Coordinating Wool Production with the Disposal of Australia's Wool Stockpile

by

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February 1993

Paper presented at the 37th Annual Conference of the Australian Agricultural Economics Society, University of Sydney, February 1993.

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Abstract

Following the dismantling of the Reserve Price scheme on 30 June 1991, Australia's wool industry began to dispose of a stockpile of approximately 800 kt of mostly apparel wool and repay an accumulated debt of over $2.5 billion. The Australian Wool Realisation Commission (AWRC) was formed for the task. Several policies were proposed which the AWRC might use in disposing of the stockpile and repaying the debt. These policies include returning the stockpile to woolgrowers, price and quantity-based rules, dynamic disposal rules and quarantining the stockpile. Each policy imposes constraints on disposal based, perhaps, on judgments of political acceptability to woolgrowers and government. In this article, optimal rules for production and disposal are derived and solved and a new policy is proposed. Results show that centralised disposal by the AWRC will almost always be preferred to competitive disposal of the stockpile by woolgrowers or quarantining the stockpile. Centralised disposal is not optimal, however. Optimal production and disposal combines the efficiency of competitive disposal with the market power of centralised disposal. To achieve this, the property rights to the wool stockpile can be redefined using payment-in-kind certificates and individual transferable entitlements. The payment-in-kind certificates assign ownership of the stockpile to individual woolgrowers who then make both production and disposal decisions. The individual transferable entitlements allow the industry to produce efficiently and extend market power from the AWRC to woolgrowers. Compared to centralised disposal by the AWRC, the industry will benefit by at least $2.7 billion.

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Occasionally, governments and industry bodies wage war against commodity markets, trying to maintain prices above market-clearing levels. Excess supply results which must be purchased and stored. It is a war which cannot be won (Watson; Gunasekera and Fisher). Eventually the accumulated stockpile becomes too big a burden and must be surrendered at reduced prices. It happened with U.S. wheat and feedgrains in 1986 and with Australian wool on 30 June 1991. By that time, the Australian Reserve Price Scheme (ARPS) had accumulated a stockpile of 4.6 million bales of wool, about 90% of annual production, and a debt of $2.5 billion. The Australian Wool Realisation Commission (AWRC) replaced the ARPS and was charged with disposing of the stockpile and repaying the debt in a way which would maximise benefits to the industry and nation.

A stockpile can be one of three things. It can be a buffer stock to stabilise prices, an asset held as a risky investment within a portfolio of investments or an exhaustible resource. Today's accumulated stockpile is most like an exhaustible resource. From the theory of exhaustible resources, we know the stockpile may have a scarcity value and should be rationed over time. The stockpile's scarcity value will be part of its disposal costs. In each year, a competitive industry will dispose of the scarce stockpile to the point where marginal disposal costs equal the market price A monopolist will dispose less, where marginal disposal costs equal marginal revenue. But stockpile disposal is only one of two sources of wool in the market. The other is newly produced wool. Again from the theory of exhaustible resources, we know the combination of wool from the two sources should be least-cost. Both a competitive industry and a monopolist will produce wool to the point where marginal production costs equal marginal disposal costs. Eventually, the stockpile will be exhausted and the industry will return to normal production. But if the benefits of normal production exceed the benefits of production with disposal, the industry should resume normal production immediately without disposing of the stockpile.

Unfortunately, there is a complication. The wool industry is half competitive, half monopolistic. Woolgrowers are responsible for the stockpile and the associated debt but disposal decisions have been centralised within the AWRC. Woolgrowers must compete among themselves and, ironically, against an AWRC with market power. Woolgrowers will produce where marginal production costs equal the market price. The AWRC will dispose of wool to the point where marginal disposal costs equal its marginal revenue. Because the market price exceeds marginal revenue, production is more costly on the margin than disposal, too much wool is produced, too little is disposed from the stockpile and the industry is inefficient. If disposal decisions were decentralised by returning the stockpile to individual woolgrowers, production and disposal decisions would be coordinated, the industry would be efficient but it would lack market power. Thus centralised disposal creates market power but causes inefficient production and disposal. Decentralised disposal is efficient but lacks market power. Ideally, a policy to maximise benefits to the industry and nation would both create market power and coordinate production and disposal decisions.

Several policies have been proposed. The Wool Review Committee recommended that wool from the stockpile not be sold until the market indicator price exceeds 500c/kg of clean wool. Stoeckel, Borrell and Quirke proposed that the AWRC pre-announce sales from the stockpile, allowing woolgrowers time to adjust. Both of these policies try to retain the market power of the AWRC while restricting its ability to compete with woolgrowers. Beare, Fisher and Sutcliff derived dynamic disposal rules which also retain the market power of the AWRC but do not restrict price or disposal. Another proposal would return the stockpile to woolgrowers. The industry would lack market power but save unnecessary costs by coordinating production and disposal decisions. Finally, several industry organisations advocate quarantining the stockpile, either by storing it indefinitely or destroying it (Wool Review Committee). If disposal has few benefits, the industry might gain by returning immediately to normal production.

There is another alternative, however, which has the potential to coordinate production with disposal and extend the market power of the AWRC to include woolgrowers. This is a policy based on property rights. There are many details to consider in implementing such a policy but the principles are simple: 1) redefine rights to the stockpile so that woolgrowers make both production and disposal decisions; and 2) restrict the total quantity of production plus disposal in the marketplace to create market power. Policies based on property rights are now widely used in natural resource management. They began 30 years ago with a seminal article by Coase and were developed further by Demsetz, Dales, Randall and Bromley, among others. Now there are transferable entitlements for many resources from water to fish to emissions (Western Australia Water Resources Council; Geen and Nayer; Tietenberg). A property rights policy was also used by the United States Department of Agriculture (Roberts, et al.) to dispose of its wheat and feedgrains stockpile beginning in 1986. From experience, woolgrowers will accept the restriction on production and disposal if they benefit from ownership of the stockpile.

The purposes of this article are to evaluate the relative merits of proposed policies for the disposal of Australia's wool stockpile and formulate a new policy which redefines property rights. In the following section, production and disposal decisions are derived for various policies. Next, benefits from the policies are calculated and compared to optimal production and disposal for the industry. Then a new policy is proposed to achieve optimal production and disposal by redefining the rights to the wool stockpile. Finally, implications for the wool industry are drawn.

Optimal Disposal over Time

Both the demand and supply for Australian wool are a challenge to model. Almost all wool is exported. Export demand depends upon demand for wool in overseas markets, supply by other producing countries and inventories held overseas. Ideally, export demand would be calculated within a world trade model linking importing and exporting countries. Supply of wool depends upon the size of the breeding herd. Realistically, supply should be calculated within a dynamic model of breeding herd adjustments in response to price changes. Nor is wool a uniform product. Modelling the various micron ranges and types of wool within each range would require systems of demand and supply equations.

Putting it all together would give a complex model of world trade in differentiated qualities of wool with dynamic supply adjustments. Constructing such a model may be important in setting policy for the wool industry. This study, however, constructs a parsimonious model. Demand and supply are specified for wool as a uniform product. Such a simple model has limitations but is more suitable than a complex model for illustrating the key features of optimal stockpile disposal.

Suppose, initially, that the industry is operated as a single enterprise by a monopolist whose objective is to maximise wealth. Wealth is the present value of net income from production and disposal. It is maximised subject to depletion by disposal of the stockpile.

(1) $$J(S_0) = Max \int_0^T e^{-rt}\left[p(Q+D)(Q+D) - \int_0^Q c(q)dq - sS\right]dt + e^{-rT}[N_T - sS_T]/r;$$

subject to:

$\dot{S} = -D$; for all t;

$Q \geq 0$; for all t;

$S_0 = \bar{S}$; and

$S_T \geq 0$.

J is the net present value of income from production and disposal; Q is the quantity of wool produced at a total variable cost of $\int cdq$, where c is the marginal production cost, and is sold for a price of p; D is the quantity of wool disposed from stockpile S which is stored at a cost of s per unit; N is the annual net income from normal production once disposal is stopped at time T; and r is the interest rate. Price p is a function of the total quantity marketed, $Q+D$, and marginal cost c is a function of the quantity produced, Q. After time T, annual net income from normal production and annual storage costs are assumed to be constant and received in perpetuity. Thus their net present value is calculated simply by dividing by the interest rate. The monopolist must choose the length of the disposal period and the production and disposal in each year.

Optimality conditions (Kamien and Schwartz, pp. 147-148) are derived from the current-value Hamiltonian corresponding to the optimisation problem in 1). A Hamiltonian is a dynamic profit function. It includes net income from production and disposal for a year but also subtracts a dynamic cost for selling wool from the stockpile instead of saving it for the future.

$$(2) \qquad H = \left[p[Q+D] - \int_0^Q c\,dq - sS \right] - \lambda D + \mu Q.$$

λ is a costate variable for the constraint on stockpile disposal and μ is a Lagrange multiplier on the inequality constraint for production. The costate variable, λ, represents marginal disposal costs which measure the effect of current disposal decisions on future profitability. Multiplying marginal disposal costs by the disposal quantity gives a dynamic measure of total disposal costs which are subtracted from net income to get dynamic profit for the year.

Assume the monopolist has power in the wool market and considers the effect of its production and disposal decisions on the sale price but has no power in input markets. Optimal production and disposal decisions are found by differentiating the Hamiltonian.

$$(3) \qquad \frac{\partial H}{\partial Q} = 0 = p + p'[Q+D] - c + \mu;$$

$$(4) \qquad \frac{\partial H}{\partial D} = 0 = p + p'[Q+D] - \lambda.$$

The derivative of price is p' and marginal revenue is $p+p'[Q+D]$. Thus, equation 3) equates marginal revenue plus multiplier μ to marginal production costs. Equation 4) equates marginal revenue to marginal disposal costs.

