the Mackenzie River.

Surrounding the proposal for the Comet dam is a debate on the appropriate price to be charged to consumers. The main consumers of the water will be these two expanding industries and thus creates the resource allocation issue. The farmer in this analysis receives the highest utility in both scenarios with its utility only marginally higher under Tariff 1. Therefore it can be concluded that the farmer would most prefer Tariff 1 however it must be noted that this does not necessarily imply a reduction in water use by farmers under Tariff 2. As incentive compatibility does not hold, it is obvious that the farmer desires a higher water allocation and may result in conflict between the two consumers.

The mine receives a positive utility in both scenarios however is worse off than the farmer. The mine would also prefer the implementation of the consumption charge as utility received is higher under this scheme. Although, if Tariff 1 is implemented the water authority experiences a loss and therefore the decision to construct the dam can only be political and suggests that the water authority may be heavily subsidised.

The implementation of Tariff 1 may also lead to decreased water efficiency and less incentive to conserve water. This policy option would be in direct contrast to the growing environmental concerns, which have already been mentioned. As the farmer and the mine still experience positive utilities under Tariff 2, it would be a practical decision to implement this policy as the water authority can recover costs and the environment does not suffer as extensively.

The increased efficiency results due to consumers having an incentive to avoid exceeding their announced allocation. However, as mentioned earlier the environment cannot become the 'reason' for higher water prices given by policy makers. Conversely, higher water prices should not be used to increase government revenue alone which may become the case with more complex multipart tariffs outlined in Appendix 1. Instead they should be implemented as a means of increasing efficiency and thereby decreasing the overall cost to the user and the environment in the long run.
### OPTION 1: Tariff Structure Options for Queensland

<table>
<thead>
<tr>
<th>OPTION</th>
<th>CHARGES</th>
<th>BASED ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Consumption Charge ($/ML used)</td>
<td>Cost of supplying an additional ML of water.</td>
</tr>
<tr>
<td>B</td>
<td>Access Charge ($ Minimum Charge)</td>
<td>Minimum charge equal to $ML of a % of allocation.</td>
</tr>
<tr>
<td></td>
<td>Consumption Charge ($/ML used)</td>
<td>Usage above minimum charge and excess charge for over-allocation use.</td>
</tr>
<tr>
<td>C</td>
<td>Connection Charge ($/Connection)</td>
<td>Administrative costs.</td>
</tr>
<tr>
<td></td>
<td>Nominal Allocation Charge ($/ML Nominal Allocation)</td>
<td>Headworks and distribution costs.</td>
</tr>
<tr>
<td></td>
<td>Consumption Charge ($/ML used)</td>
<td>Part operation costs and excess charge for over-allocation use.</td>
</tr>
<tr>
<td>D</td>
<td>Nominal Allocation Access Charge ($/ML nom alloc.)</td>
<td>Headworks infrastructure maintenance costs and capital replacement.</td>
</tr>
<tr>
<td></td>
<td>Distribution Access Charge ($/nominal/s)</td>
<td>Distribution infrastructure maintenance costs and capital replacement.</td>
</tr>
<tr>
<td></td>
<td>Consumption Charge ($/ML used)</td>
<td>Operational costs and excess charge for over-allocation use.</td>
</tr>
</tbody>
</table>

APPENDIX 2: Price of Coal Computation

The approximate price of coal was obtained from personal communication with BHP Australia and is estimated at $US50. A regression was carried out to determine the price received by Curragh for coal. A range of water usages was used as the independent variable whilst a range of exchange rates used for the dependent variable. These are shown in the table below.

<table>
<thead>
<tr>
<th>WATER USAGE (ML)</th>
<th>EXCHANGE RATE</th>
<th>PRICE ($/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Variable</td>
<td></td>
<td>Dependent Variable</td>
</tr>
<tr>
<td>2000</td>
<td>0.7</td>
<td>71.42857</td>
</tr>
<tr>
<td>2500</td>
<td>0.72</td>
<td>69.44444</td>
</tr>
<tr>
<td>3000</td>
<td>0.74</td>
<td>67.56757</td>
</tr>
<tr>
<td>3500</td>
<td>0.76</td>
<td>65.78947</td>
</tr>
<tr>
<td>4000</td>
<td>0.78</td>
<td>64.10256</td>
</tr>
<tr>
<td>4500</td>
<td>.8</td>
<td>62.5</td>
</tr>
</tbody>
</table>

