WORKING PAPERS IN ECONOMICS

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IS MEDIUM TEMPERATURE SOLAR THERMAL PROCESS STEAM VIABLE FOR AUSTRALIA? SOME PRELIMINARY RESULTS

by

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Abstract

A new solar boiler technology is shown to be financially viable (in mid-1986 $A prices) against LPG for private industry conditions in inland New South Wales. This conclusion could also hold against natural gas for the Sydney region in the near future. If continuous positive net cash flow is required by the business enterprise, then some form of loan strategy should be preferred to up-front purchase of the solar collector.

The technology is also shown to be economically viable for public sector installations. Slightly longer time periods are required for positive net present values to be obtained than for industry, and in three of the four cases examined this was achieved before the end of the solar collector's first life cycle. For the fourth case, a positive net present value was obtained when the annual energy collected was taken as 2.6 rather than 2.0 GJ per M^2. The higher figure is considered realistically representative of the more advanced version of the solar collector currently being developed.

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IS MEDIUM TEMPERATURE SOLAR THERMAL PROCESS STEAM VIABLE FOR AUSTRALIA? SOME PRELIMINARY RESULTS

V.B. Hall and D.R. Mills*

1. INTRODUCTION

In a recent Energy 2000 Discussion Paper, it was concluded by the Australian Department of Resources and Energy (1986, p.vii) that the major impediment facing most renewables is a lack of economic viability. In the area of solar thermal energy, residential solar water heating was judged to be currently viable, while solar water heating for industry was considered to have short to medium-term potential. Specifically in relation to industry (1986, p.4), it was considered that:

> "... at high production rates and current energy prices, it is economically viable to use flat-plate and evacuated-tube collectors in situations which require temperatures up to 80°C. Above 80°C these systems remain workable, but become increasingly uneconomic as system complexity increases...R & D into solar thermal industrial systems should focus on extending the economically viable temperature range from 80°C to perhaps 120-150°C. Evacuated tube collectors are seen to be the most likely to achieve this goal"

This paper provides new results on the life-cycle financial and economic viability of "above 80°C" systems, utilising pilot study data for a new solar steam boiler technology. The technology is suitable for producing both industrial and public sector process steam[1], and so results on viability are presented for both sectors. The technical data used relate to a conventional boiler installation which has been operating for some time at the Parkes District Hospital in inland

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1 Some preliminary results for domestic hot water installations, based on this technology, have been published in Hall and Mills(1986).

New South Wales(NSW).

The financial viability results are more relevant for an entity operating under private sector industrial conditions, as the underlying assumptions used reflect private sector costs. In particular, net transfer payments from the public to the private sector are explicitly taken into account. In contrast, the economic viability results exclude transfer payments, reflect an economic or social cost analysis[2], and are therefore more appropriate for representing the viability of public sector installations. Conclusions have been derived with the assistance of a small set of personal computer-based models, focusing on life-cycle net present values for energy produced by solar thermal and its closest fossil fuel competitor.

Section 2 provides summary information on the solar boiler technology, and key cost and fuel parameters. Section 3 presents a brief description of the evaluation methods used. Empirical results for the industrial and public sector installations are given in sections 4 and 5. In both sections, analyses are presented for a case where the solar collector is purchased and installed on an up-front basis, and for two illustrative loan strategies. One loan strategy is based on traditional borrowing methods, and the other on flexible financing which tailors principal and interest payments to net fuel savings. Major conclusions are summarised in section 6.

2. THE SOLAR STEAM BOILER TECHNOLOGY, KEY TECHNICAL AND COST PARAMETERS

The new medium temperature solar technology[3] is directed at the market for thermal energy between 100^{o}C and 250^{o}C. It would therefore cover such established activities as food processing, refrigeration, laundering, and steam heating of buildings. We are not aware of any comprehensive analysis having been done on potential markets[4]. For the purposes of this study which is focused primarily on viability, it is sufficient to note that the industrial sector would seem to provide a potentially

2 Social or economic analysis is concerned with the most efficient allocation of resources for society as a whole, leading to optimum overall production at lowest cost.

3 This technology has been developed by the Department of Applied Physics at the University of Sydney. For further technical details on the evacuated tube and other aspects of the solar collector, see Mills(1986).

4 McLennan Magasanik(1985, pp.63-68,90) have done some preliminary analysis on market constraints applying to SIPH systems. One of their major conclusions was that, for the forseeable future, solar's potential market would be constrained mainly by the increased ready availability and low cost of natural gas.

greater market than the public sector.