By complementary slackness, multiplier μ in equation 3) can be positive only when production Q is zero. This could occur if production is easily adjusted in the short-term and disposal is inexpensive, as in Figure 1. Marginal production costs, shown as the supply curve, are always positive. The stockpile is large, has no scarcity value and marginal disposal costs equal the costs avoided by selling rather than storing the wool in perpetuity. Marginal disposal costs are negative. In Figure 1, the optimal disposal quantity is 925 kt where marginal revenue equals marginal disposal costs of -\$0.60 / kg. Marginal production costs always exceed marginal disposal costs and optimal production is zero. Unnecessary production and storage costs are avoided and the industry benefits from market power because the price of $4.45 / kg exceeds marginal disposal costs by $5.05 / kg.

Figure 1 here

More realistically, production will be greater than zero. This occurs if production is not easily be adjusted in the short-term and adjustment costs can be avoided by continuing to produce as the stockpile is sold. Supply is inelastic. The marginal costs of production are negative at lower quantities, as shown by the supply curve in Figure 2. In addition, the stockpile may be small and have a scarcity value. If the scarcity value is large enough, marginal disposal costs can be positive. In Figure 2, optimal production of 613 kt and disposal of 189 kt both have marginal costs of $0.74 / kg. Production and disposal are efficient. Marginal revenue also equals $0.74 / kg at the total quantity marketed of 802 kt. The price o. $5.12 / kg exceeds marginal revenue by $4.38 / kg and the industry benefits from market power. Thus, equations 3) and 4) determine the least-cost combination of production and disposal and the total quantity to be marketed, once marginal disposal costs are determined.

Figure 2 here

Marginal disposal costs change over time as the stockpile changes and are anchored at time T by the transversality condition for the stockpile.

(5) $$-\frac{\partial H}{\partial S} = \dot{\lambda} - r\lambda = s;$$

(6) $$\lambda_T = \nu_t - s/r.$$

The Lagrange multiplier, ν, corresponds ι constraint on the ending stockpile and measures the scarcity value. Storage costs per unit divided by the interest rate, s/r, are the costs of storing a unit of wool in perpetuity. Solving differential equation 5), using transversality condition 6), gives marginal disposal costs at any time prior to the end of the disposal period[1].

(7) $$\lambda = \nu_t - s/r.$$

If the stockpile is not exhausted, ν is zero by complementary slackness, and the stockpile has no scarcity value, as in Figure 1. Marginal disposal costs are negative and equal to storage costs that could be avoided by disposing of a unit of wool rather than storing it in perpetuity.

Optimal Disposal of the Wool Stockpile

If the stockpile is exhausted, as in Figure 2, marginal disposal costs will exceed the avoided storage costs by the scarcity value. As with other exhaustible resources, the scarcity value of the stockpile increases at the rate of interest. Marginal disposal costs increase at the rate of interest plus a factor for storage costs. Unfortunately, there is no analytical solution to the general optimisation problem and marginal disposal costs must be determined empirically.

In addition to production and disposal, the optimal length of the disposal period is chosen. Here there are two alternatives. The first alternative is to continue production and disposal. The second alternative is to switch to normal production with no disposal and pay storage costs on any remaining stockpile. The profitability of the first alternative is the Hamiltonian in equation 2); the profitability of the second alternative is net income above storage costs at the end of the disposal period, $N - sS$, from the objective function in 1). Production and disposal should continue so long as it is the more profitable alternative. The time to switch, T, occurs when its profitability falls to equal the profitability of normal production.

$$(8) \qquad 0 = p_T[Q_T + D_T] - \int_0^{Q} c\,dq - sS_T - \lambda D_T - [N_T - sS_T].$$

Switching time, T, can be any number from zero to infinity, making this free-time optimisation problem more difficult to solve than the usual fixed-time problem.

Other policies can be modelled by imposing constraints on the problem in 1). A policy to quarantine the stockpile and never sell it would constrain the length of the disposal period, T, to zero. The stockpile could be destroyed rather than stored, with destruction costs replacing storage costs in the objective. A policy of returning the stockpile to woolgrowers who lack market power would set the derivatives of price, p', to zero in equations 3) and 4). Woolgrowers would equate the price, instead of marginal revenue, to marginal production and disposal costs.

Centralised disposal of the stockpile requires an as umption about the objective of the AWRC. A benevolent AWRC will try to maximise industry benefits. Woolgrowers, however, produce quantity Q where marginal production costs, c, equal the market price, p. This constrains the decisions of the AWRC and equations 3) and 4) must be augmented.

$$\frac{\partial H}{\partial Q}=0=p+p'[Q+D]-c+\mu+\eta[p'-c'];$$
$$\frac{\partial H}{\partial D}=0=p+p'[Q+D]-\lambda+\eta p'.$$

Multiplier η corresponds to the constraint p-c=0. Cancelling p-c and assuming positive production with multiplier μ equal to zero in the first equation, solving both equations for multiplier η and equating the result gives a single optimality condition for disposal by a benevolent AWRC.

$$(9) \quad 0=p+p'[Q+D]\left[\frac{c'}{c'-p'}\right]-\lambda.$$

The AWRC knows that an increase in disposal will lower the market price which, in turn, will cause woolgrowers to decrease their production. This decrease in production reduces the effect of disposal on the price and marginal revenue rotates, as shown in Figure 3. The total quantity marketed is 979 kt where marginal disposal costs and the new marginal revenue equal \$0.20 / kg. Marginal revenue is \$3.96 / kg below the market price of \$4.16 / kg and the industry benefits from market power. Production is 865 kt, where marginal production costs equal the price, and disposal is the remaining 147 kt. Marginal production costs exceed marginal disposal costs by \$3.96 / kg Disposing of the marginal kilogram of wool from the stockpile instead of producing it would save \$3.96. Although the industry benefits from the market power of the AWRC, it loses from inefficient production and disposal.

Figure 3 here

Beare, Fisher and Sutcliff analyse a similar policy but also restrict marginal cost, c, to be zero in the objective function. The price-based rule of the Wool Review Committee and the disposal rule of Stoeckel, Borrell and Quirke place additional constraints on the price and on disposal. These additional constraints can only reduce benefits to the industry.

If the AWRC is not benevolent, it will try to maximise its net income from disposal, regardless of the effect on woolgrowers. Its objective will not include net income from production but only disposal benefits and its optimality conditions will be simplified.

$$\frac{\partial H}{\partial Q} = 0 = p'[D] + \mu + \eta[p' - c'];$$
$$\frac{\partial H}{\partial D} = 0 = p^{*} + p'[D] - \lambda + \eta p'.$$

These two equations are combined into a single equation for disposal by an AWRC which maximises its own disposal income.

$$(10) \quad 0 = p + p'D\left[\frac{c'}{c' - p'}\right] = \lambda.$$

Because the AWRC does not consider the effect on woolgrowers, the new marginal revenue does not begin at the origin but, instead, where disposal is zero at the intersection of demand and supply in Figure 4. The new marginal revenue is shifted to the right. A total of 1056 kt is marketed at the point where marginal disposal costs and marginal revenue equal \$2.72 / kg. Of this, 805 kt is produced, where price and marginal oduction costs equal \$3.74 / kg, and 251 kt is disposed from the stockpile. Price exceeds marginal disposal costs by \$1.02 / kg and marginal production costs exceed marginal disposal costs by the same \$1.02 / kg. Again, the industry benefits from the market power of the AWRC but production and disposal are inefficient. Beare, Fisher and Sutcliff also analyse centralised disposal with the AWRC maximising disposal income.

Figure 4 here

A Comparison of Policies

Five scenarios will be compared: 1) optimal production and disposal, 2) competitive disposal of the stockpile by woolgrowers, 3) centralised disposal with the AWRC maximising industry benefits, 4) cent·alised disposal with the AWRC maximising disposal income and 5) quarantine of the stockpile from the market. The first two scenarios will coordinate production with disposal. The first scenario would apply if the AWRC immediately returned the stockpile and debt obligations to woolgrowers and could extend its market power to them. The second scenario would apply if the AWRC returned the stockpile and debt but didn't extend its market power. The last three scenarios do not coordinate production with disposal. The third scenario requires the AWRC to be benevolent and voluntarily restrict disposal while woolgrowers show no restraint. In the fourth scenario both the AWRC and woolgrowers try to maximise their own benefits regardless of the effect on the industry. In the fifth scenario, the stockpile must be either stored indefinitely or destroyed. The industry returns immediately to normal production without disposal. The proposals of Beare, Fisher and Sutcliff are represented by the third and fourth scenarios. The price constrained proposal of the Wool Review Committee and the disposal constrained proposal of Stoeckel, Borrell and Quirke are more restrictive versions of the third scenario.

Solving the model in 1) gives optimal production and disposal for the first scenario. Solving the model subject to additional constraints gives scenarios two through five. Unfortunately, the model is difficult to solve. Beare, Fisher and Sutcliff found an analytical solution to their model by assuming marginal disposal costs converge to marginal revenue at the end of the disposal period. The more general transversality condition 6) shows that marginal disposal costs need not include a scarcity value and may not converge to marginal revenue. But it is the optimality condition for the length of the disposal period, equation 8), which makes the free-time problem more difficult to solve than the typical fixed-time problem. Hertzler has developed a method to convert free-time problems to fixed-time problems and solve them by nonlinear programming. A special case of the method is presented in the Appendix.

The model was solved using the nonlinear programming software, GINO (Liebman, et al.). Parameters of the model are listed in Table 1. Demand and supply curves, storage costs and the interest rate were taken from Beare, Fisher and Sutcliff. Recent events suggest demand is strong and the curve in Table 1 may be a low estimate. There is also some suggestion that supply may be more elastic than previously thought. The calculation of normal producers' surplus, once disposal is finished, assumes woolgrowers will no longer be influenced by the AWRC and will lack market power. Instead of marginal revenue they will equate price to marginal production costs. Marginal production costs can never go below marginal disposal costs for a large stockpile with no scarcity value, or s/r = -$0.60/kg. Thus, normal producers' surplus will be assumed to equal the area in Figure 2 above -0.60, above the supply curve and below the intersection of supply and demand. The initial stockpile assumes a starting date of 1 July 1991.

