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REAL OPTIONS ANALYSIS – A CASE STUDY

TECHNOLOGY ASSESSMENT REPORT 23

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Executive summary

There is currently a high level of uncertainty in taking investment decisions in the coal and energy related sectors of the economy. This uncertainty is being driven by rapid changes to the environmental, market and political context in which coal and energy investment projects must operate. The risks are compounded when investments are highly capital intensive and long term. In these circumstances organisations cannot take a fixed view of investment projects, but must consider investments which offer flexibility by adapting to a range of market or regulatory conditions.

Discounted cash flow (DCF) or net present value (NPV) techniques form the basis of most corporate investment decisions. In recent years, an alternative to DCF and NPV analysis has been developed based on financial option theory. Put most simply, financial option theory is a methodology for adjusting for risk and allocating value to flexibility. Financial option theory recognises that, since conditions change as new information arrives, as long as an option remains open it has an economic value that should be priced (that is, it has value).

This report undertakes a case study of three power station investments to demonstrate and evaluate whether real options analysis should be adopted by the CRC for Coal in Sustainable Development (CCSD), taking into account any limitations and scoping out what any future real options research would entail.

Some key limitations of real options analysis identified in this report are briefly summarized below:

- If the flexibility being considered is too costly to procure, preserve or exercise then real options analysis provides nothing more than confirmation that the flexibility has no value.
- Flexibilities must be identified in order to value them.
- Flexibilities may be very investor specific.
- If the investment or decision was already either strongly ‘in’ or ‘out of the money’ on an NPV basis, the investment decision arrived at by applying real option analysis is likely to be no different.

Despite these limitations, overall there would appear to be a broad scope for applying real options in the CCSD. The following recommendations were arrived at taking into account the limitations of real options and the objectives of Program 4 and the CCSD in general.

Real options analysis can be used to help guide and value CCSD research. However there were two major concerns raised. One is that, the benefits of some research projects or programs may be difficult to quantify accurately. The second is that the analysis would be costly. Therefore it follows that:

Recommendation 1: The CCSD should consider applying real options analysis to find the value of current and future research program outcomes, where:

- *the research outcomes and their value to CCSD members is clearest, and*
- *the project is large enough to justify the additional cost that would be required to conduct the real options analysis.*

This report discussed in broad terms how the CCSD could use real options analysis to evaluate society’s choices in relation to coal’s role in Australia’s uncertain future. Real options analysis was found to be an appropriate tool for such studies providing the policy

question was framed appropriately for the Australian context and the future challenges facing the coal industry were considered against all available options. The recommendation which follows this observation is:

Recommendation 2: The CCSD should continue to apply real options analysis to the policy issues that the CCSD is most concerned about, such as coal's role in the future energy mix in Australia. Doing so requires bringing together two major elements of research:

- *the first is an understanding of all the options that are available, including coal based technologies, mixes of coal and other alternatives, as well as their implications in terms of the environment and costs.*
- *the second element is an understanding of the future challenges and opportunities as well as their associated risks and uncertainties.*

This research would involve a combination of scenario development, economic modelling and process/technology data gathering activities.

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1.0 Introduction

There is currently a high level of uncertainty in taking investment decisions in the coal and energy related sectors of the economy. This uncertainty is being driven by rapid changes to the market, environmental and political context in which coal and energy investment projects must operate. The risks are compounded when investments are highly capital intensive and long term. In these circumstances organisations cannot take a fixed view of investment projects, but must consider investments, which offer flexibility by adapting to a range of market or regulatory conditions.

Discounted cash flow (DCF) or net present value (NPV) techniques form the basis of most corporate investment decisions. These techniques are entirely appropriate when valuing an asset whose future cost and revenue streams are not affected by uncertainty. However, when assets are risky, these traditional techniques make inappropriate adjustments to account for risk and fail to price the flexibility that is inherent in managing risky assets. For example, the simplest adjustment is usually to incorporate an inappropriately large hurdle or discount rate, in an attempt to account for risk, often resulting in an undervaluing of future net income from the asset.

In recent years, an alternative to DCF and NPV analysis has been developed based on financial option theory. Put most simply, financial option theory is a methodology for adjusting for risk and allocating value to flexibility. Financial option theory recognises that, since conditions change as new information arrives, as long as an option remains open it has an economic value that should be priced (that is, it has value). The option or options could relate to the degree of exposure to the investment project or the way in which the asset is operated once the investment has taken place.

At first, financial option theory provided analysts with methods of pricing derivative securities (financial options to purchase a stock) and of calculating optimal rules for exercising these financial options. In the mid-1980s, however, economists began to realise that financial options theory could also be applied to real (as apposed to paper) asset investment decisions. Progress has been slow, however a significant body of work has begun to build up in the last 10 to 20 years and some companies, particularly in the United States, have begun adopting real options techniques. Indeed, real options techniques are now considered to be the state of the art in investment decision analysis.

However, there are some practical and theoretical limitations to the adoption of real options technique for the regular appraisal of investment opportunities. The aim of this report is to demonstrate and explain whether real options should be adopted by the CRC for Coal in Sustainable Development (CCSD), taking into account any limitations and scoping out exactly what any future real options research would entail. This includes determining what sort of research questions it is most suited to answering, what software is required and what lesson can be learnt from existing studies such as that which has been done by the Electric Power Research Institute (EPRI).

In the next section of this report the authors define real options in more detail and, as a means of demonstrating the theory and its limitations, a case study of various power station investments is presented. Specifically, real options techniques are used to value some of the power station related operating and investment flexibilities that are available to investors to deal with energy market uncertainties. In Section 3 we consider what specific uses the real options technique might be put to in future CRC work, providing some simplified examples. Finally we form a set of conclusions and recommendations, in Section 4.

2.0 Theory and case studies

2.1 Real options theory

The easiest way to understand real options is to see it as an investment decision- making tool such as the calculation of Net Present Value (NPV). In fact calculating the real option value (ROV) of a project is not very different from calculating its NPV. It requires much the same data and in certain circumstances will give exactly the same results (more about this later). However, the important difference between the NPV and the ROV of an investment opportunity or project is that the ROV includes any additional strategic value inherent in a project. Or, more simply stated:

$$\text{ROV} = \text{NPV} + \text{strategic value}$$

Note it follows from this statement that:

1. The ROV of a project can never be less than its NPV,
2. The ROV of a project is equal to its NPV if there is no strategic value in the project, and
3. A project can still have value even if its NPV is less than or equal to zero.

In relation to the last point, a good example is that of a company who buys a closed mine that has a zero net present value at current mineral prices. The strategic value of the mine is that one day the price of coal, for example, may rise and the company can reopen the mine. Thus, it is argued in the literature that traditional NPV calculations under-value some assets by not including their strategic values. ROV is a methodology for specifically including any strategic value in an investment valuation.

2.1.1 Strategic project value

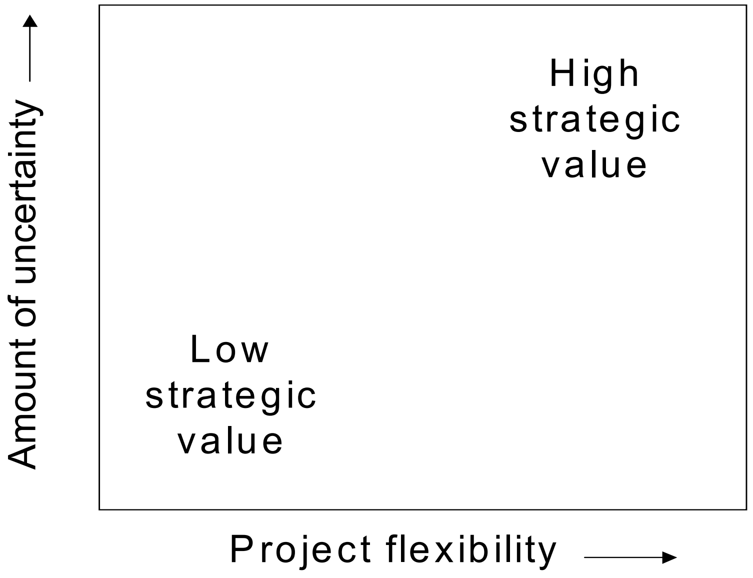
Strategic project value arises and increases the more a project has a combination of two things: uncertainty and flexibility. Project uncertainty can arise from a variety of issues (such as market prices, exchange rates, technological change, etc) which make both the future costs and revenues flows from a project uncertain.

The existence of uncertainty does not provide any strategic value to the investor unless there are flexibilities in the project which allow one to deal with those uncertainties. For example, if one is aware of various uncertainties regarding project revenues but that the project must be invested in ‘now or never’, then there may be no strategic value in the project and the ROV may be no different to an ‘expected’ NPV calculation (the ‘expected’ is because the true project value is unknown in the present). With no project flexibility NPV = ROV.

Common types of project flexibility or options include the option to defer investment in the project, the option to temporarily shutdown, option to permanently shutdown, option to switch inputs or outputs and multiple sequential options where one option to invest in a project provides the option to invest in another project.

Project flexibilities can deliver additional strategic value whether there is uncertainty or not. Take the example where an investor has the flexibility to defer an investment for a period of time without relinquishing exclusive rights to that investment. Whether the investor knows that the net return from the project is rising with certainty or not, as long as there is a possibility of the net return from the project rising in the future, then the option to defer the investment until such a time has value. Of course, the degree of uncertainty is still important in determining the size of the strategic value gained by such an option (as shown in Figure 1). The importance of the degree of uncertainty and other factors are explored further in the power station investment case studies.

Figure 1: Elements which impact on the size of the strategic value



2.2 Real options case studies: power station investment

One of the limitations of real options analysis is that its proponents often fail to get its various messages across. This is because real options requires a different way of thinking about all investment decisions where one must always be searching for strategic value. In some cases this is not difficult since some investment such as basic research provide no immediate return and are therefore composed entirely of strategic value. With other investments one may have to look much harder.

Three different plants are studied. Each plant has a set of common and specific flexibilities and uncertainties associated with them which determine their strategic value. These flexibilities and uncertainties are first listed and then incorporated into various models. In each case the NPV, ROV and strategic value (SV) are calculated. Some sensitivity analysis is also conducted.

The three proposed electricity generation asset investments are:
- a conventional pulverised coal fueled power plant (CPF)
- a coal fueled integrated gasification combined cycle power plant (IGCC)
- a gas fueled combined cycle power plant (NGCC)

Table 1 lists some examples of potential flexibilities and uncertainties associated with an investment in each of these projects. The list is not necessarily complete and, in theory, is only limited by the investor or owner's imagination and creativity. However, these are the main flexibilities one finds in the real options literature. The uncertainties listed are considered to be the most important ones in the current Australian political, environmental and market setting.

Table 1: Potential flexibilities and uncertainties in power station investments

Uncertainties	*Flexibilities*
Price of carbon permits	Option to wait before investing
Arrival of carbon permit scheme	Option to shut down
Wholesale electricity price	Option to install various scrubbers
FCAS prices	Option to switch fuels
MRET prices	Option to move sites
Price of coal/gas/biomass	Option to depreciated faster
Plant availability/breakdowns	Option to participate in FCAS market
Change in license policy	Option to do research
-cooling water license	
-emissions licenses (SO_X and NO_X)	

The models were constructed in Microsoft Excel and are provided as part of this report. Appendix B describes the various methodological issues in computing ROVs and so interested readers are directed to study that section as well as the various references provided. A general discussion of software requirements and issues associated with the transparency of the modelling process are discussed in Appendix D.

As discussed most of the data underlying the investment projects is uncertain. However, we do use a base case or mid-point estimate to give consistency between the various examples. This base case data is reported in Table 2 and again in the Excel spreadsheets.

For each flexibility we have not necessarily assumed that all of the uncertainties identified need to be taken into account. Rather only one or two are taken into account at one time. This makes it easier to identify exactly how each uncertainty affects the valuation and avoids unnecessarily complicating and lengthening the mathematical solution processes. When examining a particular project flexibility some uncertainties will be more relevant than others. For example, the existence of fuel price uncertainty is important when considering the value of a fuel switching option.

We will now proceed to find the ROV of each of the projects by studying one of five flexibilities one at a time. However, first some data issues are discussed.

2.2.1 Data issues

When a company considers investing in a power station it conducts a feasibility study which presumably includes a team of engineers, accountants/financial officers, market analysts and lawyers. The aim below is not the replicate such an exercise but rather to present a financial analysis which takes into account only the principal factors effecting the value of a power station investment. This simplification was necessary given the limits of the qualifications of the authors, the need to make the examples generic and because of the time budgetary constraints of the project. Specifically we make the following assumptions unless altered later for a particular example:

- The cost of grid interconnection and transmission and distribution charges are taken to be included in the electricity prices assumed.

- The electricity price formation process is independent of the investor choice to invest or not invest. Thus the decision to invest in a power station in the National Electricity Market does not affect the price the investor receives in that market.
- The results do not include costs of securing water access and land costs.
- The cost of consumables such as chemicals and water have not been estimated separately. Such cost are included in the estimates of variable operating costs sourced from the literature.
- The result are before any adjustment for tax deductions or benefits.
- The potential for earning revenue from the provision of auxiliary services to the National Electricity Market is not taken into account in any of the cases studies.
- The plants are assumed to have access to their primary fuel source and any fuel transport costs should be taken to be included in the fuel price.

The data, which is included in the model, are presented in the spreadsheets and varies depending on the problem being examined. Data, which is common to all the spreadsheets, is presented in Table 2. The calculated costs are generally higher than current average electricity prices because of the impact of the current low exchange rate on capital costs.