Like most solar thermal installations, the solar collector system evaluated here is a solar/fossil fuel hybrid. That is, solar is used as a fuel saver, and the cheapest fossil fuel becomes the back up energy source when required. The new collector uses a patented evacuated absorber tube in combination with an inexpensive stainless steel parabolic mirror. The system has no moving parts save for the mirrors, which are adjusted manually *en masse* about 15 times a year. Natural two-phase circulation is used for heat transfer, and on site no heat exchanger is required because the solar collector is treated simply as another boiler in parallel with existing conventional boilers, connecting directly into the main steam distribution lines.

The installed system cost (in mid-1986 $A) was estimated to be $150-180 per meter squared(M^2), a much lower figure than for previous medium temperature technologies. This is consistent with an ex-factory price of the industrial process heat system of about $90 per M^2 in large scale production, including 28 per cent (before tax) profit. At the Parkes site, annual collected energy has been estimated at 2 gigajoules(GJ) per M^2, using the current technology. Improved technology is under development which could increase performance by 25 per cent[5], with little or no increase in relative cost. However, base calculations in the current paper have been based upon current technology because the cost of improvements is not yet certain.

Steam is used at hospitals for various purposes such as laundering, sterilisation of instruments, and hot water heating. At Parkes District Hospital, the laundry shuts down on weekends, but there is still enough residual demand in other areas to utilise the entire solar output. To date, the solar system output has matched daytime demand extremely well, but has not been able to satisfy either peak load or the whole of total annual demand. Thus, no storage is required because all of the solar output can be utilised at all times[6]. Total annual demand is 3900 GJ of steam at 150°C, of which 1820 GJ can be supplied from the hospital roof.

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5 A 200M^2 pilot roof-mounted array will be installed in 1988 at Campbelltown Hospital on the outskirts of Sydney, providing a peak of 80kw to a steam dish-drying facility five floors below. It will therefore provide data for a more comprehensive viability study in the future.

6 Annual net fuel savings would, of course, be somewhat lower than calculated here if a seven day week were not operated. In this context, however, it should also be pointed out that no savings in conventional plant have been assumed. Some savings in labour, capital cost and maintenance should occur in actuality if the solar system were to supply a sizeable fraction of peak load.

Both LPG and electricity have at times been used at Parkes to satisfy the total annual demand load for steam, but as electricity then became relatively much more costly, it has been assumed here that the entire back-up load is carried by LPG at the (mid-1986) price for that site, $8.54 per GJ.

The present LPG steam boiler has a thermal efficiency of 72 per cent, and line distribution losses are 30 per cent; these will be virtually unchanged by installation of the array. The solar output includes module feedline losses, so we may assume a 100 per cent utilisation of this energy as a first approximation. Each GJ of solar output will, as a result, replace 1/.72 = 1.39 GJ of LPG. A conservative 15 year length of life of the solar hot water tank has been assumed. Length of life of the array would be considerably longer than this, but for convenience has also been taken as 15 years.

In summary, capital and recurrent costs for inland NSW country conditions have been taken as:

- installed solar system costs are $150-180 per M^2, based on estimated annual collected energy of 2GJ per M^2
- corresponding operating and maintenance costs are $3 per M^2 per annum
- the cheapest competing fossil fuel is LPG, priced at $8.54 per GJ
- the LPG boiler efficiency is 72 per cent, so that each GJ of solar will replace 1.39 GJ of LPG

3. THE EVALUATION METHOD

The accepted procedure[7] for this class of problem involves the use of discounted cash flow methods to arrive at the net present value (NPV) of relevant annual net cash flows (NCF) less the installed capital cost of the solar collector(K_o). Calculations can be done in either nominal or real terms, so long as all items in the numerator and denominator are treated consistently.

The NPV formulation, with the right hand side variables in <u>nominal</u> terms, can be written <u>generally</u> as:

$$NPV = \sum_{n=1}^{N} \$NCF_n/(1 + r)^n - \$K_o \qquad (1)$$

where r = nominal discount rate, n = time period (in years), and N = number of years under consideration. The term $NCF can in turn be expressed as:

7 Explanations of the procedure can be found in Kreith and Kreider(1978) or in Copeland and Weston(1983)

$$\$NCF = \$CFLSV + \$TAXSV - \$SOPMC - \$INT - \$LOANRP \quad (2)$$

$$\$TAXSV = t(\$SOPMC + \$DEPRCN + \$INT - \$CFLSV) \quad (3)$$

where for year n, \$CFLSV = savings on conventional fuel costs, \$TAXSV = tax savings out of net recurrent deductable expenses, \$SOPMC = operating and maintenance costs for solar, \$INT = interest payments per annum on borrowed funds, \$LOANRP = loan repayment instalment, t = nominal (marginal) corporate income tax rate, \$DEPRCN = depreciation deductable per annum on $\$K_o$.