Results are summarised in Tables 2 and 3 and in Figures 5 through 10. Table 2 shows the net present value of benefits for each of the five scenarios. In each scenario, benefits from production far outweigh benefits to disposal. However, most benefits are from normal production following the disposal period. For example, a quarantine of the stockpile constrains the disposal period to zero and stores the stockpile in perpetuity for a cost of only $0.5 billion. Production benefits are the largest for this scenario at $41.1 billion. If the stockpile could be costlessly destroyed, disposal benefits would be zero and the industry would also benefit by $41.1 billion. In other scenarios, the $41.1 billion is received at the end of a disposal period and its present value is much smaller. The scenario for optimal production and disposal maximises disposal benefits of $3.4 billion and total industry benefits of $44.2 billion. Disposal benefits could retire the $2.5 billion debt on the stockpile and leave a $0.9 billion surplus. The four remaining scenarios: competitive stockpile disposal, the AWRC maximising

Table 1. Model parameters.

Parameter	Equation
Demand ($ / kg)	$p = 9.500000 - 0.005460[Q+D]$
Supply ($ / kg)	$c = -8.821430 + 0.015599Q$
Storage costs per unit ($ / kt)	$s = 0.06$
Interest rate	$r = 0.10$
Normal producers' surplus ($'000,000 / year)	$N_T = 3736.96$
Initial stockpile (kt)	$S_0 = 800$

Source: Beare, Fisher and Sutcliff

industry benefits, the AWRC maximising disposal income, and costless destruction of the stockpile, have similar industry benefits in the range of $41.1 billion to $41.5 billion. The efficiency of competitive disposal almost matches the market power of centralised disposal by the AWRC. Whether the AWRC is benevolent or not makes some, but not a lot, of difference. A benevolent AWRC trying to maximise industry benefits will prolong the disposal period, allowing more time to exercise market power. An AWRC trying to maximise its own disposal income will shorten the disposal period and let woolgrowers quickly resume normal production. For the parameters in Table 1, a quarantine of the stockpile is the least preferred option and woolgrowers would have to be taxed to repay the debt. In all other scenarios, disposal benefits are at least as large as the debt.

Also listed in Table 2 are consumer benefits calculated as consumers' surplus. Even though wool is almost entirely exported and benefits to consumers leave Australia, it may be important to anticipate how wool buyers might react to different policies. Consumer benefits are around $25 billion for three scenarios: competitive stockpile disposal, the AWRC maximising industry benefits and the AWRC maximising disposal income These offer large quantities of wool for sale. Consumer benefits are much smaller for optimal production and disposal because the wool industry is an effective monopolist.

Table 2. Benefits from Five Production and Disposal Scenarios.

Scenario	Production Benefits $'000,000	Disposal Benefits $'000,000	Industry Total $'000,000	Consumer Benefits $'000,000	Society Total $'000,000
Optimal Production and Disposal	40,798	3,376	44,174	20,302	64,476
Competitive Stockpile Disposal	38,570	2,587	41,156	25,652	66,809
AWRC Maximising Industry Benefits	38,922	2,533	41,455	25,036	66,491
AWRC Maximising Disposal Income	38,696	2,686	41,382	25,414	66,796
Quarantine of the Stockpile	41,107	-528	40,579	22,730	63,308

The last four scenarios are compared with optimal production and disposal in Table 3. Except for a small gain to production if the stockpile is quarantined, both woolgrowers and the AWRC lose from the last four scenarios. In total, the industry loses at least $2.7 billion. Capturing this $2.7 billion requires a policy which can coordinate production with disposal and extend market power from the AWRC to woolgrowers. Competitive stockpile disposal coordinates production and disposal but has no market power and loses $3.0 billion. Centralised disposal by the AWRC creates market power but causes inefficient production and disposal and loses at least $2.7 billion. Disposal by an AWRC which maximises only disposal income loses an additional $0.1 billion for a total of $2.8 billion. A quarantine of the stockpile loses either $3.1 billion or $3.6 billion, depending upon whether the stockpile is costlessly destroyed or stored in perpetuity. The industry's losses are consumers' gains, however. In every scenario but a quarantine, consumers gain more than the industry loses. In theory, side-payments from consumers to the industry in exchange for competitive disposal by woolgrowers could benefit society by a total of $2.3 billion. In practice, this won't happen and the industry can maximise its own benefits at the expense of consumers.

Another important consideration is the timing of benefits. Woolgrowers must maintain an adequate cash-flow and the AWRC must meet a seven-year repayment schedule for the $2.5

Table 3. Gains and Losses Compared to Optimal Production and Disposal.

Scenario	Production Loss $'000,000	Disposal Loss $'000,000	Industry Loss $'000,000	Consumer Gain $'000,000	Society Gain $'000,000
Optimal Production and Disposal	0	0	0	0	0
Competitive Stockpile Disposal	-2,228	-789	-3,017	5,350	2,333
AWRC Maximising Industry Benefits	-1,876	-842	-2,719	4,734	2,015
AWRC Maximising Disposal Income	-2,102	-690	-2,792	5,112	2,320
Quarantine of the Stockpile	308	-3,904	-3,595	2,428	-1,168

billion debt (Beare, Fisher and Sutcliff). Figures 5 through 8 show annual benefits, undiscounted, for the first four scenarios. At the end of their respective disposal periods, all four revert to normal production with annual benefits of $3.7 billion a year, the same as the fifth scenario, a quarantine of the stockpile with costless destruction. Optimal production and disposal in Figure 5 exhaust the stockpile in 6.8 years. In each of these years, industry benefits are above the annual benefits of normal production. Disposal benefits more than repay the debt and improve the industry's cash-flow. The repayment schedule shown is not the one currently in force but is designed specifically for optimal production and disposal. Competitive stockpile disposal in Figure 6 takes only 3.4 years. Woolgrowers receive the total industry benefits from production and disposal. Disposal benefits will repay the debt but production benefits are lower than for any other scenario. To alleviate cash-flow problems in early years an extended debt repayment schedule will be required. In Figure 7, disposal by the AWRC maximising industry benefits lasts 8.8 years. The stream of disposal benefits will just repay the debt and the current 7 year repayment schedule will have to be lengthened to match. Disposal by the AWRC maximising disposal income in Figure 8 exhausts the stockpile in 5 years. Woolgrowers only receive production benefits and will have cash-flow difficulties. Again the stream of disposal benefits just repays the debt. If the current 7 year repayment schedule remains in force, the AWRC must accumulate a surplus in the first 5 years to make payments in years 6 and 7.

Figures 5, 6, 7 and 8 here

Optimal production and disposal give benefits in each year and a net present value well above those of any other scenario. The advantage over competitive disposal is easily explained. Competitive disposal lacks market power and collects no monopoly rents. The advantage over centralised disposal by the AWRC is explained by Figures 9 and 10. Production is not coordinated with disposal and the industry is inefficient. Woolgrowers, trying to maximise their individual benefits, produce too much in Figure 9 and drive the price too low in Figure 10. Marginal production costs exceed marginal disposal costs by about $4 / kg in all years. Selling one more kilogram from the stockpile and producing one less would save the industry $4. In total, the industry could save $2.7 billion.

Figures 9 and 10 here

Many parameters of the model are difficult to measure. Table 4 gives the relative benefits of the five scenarios for the base case of Table 2 and three parameter changes. Total benefits are sensitive to parameter changes but the differences among policies are not. Centralised disposal by the AWRC is always the second-best policy. It matters little whether the AWRC maximises industry benefits or its own disposal income. Competitive disposal is a viable alternative but a quarantine of the stockpile is not. If demand shifts to the right and intersects supply at 970 kt instead of the 870 kt, the industry would lose \$0.1 to \$0.2 billion more from both competitive and centralised disposal and \$0.4 billion more from a quarantine compared to the optimal policy. If production can be easily adjusted and the elasticity of supply is 0.89 at a quantity of 870 kt instead of 0.35, competitive stockpile disposal becomes more favourable but is still not preferred to centralised disposal by the AWRC. Finally, if the interest rate is lower, the large benefits from normal production are discounted less and quarantining the stockpile may become viable.

A Proposal for the Wool Industry

What kind of policy could achieve optimal production and disposal? A successful tax

Table 4. Industry Losses (\$'000,000) Compared to Optimal Production and Disposal for Different Model Parameters.

Scenario	Base Case[a]	Strong Demand[b]	Elastic Supply[c]	Lower Interest[d]
Optimal Production and Disposal	0	0	0	0
Competitive Stockpile Disposal	-3,017	-3,165	-3,126	-3,255
AWRC Maximising Industry Benefits	-2,719	-2,921	-3,000	-3,009
AWRC Maximising Disposal Income	-2,792	-2,994	-3,020	-3,086
Quarantine of the Stockpile	-3,595	-4,006	-4,686	-3,386

[a]From Table 3. [b]For demand $p=11.6058-0.005460[Q+D]$. [c]For supply $c=-0.60 +0.006149Q$. [d]For interest rate $r=0.075$.

or subsidy policy is unlikely[2]. For the base case, the required marginal tax is the difference between the optimal price and the optimal marginal costs in Figure 10 and is greater than $4 / kg in most years. Such a tax would leave woolgrowers impoverished. Nor has the AWRC any money to pay subsidies. However, both woolgrowers and the AWRC could accept quotas at the optimal production and disposal levels in Figure 9. From Table 3, woolgrowers would gain $1.9 billion directly and the AWRC would gain $0.8 billion which could be distributed back to woolgrowers. If the problem is so easily fixed, why hasn't it been?

There are two difficulties. First, quotas must apply to individual woolgrowers and second, all woolgrowers plus the AWRC must accept them. Individual quotas could be based on past sales under the Reserve Price Scheme but woolgrowers have already started adjusting to the new wool market. Not all those producing wool a few years ago are producing wool now. Those still producing wool are probably not producing in the same way. Many have substituted other enterprises. Rigid quotas based on past production would be inflexible and inefficient. Nor will woolgrowers accept quotas they consider unfair. Many may believe past woolgrowers should be responsible for the stockpile and debt, but quotas penalise present and future woolgrowers. Further, everyone must participate, including the AWRC. It would be for nought if woolgrowers accept quotas and the AWRC goes about business as usual.