Table 2: Principal data used in the report

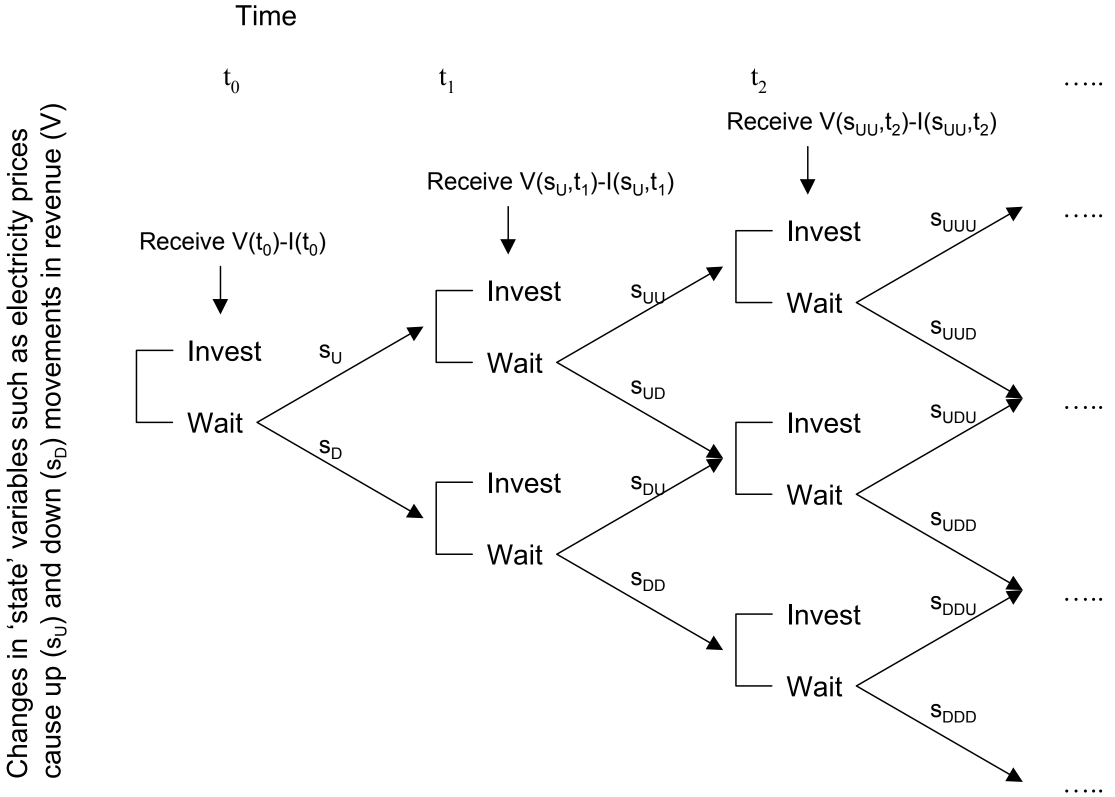
		CPF	IGCC	NGCC
Assumptions				
Unit size[a]	MW	660	660	660
Capacity factor[a]	rate	0.9	0.9	0.85[c]
Fuel cost[b]	$/GJ	1	1	3
Plant cost	US$/kW	1100[a]	750[b]	1500[b]
Fix operating cost[b]	% of plant cost	2	2	1.5
Variable operating cost[b]	$/MWh	2	3	4
Construction time[b]	years	4	4	2
Fuel efficiency HHV[a]	rate	0.36	0.43	0.48
Auxiliary power[a]	rate	0.05	0.05	0.05
Plant life[a]	rate	30	30	25
Calculated values[d]				
Fuel cost	$/MWh	10.5	8.8	23.7
Operating cost	$/MWh	4.9	7.0	5.6
Capital cost[e]	$/MWh	25.8	35.2	16.8
Total cost	$/MWh	41.3	51.0	46.1

a Project team estimate or various sources
b CRC for Black Coal Utilisation (1999).
c The lower capacity factor for NGCC is partially offset by assuming its average price received for output is $0.50 per MWh higher on the assumption is offline during some of the lower priced periods of the day or year.
d The exposure of Australian investors to the $A/$US exchange rate is assumed to be around 80%. This factor has been applied together with an assumed exchange rate of $A0.55 per US$.
e Including interest during construction.

2.2.2 The option to defer the investment

The option to defer means that the investment in each of the electricity plant may be deferred indefinitely without relinquishing the right to invest in the project. The investor is free to choose the optimal time to start the project give what is known about the uncertainties (see Figure 2). Does such a flexibility ever really exist? Given the Australian electricity market is more or less deregulated, no one company is obliged to build new electricity generation capacity. Thus each company can either invest in new plant now or wait. So certainly the option to wait is real. Also, even though other companies may enter the market in the mean time, one still retains the option to invest potential revenue may have fallen or risen in the meantime.

Figure 2: Diagrammatic representation of the option to defer



To demonstrate this flexibility we assume electricity price uncertainties and uncertainty as to whether a carbon tax will be imposed or not in years to come. These are the most important uncertainties and so we will also use them frequently in other examples below. As this is the first time we have considered these uncertainties interested readers should refer to Appendix C for a discussion of what form these uncertainties are assumed to take.

In the first set of results shown in Table 3 we first show the results of the simulation when it is assumed there is no probability of a carbon tax being imposed during the life of the assets. The results show that under that and the base case assumptions the generation asset that would return the highest expected NPV is a CPF primarily due to its low costs. However, even in that case the NPV is slightly negative because current and expected electricity prices do not reflect the current cost of purchasing capital in US dollars. The NPVs of the NGCC and IGCC power stations are much more negative reflecting their higher costs. The rule for NPVs is that an investor should proceed with the investment if the value is positive. Thus the NPV recommends that the investor should not proceed with any of the investment options. The IRR shows the discount rate that would have been required to lift their NPVs to at least zero. The actual discount rate used in this study is 8 percent.

Table 3: Value of power station investment assuming no possibility of a carbon tax

		CPF	IGCC	NGCC
NPV	$m	-13	-556	-256
IRR	%	7.9	4.7	4.0
Action		Do not invest	Do not invest	Do not invest
ROV	$m	138	28	58
Strategic value (of option to defer)	$m	151	583	315
Action		Wait	Wait	Wait

The ROV of the three power station investments are all positive. Given the 5 year opportunity to wait for better conditions (higher exchange rates, or alternatively an increase in the electricity price) the ROVs are all higher than their respective NPVs. Thus an additional 151, 583 and 315 million dollars, respectively, worth of strategic value has been identified for the CPF, IGCC and NGCC power stations. The more marginal the project the more beneficial it is for the investor to be able to wait.

The investment rules for ROVs varies depending on the type of investment option being evaluated. In this case the invest rule is that one should only proceed immediately with the investment if the additional strategic value from waiting is less than the value which can be gained from investing now (i.e. the current NPV). Put another way, invest when there is no strategic value in waiting. In the example above, in all cases the ROV recommendation is to wait. Using this investment rule, the ROV can be used to forecast the optimal timing of an investment. For example, by trying different starting prices, one can quickly determine that one should not proceed with the CPF investment until the electricity price reaches $48 per MWh. For the other projects, the price is higher still. Of course, in practice, to avoid competitors gaining first mover advantage and because there is a long construction lag, an investor may move before the price reaches $48 per MWh.

Both the IGCC and NGCC technologies have been designed for a world in which environmental pollution is less desirable. If we now take this into account by including the possibility of a carbon tax we would expect that a CPF plant will not be so attractive. It is now assumed that a carbon tax of $30 per tonne of CO_2 equivalent is expected to arrive 8 years from the present. This would roughly coincide with the middle of the Kyoto Protocol commitment period (2010) as well as two years prior to the so called ‘review period’ (2012) of the United States greenhouse policy in which the possibility of introducing a trading scheme there has been flagged. The results for the three investments under these assumptions are presented in Table 4.

Table 4: Value of power station investment assuming carbon tax is expected to arrive in 8 years (but actual arrival date remains uncertain)

		CPF	IGCC	NGCC
Net present value	$m	-248	-557	120
Internal rate of return	%	5.9	4.5	9.5
Action		Do not invest	Do not invest	Invest now
Real option value	$m	76	28	180
Strategic value (of option to defer)	$m	324	604	60
Action		Wait	Wait	Wait

Compared to our example where there was no possibility of a carbon tax, the NPV of the CPF project is $231 million lower whilst the NPVs of the NGCC project has improved by around $375. This reflects its lower emission intensiveness and the fact that we have assumed that the in creases in electricity prices is higher than the emissions cost of an NGCC. The possibility of a carbon tax has a neutral or slightly negative impact on the IGCC project. Although IGCC is more efficient than CPF, it was not efficient enough to improve its position under the assumptions here. Specifically the IGCC project's carbon permit fees were calculated at $26 per MWh whilst electricity prices only rose $25 per MWh. Thus, for those years when the carbon tax is not in place, IGCC projects would be losing money. NGCC plants, on the other hand, stand to gain considerably. Of course, if lower carbon abatement options are available, all plants would receive a lower electricity price but this would not effect the merit order. The new merit order is NGCC, CPF and then IGCC.

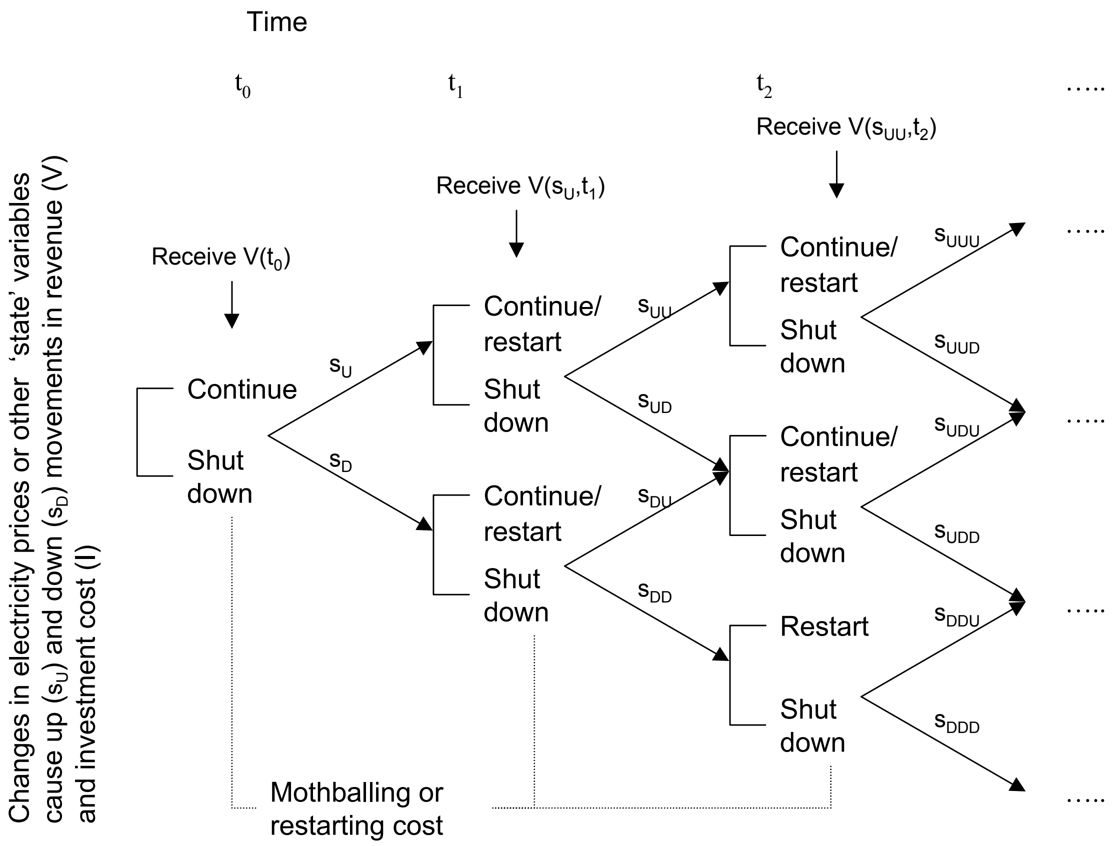
The actions resulting from the ROV investment rules are the same as the previous example in that there is no strategic value in waiting to invest. However, in the case of the NGCC project, the NPV investment rule indicates that the investor should invest now sine the NPV is positive and waiting is not an available option.

For this example, we conducted sensitivity analysis on several variables which help to provide a better understanding of what influenced the ROV results. The sensitivity results are presented in Appendix A.

2.2.3 Shut down option

The flexibility to shut down means that, once the particular plant is in operation, the owner has the option to temporarily shut down the plant during periods when it cannot recover enough revenue to meet its operating costs (see Figure 3). Although not a decision which would be taken lightly, there are some instances where it is optimal to intentionally shut down a plant. For example, a plant may be shutdown to optimize the value of other generating units owned by the company (i.e. by reducing competition in an oversupplied bidding market). They might also be shut down permanently because new competition or legislation makes them unviable. This is particularly relevant when one considers the potential impact of a carbon tax on some generators. Another driver could be a change in the price of fuel.

Figure 3: Diagrammatic representation of the option to shut down



For this example we assume that the carbon tax and the electricity prices are the trigger for any temporary or permanent shutdowns. It is assumed that there is no waiting period and the plant must be invested in now or never. In this sense the ROV will be much the same as an NPV except the NPV does not take into account the ability to shutdown during adverse price conditions. The results are presented in Table 5.

Table 5: NPV and ROV of power station investment with option to shut down

		CPF	IGCC	NGCC
NPV	\$m	-248	-577	120
Internal rate of return	%	5.9	4.5	9.5
Action		Do not invest	Do not invest	Invest now
ROV	\$m	-238	-575	127
Strategic value (of option to shut down)	\$m	10	2	7
Action		Do not invest	Do not invest	Invest now

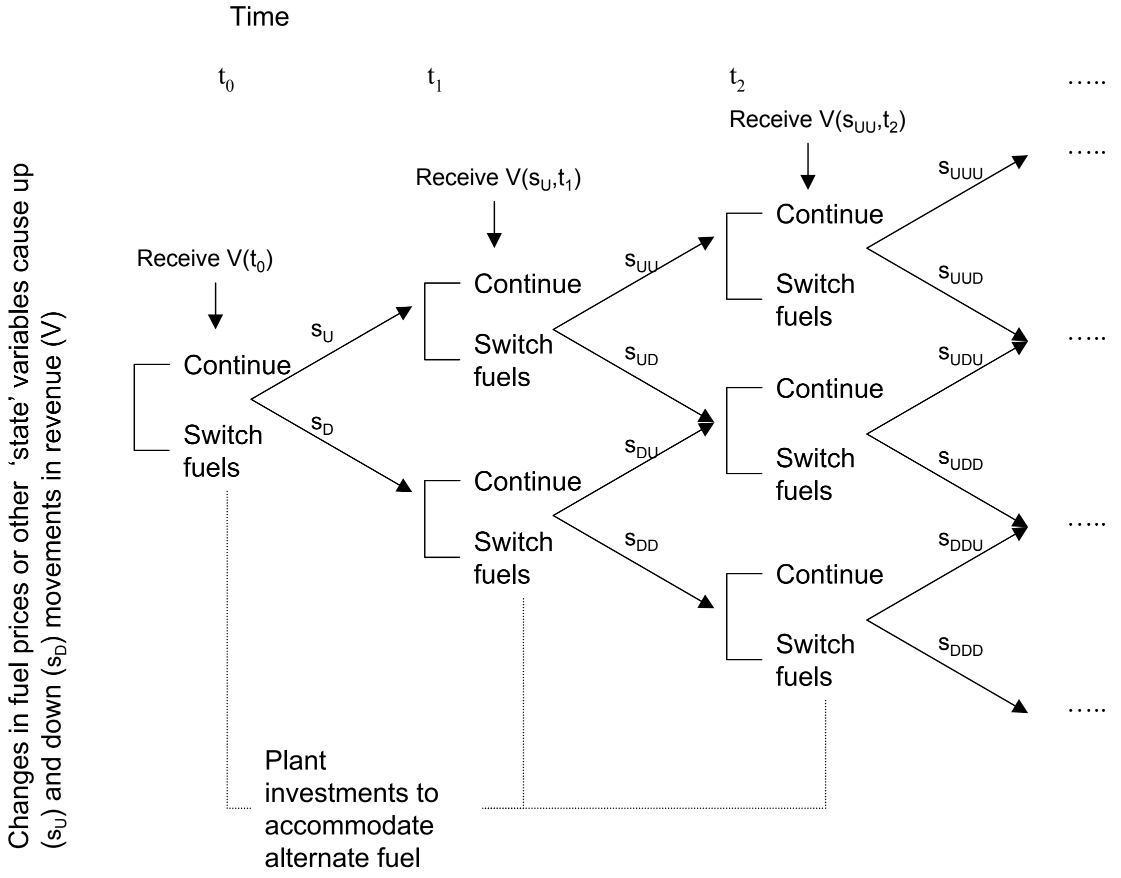
The real options analysis finds additional value in the investments of \$10, \$2 and \$7 million for CPF, IGCC and NGCC respectively. The ability to shut down is of most value to the CPF power station because it may be more profitable for it to shut down than proceed when and if a carbon tax is introduced (ignoring all other options such as CO_2 capture). If there is no possibility of a carbon tax the strategic values become \$1, \$2 and \$39 million (in the same respective order). In that case NGCC has the highest strategic value because, without the assistance of a carbon tax, its operating cost is untenable at prevailing electricity prices and therefore is the most at risk of needing to exercise the shutdown option.