Equations (1) to (3) are then used in different specific forms, according to whether the viability analysis is for the public or private sectors, according to whether the analyst has a preference for working with right hand side variables in nominal or real terms, and according to whether finance is provided up-front or through some form of loan.

For an individual business enterprise operating under private industry financial assumptions[8], the financial analysis would require:

- for up-front (or equity financed) purchase: $\$K_o > 0$; r being replaced by the nominal after-tax discount rate, $d = r(1-t)$; $0<t<1$; $\$TAXSV \leq 0$ or >0; \$INT = 0 and \$LOANRP = 0
- for an installation based on borrowed funds: $\$K_o = 0$; \$INT>0 and \$LOANRP>0 during the relevant repayment period

For the public sector (i.e. economic or social cost) analysis, however, r is the nominal before-tax discount rate, and t = 0, as is \$TAXSV. Settings of the remaining parameters for up-front purchase or loan-based work are as indicated in the previous paragraph. That is, $\$K_o > 0$, \$INT = 0 and \$LOANRP = 0 for purchase, and $\$K_o = 0$, $\$INT \geq 0$ and $\$LOANRP \geq 0$ for loan financing.

If it is preferred to conduct the analysis using variables on the right hand side of equations (1) to (3) in real terms, it is necessary to define real discount rates. For the private sector case, the real after-tax discount rate, d', is defined to vary with the relevant nominal before-tax rate of return on invested funds (r), the income tax rate as defined above, and a common escalation rate (p)[9]. We therefore have:

8 Recall that the industrial case is distinguished from the public sector case, primarily through the deductability of expenses and assessability of fuel savings as income for corporate income tax purposes, and hence through the existence of positive or negative tax savings.

9 This formulation implies a constant-over-time nominal discount rate, interest rate, tax rate, and inflation rate. Fuel prices and costs are assumed to escalate at the common inflation rate. Differential escalation rates, allowing in particular for fuel prices to change at different and non-constant rates, can be incorporated into the analysis without significant difficulty

$$d = r(1 - t) \quad (4)$$

and

$$d' = (1 + d)/(1 + p) - 1 \quad (5)$$
$$= (d - p)/(1 + p)$$

Hence, equation (1) can alternatively be written in <u>real</u> terms as:

$$NPV = \sum_{n=1}^{N} NCF_n/(1 + d')^n - K_o \quad (6)$$

with NCF and its relevant components for each year n, and K_o being expressed in mid-1986 $A prices.

The corresponding real terms expressions for a <u>public</u> sector application would be:

$$r' = (1 + r)/(1 + p) - 1 \quad (7)$$
$$= (r - p)/(1 + p)$$

and

$$NPV = \sum_{n=1}^{N} NCF_n/(1 + r')^n - K_o \quad (8)$$

The NPV figures for each year n, emanating from use of equations (1), (6) or (8) are used as the summary measures for our empirical results presented in Figures 1 to 12. They reflect, for each year of a solar collector life cycle, the <u>net</u> positive and negative values resulting from LPG generated process steam being replaced by that produced from solar thermal output.

An additional important summary measure is obtained by calculating the present value per GJ,(PV/GJ), for solar and LPG individually. Equations (1),(6) or (8) are therefore used here for each of solar and for LPG, and the resulting PV figures divided by the number of GJ produced over time up until the period required. The PV/GJ figures for the individual fuels, as at the end of the first solar life cycle period (i.e year 15) are presented in Table 1.

Representative values chosen for the (financial) parameters in equations (1),(4),(5) and (7) are consistent with Australian experience over the past decade or so. For r, reflecting before-tax interest rates, the values were in the range .12 to .20, leading to r' being between .087 and .026. The corresponding after-tax rate values for d were from .102 to .061, consistent with d' between -.058 and .030. These figures reflect aggregate inflation rates of 3 to 17 per cent (i.e. positive real interest rates of 9 and 3 per cent), and a corporate income tax rate of 49 per cent. A fixed depreciation rate of 20 per cent per annum was chosen, allowing full write-off of the installed capital cost after five years.