Managing the wool stockpile is similar to managing a fishery, allocating water in a catchment, or controlling air pollution. Without an effective policy to manage a natural resource, producers use the resource to maximise their own short-term benefits and ignore the effects of their decisions on others. With no coordination between production and disposal, woolgrowers and, perhaps, the AWRC will maximise their own short-term benefits and market too much wool, to the detriment of the industry as a whole. The policy lessons learned in natural resource management can be applied to managing the wool stockpile.

The first lesson is that quotas administered by a central authority are dreadfully inefficient (Tietenberg). The least-cost producers should hold the quotas but the central authority has no way of knowing who they are. The solution is to allocate individual entitlements to producers and set up a market to make any transfers as easy as possible. These individual transferable entitlements (ITE's) are not regulations administered by a central authority but property owned by individual producers. Rights to an ITE can be bought and sold just like any other property. The second lesson is that ITE's, like other property, are wealth and must be safeguarded as such. Although ITE's will be quickly traded to the least-cost producers, the initial allocation has large distributional consequences and is crucial for fairness and acceptability of the policy. The final lesson is that producers will readily accept ITE's if the benefits to them are obvious.

By themselves, ITE's are not sufficient to coordinate the disposal of a stockpile. Recently, the U.S. government used a property-rights policy to dispose of its wheat and feedgrains stockpile (Roberts, et al.). Prior to 1986, the prices of wheat and feedgrains were supported by a complex policy of non-recourse loans which guaranteed a minimum price to farmers. For a decade, this price was set too high and the government accumulated a stockpile equivalent to just less than 90% of annual production. With the Food Security Act of 1985, the Payment-in-Kind (PIK) program was implemented. Ownership of the stockpile was transferred to farmers through a complex mechanism. Farmers were paid a subsidy, called a deficiency payment, based on past production and on the difference between an arbitrary target price and the prevailing market price. Payments were not in cash, however, but in kind, with PIK certificates[3]. These could be bought and sold or redeemed for grain from the stockpile. In return for the certificates, farmers agreed to reduce the area planted to crops by up to 27.5%. The PIK program was voluntary but almost 90% of farmers participated and, with the help of a drought, the stockpile was reduced to 20% of annual production within 3 years.

A policy to dispose of the wool stockpile could combine PIK certificates with ITE's. The PIK certificates would transfer ownership of the stockpile without physically relocating it. The ITE's would extend market power from the AWRC to woolgrowers. Together, PIK certificates and ITE's would ensure efficient production and disposal. Implementing such a policy would take several steps.

Initially:

1. Determine the proportion of wool sales by each grower for the previous 10 years and for the previous 1 year.

2. Issue 800 million PIK certificates, one for each kilogram in the stockpile, to woolgrowers who agree to participate in proportion to their wool sales for the

previous 10 years. Each certificate transfers ownership of one kilogram of wool and may be redeemed at any time. In return, woolgrowers agree to repay their proportion of the debt according to the schedule in Table 5 and pay storage costs for unredeemed certificates.

Each year:

3. Issue 189 million ITE's, one for each kilogram of optimal disposal in year 0, to woolgrowers in proportion to their wool sales for the previous 10 years. Issue 613 million ITE's, one for each kilogram of optimal production in year 0, to woolgrowers in proportion to their wool sales for the previous 1 year. In subsequent years, issue fewer ITE's for disposal and more for production according to the schedule in Table 5.

4. Conduct frequent auctions for PIK certificates and ITE's.

5. Conduct wool sales. Woolgrowers could deliver wool or redeem PIK certificates. Wool or redeemed certificates covered by an ITE would not be taxed. Wool or certificates not covered by an ITE would be taxed according to the schedule in Table 5. These sales must be compulsory, wi..i no direct sales to customers.

6. Invoice the initial recipients of PIK certificates for their share of debt repayments. Invoice the current owners of unredeemed PIK certificates for storage costs.

The policy has stick for woolgrowers who do not participate and a carrot for those who do. The stick is the optimal tax listed in Table 5 as the difference between the price of wool and marginal disposal costs. In practice, woolgrowers would not pay the tax. It is only a

Table 5. Prices, Marginal Costs, Tax, Quantities and Debt Repayments for a Policy of Optimal Production and Disposal.

Year	Price ($/kg)	Marginal Costs ($/kg)	Optimal Tax ($/kg)	Production (kt/yr)	Disposal (kt/yr)	Production plus Disposal (kt/yr)	Stockpile (kt)	Debt Repayments ($'000,000)
0	5.12	0.7.	4.38	613	189	802	800	591
1	5.19	0.87	4.31	622	168	790	611	578
2	5.26	1.02	4.24	631	145	776	443	549
3	5.34	1.18	4.16	641	120	761	297	499
4	5.43	1.36	4.07	653	92	745	177	422
5	5.53	1.56	3.97	665	62	727	85	310
6	5.63	1.76	3.87	6"8	30	709	23	129
6.775	4.75	4.75	0	870	0	870	0	0

threat to prevent free-riding. For example, the initial year is graphed in Figure 2. Woolgrowers who try to free-ride will, instead, add the tax of $4.38 / kg to their marginal production costs, equate the sum to the price and produce the optimal amount, on average. The carrot of the policy is the transfer of wealth as PIK certificates and ITE's. The market price of an ITE should equal the tax per kilogram of wool. For example, during the initial year of the policy shown in Figure 2, a woolgrower holding an ITE to cover a PIK certificate would require at least the wool price minus marginal disposal costs before he would sell the ITE. A grower needing an ITE to cover newly produced wool would pay the wool price minus marginal production costs. At the equilibrium, marginal production costs equal marginal disposal costs and the market price for the ITE is the wool price minus marginal costs or, in other words, the optimal tax. In addition, adjustments to production may be easier on wheat and sheep farms than on specialist farms or stations. Transferring ITE's to specialist farms and stations will also equilibrate marginal production costs across woolgrowers. The market price of PIK certificates should equal marginal disposal costs. Suppose a grower has sold the ITE which covered a PIK certificate. He can redeem the PIK certificate, receive the wool price, pay the optimal tax and net an amount equal to marginal disposal costs. Alternately, he can sell the PIK certificate at a market price equal to marginal disposal costs[4]. He will no longer pay storage costs but, as the original recipient of the certificate, must continue to meet debt repayments.

Unlike the current policy of centralised disposal, a property rights policy assigns all benefits to woolgrowers. In Figure 11, the allocation of ITE's gives woolgrowers monopoly rents from both production and disposal. The allocation of PIK certificates gives them an annual surplus from disposal. Added to producers' surplus, woolgrowers retain the total value of the industry, or $44.1 billion before debt repayments[5].

Transfers of PIK certificates and ITE's among individual woolgrowers ensure efficiency, but the initial allocation is crucial for fairness of the policy. The allocation, as proposed, would initially grant all the PIK certificates to woolgrowers who contributed to the stockpile. Then in each year, it would grant enough ITE's for optimal disposal to woolgrowers who contributed to the stockpile and the remainder of the ITE's to woolgrowers who are currently producing. There should be considerable overlap among two the groups but disagreements are bound to arise. For example, a woolgrower who only began the previous year will be restricted in his production because of the stockpile created by earlier woolgrowers. He will receive a higher price but may feel under compensated for the restriction on his production.

Conclusions

Quarantining the stockpile will seldom be optimal. Only if supply adjustments are very difficult or interest rates low should a quarantine policy be considered. Except for the timing of benefits, it makes little difference whether the AWRC is benevolent and tries to maximise industry benefits or is selfish and tries to maximise its own disposal income. A more informative comparison is between competitive disposal by woolgrowers and centralised disposal by the AWRC. Competitive disposal is a viable alternative but centralised disposal is somewhat better. Centralised disposal is a second-best policy, however. Optimal production and disposal are always best, combining the efficiency of competitive disposal with the market power of centralised disposal. Benefits to the industry are at least $2.7 billion greater. The relative advantage of optimal production and disposal is insensitive to changes in parameters of the model.

To achieve optimal production and disposal, a new type of policy is needed. Precedents are the ITE's used in natural resource management and the PIK program recently used in the U.S. to dispose of its wheat and feedgrain stockpile. A policy to dispose of the wool stockpile should combine elements of both. PIK certificates assign ownership of the stockpile to woolgrowers. ITE's govern the marketing of wool. The PIK certificates ensure coordination of production and disposal by giving both decisions to woolgrowers. ITE's extend market power from the AWRC to growers and allow wool production to respond flexibly to changes in market conditions.

In addition, the property rights policy will let the industry adjust to any errors in its formulation. The critical parameters are for the demand for wool. Woolgrowers can respond flexibly to counteract errors in the estimates of other parameters. In contrast, centralised disposal also requires an accurate estimate of the supply of wool.

Participation in the property rights policy is voluntary. Even without the threat of a tax, almost all growers should participate and receive an allocation of PIK certificates and ITE's. This allocation is a large transfer of wealth. Although an allocation formula is proposed, further consideration should be given to fairness for all woolgrowers.

The model treats wool as a uniform commodity. Perhaps PIK certificates and ITE's should be denominated by categories of wool. If so, more detailed modelling is required to determine the number of PIK certificates and ITE's for each category.

Finally, the policy rights policy would free the AWRC for more important tasks. One task is to manage market risks without the old Reserve Price Scheme. The AWRC could follow the lead of the wheat industry and offer forward, futures and options contracts to growers.