We do not take into account the costs associated with shutting down and so the strategic values would in fact be less than that shown here. Providing the net value from the shutdown option is still positive when costs are taken into account, the option would appear to be most valuable for NGCC if there is a low probability of a carbon tax being imposed, and most valuable for CPF is there is a high probability of such an event. Sensitivity results are presented in Appendix A.

2.2.4 Input switching option: fuel

The fuel switching option or flexibility is relevant to power station operations in a number of ways. CPF projects could switch to a mixture of coal and biomass in the event of a carbon tax. They could also switch between high and low sulfur coals if financial penalties for sulfur emissions were high enough.

Figure 4: Diagrammatic representation of the fuel switching option



IGCC plants could stage their construction to run on gas initially while the balance of plant is being built or until gas becomes too expensive relative to gasifying coal. Once the IGCC plant is fully constructed there would be little economic incentive to switch back to gas since the high cost of IGCC plant together with the relatively high costs per energy of gas fuel would make the plant's output cost too high. Taking this into account the best way to look at fuel switching options for an IGCC or NGCC project is to start with a NGCC plant and assume it has the option to switch to coal by later converting it into an IGCC plant. This makes good sense when one considers that gas prices are more likely to rise in the future compared to coal due to their relative scarcity. Of course, gas is sourced on a long term contract basis and so it will only have to opportunity to switch at one or two opportunities during its plant lifetime when gas contracts expire. As with a coal to biomass fuel switch there would be some compromises in the plant design and location to achieve this potential flexibility. The plant will need to be located near gas and coal supplies. As such the additional strategic value created by this flexibility should be weighted against its additional cost to the project.

For a new CPF plant, it will only have the biomass fuel switching optioning if it locates near a sufficient biomass resource. Locating near that resource could incur a land premium cost, greater environmental approvals costs, greater transmission a costs and a variety of other problems. There is also the issue of modifying the fuel delivery systems. Rather than try to predict what all these costs may add up to, the following models determine the strategic value of having the fuel switching option. This information can then be used by future researchers to determine whether that value is great enough to justify incurring the costs required to obtain that option.

First we assume that with minimal plant modification the CPF can switch to a 5/95 per cent biomass/coal fuel mixture when a carbon tax arrives. As an alternative example we also run a scenario where a 20/80 percent biomass/coal mix is possible. This would require serious modification of the plant. Again, we assume the electricity price and the time of arrival of the carbon tax are uncertain. The results are shown in Table 6.

Table 6: NPV and ROV of CPF power station investment with option to switch to biomass co-firing and NGCC power station with option to switch to an IGCC plant

		CPF 5/95% fuel mix	CPF 20/80% fuel mix	NGCC to IGCC
NPV	$m	-248	-248	-174
Internal rate of return	%	5.9	5.9	5.5
Action		Do not invest	Do not invest	Do not invest
ROV	$m	-226	-160	22
Strategic value (of option to switch fuels)	$m	22	88	197
Action		Do not invest	Do not invest	Invest now

The results show that the option to co-fire coal with biomass in the event of a carbon tax adds $22 and $88 million to the strategic value of the projects with 5 and 20 per cent biomass co-firing respectively. This is not enough additional value to make the ROV positive. However, it indicates how much should be spent on gaining the option to co-fire biomass if it were a profitable proposition. Modifications to the proposed plant design and location to accommodate 5/95 percent biomass/coal fuel mixture should only proceed as long as they cost less than $22 million. Similarly, investors should be prepared to spend up to $88 million to make the 20/80 option available to the new plant.

The cost of the biomass fuel and the size of the carbon tax are obviously important factors in determining the value of this fuel switching option. If the cost of biomass is too high or the carbon tax too low then switching to co-firing may be more costly than staying with a pure coal fuel mixture after adjusting for carbon tax payments. If this occurs then the option to switch fuels will never be taken up and the ROV would equal to the NPV. Alternative assumptions about biomass fuel prices are included in the sensitivity analysis in Appendix A.

In the example of switching from gas fueled NGCC to coal fueled IGCC, the uncertainty in the gas price is a strong driver of whether the fuel switching option will be taken up. We have seen above that generally NGCC plants provide a better rate of return than IGCC plants. However, if gas price rises are expected during the life of the plant then this is not necessarily be correct or, if one does invest in NGCC an option to switch to coal may need to be considered. Uncertainty whether gas resources will be adequate beyond the next 20 years suggests gas prices could rise. On the other hand fixed price gas supply contracts do provide short term security.

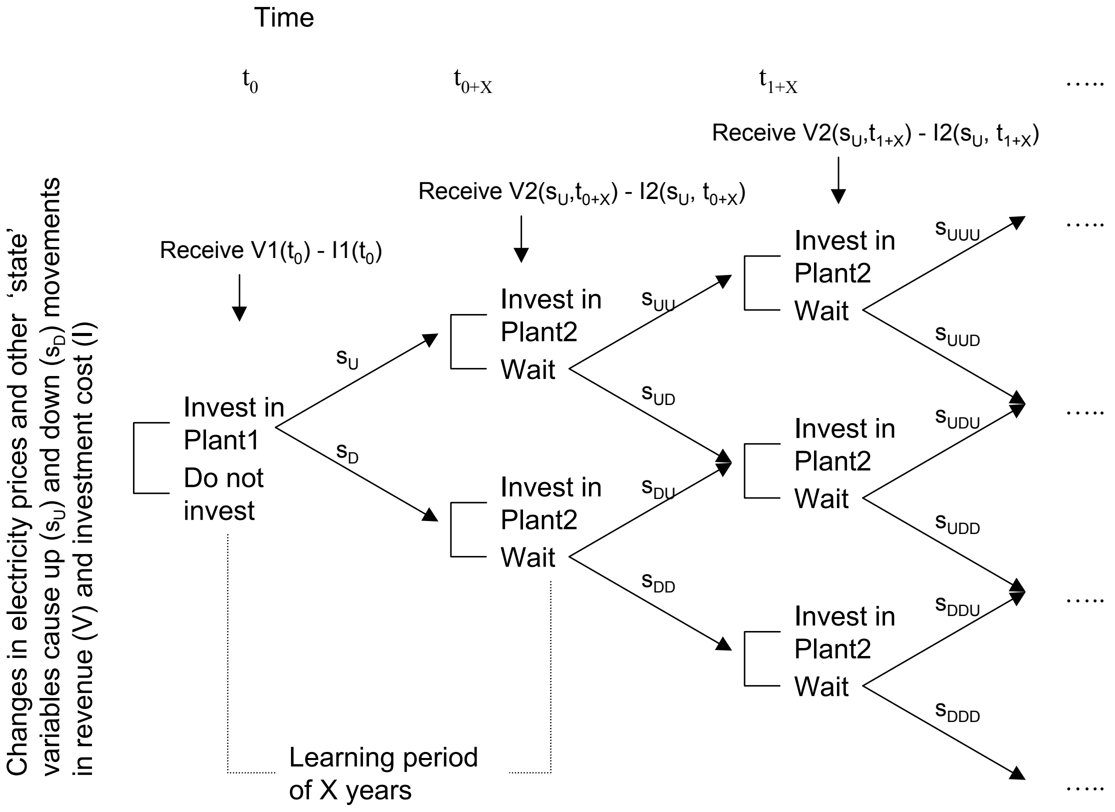
Given this background we assumed that a NGCC project exists that can obtain a contract for a fixed price of gas of $3/GJ covering the first 10 years of operation. After that it is able to fix the price in two further 10 years periods but at prices which reflect increasing gas resource scarcity. Initial assumptions include a trend annual rate of change of 2% plus a standard deviation of 25% per decade. Thus gas prices could range from a minor to a very large increase beginning early next decade. The electricity price is assumed to be constant and certain. The arrival of a carbon tax remains uncertain.

Now that we have taken gas price uncertainty into account by adding an upward trend and some additional volatility, the NPV of the NGCC plant is negative. However, when the option to switch to coal is included Table 6 shows that this option delivers an additional $197m to the project. This strategic value makes the returns from the investment a positive $22 million. Thus the investor should be willing to spend up to this amount to make the fuel switching option available (for example by locating near both coal and gas resources). Appendix A presents some sensitivity analysis

2.2.5 Platform option

In the real options literature a platform option is where an investor considers investing in a project because owning that asset or project gives the investor the option to take part in further investments which it otherwise would not have had the opportunity to. Although not necessarily unprofitable on its own, the main reason for the first investment is because it provides the investor with indirect benefits such as market knowledge, technical understanding, practical experience or brand recognition. These strategically valuable benefits of the first investment are then used to make further profitable investments (see Figure 5).

Figure 5: Diagrammatic representation of the platform option



Below we take the example of a power station investment but this time assume that the initial investment in the power station is a platform option because it provides the investor with the option to invest in a second power station using the same technology. The investor gains experience from the first power station investment and as a result the second power station investment is lower cost. This scenario is probably only relevant for IGCC which is the newest of the three technologies considered in this report. Most investors would expect that both capital and operating costs of IGCC power stations could be reduced in the future through better understanding of an operating power station. Only some of that understanding, however, will be shared between companies. Those that invest first should be able to capture some additional advantage.

The ordinary NPV of an IGCC power station investment as well as the ROV which includes the strategic value of the platform option are presented in Table 7. The assumptions were that the second plant is commissioned ten years later. Operating cost reductions of 30% are achieved in the second power plant due to learning and experience gained with the first power plant. Capital costs are assumed to be 20% less for the second power plant. Capital cost reduction are not due to investment in the first plant but rather an expectation that plant manufacturers will be successful in pursuing cost reductions. Electricity prices and the imposition of the carbon tax were assumed to be uncertain.

Table 7: NPV and ROV of IGCC power station investment with option to build second

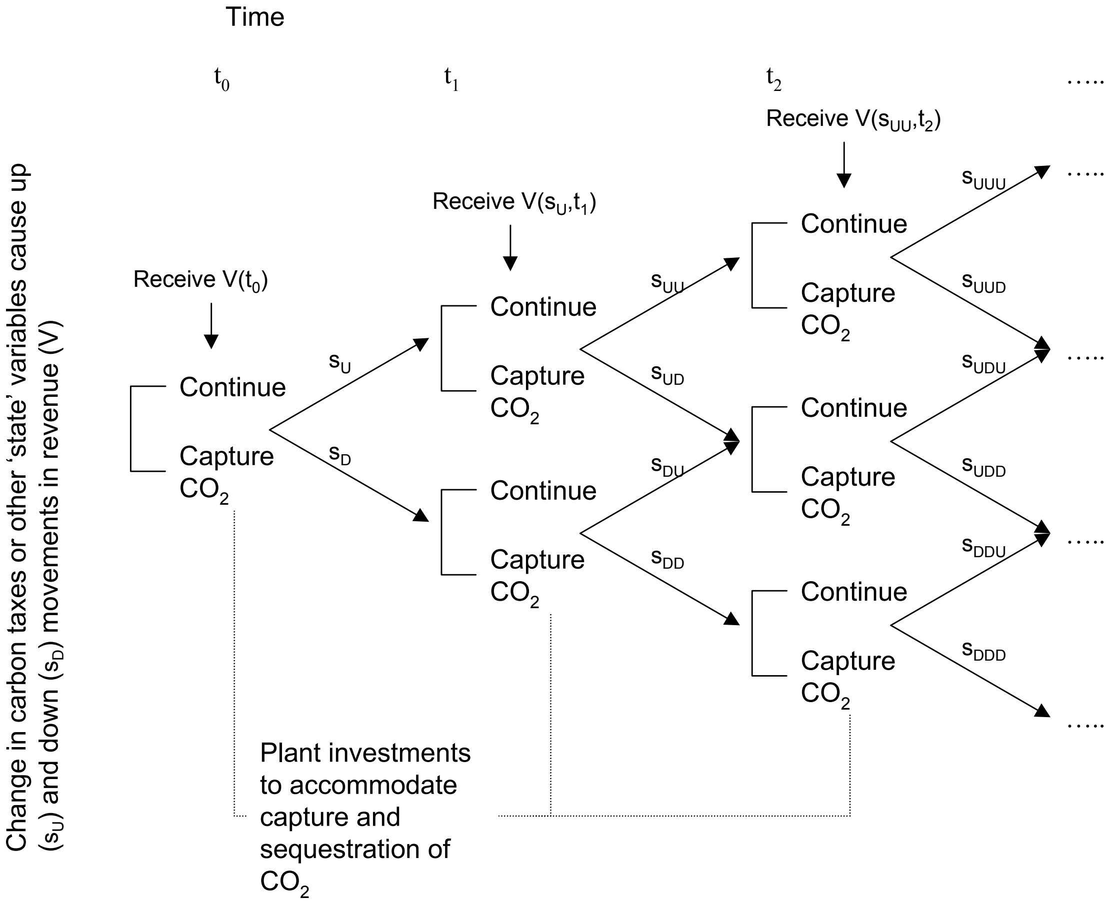
		IGCC
NPV	$m	-577
Internal rate of return	%	4.5
Action		Do not invest
ROV	$m	-515
Strategic value (of option to invest in second plant)	$m	61
Action		Do not invest

The results in Table 7 show that relative to a one-off investment analysis as is usually presented in NPV analysis, the addition of the strategic value of further investments increases the overall value of the power station investment. In this case, the increase in value is not enough to cover the large losses from the first investment and so it may be better to wait until the cost of the technology falls further. The strategic value of the platform option is $61 million. This is based on the ability to capture $61 million in positive net returns from the second investment which would not otherwise have been available. Sensitivity analysis of these results are presented in Appendix A.