4. INDUSTRIAL SECTOR EMPIRICAL RESULTS: FINANCIAL VIABILITY

Up-front Purchase

For up-front purchase of the solar collector from existing equity capital, or from some other form of budgeted corporate funds, the NPV outcomes over two life-cycles are presented in Figures 1 and 2. Both Figures show results for the alternative installed solar capital costs of \$150 and \$180 per M^2; the distinguishing feature being a d' of -.058 in Figure 1 and a d' of .030 in Figure 2.

Using the accepted criterion that NPV must be positive at the end of the life cycle for the incremental investment to be worthwhile, the overall conclusion from the two Figures is that installing the new solar boiler technology is financially viable for all four parameter sets. Negative NPV's exist for 7 to 13 years of the first life cycle, depending on the set chosen.

From the after-tax PV/GJ fuel costs for each of solar and LPG, presented in Table 1 for the 15th (life-cycle) year, it is clear that values differ substantially according to the discount rate used. More importantly, however, for both discount regimes and irrespective of the installed capital cost value used, the PV/GJ costs for solar are well below values for LPG. For the more expensive solar installation, for example, solar is estimated to cost \$4.14 per GJ(d' = .030) and \$5.06 per GJ(d' = -.058), as against corresponding values of \$4.80 and \$10.10 for LPG.

Traditional and Flexible Borrowing

Key additional elements affecting whether a corporation should adopt some form of borrowing strategy are the tax deductability of interest payments and the opportunity to achieve a somewhat smoother pattern of net cash flows over time.

To this end, loan periods in the <u>traditional borrowing</u> case have been chosen as short as possible, consistent with achieving sustained positive NPV's. A traditional borrowing pattern involves a constant nominal annual repayment of principal and interest. This has been calculated from the "annuity formula", $\$K_o[r/1 - (1 + r)^{-T}]$, where T is the period chosen for the loan. Yearly interest payments are calculated on the previous year end's reducing balance, and will therefore become steadily smaller over time.

Under these conditions, the loan periods shown in Figure 3 for the \$150 per M^2 and \$180 per M^2 installations are 8 and 9 years respectively. In Figure 4 the corresponding periods are 10 and 12 years.It is evident from Figures 3 and 4 that negative annual net cash flows in the early years can be eliminated through use of a traditional loan with appropriately structured length.

Results for a more <u>flexible borrowing</u> method, which is also consistent with achieving sustained positive net NPV's, are depicted in Figures 5 and 6. Under this procedure, each year's net savings on conventional fuel use are applied first towards payment of interest and the balance goes towards repayment of principal. Excess monies are shown to cumulate variously from 7 to 13 years onwards, and could then be applied either to purchase of a new solar collector, or to investment outside the firm, or to use in other parts of the business.

The advantage of this type of financing is that the firm doesn't pay more than it otherwise would have for continuing to use conventional fuel in any given year. It therefore helps to overcome the payback time concerns of certain commercial firms in Australia who would otherwise demand that the distributed solar energy pay for itself within 2-5 years against long term amortized conventional fuel sources. It also allows the low life-cycle cost of solar to become immediately apparent to the industrial process heat consumer.

5. PUBLIC SECTOR EMPIRICAL RESULTS: ECONOMIC VIABILITY

<u>Up-front Purchase</u>

For hospitals and other public sector institutions installing collectors out of budgeted funds, NPV outcomes are presented in Figures 7 and 8. Positive NPV's are recorded for three of the four parameter sets prior to the end of the first life cycle, so in these cases the new solar boiler technology is clearly economically viable. For the fourth set, reflecting the higher installed cost of \$180 per M^2 and the higher real discount rate of .087, installation should be regarded economically viable at the margin, as a small positive NPV is achieved only if the collector were to have a 17 year rather than a 15 year lifetime.

The corresponding life cycle fuel costs in PV/GJ for solar and LPG are presented in columns 3 and 4 of Table 1. For the real discount rate of .026, solar's life cycle costs of \$6.23 and \$7.23 are well below LPG's \$9.74. This remains the case for a discount rate of .087 and the installed cost of \$150 per M^2. However, for a collector costing \$180 per M^2, the discount rate of .087 leads to LPG's cost of \$6.47 being slightly lower than the \$6.82 for solar.