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Appendix: Mathematical Programming Solution

The free-time optimal control problem in 1) can be converted to a fixed-time problem by replacing the variable, t, by a series of auxiliary variables, ϑ, one for each time period (Hertzler). If each time period is one year long, as in this example, the auxiliary variables must be constrained between zero and one. Problem 1) in discrete time with auxiliary variables becomes:

$$J\,(S_0) = \sum_{t=0}^{T-1}\left(\frac{1}{1+r}\right)^{\sum_{i=0}^{t}\vartheta_i} \vartheta_t\left[p_t[Q_t + D_t] - \int_0^q c\,dq - sS_t\right] + \left(\frac{1}{1+r}\right)^{\sum_{i=0}^{T}\vartheta_i}[N_T - sS_T]\frac{1+r}{r};$$

subject to:

$$S_{t+1} - S_t = -\vartheta_t D_t;$$
$$\vartheta Q_t \geq 0;$$
$$0 \leq \vartheta_t \leq 1;$$
$$S_T \geq 0;$$
$$S_0 = S^*.$$

Terminal time T is now a number larger than any possible length of time needed to dispose of the stockpile. The optimal length of the disposal period is the sum of the ϑ variables from t=0 to T-1. During disposal, each ϑ should be at its upper bound which, in this case, is one. Following disposal, each ϑ should be at its lower bound of zero. At the optimal time of switching, ϑ can be between zero and one. In other words, each ϑ is a switch, turning time either on or off.

The are two difficulties in solving the problem using mathematical programming software. The first difficulty is that the simple linear state equation for the wool stockpile becomes a highly nonlinear constraint. The MINOS software (Murtagh and Saunders) uses a projected Lagrangian algorithm for nonlinear constraints, can converge quickly but often gets lost among the nonlinearities. The software GINO (Liebman, et al.) uses Newton's method to ensure the nonlinear constraints are satisfied at each iteration and rarely gets lost. The second difficulty is that the software must allow control over differentiation. A ϑ variable turns the Hamiltonian on or off in each period. Optimality conditions require that the Hamiltonian be maximised. The normal method for doing this differentiates the Hamiltonian with respect to quantities produced and disposed from the stockpile and sets the derivatives to zero. Software which takes derivatives automatically, multiplies a derivative by ϑ and sets the result to zero. If ϑ is already zero, the result is zero without maximising the Hamiltonian. Therefore, a special set of derivatives is required which ignore ϑ. MINOS allows control of the derivatives, GINO does not. Because existing software cannot solve the free-time problem, a practical alternative is to guess at the optimal length of the disposal period, fix that many ϑ variables to one, the rest to zero, and solve the problem. Then vary the length of the disposal period by fixing a new number of ϑ variables above zero and solve the problem again. Repeat the process, searching until the objective function is maximised.

[1]The steps in the solution are: $\lambda = -s/r + e^{-r(T-t)}[\lambda_T + s/r] = -s/r + e^{-r(T-t)}V_T = -s/r + V_t$ where $V_t = e^{-r(T-t)}V_T$.

[2]Table 2 indicates the value of the stockpile is greater than the debt. The studies by Beare, Fisher and Sutcliff and by the Wool Review Committee calculate benefits smaller than the debt and propose a tax levied on future wool sales to help repay it. Initially, woolgrowers were heavily taxed, although the tax has now been lowered. But a tax to repay the debt is much smaller than an optimal tax policy to coordinate production with disposal.

[3]PIK certificates are similar to convertible wool bonds proposed as a way to transfer ownership of the wool stockpile to woolgrowers.

[4]For proof, see footnote 5.

[5]The relationships between benefits in Figure 11 and the objective function in 1) are as follows. In Figure 11, annual benefits from ITQ's allocated for production are $[p-\lambda]Q$. Producers' surplus is typically $\lambda Q - \int c dq$. This would be a triangle with height extending from -8.82, where marginal production costs intercept the vertical axis, to λ. In Figure 11, however, everything below $-s/r$ has been truncated. In total, annual benefits from production equal revenue minus variable costs, $pQ - \int c dq$, with a net present value as written in the objective function. Annual benefits from ITQ's allocated to disposal are $[p-\lambda]D$ and annual benefits from PIK certificates are $V_t D$. According to equation 7), $V_t = \lambda + s/r$ and total annual benefits from disposal equal revenue plus storage costs avoided, $[p + s/r]D$. The objective function, however, writes the net present value of benefits to disposal as $\int_0^\infty e^{-rt}[pD - sS]dt$. But storage costs, $\int_0^\infty e^{-rt} sS dt$, equal $\int_0^\infty e^{-rt} s\left[S_0 - \int_0^t D d\tau\right]dt$, after solving the equation of motion and substituting for the stockpile. Integration by parts gives $[s/r]\left[S_0 - \int_0^\infty e^{-rt} D dt\right]$. Therefore, benefits to disposal can be separated into ITQ benefits and PIK benefits, as shown in Figure 11, as well as a fixed cost, $\int_0^\infty e^{-rt}\{[p-\lambda]D + V_t D\}dt - [s/r]S_0$. The fixed cost is for storing the initial stockpile in perpetuity. PIK benefits arise by avoiding this cost. Because the scarcity value grows at the rate of interest, $V_t = e^{rt} V_0$, the net present value of PIK benefits minus the fixed cost of storage can also be written as $[V_0 - s/r]S_0$, or $\lambda_0 S_0$. The marginal disposal costs are the implicit price of wool in the initial stockpile and also the market price of PIK certificates. By Bellman's principle of optimality the stockpile at any time is the initial stockpile for optimal decisions in the future. Therefore, the marginal disposal costs in any year are the market price of PIK certificates.

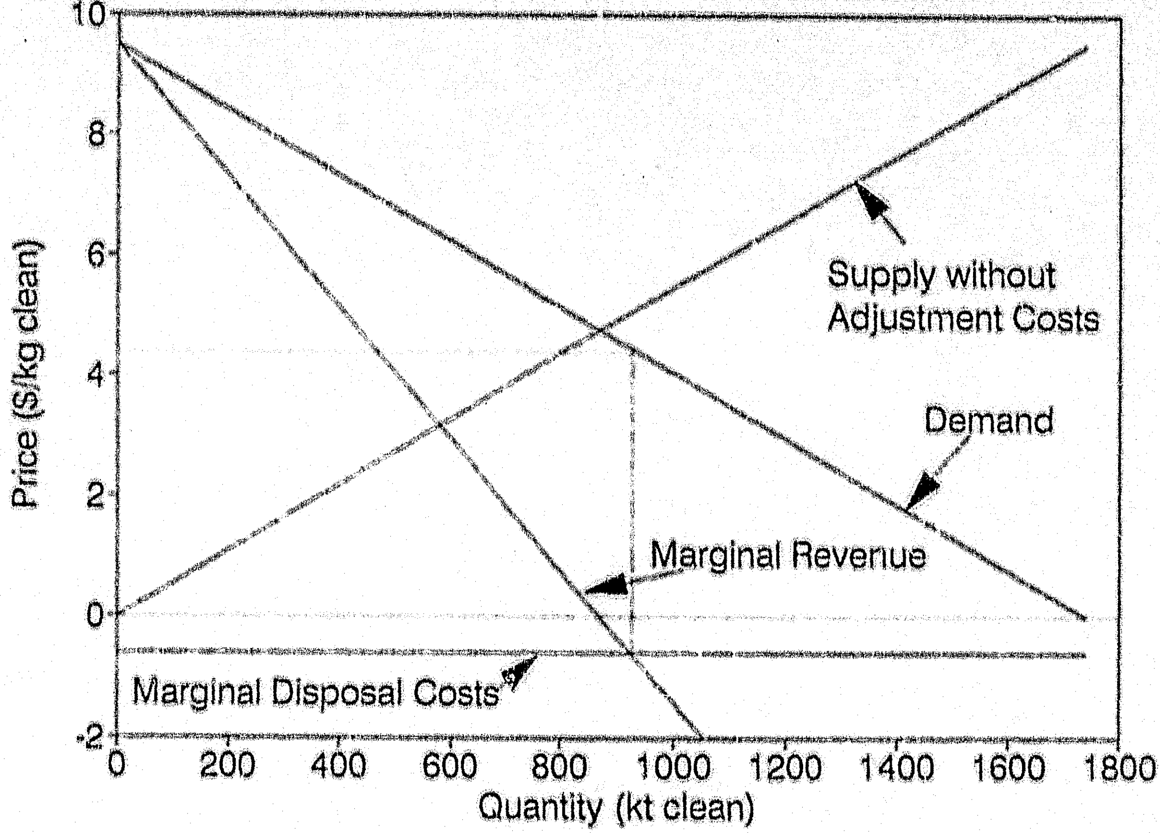

Figure 1: Optimal Production without Short-term Adjustment Costs and Disposal from a Large Stockpile

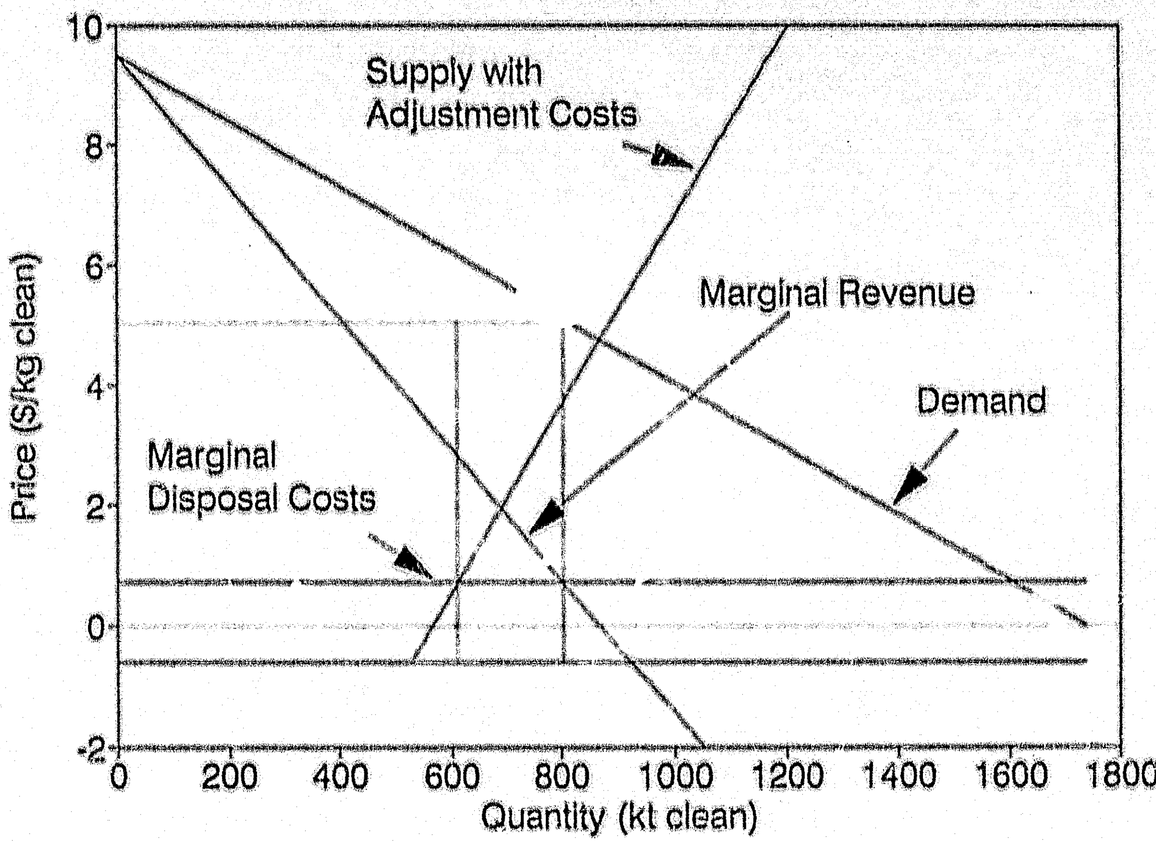

Figure 2: Optimal Production with Short-term Adjustment Costs
and Disposal from a Small Stockpile