2.2.6 The option to install CO_2 capture and sequestration

Given the immaturity of CO_2 capture and sequestration technology it is best to look at the utilization of such technology as an option which can be exercised at an appropriate point in the future rather than as a central feature of a viable power station design for consideration in today's market. If there is no carbon tax to levelise the cost of power on the basis of CO_2 equivalent emission intensity then CO_2 capture and sequestration technology will never be financially viable. There is no large scale demand for waste CO_2 nor sufficient gas and oil fields near power generation in New South Wales and Queensland to for enhanced recovery. Therefore, for any power station to include CO_2 capture and sequestration technology it would only be considered as an alternative to paying a carbon tax or shutting down the existing generator.

Figure 6: Diagrammatic representation of the CO_2 capture option



Given this background real options analysis can be used to determine if such an operating option (that is, to switch to CO_2 capture and sequestration technology in the event of a carbon tax) increases the value of a power station project. Although technically possible it was assumed that the option to install CO_2 capture and sequestration technology would only be applicable to the coal fueled projects since gas fueled power stations already have an emission advantage over coal and the cost of capture is much greater due to the low concentration of CO_2 in the waste gas stream. The NGCC project is included in the table of results for comparative purposes only.

Table 8: NPV and ROV of when CPF and IGCC power stations have the option to install CO_2 capture and sequestration

		CPF	IGCC	NGCC
NPV	$m	-291	-619	489
Internal rate of return	%	5.5	4.2	9.1
Action		Do not invest	Do not invest	Invest now
ROV	$m	-291	-619	-
Strategic value	$m	0	0	-
(of option to install CO_2 capture and sequestration)				
Action		Do not invest	Do not invest	-

Table 8 shows that the ROV is exactly the same as the NPV. This is because, under current assumptions the option to install CO_2 capture and sequestration technology is too expensive and therefore never exercised. This demonstrates an important lesson about real options analysis. If a flexibility is too expensive then calculating the ROV offers no real advantage over the NPV.

On the other hand, if CO_2 capture and sequestration technology were less costly or the carbon tax (and associated flow-on electricity price increase) higher once introduced then we would expect the ROV to increase to a level higher than the NPV as the CO_2 capture and sequestration delivers additional value. The sensitivity results in Appendix A consider some of these scenarios.

2.3 Critical analysis of real options

2.3.1 Lessons from the case studies

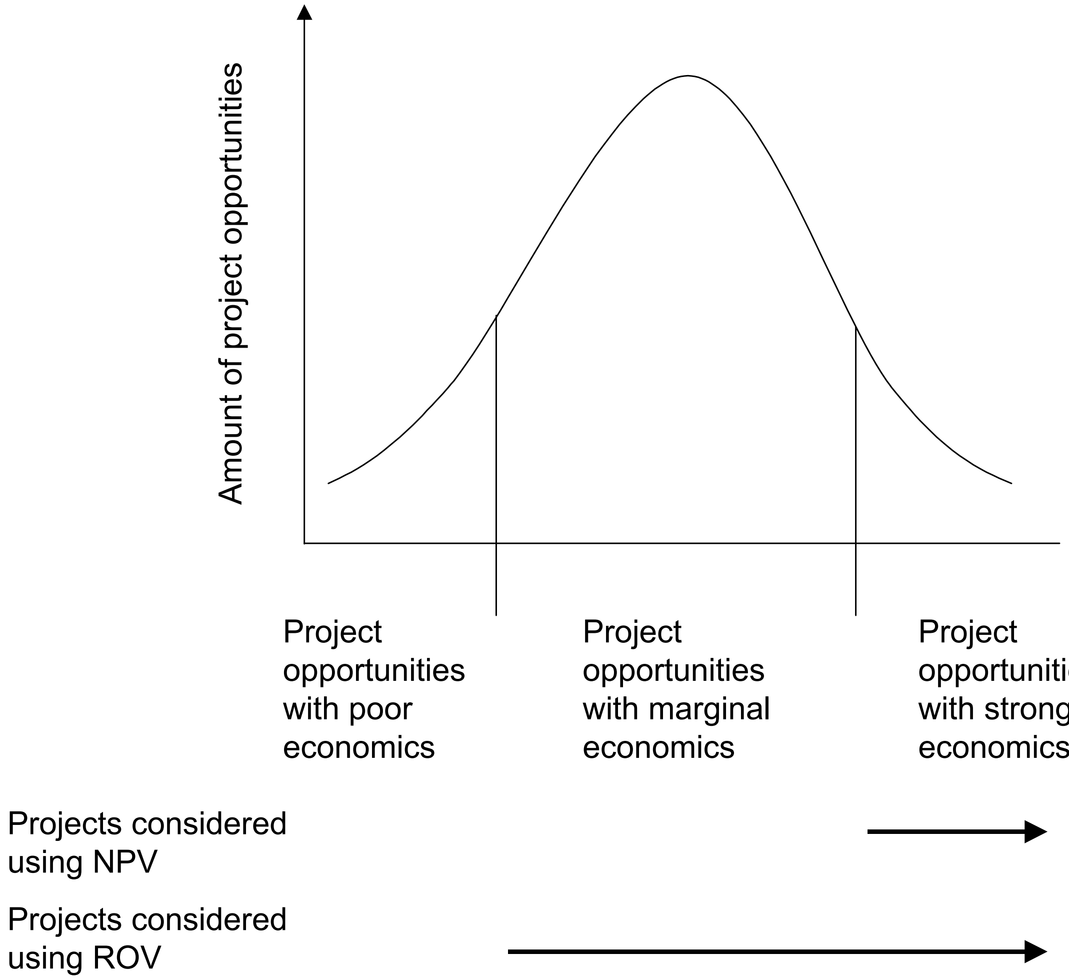
The case studies above have demonstrated how real options analysis can be used to value power station investments which include some flexibility to deal with market and regulatory uncertainties. Without this flexibility the real options value, ROV, is exactly the same as an NPV. This is obviously not a criticisms of real options analysis since, particularly in the current climate, investors should primarily be interested in projects with some flexibility. However, it can be disappointing initially to learn that the only consequence of using NPV instead of real options analysis is the under-valuation of potential projects.

There are some other limitations of real options. Firstly, one needs to know what flexibilities are available in order to value them. Those presented here were only a very small sub-set of the options available to power station investors. Other research programs within the CCSD should be able to broaden this set substantially.

A second limitation is that some flexibilities are very investor specific. For example, in order to take advantage of the option to biomass co-fire the investor needs to have access to biomass resources. Presumably there are many other factors which could be investor specific which are related to the location of the plant such as access to other fuels such as solar radiation, wind, coal and gas, access to the grid and local pollution limits. These issues can still be dealt with by real options analysis, however, the CCSD or its clients would need to gather information on specific locations and the results would be specific to that location.

A third limitation of real options is that it often does not lead to an investment decision which is any different to that which one arrives at using NPV analysis. If an investment project has strong positive return or very much ‘in the money’ based on NPV analysis, undertaking real option analysis usually only reveals that the investment is still ‘in the money’ or even more ‘in the money’ than originally thought. This was the case for the NGCC investment in the shutdown option example. Thus the decision does not change – invest either way. Alternatively, if an NPV analysis reveals that an investment project has strong negative returns or is very much ‘out of the money’ then it is unlikely that a real options analysis will find enough additional strategic value to bring an investment project back into positive returns. This was the case for the project in the IGCC in platform option example.

Figure 7: Comparison of project opportunities identified with NPV and ROV



Real options analysis only changes the investment decision if a project that first appeared marginal when examined using NPV analysis has some identified flexibility to which real option can attribute value. This was the case with the NGCC project in the fuel switching example. Such marginal projects abound and so arguably real options analysis allows one to consider a much broader range of projects as demonstrated in Figure 7.

A final limitation is that flexibilities identified may have no strategic value. For example, in the CO_2 capture example it was found that the flexibility was too costly to implement and so added no strategic value. More generally, there is no strategic value from a flexibility if:

- the flexibility does not increase the value of the project at the time it is exercised.
- the flexibility costs more to procure than it could ever add to the project's net value.
- the flexibility costs more to preserve than it could ever add to the project's net value.

Although not a limitation of real options an issue which is common to both real options and NPV analysis is that the decision to invest or exercise various flexibilities could itself alter the benefits gained due to the effects of market forces. In all the cases above we assumed that when the investor or owner of the plant exercised an option or flexibility, its actions did not have any effect on the market itself. To some extent this assumption is true, The National Electricity Market in the Eastern States is a competitive market with many individual suppliers. On the other hand various studies have examined the possibility that some power station owners are large enough to have the ability to affect market prices by exercising their option to withhold or increase output either intentionally for market gain or unintentionally due to technical problems (see, Swan and Klijn (1999), for example).

Ignoring market power issues there are also basic market dynamics which could break our assumption of no impact on the market. If one supplier takes action that results in lower operating costs then they could bid the same price into the market and capture more profits. Alternatively they might bid the price down to capture more volume. As a result the price that all market generators receive is lower because one generator exercised an option. The point is that net present value and real options analysis are both limited by the perspective to which they are applied and should ideally be augmented with some consideration of wider market implications and effects.

Another limitation that is equally true for NPV analysis is that regardless of how positive results may seem for one project design one should always take care to consider whether there is another investment project design, perhaps incorporating a different strategic approach, that could create even more value.

3.0 Utilisation of real options techniques in the CCSD

The previous chapter set out a series of real options case studies of power station investment in order to provide practical examples of how the technique is applied and determine what value it has over traditional NPV and cashflow analysis. While the case study examples were varied they did not extend much beyond the perspective of an individual power station investor. We could just as easily have carried a number of case studies which examined various real options valuations of coal mining investment decisions. But again, this is only looking at investment valuation from an individual company perspective. This perspective is valuable to the CCSD because its members are active in large energy infrastructure investment and therefore use quantitative investment analysis techniques regularly. Indeed some may already use real options approaches. However, it is the intention here to also demonstrate that real options can be applied to much broader perspectives that are also relevant to the CCSD's members.

We now take this opportunity to discuss and demonstrate how appropriate the real options approach would be in determining the relative value of a variety of other investments. Rather than just individual company investments, these are from the perspectives of the CCSD and Australian society as a whole. They include:

- finding the value of research to the CCSD which has the potential to make a less costly or more environmentally sustainable coal-based technology or process available,
- finding the value for Australian society of investing in technological research which provides the option to follow a more sustainable coal-based technological path,
- finding the value for Australian society of having the option to participate in carbon trading schemes such as the Clean Development Mechanism.

For reasons which will become apparent we do not try to actually value these in this report. The aim of the discussions below and accompanying examples is to provide a 'how to' guide for the CCSD on applying real options analysis from these broader perspectives.

3.1 Finding the value of CCSD research to the CCSD

It will be apparent to those who have read previous chapters that real options analysis is mostly about finding strategic value in a project. Research, as apposed to investment in power stations, has no immediate value and is only carried out because of the strategic value it creates when the research outputs are applied in the commercial arm of the research client. Given the high strategic value content, real options analysis is ideally suited to valuing research. In fact the precursors to real options such as decision tree analysis and Monte Carlo simulation techniques were mostly developed and used by research organizations who needed a methodology to help them determine what type, when and how to invest in research. Among the most obvious examples are the pharmaceuticals industry where there are very long lead times and great uncertainty in the process of in commercializing research.

In order for the CCSD to achieve its objectives its research program must be aligned with financially viable business models which deliver value to Asia-Pacific clients and to the CCSD members themselves. To do this one needs to take into account the end-use markets of the research and its uncertainties as well as the uncertainties of the research process itself. We have seen in the examples above how to model one of the end-uses of research – power station investment and operation. The uncertainties in power station operation were either due to technical issues relating to cost or external market and regulation issues. The uncertainties in research are mainly of a technical nature. Either one is unsure of what outcome will be achieved or, alternatively, one is fairly certain an outcome is attainable but the precise cost of achieving that outcome is unknown.

Let us assume that the aim of a hypothetical research program is to improve the efficiency of IGCC power stations by 2% via altering various processes. We will assume that the CCSD expects this can be achieved for around \$3 million but the final cost remains uncertain. Due to the constraints of building up expertise in researchers and competing budgetary constraints, it is assumed the maximum the CCSD can invest in this program each year is \$1 million. Given it is uncertain that it will really cost \$3 million and it can only invest \$1 million a year, it is therefore also uncertain about how long the research will take. However, when the research is completed it is assumed that it does achieve its goal.

The simplest method for determining the value of achieving this goal would be to follow our examples above and determine what additional value it would bring to an investor in an IGCC plant. We now proceed to doing this but will also discuss below whether this was the most appropriate method.

The cost of the research is assumed to follow the following stochastic process

$$C_{t+1} = C_t - I_t + \beta(I \,.\, C_t)^{1/2} \,.\, \varepsilon_t$$

This formulation is similar to examples in Dixit and Pindyck (1994). It means that the total amount of research costs to be paid out next year, C, equals the total amount that was remaining this year minus the constant rate of investment, I, (\$1 million) plus a random component, ε_t, that may increases or decrease as a function of the constant rate of investment and the remaining amount to be invested. This particular functional form was chosen because it has some good logical properties. For example, it implies that the cost of the project does not change unless some research is undertaken. When research does take place the expected rate of change in total research costs is -\$1 million. However the actual realized change can be greater or smaller. The greater the constant rate of investment the greater the variance of the change in costs. In other words, the greater annual budget allocated to a project the greater the possibility of either a cost 'blow-out' or an early success. Also, the smaller the remaining cost the smaller the variance of the rate of change in costs. Thus as one approaches the end of the research project one has less uncertainty with regard to the size of the remaining costs. The multiplier term, β, can also be set to reflect project specific volatility. A β of zero would mean there is no uncertainty for the project's cost. Given this problem is hypothetical it is set arbitrarily at 0.5. To complete the equation one must start with an initial guess about the expected costs of the research - $3 million.