So, while economic viability has been established for three of the illustrative public sector parameter sets, less favourable results were obtained for the fourth set. This marginal case was therefore run with a somewhat higher value for annual collected energy, in order to provide some guide as to how outcomes might change in the forseeable future. The assumed value of 2.6 GJ per M^2 is in contrast to the base value of 2.0, but was considered realistically representative of the technically more advanced version of the collector currently being developed. Results incorporating the value of 2.6 are represented by the dashed lines in Figure 8. This leads to positive NPV's after only 8 and 10 years for the \$150 and \$180 collectors, and provides a solar life cycle cost in PV/GJ of \$5.25 for \$180, now comfortably below the \$6.47 for LPG.

Traditional and Flexible Borrowing

For ease of comparison, public sector loan period lengths were initially chosen the same as for the private sector, i.e. 8 and 9 years for r' = .026, and 10 and 12 years for r' = .087.

From Figures 9 and 10 for traditional loans, it is clear that small negative NPV's persist for a number of years. Sustained positive NPV's can, however, also be achieved for the public sector either by lengthening somewhat the period of the traditional loan or, as shown in Figures 11 and 12, employing the flexible borrowing method. The dashed lines again reflect annual collected energy being 2.6 GJ per M^2 rather than 2.0.

6. CONCLUSIONS

Under representative empirical assumptions about current technology and inland NSW fuel costs, positive conclusions reported recently by the DRE(1986) on the economic viability of low temperature solar thermal industrial systems have been extended to the medium temperature (150^{o}C) range. This conclusion could be extended to the Sydney region in the forseeable future, when considerably improved technology currently being developed becomes commercially available.

Positive NPV's for solar, and therefore life cycle PV/GJ costs which are lower for solar than LPG, were obtained initially for all cases save one. This case was then shown to be viable if either the collector were to last 17 rather than 15 years or technological advances currently under development were to be taken into account.

For a private sector enterprise, borrowing under structured loan conditions is a more viable shorter-term strategy than up-front purchase. The up-front purchase strategy, while also viable in the long term, leads to negative NPV cash flows for the earlier years. Flexible loan programs, with repayments linked to replaced conventional fuel costs, can often eliminate negative cash flows in early years, thereby avoiding payback time concerns of some corporations.

For a public sector installation, negotiating a flexible loan would be better than either up-front purchase or a traditional loan of the same length used by the private sector.

Finally, it should be emphasised that none of the conclusions presented rely on any form of direct cash or tax subsidy for installation of the solar thermal collector.

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Table 1. Industrial and Public Sector Process Steam (150°C): Life Cycle Costs in PV/GJ for Solar and LPG (in mid-1986 $A)*

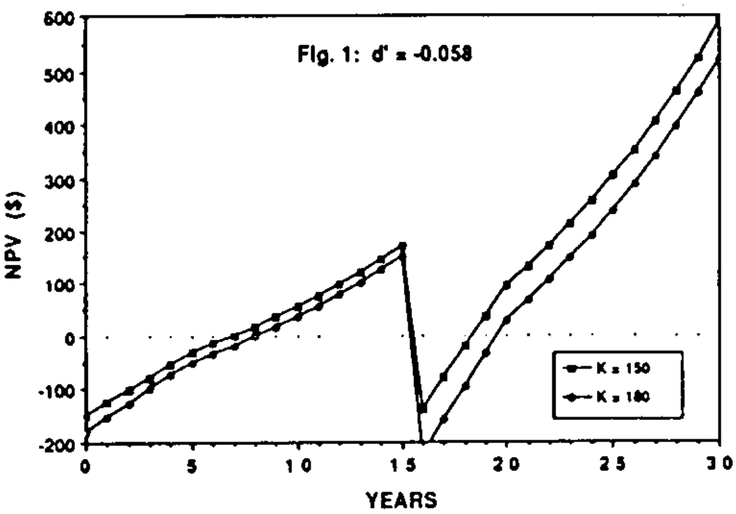
	Industrial Sector (after-tax $A)		Public Sector (non-taxed $A)	
	d'=-.058	d'=.030	r'=.026	r'=.087**
Year 15				
Solar ($150/$M^2$)	$4.43	$3.55	$6.23	$5.82
Solar ($180/$M^2$)	$5.06	$4.14	$7.23	$6.82
LPG	$10.10	$4.80	$9.74	$6.47