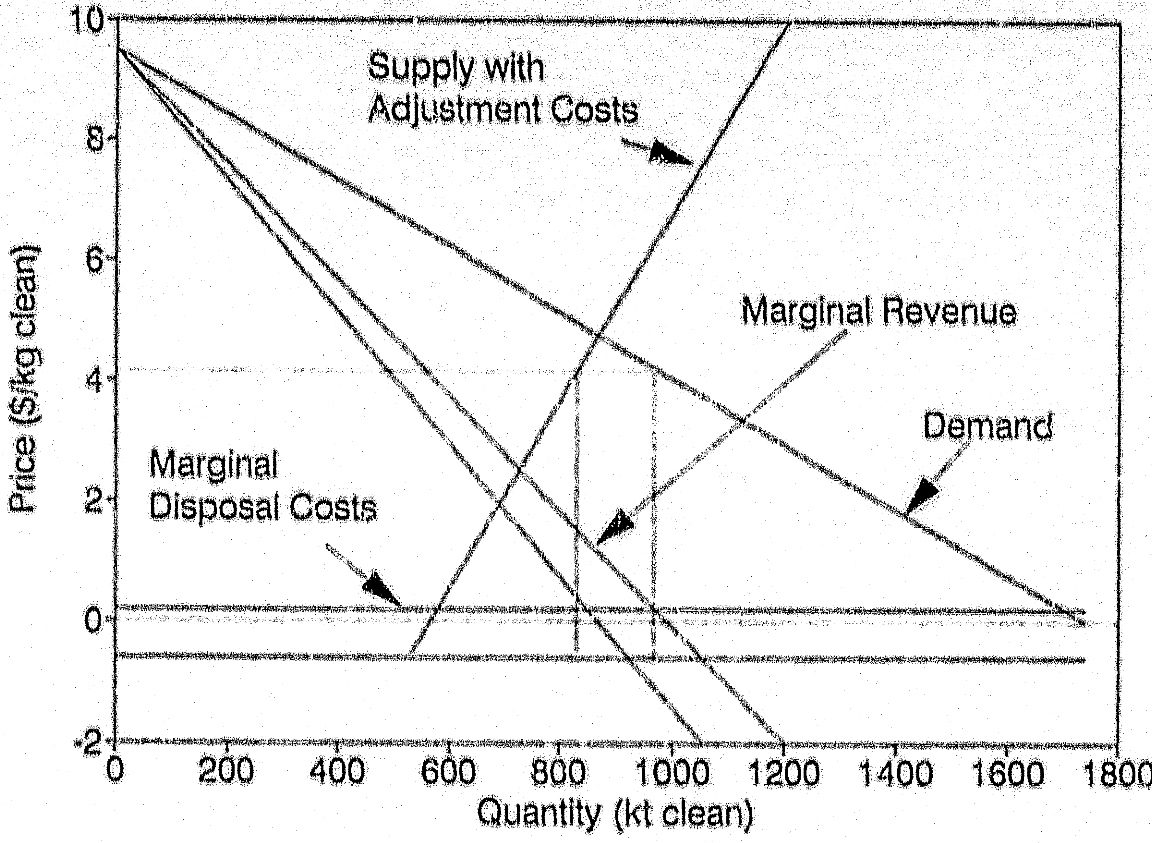

Figure 3: Uncoordinated Production and Disposal with the AWRC Maximising Industry Benefits

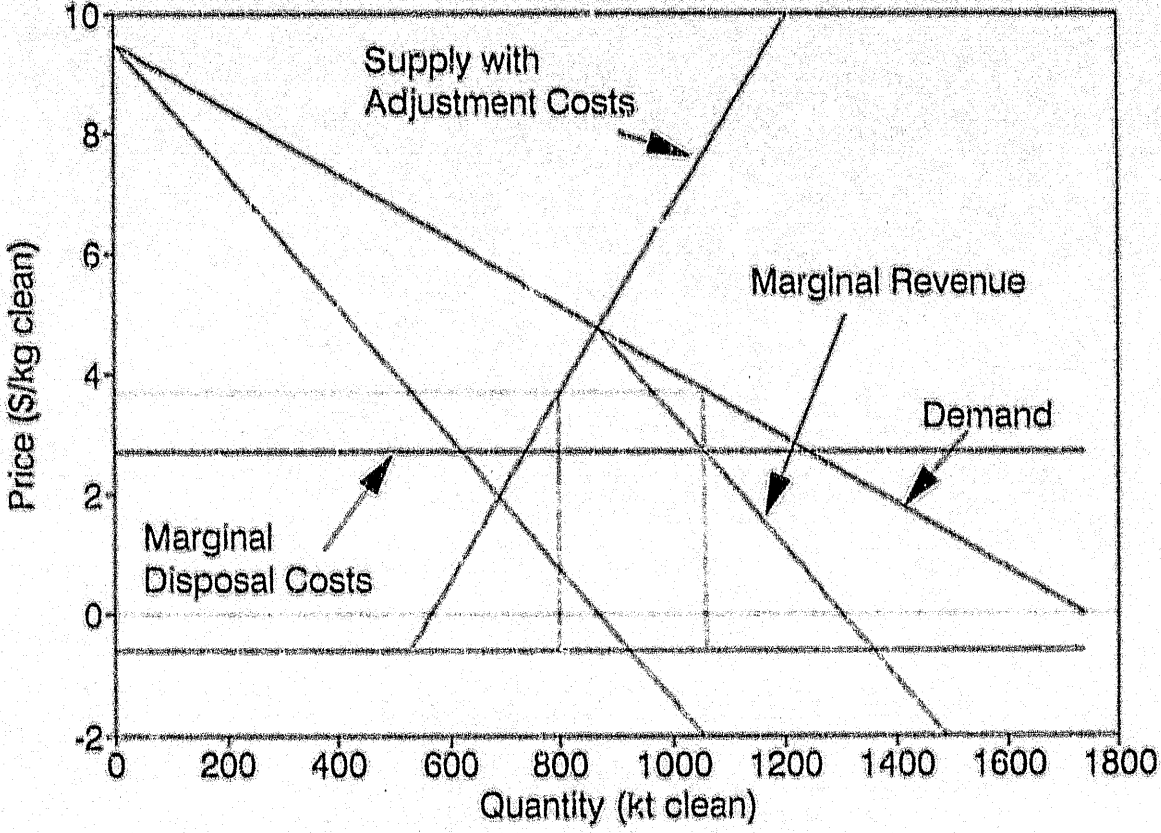

Figure 4: Uncoordinated Production and Disposal with the AWRC Maximising its Disposal Income