In the event of a successful research outcome, it is assumed that if an IGCC plant investor chooses to take up the option of having a higher efficiency plant they must make an additional $50m in IGCC plant design alterations. Therefore the net benefit of the research to the IGCC project investor will be the additional cost savings from applying the new process minus the cost of implementing it. Based on the standard assumptions in the case studies above the value of the increased efficiency comes to $22 million.

Given that the research will take some unknown time to complete, the benefit of the $22 million will not be received for some time and must therefore be discounted. The discounting needs to be calculated as part of the modelling process since the time of receiving the benefit of the research is unknown. Using real options modelling and the research cost function above, Table 9 shows the calculated net value of the research to the power station for several data assumptions for β (the budget volatility) and for two assumptions about the expected cost of the research.

Table 9: Value to the power station of research to improve IGCC plant efficiency

Expected research budget	$3m			$6m		
	β %	**Value $m**	**Research decision**	**β %**	**Value $m**	**Research decision**
	0.5	$13.2m	Proceed	0.5	$5.9m	Proceed
	0.75	$12.8m	Proceed	0.75	$6.6m	Proceed
	1	$12.9m	Proceed	1	$7.9m	Proceed

The results show that for a research cost of either $3 or $6 million the research should proceed because it provides a positive net value. At a minimum the value, net of costs, is around $6m. The higher the volatility (β) of project costs the greater is the likelihood that cost will be much higher or lower than expected. If cost are much higher then the model assumes that the research managers abandon the project. If the costs are much lower than expected the project is pursued. Given that the research manager has this flexibility, returns to research can actually be higher the more volatile are project costs. This is more true if the annual budget is just a sixth of the total expected costs but less so if it is a third of the total expected costs. The greater the annual budget relative to the total expected budget, the greater the loss if costs 'blow out'.

A desirable modification to the approach could be to alter the view of the research process. Rather then conforming to a probability distribution where project cost volatility moves up or down with equal probability, costs could in some cases be one sided. For example, budgets may tend to over-run rather than under-run. One could also take into account the increase in cost of wages over time.

The two biggest problems with applying this methodology in practice are valuing the research benefits in a credible way and carrying out such an analysis cost effectively relative to the size of the total CCSD research budget. The next two paragraphs address these two points.

This example has shown how to value CCSD research by calculating its net worth to a power station. The real value of the benefits from research to the CCSD depends on how many members of the CCSD are in a position to utilize the research outputs or, alternatively, how well the CCSD can commercialize the intellectual property. For example, because the results of the research will be known by all members of the CCSD this reduces its competitive value. On the other hand, the more power station operators that take up the new process or technology the greater the total benefit. Another problem with valuing the benefits is that, unlike our simple example of increasing power station efficiency, many of the current CCSD project do not have such clearly defined and quantifiable outcomes. The methodology does not completely deal with these issues although it may be possible to do so with some modifications.

Assuming the problem with valuing benefits could be overcome, if a real options study of CCSD research projects were to go ahead it could potentially cost almost as much as a small research project itself. As such it would only be cost-effective to study a large research project or program.

3.2 Finding the value of CCSD research to Australian society

For valuing the benefits of CCSD research to Australian society we are fortunate to be able to draw on research carried out at EPRI in the United States that applied real options to determine the value of coal research there (see Dalton, Platt and Armor (2001)). The following section outlines how this real options valuation was carried out, what problems they encountered and whether carrying out such an exercise would be desirable for the CCSD.

3.2.1 EPRI's study: "Real options valuation of coal-fired generation – why coal makes economic sense to our society"

3.2.1.1 EPRI's framework for valuing US coal research

EPRI frame the real options coal research investment problem as being one where society in the US has a choice. On the one hand they can choose to invest in coal R&D and, upon completion, 25 per cent of existing coal-fueled power stations can be replaced by new coal-fueled power stations or refurbishments by 2030. Alternatively, they can do no research and replace the 25 per cent of existing coal-fueled electricity generation capacity with gas turbines and combined cycle power stations. The timeframe was the present to 2030. Regardless of the choice made between the two alternatives all additional demand growth in the 2007 to 2030 period is assumed to be met by gas-based electricity generation. <u>As such, the investment decision is only about what to replace 25 percent of existing coal-based capacity with</u>. Neither, coal capture and sequestration or renewables were considered as alternatives in this study.

Problems with this framework:

- The framework is not specifically set up with greenhouse gas emissions in mind. EPRI could not say whether either case had higher total GHG emissions although judging by the efficiencies assumed in the paper the coal R&D option has higher emissions. Is this a fair comparison of options? If there is no greenhouse impetus then why would society choose expensive gas?

- The framework is focussed on justifying coal R&D research funding. For this reason, whatever its technical merit, such work would probably be perceived as being biased.

3.2.1.2 EPRI's methodology and data

Real options analysis requires that something be known about the stochastic behavior of the uncertainties which affect the investment decision. The study assumes certainty with regard to research outcomes as well as the costs and performance characteristics of new electricity generation plant. The principle source of uncertainty identified and therefore upon which the analysis largely rests is electricity prices from 2007 to 2030. EPRI go to a great deal of effort to correctly determine the likely behavior of electricity prices. They recognise that uncertainty in the electricity price is a derived uncertainty. That is, the uncertainty in the electricity price is driven by uncertainty in underlying fundamentals such as the weather, transmission and distribution systems constraints and electricity demand growth.

Typically real options models rely on econometric estimation of the stochastic behavior of variables such as the electricity price by using historical data. However, in this case, the investment option itself effects the characteristics of the price by altering the cost of electricity supply which is one of the main determinants of price. If they were only looking at one firm making a small investment then it would not effect the total market price of electricity. However, replacing 25 percent of existing capacity will affect electricity prices.

Their solution to the problem of identifying the behavior of electricity prices associated with the two scenarios was to use an electricity market simulation model called UPLAN. UPLAN is no doubt similar to the range of electricity market simulation models available in Australia (e.g. PROPHET, PROSCREEN, GRIDSIM) which simulate the competitive electricity price pool and subsequent dispatch process. UPLAN calculates hourly electricity prices over the entire 2007 to 2030 period. By altering various assumptions in regard to electricity demand growth, regional interconnector limits, etc, they build up a probability distribution for the behavior of prices for the two alternatives scenarios.

There are few problems with this methodology if it were to be applied to the Australian context are. Models similar to UPLAN are available in Australia so there is no technical reason why this methodology could not be duplicated. One note of caution is that using such models is fairly labor intensive and one needs to be sure that the model does suit the needs of the study. There may be alternatives to the methodology chosen by EPRI. For example one could use a simpler model to determine annual price changes rather than simulate every hourly price for twenty or more years.

3.2.1.3 EPRI's conclusions

Coal R&D is a flexibility mechanism available to the public to avoid higher future electricity prices. EPRI found that, in the scenario characterized by the abandonment of coal R&D, prices are on average US$4-8/MWh higher compared to the scenario where society does invest in coal R&D. EPRI conclude that investment in coal R&D is easily justified for US society. The US coal industry should be prepared to fund up to $4-5 billion of coal R&D to achieve this flexibility. Electricity consumers who collectively benefit much more in total (measured in trillions of dollars) should be prepared to fund a great deal more.

This is a very strong conclusion. The EPRI presenters were asked by CCSD members how successful they were in getting this conclusion across. EPRI's response was that they experienced some difficulty presumably because the approach is still relatively new.

3.2.1.4 Further comments and conclusions concerning on EPRI's study

As discussed the same data could be collected for Australia (using Australian electricity market models) and a similar investment problem posed. Below are some further comments which mainly address whether this approach is appropriate for the Australian experience:

1. EPRI assumed all new electricity demand will be met by gas-based electricity generation. This is perhaps not appropriate for Australia (perhaps not for the US either). There needs to be some consideration of where the gas resources would be obtained and what is realistic in terms of sustainable use of gas in electricity generation.

2. Australia's coal R&D sector is not big enough to substantially reduce the cost of imported coal-based electricity generation technology. Therefore Australian coal R&D could not be expected to provide the same type of flexibility mechanism for society as US coal R&D.

3. The ability to more effectively utilize coal capture and sequestration technology should be considered as a possible outcome of investment in coal R&D. Use of and investment in renewable energy technologies should be considered as a competing investment option for society. Investing in both technological paths should also be an option, perhaps as a means of spreading risk.

4. Research outcomes are by no means certain. The costs and timing of research should be modelled as an uncertain process. See section 3.1 for an example of how to model research uncertainty.

5. The coal versus gas paradigm is too narrow. The scenarios should be based on different ways of achieving society's goals. For example, an obvious driver for scenarios is alternatives ways of reducing GHG emissions.

Despite these many concerns about the finer details of EPRI's research, its approach is generally sound. In order to find the value to society of investment in research one must simulate what the consequences for society would be if that research did or did not take place (or proved too expensive and was abandoned). If the consequences of not doing the research are at all significant then it can be concluded that society should invest in some level of research. This is a point easily understood. Most of the work effort, as EPRI found, is in defining those alternative scenarios.

3.3 Finding the value for Australian society of having the option to participate in international flexibility mechanisms

If the Australian government were to alter its current policy and ratify the Kyoto Protocol Australia would have the option to meet the target by either making the appropriate structural changes domestically or by utilizing certain international flexibility mechanisms that were provided for in the Protocol. The flexibility mechanisms include Joint Implementation, emissions trading and the Clean Development Mechanism.

The Clean Development Mechanism allows Annex B parties which comprise of most developed countries to obtain certified emission reduction credits through financing emission reduction projects in non-Annex B countries. Joint implementation is very similar except that it allows the transfer of emission reduction credits between Annex B countries only. Joint Implementation and Clean Development Mechanism emission reduction projects can include sinks such as afforestation. Emissions trading allows any credits an Annex B country gains either through domestic greenhouse reduction activities or through the Joint Implementation and Clean Development Mechanisms to be traded.

The common feature of all of these mechanisms is that they give a country the flexibility to make meet some of its emission reduction targets by effectively making emission reductions in a different location (country). If it is less costly to do so, then this flexibility or option will be taken up. Alternatively, if one finds that emission reduction are less costly domestically then a country could still take up the option but this time to sell some emission reduction credits thereby gaining additional revenue than it otherwise would have.

Real options is an ideal technique for valuing these flexibility mechanisms because, as we have seen above, real options is essentially about valuing investments which have flexibilities. Although the point of decision making on this policy has already past, if appropriate one could certainly apply real options to determine what the value of the flexibility mechanisms would be to Australia. As with valuing coal R&D one simply needs to construct plausible scenarios of what Australia's economic position would be with and without the flexibility mechanisms taking care to take into account the most relevant uncertainties effecting those scenarios. The value of the flexibility mechanisms would then be calculated as the sum of net benefits in the scenarios with flexibility mechanisms minus the net benefits in the scenario without.

Such information could be gathered from original research probably using a global trade model. Alternatively ABARE or other research institutions might already have such scenarios available for little cost.

3.4 Concluding comments on utilization of real options analysis in the CCSD

Chapter 2 of this report showed how to value various power station investments using a real options approach. Taking into account the flexibilities available to each prospective project as well as the relevant uncertainties, real options analysis determines whether these flexibilities add any strategic value to the project's cost and revenue streams. Power station investments are often preceded by research which more fully defines the options available. The aim of research is to create options which allow the owner to financially optimize the design and operation of a prospective plant. In this light, Section 3.1 demonstrated how to value research whose goal is ultimately to provide an improved financial outcome for new and existing assets of CCSD members. Uncertainty regarding how much the research would cost or when it would be completed was taken into account.

Sections 3.2 and 3.3 discussed how real options has and can be used to value alternative societal choices or policies. The policies discussed whether to invest in more coal research and use of the flexibility mechanisms in the Kyoto protocol. It was concluded that real options is suitable for both. However the costs and benefits of undertaking such studies should be carefully examined. Both require a substantial modelling effort to define the benefits or scenarios upon which the analysis is based.

Note, the policies presented were examples. The CCSD should consider examining a variety of other policies or societal choices consistent with its goals. For example, Lessons from the EPRI study discussed in Section 3.2 suggest a study which considers a portfolio of power generation options (not just gas versus coal) against greenhouse as well as costs and other constraints or concerns could be a much better approach to defining the role of coal in Australian society.

4.0 Conclusions and recommendations

In this section we discuss our conclusions about the scope for adopting real options analysis within the CCSD as a tool and driver for identifying and valuing investments which have the flexibility to deal with risk, for valuing its own research and for evaluating coal related policies or societal choices. We then discuss recommendations for further research including the options for how that work could be carried out.

4.1 Conclusions

Real options has its greatest value over traditional NPV analysis when applied to situations in which the investment climate is uncertain and investors have a smorgasbord of flexible investment and operating mechanisms available to deal with this market risk. Such an investment climate is especially relevant to power stations as the case studies in Section 2 demonstrated.

Uncertain outcomes and project flexibility is also a good description of the investment climate the CCSD faces in respect to its research. The timing, success, relevance and cost of CCSD research outcomes are characterized by a high degree of uncertainty and risk. On the other hand the ability for senior management and project leaders to periodically review the progress of research and its potential application in end-use markets provides significant flexibility to deal with this risk.

Energy policy and planning is also another area where society and government policy makers face significant uncertainty over the future but have wide variety of flexibilities, policies or mechanisms by which they can deal with such uncertainty. The example presented in this report was the Clean Development, emission trading and Joint Implementation flexibility mechanisms that were provided for under the Kyoto Protocol. Other flexibilities, many of which have already been taken up by the government, include mandating a proportion of electricity to come from a particular set of energy technologies or resources, voluntary agreements to achieve efficiency standards and conducting reviews of energy policy. All of these actions create value for the Australia people by improving their ability to cope with uncertain events in the future.

Overall there would appear to be a broad scope for applying real options in CCSD. However, the approach is not without some limitations. Some key limitations of real options analysis identified in this report are briefly summarized below:

- If the flexibility being considered is too costly to procure, preserve or exercise then real options analysis provides nothing more than confirmation that the flexibility has no value.
- Flexibilities must be identified in order to value them.
- Flexibilities may be very investor specific.

- If the investment or decision was already either strongly ‘in’ or ‘out of the money’ on an NPV basis, the investment decision arrived at by applying real option analysis is likely to be no different.