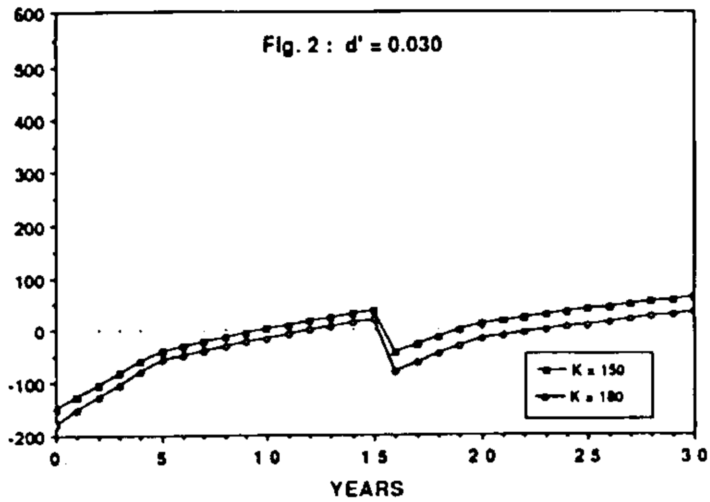
* As the values presented are for year 15, figures are the same whether up-front purchase, traditional or flexible loan methods are used.

** For the assumed value of 2.6 GJ per M^2 for annual collected energy, the corresponding figures are $4.48, $5.25 and $6.47.