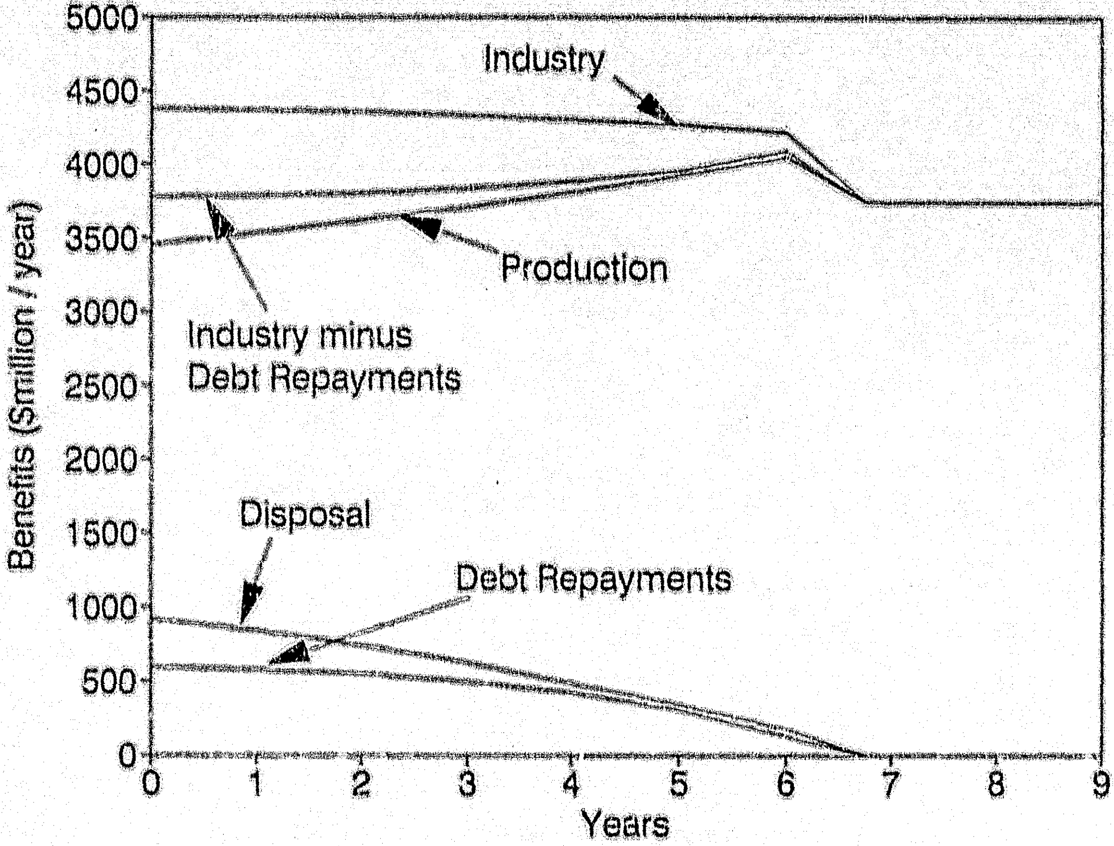

Figure 5: Annual Benefits from Optimal Production and Disposal

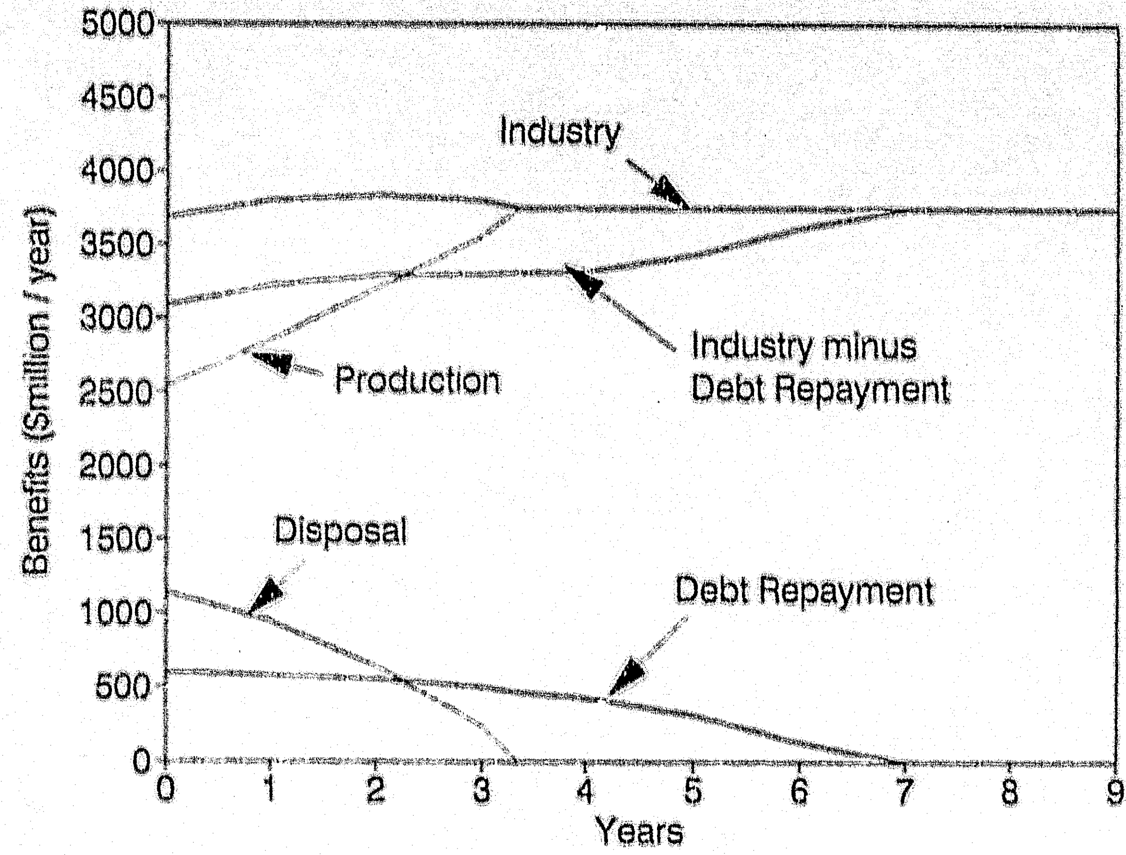

Figure 6: Annual Benefits from Competitive Stockpile Disposal

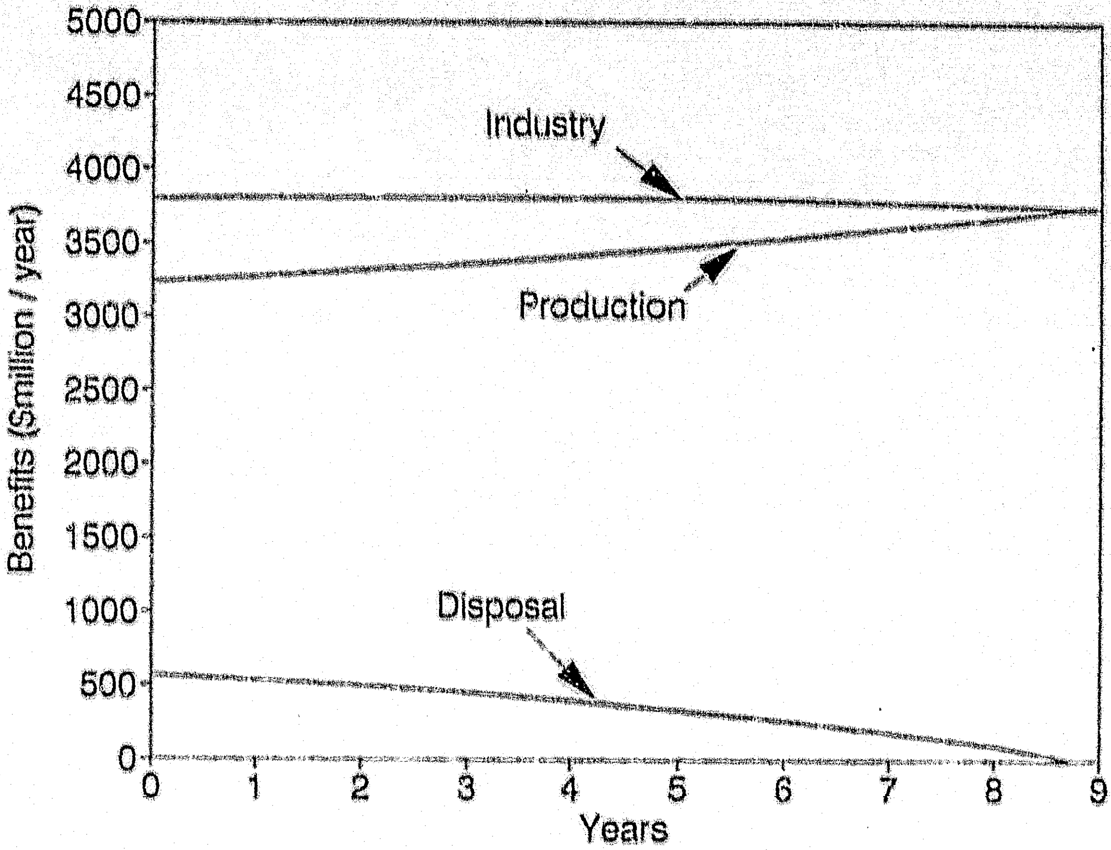

Figure 7: Annual Benefits with the AWRC Maximising
Industry Benefits

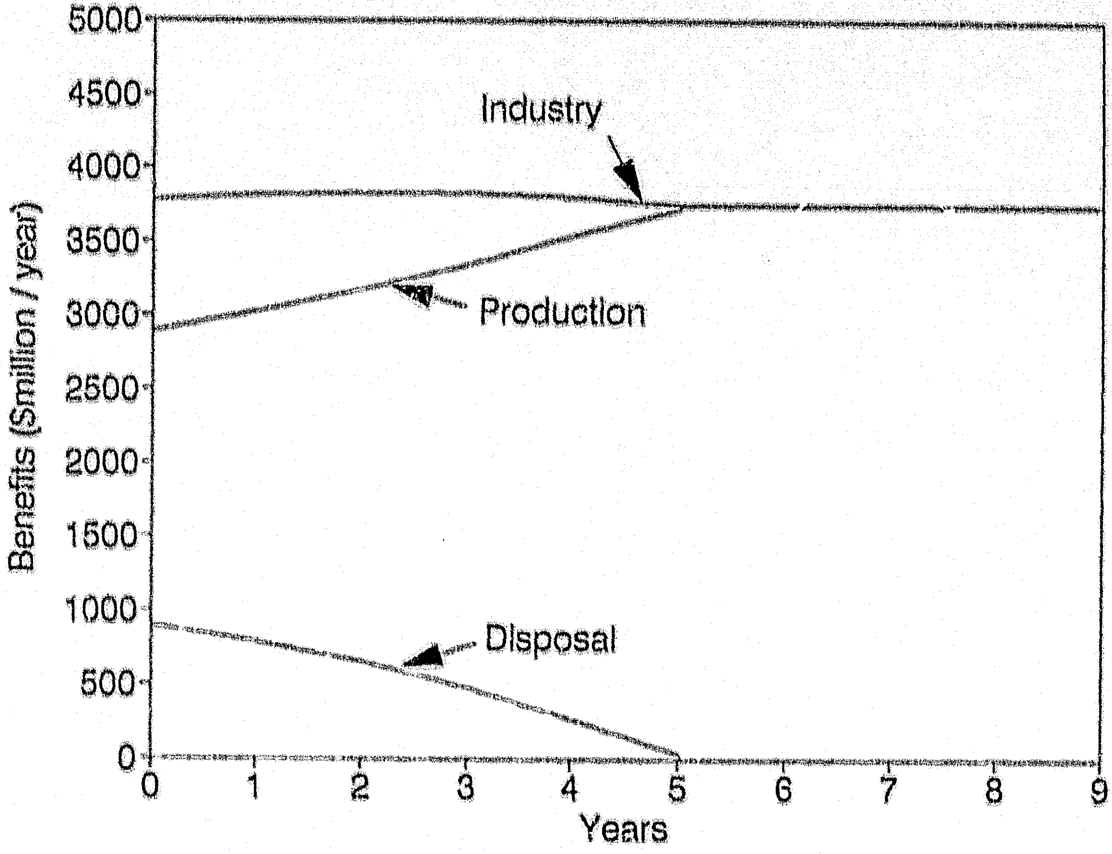

Figure 8: Annual Benefits with the AWRC Maximising Disposal Income