The existence of these limitations means that real options analysis is not always appropriate. Rather real options analysis should be considered as an extra tool alongside NPV analysis to be called upon if the investment valuation meets the right criteria. For the CCSD’s purposes, this should be reasonably frequently as examples in this report have demonstrated. A simple set of rules can be applied when determining which approach to follow. First, consider all the uncertainties that the potential project or policy question faces. Next, consider all the possible ways in which the response can be managed in a more flexible way to deal with those uncertainties. If there are no flexibilities available or they are likely to be too costly, carry out a normal NPV analysis. If there are potentially cost effective flexibilities, then a real options analysis is more appropriate.

4.2 Recommendations

The following recommendations were arrived at taking into account the limitations of real options and the objectives of program 4 and the CCSD in general.

As discussed in Section 3.1, real options analysis can be used to help guide and value CCSD research. However there were two major concerns raised. One is that, the benefits of some research projects or programs may be difficult to quantify accurately. The second is that the analysis would be costly. Therefore it follows that:

Recommendation 1: The CCSD should consider applying real options analysis to find the value of current and future research program outcomes, where:
- *the research outcomes and their value to CCSD members is clearest, and*
- *the project is large enough to justify the additional cost that would be required to conduct the real options analysis.*

This report discussed in broad terms how the CCSD could use real options analysis to evaluate society’s choices in relation to coal’s role in Australia’s uncertain future. Real options analysis was found to be an appropriate tool for such studies providing the policy question was framed appropriately for the Australian context and the future challenges facing the coal industry were considered against all available options. The recommendation which follows this observation is:

Recommendation 2: The CCSD should continue to apply real options analysis to the policy issues that the CCSD is most concerned about, such as coal’s role in the future energy mix in Australia. Doing so requires bringing together two major elements of research:
- *the first is an understanding of all the options that are available, including coal based technologies, mixes of coal and other alternatives, as well as their implications in terms of the environment and costs.*
- *the second element is an understanding of the future challenges and opportunities as well as their associated risks and uncertainties.*

This research would involve a combination of scenario development, economic modelling and process/technology data gathering activities.

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Appendix A

A.1 Sensitivity analysis

Figures 8-12 set out the results of the sensitivity analysis of the case studies presented in the main body of this document.

Figure 8 shows the results of sensitivity analysis of the first example which was presented, the option to defer the investment. The diagrams show how the real option value and the strategic value calculated vary with changes in selected key assumptions. The following conclusions can be drawn from these results:

- the more volatile the electricity price the more strategic value there is in being able to defer the investment and the higher the overall value of the projects.
- the more positive the trend or rate of growth in the electricity price then the less strategic value there is in being able to wait but the higher the overall value of the investment proposition.
- increasing the numbers of years until the expected imposition of a carbon tax leads to a decrease in the overall value of the NGCC project but the strategic value of being able to defer the project increases. The opposite is true for the CPF and IGCC projects.
- increasing the period over which the option to defer remains open generally increases both the strategic and overall value of all projects.
- if the current expectations of what the electricity price will be in the first year of the project is high then the overall value of the projects is higher but strategic value of the option of being able to defer the investment is lower.

Figure 9 shows the results for the example where the project had the option to shutdown. The following conclusions were drawn from the results:

- higher electricity price volatility increases both the strategic value of the ability to shut the plant down temporarily as well as the overall value of the project.
- the more positive the trend rate of growth in electricity prices then the greater the value of the project, however, the strategic value of the option to shutdown at some point in the future eventually declines to zero.
- as with other examples NGCC generally benefits from bringing the imposition of the carbon tax forward while CPF does not and the effects on the IGCC project is fairly neutral. The strategic value of the option to shutdown is not greatly effected.
- a higher exchange rate improves the expected value of all projects but has no effect at all on the strategic value since, in the model, it mainly effects up-front costs rather than operating costs. In reality, depending on the way debt repayments are structured, ongoing debt servicing could be effected by the exchange rate.

Figure 10 shows the results for the example where the projects have the option to switch fuels. The first two graphs show the implications of different assumptions with regard to the future behavior of gas prices in the example where an NGCC plant can switch to an IGCC plant. They show that:

- the more volatile the price of gas the greater the strategic value of being able to switch to an IGCC and the higher the overall value of the project.
- the more positive the rate of growth in gas fuel prices the greater the strategic value in being able to switch to an IGCC plant design but the lower the overall value of the project.
- the third graph shows that the further away is a carbon tax regime the lower the overall value of the project.

The last two graphs show the sensitivity of the two biomass co-firing projects to the expected number of years until the carbon tax is imposed and the biomass fuel price. They show that:

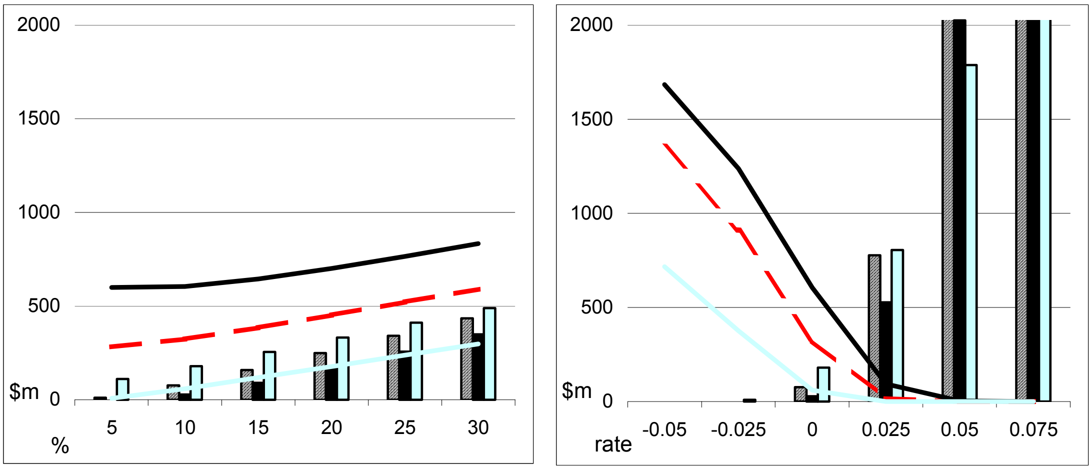
- the further away a carbon tax regime is, the lower the strategic value of being able to switch to biomass co-firing option but the greater is the overall value of the two projects.
- the higher the biomass fuel price the lower is the value of the fuel switching option and the overall value of the projects.

Figure 11 shows the sensitivity results of the platform option example. In contrast to the previous example, in this example the strategic value and the overall project value both move in the same direction in response to the changes in the chosen variables. In fact the results may be simply summarized by saying that greater electricity price volatility, the more positive the rate of growth in electricity prices, and the lower the capital or operating costs the higher the strategic value of being able to invest in a second identical, but lower cost, project. Consequently, the overall value of the combined project increases.

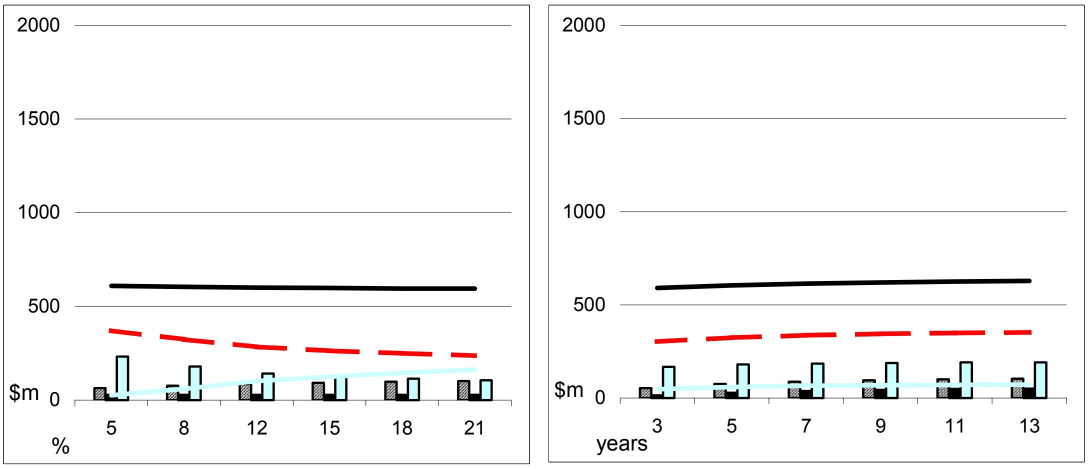
Finally, Figure 12 shows the sensitivity analysis for the example where the CPF and IGCC projects have the option to install CO_2 capture and sequestration. Installing such technology is currently a very marginal prospect and so there is not a great deal of variation amongst the results. However, the following conclusions may be drawn:

- greater volatility in the rate of decline in the costs of the technology (which could be interpreted as the potential for a breakthrough in the cost of the technology) results in an increase in the strategic value of the option to install CO_2 capture and sequestration in IGCC's and an increase in the overall value of the project. In the range examined, this higher volatility had no effect on the value of the CPF project.
- in the range of trend rates of reduction in costs examined, there was no effect on the value of the projects. Clearly it is difficult for cost to fall quickly enough to make a difference to projects which are to begin in the next few years.
- higher carbon taxes and associated flow-on increases in electricity prices improves the strategic value of the option to install CO_2 capture and sequestration but not to a point where the projects are expected to make positive returns (at least in the range examined and at current costs).
- lowering the current level of capital costs leads to a positive strategic value for the option to install CO_2 capture and sequestration in the case of IGCC. However, this is not the case for CPF when examined up to point of a 35 per cent reduction in capital costs.

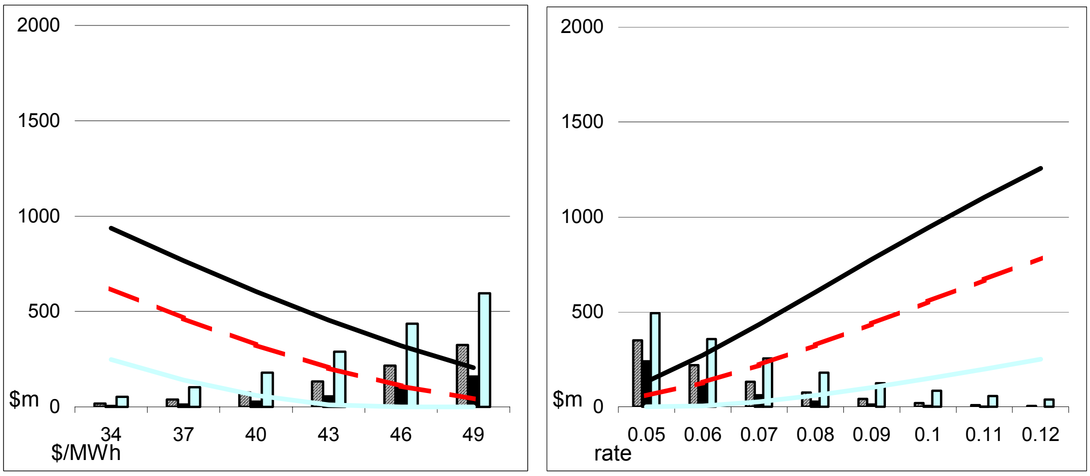
Figure 8: The option to defer the investment - sensitivity of the real option value (ROV) and strategic value (SV) to changes in selected variables



Annual volatility of electricity price Annual trend in electricity price



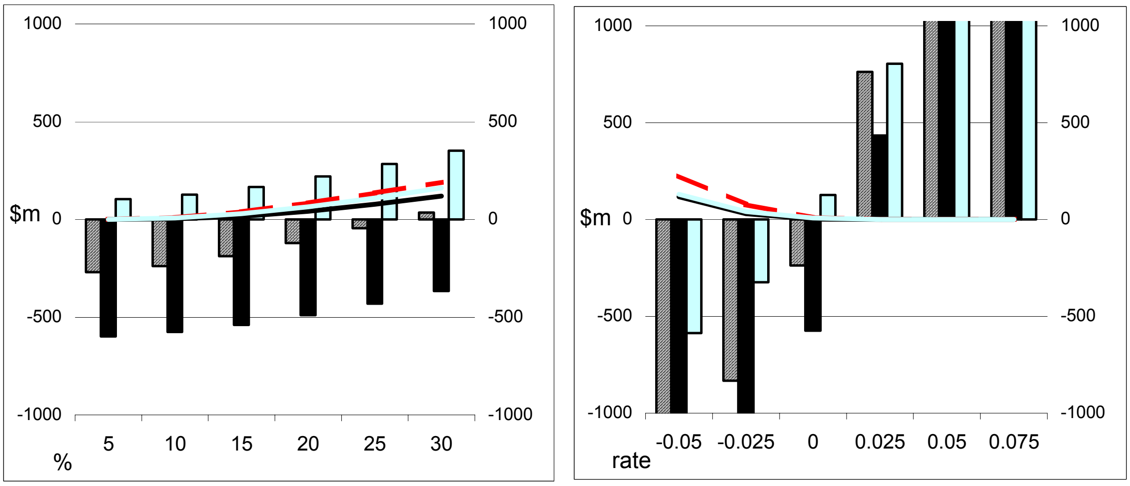
Time until the carbon tax is expected to be imposed Waiting period



Starting electricity price level Discount rate

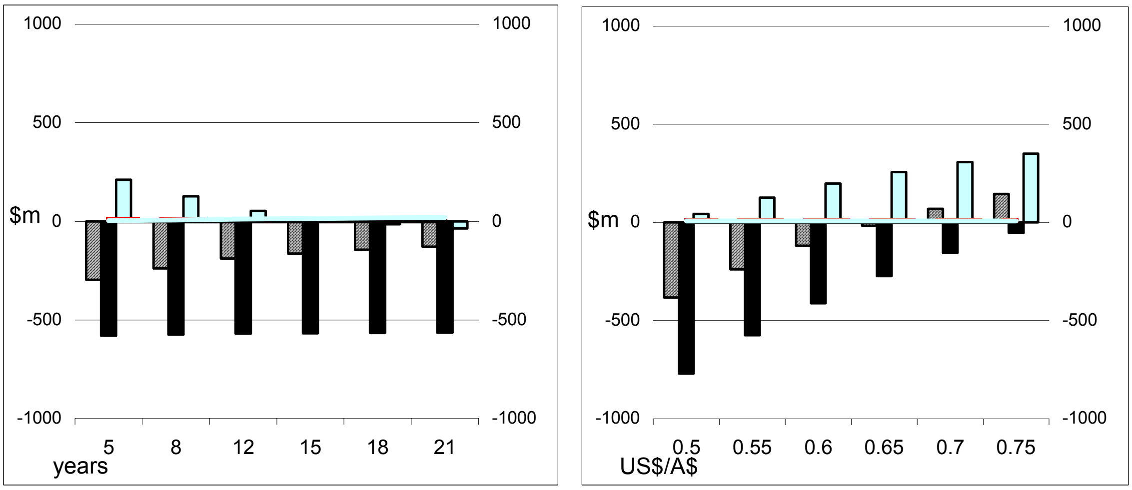
▨ ROV CPF ■ ROV IGCC □ ROV NGCC – – SV CPF — SV IGCC — SV NGCC