The regression resulted in the constant equal to $78.4026 per tonne and the coefficient equal to -0.00357 which become a and b respectively in the equation $P_m = a - bQ_g - z$. The z value was computed by carrying out a regression on prices and the water usages of other mines in the Central Queensland region. Table 3 showed the production levels and water usages of these mines and by using varying exchange rates the value of z was found to be $56.14/t.
APPENDIX 3: Sensitivity Analysis

A sensitivity analysis was conducted to determine the impact of using different crops, with varying usages of water, prices and yields. Figures 1 and 2 show the impact of planting wheat and peanuts respectively, compared to cotton, on the utility of the farmer and shows that cotton derives the highest utility while wheat yields the lowest utility.

![Utility of Farmer - Cotton and Wheat (200ha)](image-url)

Figure 1: Utility of Farmer - Cotton and Wheat (200ha)
A sensitivity analysis is also conducted on the values of $c$ and $i$ for Tariff 1 and the results are shown in the tables below. An average of the twenty year interval from 1973 to 1993 was chosen as an example of the sensitivity of the model to certain variables.

**Table 1 - Sensitivity Analysis: Varying Capital Cost of Water (measured in Utls.)**

<table>
<thead>
<tr>
<th>YEAR</th>
<th>TYPE</th>
<th>C=$10.35</th>
<th>C=$20.35</th>
<th>C=$30.35</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mine</td>
<td>12.71221</td>
<td>12.7121</td>
<td>12.71198</td>
</tr>
<tr>
<td></td>
<td>Dam</td>
<td>-219.42</td>
<td>-431.404</td>
<td>-643.396</td>
</tr>
</tbody>
</table>

Table 1 demonstrates that there is no variation between the utility values for the farmer, a slight decrease in the...
utility for the mine and a decrease in profit for the water authority. The utility of the farmer appears to be very insensitive to any kind of variation and may be due to several factors. The design of the actual tariff schemes may be causing this to happen or perhaps the log form of the function. The decrease in utility for the mine may be due to the fact that as the capital cost of water increases, this increases the cost function of the water authority which in effect reduces the utility of the mine if one analyses the optimal utility equation for the mine. The decrease in profit for the water authority can be explained by the fact that as the capital cost of water increases, the opportunity cost also increases.

Table 2 shows the impact of varying the interest rate and once again there is only slight variations with the same trend being observed as above. The explanations for the utility responses are also similar to the ones provided above.

Table 2 - Sensitivity Analysis: Varying Interest Rate
(measured in Util)

<table>
<thead>
<tr>
<th>YEAR</th>
<th>TYPE</th>
<th>i=1%</th>
<th>i=10%</th>
<th>i=50%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mine</td>
<td>12.71229</td>
<td>12.71198</td>
<td>12.71061</td>
</tr>
<tr>
<td></td>
<td>Dam</td>
<td>-64.3396</td>
<td>-643.396</td>
<td>-3216.98</td>
</tr>
</tbody>
</table>

Table 3 analyses the impact of increasing the values of the minimum charge and the resulting differences are interesting to observe. Firstly, the utility of the farmer decreases at a charge of $100.35/ML and then continues to decrease at a charge of $1000.35. This indicates that the utility of the farmer becomes sensitive under Tariff 2 but only at high levels of minimum charges. The response of the utility of the mine is difficult to establish as errors became evident at the two higher levels. This may be once again due to the design of the tariff system or perhaps indicates that there is not an infinite set of optimal values. The profit of the water authority increases significantly at a level of $100.35 however ceases to increase after this point which may suggest that the price charged to consumers is desired to be higher by the water authority.

Table 3 - Sensitivity Analysis: Varying Minimum Charges
(measured in Util)

<table>
<thead>
<tr>
<th>YEAR</th>
<th>TYPE</th>
<th>C_{min}=$10.35</th>
<th>C_{min}=$100.35</th>
<th>C_{min}=$1000.35</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mine</td>
<td>12.59829</td>
<td>ERR</td>
<td>ERR</td>
</tr>
<tr>
<td></td>
<td>Dam</td>
<td>42840.52</td>
<td>4448341</td>
<td>4448341</td>
</tr>
</tbody>
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REFERENCES


25