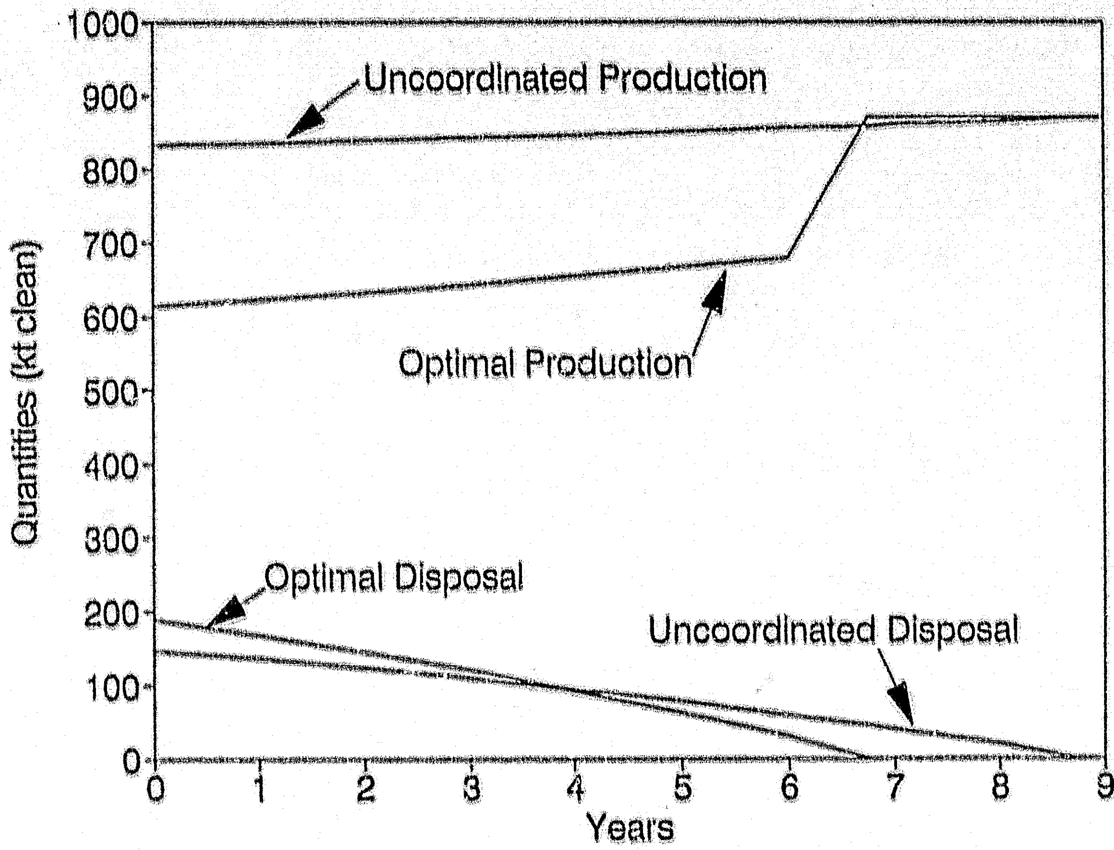

Figure 9: Quantities for Optimal Production and Disposal and for the AWRC Maximising Industry Benefits

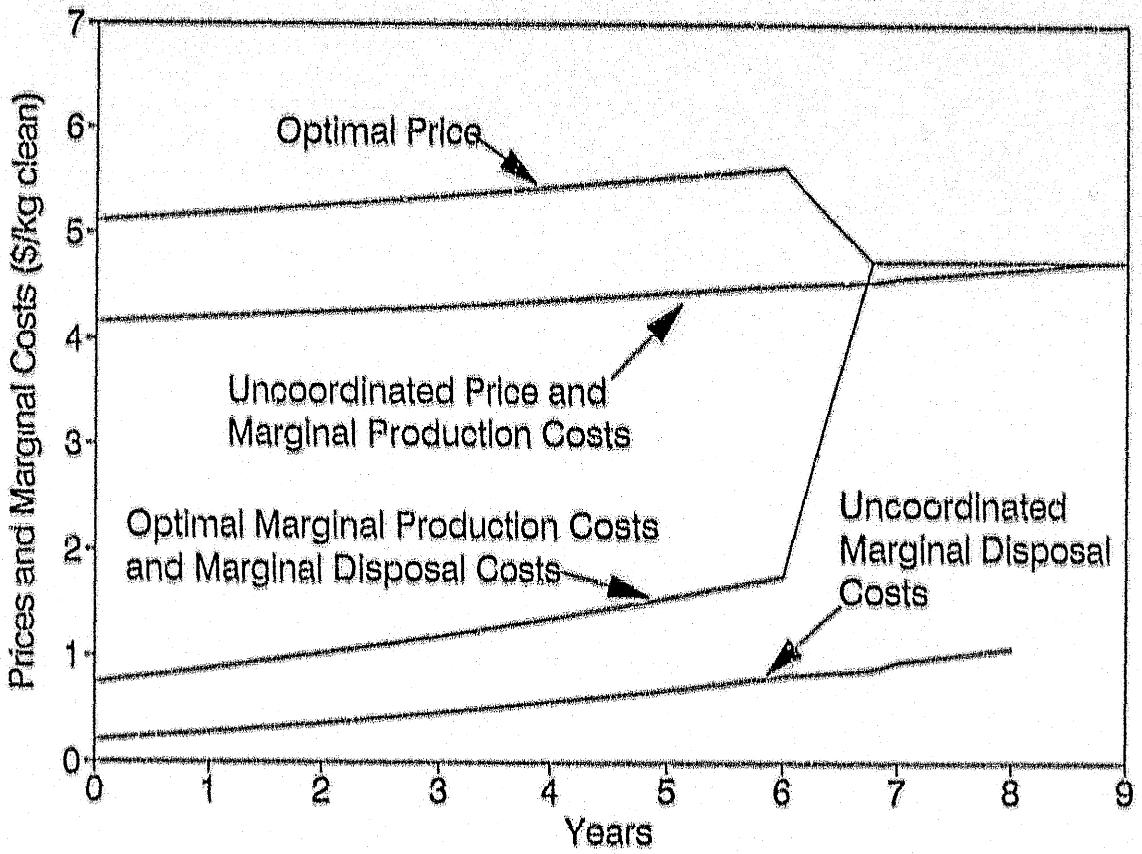

Figure 10: Prices and Marginal Costs for Optimal Production and Disposal and for the AWRC Maximising Industry Benefits

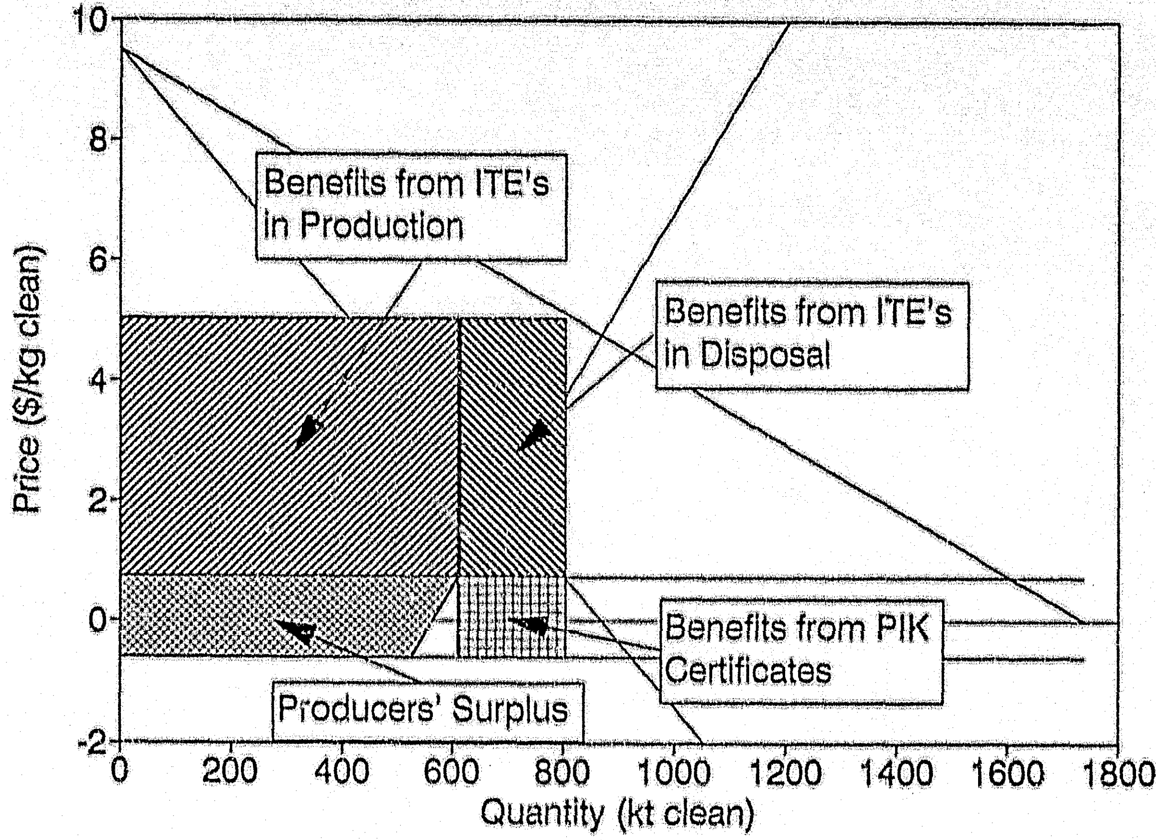

Figure 11: Annual Benefits from a Property Rights Policy with PIK Certificates and ITE's