Figure 9: The option to shut down - sensitivity of the real option value (ROV) and strategic value (SV) to changes in selected variables



Annual volatility of electricity price

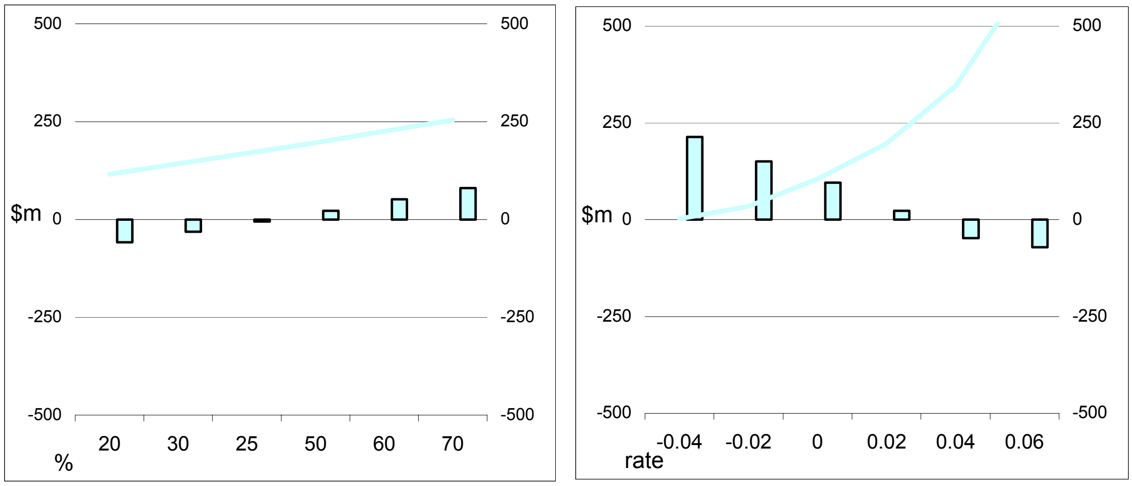
Annual trend in electricity price



Time until the carbon tax is expected to be imposed

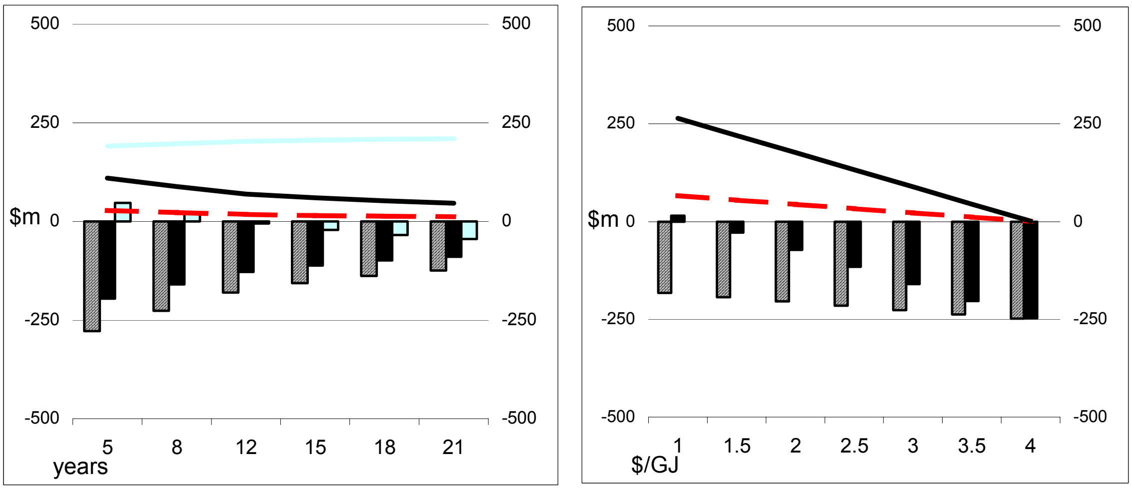
Exchange rate

Figure 10: The option to switch fuels - sensitivity of the real option value (ROV) and strategic value (SV) to changes in selected variables



Gas price volatility per decade

Annual rate of growth in gas price



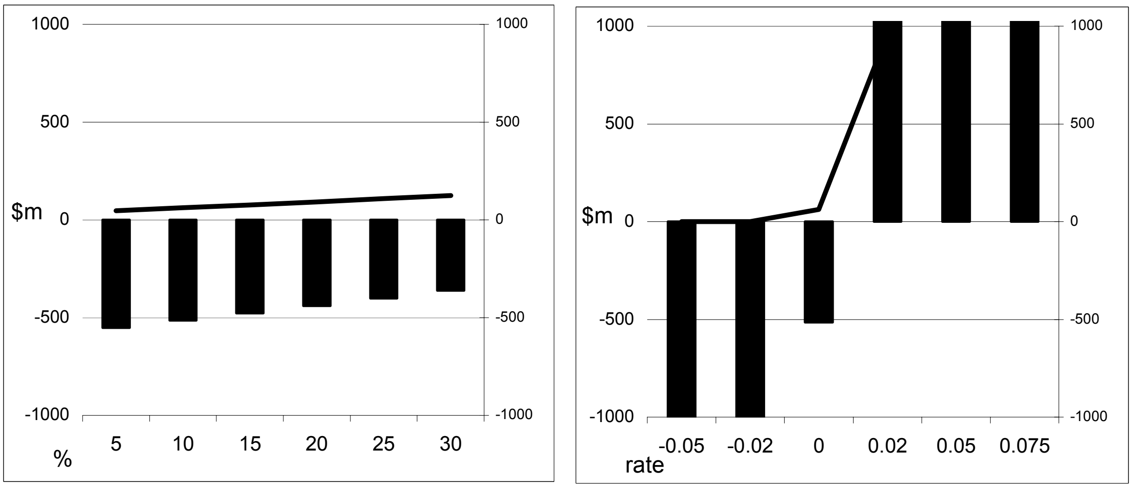
Time until the carbon tax is expected to be imposed

Biomass fuel price

▨ ROV CPF 5/95 ■ ROV CPF 20/80 ▭ ROV NGCC/IGCC

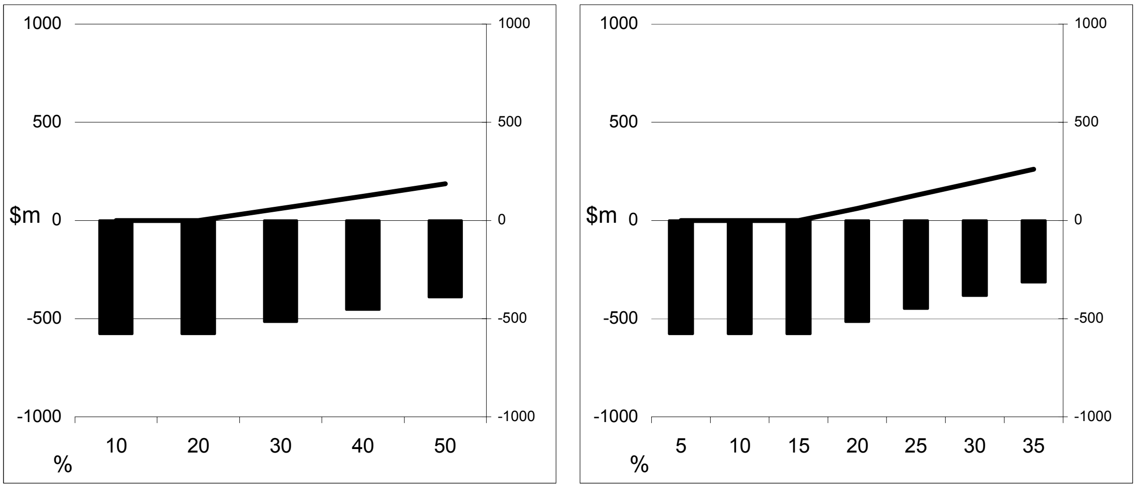
– – SV CPF 5/95 — SV CPF 20/80 — SV NGCC/IGCC

Figure 11: The platform investment option - sensitivity of the real option value (ROV) and strategic value (SV) to changes in selected variables



Annual volatility of electricity price

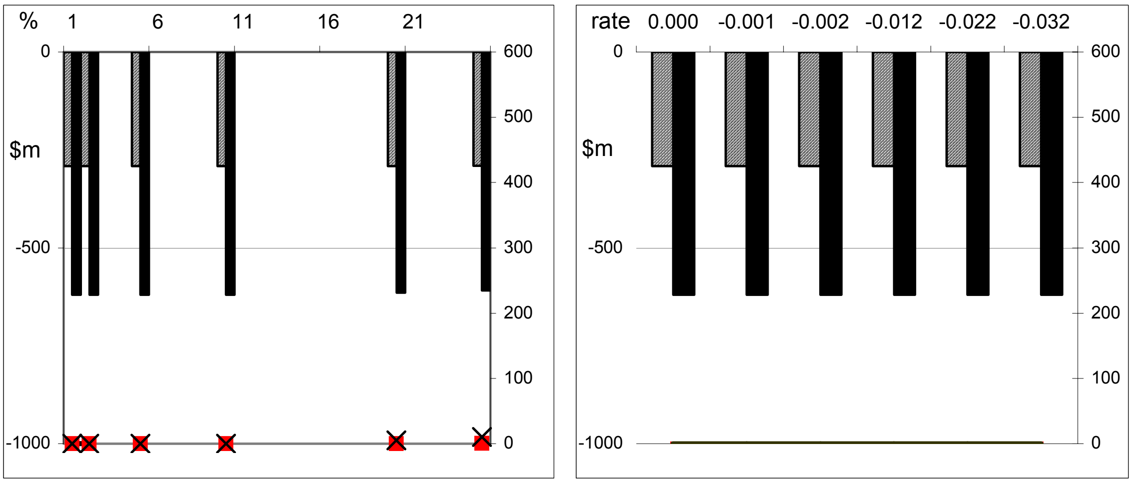
Annual trend in electricity price



Reduction in operating costs

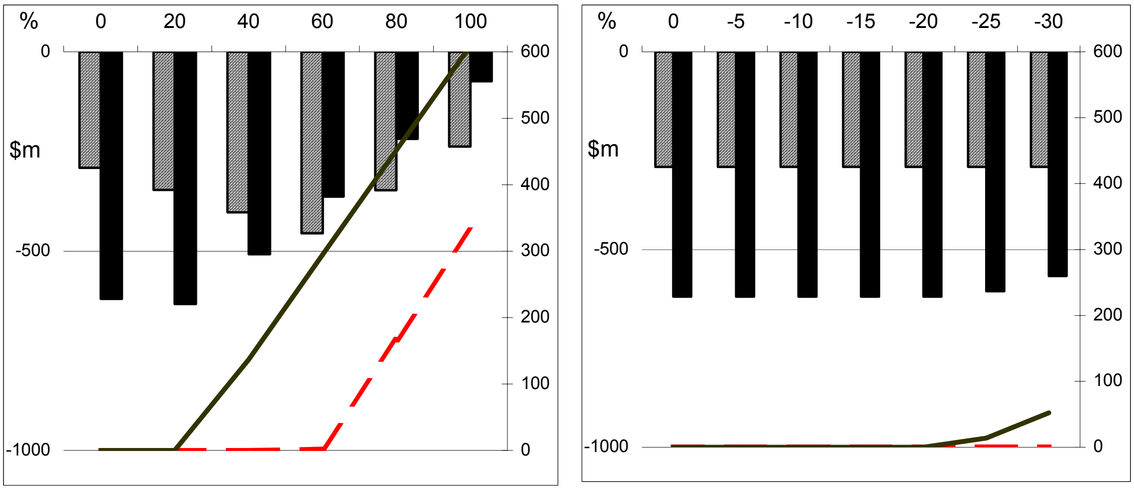
Reduction in capital costs

Figure 12: The option to install CO_2 capture and sequestration - sensitivity of the real option value (ROV) and strategic value (SV) to changes in selected variables



Volatility of technological change process

Annual rate of decline in capital costs



Carbon tax and electricity price

Initial capital cost of CO_2 plant

(immediately above both in terms of percent change from standard assumptions)

▨ ROV CPF ■ ROV IGCC – – SV CPF — SV IGCC

Appendix B

B.1 Calculating the real option value of an investment

Calculating the real option value of an investment requires almost the same data as calculating an NPV however the calculation process is different. As stated in the body of this report, a real options valuation incorporates the expected NPV but also includes any strategic value the project may also deliver. Hence the equation:

ROV = NPV + strategic value

For the purposes of real options calculations, the project's strategic value equals the value that the investor would have gained at any future time if they had exercised any options available to them as part of the investment (assuming, of course, they only exercise profitable options). In practical terms, the value of all future profitable options must be calculated and then one must determine which of those options were profitable and which ones would have been taken up. Note, if the option can only be taken up once, it can only be counted once (at the first instance in which the option is expected to be exercised).

B.2 Continuous versus discrete time perspectives

The solution method necessarily involves using mathematics which recognize dynamic relationships where events which happen at one point in time have effects in other points in time. Dynamic mathematical relationships can take one of two forms – continuous or discrete time mathematics. One could argue that since most options are continuously available to an investor one should represent the investment process as a continuous one. In this case the calculation method would utilize partial differential equations.

On the other hand, one could argue that an investor or manager often faces many decisions at once and as a result may set aside particular investment decisions for months at a time. In this case a discrete time process is sufficient.

One could also argue that the most important thing to take into account is the market that the investor is operating in. For example stock market prices vary almost by the second and therefore are more akin to a continuous process. On the other hand it has been proven that discrete time processes are mathematically equivalent to continuous time processes in the limit as the number of discretizations increases. If one chooses discrete time mathematics, the calculation method for real options problems is the binomial lattice approach.

There are also two more important issues to remember. The first issue is that all data is, by definition, in discrete time and gathering data for a continuous time calculation requires further data manipulation. The second issue is that even if continuous time methods are used, unless the partial differential equations can be solved analytically (i.e. where the solution can be reduced to one variable as a function of all other parameters) then ultimately the finite difference method or similar numerical procedure will be employed which is a type of discretization in itself.