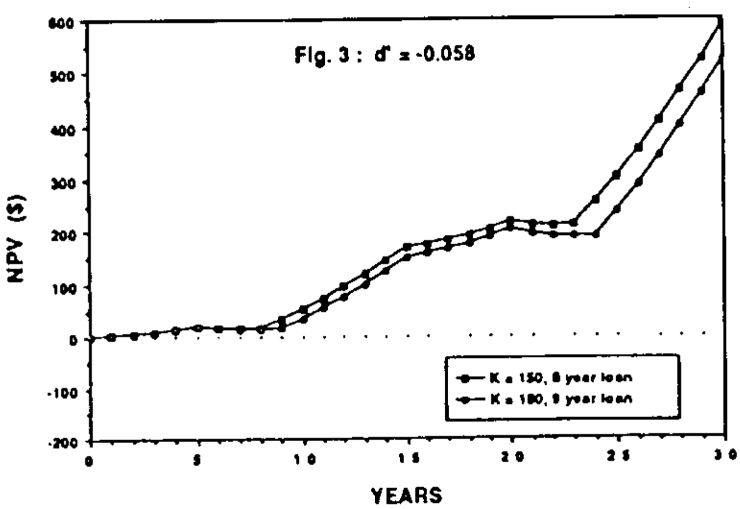
INDUSTRIAL PROCESS STEAM

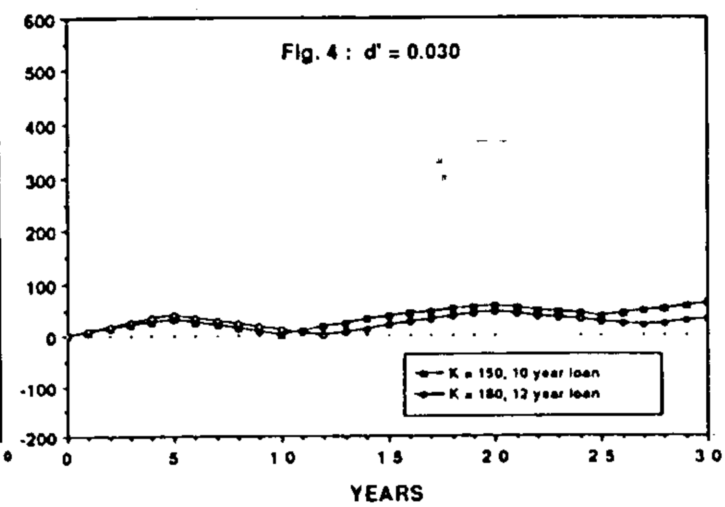
UPFRONT PURCHASE





TRADITIONAL LOAN





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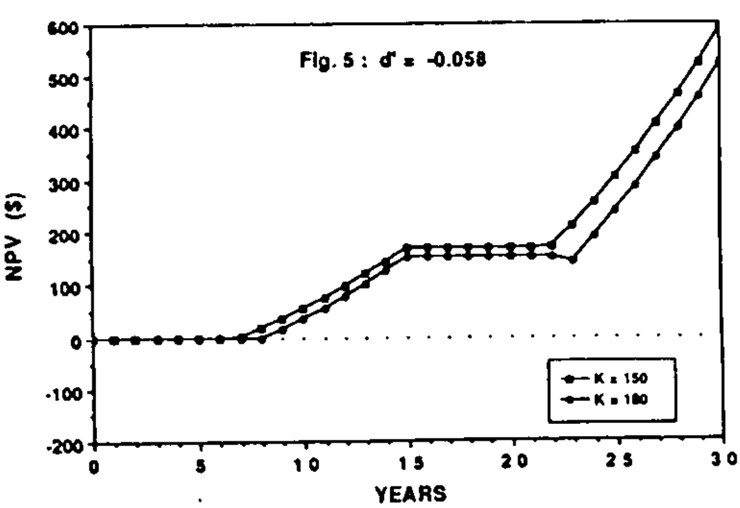
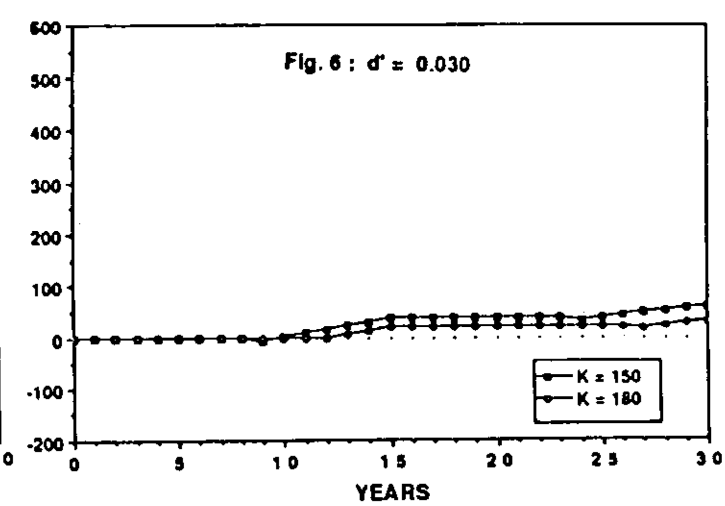
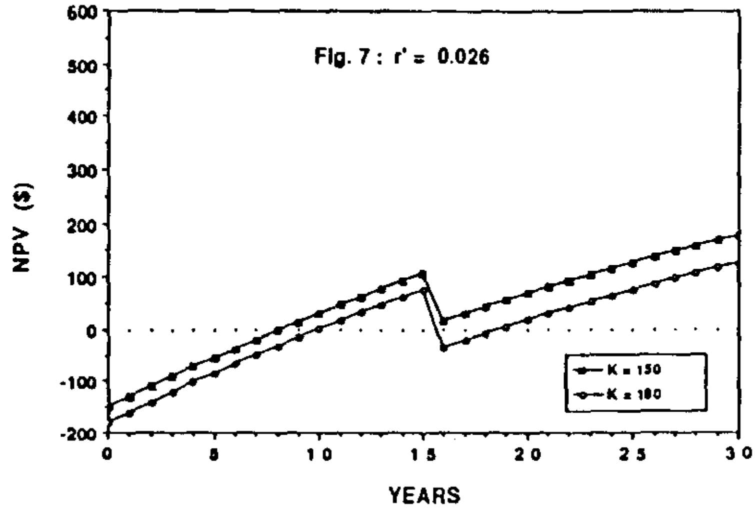
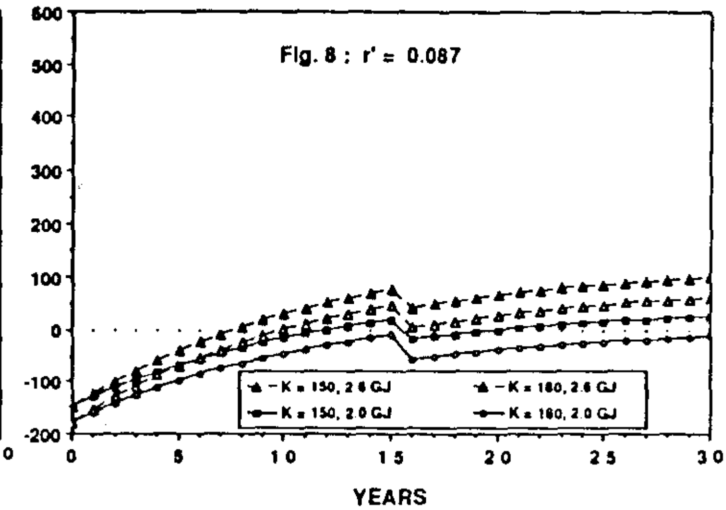




PUBLIC SECTOR PROCESS STEAM

UPFRONT PURCHASE





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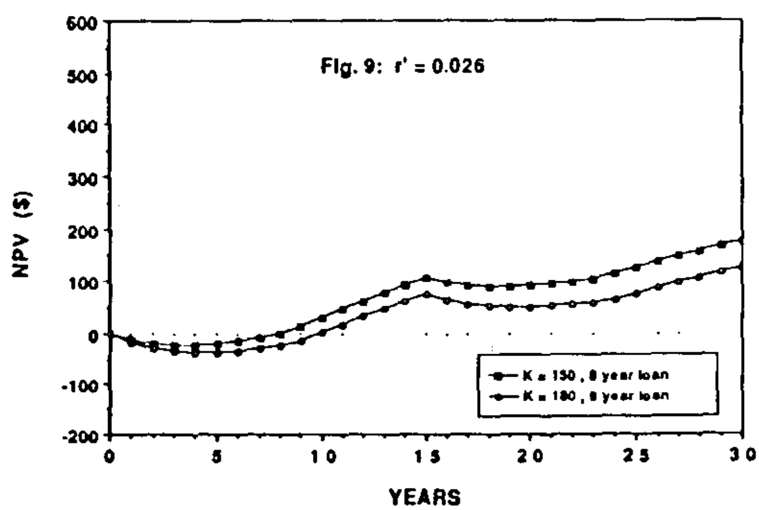

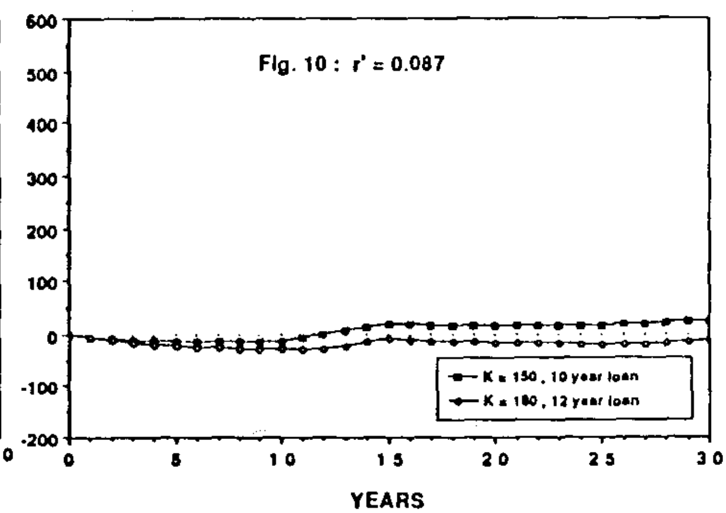

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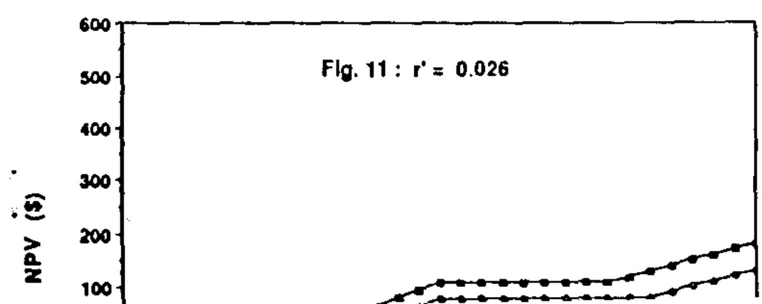

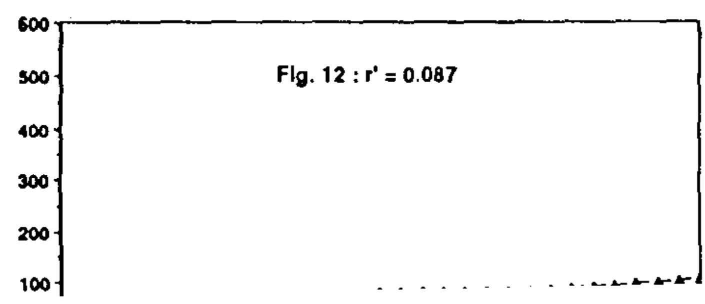

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