On theoretical grounds there seems equal justification for either a continuous or discrete time approach. Given that either methodology involves a reasonable amount of mathematical rigor, the best approach is for the practitioner chooses the mathematical framework they are most comfortable with given their particular set of knowledge and background.

However, for those readers who require a more definitive answer Trigeorgis (1996) summarizes some criteria which could be used to choose between the two approaches on the basis of the type of investment problem being addressed:

Partial differential equations "..are more efficient when a whole menu of starting (time = 0) option values is desired. They can also handle several state variables in a multi-dimensional grid….. Special care must be exercised in choosing an appropriate set of finite-difference approximations to the partial derivatives to avoid problems of stability and consistency (accuracy), although certain logarithmic transformations can be helpful…… In general, finite-difference methods may not be readily used with history dependent-payoffs, and they cannot be used at all when the partial differential equations describing the option-value dynamics cannot be specified. In comparison with lattice approaches their implementation is more mechanical and affords less intuition, although they can be more powerful when crunching a large number of different option values.
Lattice values emulate the dynamics of the underlying stochastic processes and are generally simpler, more intuitive, and practically more flexible in handling different stochastic processes (e.g., diffusion, jump or mixed, mean reversion), option payoffs, early exercise or other intermediate decisions and optimal policies, several underlying variables, etc…….. More important, the binomial lattice approach can easily handle a variety of possibly interacting options, a series of investment outlays or exercise prices (compound options), non-proportional cash flows (dividends), exogenous jumps (competitive arrivals), and other complications. The main limitation of lattice approaches is their inability to handle more than one starting price at a time, resulting in a relative loss of power when a large number of starting options values involving multiple runs are required. However, this is not a limitation in the case of valuing real options, since they typically involve one (or a few) estimates of initial values."

The models in this report use the binomial lattice approach because. Trigeorgis is no doubt a strong proponent of binomial lattice approaches and has pioneered his own log-transformed binomial approach which has some benefits with regard to increased consistency (accuracy per number of discretizations). Despite Trigeorgis' obvious bias, the experience of the authors was that most of his comments appeared to be true. The binomial lattices were intuitively easy to construct once one had a good handle on what the options available to the investor were. We were able to formulate models involving multiple stochastic processes, compound options, jump processes and various other features. On the other hand we also were aware that if we wished to examine different starting prices or other assumptions that it was less capable in this area. The model would have to be re-run each time or run in several loops which would require re-coding of the underlying Visual Basic model and more computing time.

B.3 A note on Simulation approaches

Whether a practitioner chooses discrete or continuous time mathematical frameworks there is another alternative to the two approaches discussed (binomial lattices and partial differential equations). The alternative is simulation. The simulation approach, also known as the Monte Carlo approach, basically simulates the stochastic processes that determine the asset value and determines what decisions would have been optimal had these conditions actually occurred. This is the opposite to the previous two methods which solve their equations recursively. Recursively means that one starts from a known end point (e.g. expiry of the investment option or end of an electricity plants' life) and works backward to take into account all possible paths which may have led to that known end-point.

Simulation, on the other hand starts at the beginning and looks at one sample path. Each simulation represents one possible outcome. Once many thousand such simulations are performed, because one knows the underlying stochastic process, one can weight these by their probabilities to determine the expected real option value of the investment. The simulation solution method is not radically different from the other methods. One of its advantages is that, in cases where one has many stochastic variables it is a more tractable approach. However, in cases where there are only a few relevant stochastic variables it offers no real advantages over binomial lattice and partial differential equation approaches. It is least useful in defining optimal policies for given starting values.

B.4 Dynamic programming versus Contingent Claims Analysis

Real options analysis is derived from financial option analysis and as a result carries with it some important and complex financial theory. However, not all of this financial theory is immediately useful to valuing real assets which often lack obvious identifiable market prices, hedging or futures markets and other intricacies of more regularly traded assets. Below we explain some of the financial economic theories and discuss how much if any needs to be incorporated into real options analysis.

Contingent Claims Analysis (CCA) is the underpinning theory behind financial option pricing. The principle behind CCA is that an investor will never hold an asset unless its return is equal to the return an investor could have earned on other investment opportunity with comparable risk characteristics. Such a statement assumes that the economy is a rich menu of traded assets with different return and risk characteristics. Thus, to value a new asset we must try to replicate its return and risk characteristics through a portfolio of existing traded assets. The price of the asset under evaluation must be equal to the market value of this portfolio. If this were not the case, then any discrepancy would be exploited by arbitrageurs who look for sure profits by buying whichever is cheaper, repackaging it, and selling it at the higher price. In short, price discrepancies for equivalent assets or portfolios could not persist. To implement such an equation, once the equivalent risk and returns on the asset and portfolios are known, the only other data which the practitioner need supply is the risk free rate in order to implement the solution of the options valuation.

Of course, such information on equivalent risk and return portfolios is not always available. The alternative in such situations is the dynamic programming (DP) approach. The idea behind dynamic programming is to split an optimization problem involving a sequence of decisions into two parts: an immediate decision or choice and the value of continuing (to put off an investment, for example) conditional on this decision. The only catch is that in order to evaluate the optimal decision the practitioner must supply the risk adjusted discount rate whereas in the CCA approach, only the risk free rate is relevant because all choices are assumed to have equal risk and return profiles. Although there are methodologies available such as the Capital Asset Pricing Model (CAPM), the choice of a risk adjusted interest rate is often subjective.

As Dixit and Pindyck (1994) point out the equations to solve either a CCA or DP inspired model are almost identical and so these considerations turn out to be somewhat trivial. However, the correct discount rate, riskless or otherwise, is an important variable in any investment valuation model and so it makes sense to conduct sensitivity analysis of the discount rate where a subjective one has been used.

The models in this report use the DP approach using a subjective estimate of the risk adjusted discount rate. Electricity industry specific returns in the past have been very small because the industry was centralized and regulated. In the new deregulated market it is assumed that industry returns will be much more volatile and decentralization means those risks may be less diversifiable unless more merger activity is allowed. Therefore a discount rate of 8% was chosen. This is approximately 5 percentage points above the current risk free rate of around 3-3.5%. The risk free rate is in real terms and is based in the current 5.8-6% 10 year Treasury bond rate minus an inflation rate of around 2.5%. The 5 percentage points difference implies that an additional return of 5% is needed in order for a risk neutral investor to be confident that any positive discounted returns from electricity sector investments will be greater than those which it could have gained from treasury bond investments.

Of course, the discount rate is sensitivity tested during the report and can be altered by the user in the spreadsheet models provided.

B.5 Representing uncertainty in real options models

A strength of real options models is that they take into account uncertainty and are therefore a more realistic representation of the reality faced by the potential investor. When one wishes to include in a model variables which vary not as a function of other variables in the model but rather, as a full or partial result of random processes outside of the model, these are referred to as stochastic variables. For example stock prices fluctuate randomly but over the long term have a positive expected growth rate.

In real options models stochastic variables are assumed to exist in only a few limited forms which have properties which are easier to solve and understand. These forms are discussed below along with some discussion as to which of these were deemed to be the most appropriate for the investment valuations and associated stochastic processes considered in this report.

One of the most fundamental assumptions is that the stochastic variables follow Markov processes. Stochastic variables that follow a Markov process have the property that the probability distribution for the expected value of a stochastic variable in the immediate future depends only on the current value of that stochastic variable and not, by definition, on any values that may have occurred in the past or by any information concerning other variables. Assuming stochastic variables exhibit the Markov property means we need only make calculations that concern variables that are removed by, at most, one period in time. If we want to forecast the future path of a stochastic process, we only need current information about that process.

A second assumption that is usually made is that of independent increments. This means that the probability distribution for the change in the process over any time interval is independent of any other non-overlapping time interval. Thus changes are indeed random.

A third assumption is that changes in the stochastic variable over any finite period of time are normally distributed with a variance that increases linearly with the time interval.

These first three assumptions can be grouped into one if we assume that the stochastic variable follows Brownian motion. Brownian motion (after Robert Brown), also called a Wiener process due to later development of the relevant theories by Norbert Wiener, is a fairly restrictive assumption and without further modification can have some undesirable properties.

Let is first take the example of Brownian motion with drift. Brownian motion is a concept that was developed as a continuous time process. However, in the limit, as the number of discretization becomes very large the discrete time binomial representation is mathematically equivalent to the normally distributed continuous time representation (i.e. the mean and variance of both representations are identical). The discrete time random walk representation of Brownian motion with drift is:

$$x_t = x_{t-1} + \alpha\ \Delta t + \sigma\ \varepsilon_t$$

or, alternatively

$$x_{t+1} = x + \alpha\ \Delta t + \sigma\ \varepsilon_t$$

Where x is the stochastic variable, Δ means ‘change in’, t is time, α is the drift rate, σ is the standard deviation of the stochastic variable and ε is a random variable with zero mean and unit standard deviation. The implications of assuming stochastic variables follow Brownian motion with drift is best illustrated with an example. Using average annual electricity prices, assume that the annual variance of electricity prices is $4/MWh (annual standard deviation of $2/MWh) and that the annual drift rate is $0.50/MWh (both measures in real terms). In this case the equation for the stochastic process of annual electricity prices is:

$$EP_{t+1} = EP_t + 0.50 + 2\ \varepsilon_t$$

Using a computer program such as Excel to generate random numbers from a normal distribution with zero mean and unit standard deviation we are able to generate values for ε_t and therefore graph some sample paths for this equation. The sample paths are shown in Figure A.1. Note three sample paths were generated and graphed along with the trend line which simply equals $37/MWh plus $1/MWH times the change in time since the expected value of 2 ε_t must be zero (ε_t is normally distributed with a zero mean). These sample paths appear quite reasonable considering they are only one of the many possible paths which are implied by the assumption of Brownian motion with drift. In fact it may be possible to narrow down the number of possible paths further if we consider the properties of financial variables. One property is that, particularly with prices, it is often very unlikely that their future path will be negative. A second property is that one might reasonably expect that prices will revert to the long term cost of supply rather than wandering to some of the more extremes possible under Brownian motion. Thirdly, some stochastic variables will also be affected by large one-off events rather than just constant random events. Equation forms which allow for these three properties are discussed below.

B.5.1 Ito processes and Geometric Brownian motion

Ito processes are very similar to Wiener processes but have the property that the trend and volatility of a stochastic process is a known function of the current value of the stochastic variable. The most common type of Ito process assumed in real options models is Geometric Brownian motion. Assuming Geometric Brownian motion the equation for the stochastic behavior of electricity prices becomes:

$$EP_{t+1} = EP_t + EP_t\ \alpha + EP_t\ \sigma\ \varepsilon_t$$

Where α is now the percentage drift rate rather than the absolute level and σ is the standard deviation or volatility as a percentage of the prevailing electricity price. Geometric Brownian motion equations are said to be lognormally distributed because it is the percentage changes in the electricity price which will be normally distributed. Many economic and financial variables display characteristics which seem to be well represented by Geometric Brownian motion. For example, under Geometric Brownian motion any positive or negative growth trend in the variable is non-linear, volatility depends on the current level of the of the variable and negative values are ruled out.

Three sample paths of the electricity price are graphed in Figure 13 this time assuming the appropriate stochastic process is Geometric Brownian motion. The trend line which is determined by α has been calibrated to reached the same end point but this time the path is non-linear such that the percentage growth rate is 1.2 percent. Similarly the standard deviation has been amended to be 5.4% per year or 2 divided by 37. The exact same sample drawings of the random variable ε_t were used for comparative purposes. The main difference is that as the electricity price rises the absolute level of volatility of the sample paths is greater in Geometric Brownian motion than Brownian motion with drift

B.5.2 Mean reversion processes

For some financial variables it could be argued that Brownian motions is inappropriate because variables may wander too far from their expected trend. In reality, there may be some market mechanism such as competition, for example, which will force price to return to a level closer to costs. However, this argument for a less volatile stochastic process is only true if costs themselves are expected to stay stable. In this report, for the financial variables considered, this seems unlikely. The costs of resources such as coal and gas and plant and equipment are clearly not expected to remain constant because they themselves are effect by changes in resource constraints and technology. For the same reasons it is unlikely that electricity prices will revert back to some known level.

Ideally one should be able to run a statistical test to see whether a particular variable is mean reverting or follows something more like a random walk with drift. However, as those familiar with the literature will know, the outcomes of such tests are often biased (in the statistical sense) and depend crucially on the length of time series data available. For non-renewable resources any long time series of prices will reveal that technology and new discoveries have constantly shifted what was previously regarded as the most likely level of future extraction costs. Therefore this report generally does not support the use of mean reverting stochastic processes.

Despite these misgivings it is perhaps worth understanding how to construct a mean reversion stochastic process. Using electricity prices again, the equation is typically written as:

$$EP_{t+1} = EP_t + \beta\,(C-EP_t) + EP_t\,\sigma\,\varepsilon_t$$

where β is the rate at which the electricity rice reverts back to the level, C which could stand for constant or costs. Figure 13 shows how the same three sample paths would behave with a mean reversion rate of 20 percent. The slower the reversion rate the more the electricity price is allowed to wander from its long term expected costs or production C.

B.5.3 Poisson or jump processes

Sometimes we may want represent the uncertainty in a given financial variable as a jump process where changes in a variable happen unevenly at future points in time but otherwise it follows a known non-random path. For this purpose a Poisson distribution can be used which allows us to represent processes subject to fixed or random jumps. The primary purpose in which this processes is employed in there expect is to represent the arrival of the imposition of a carbon tax. It is unknown if or when a carbon tax will be imposed on electricity generation in Australia. Such a process can be represented by the following equation:

$$CT_{t+1} = CT_t + TL \,.\, PD$$

Where CT is the carbon tax which is currently zero, TL is the tax level it will increase to if imposed and PD is the Poisson distribution which returns integer values of whether the event has occurred or not. The Poisson distribution is defined by the mean arrival rate or number of events per unit of time and is usually represented by the symbol lambda (λ). Let's assume that an increase in the carbon tax is only expected to arrive once in the next 20 years but we do not know exactly when. In this case, the value of λ is 1/20 or 0.05. Using Excel to generate a Poisson distribution we have graphed three sample paths. Note the expected sample path is that the carbon tax will arrive in 2022, 20 years or $1/\lambda$ years after the current date, 2002.

Figure 13 shows the samples paths and expected arrival date. In two of the samples the carbon tax arrives before 20 years has passed while another arrives after 20 years has passed.

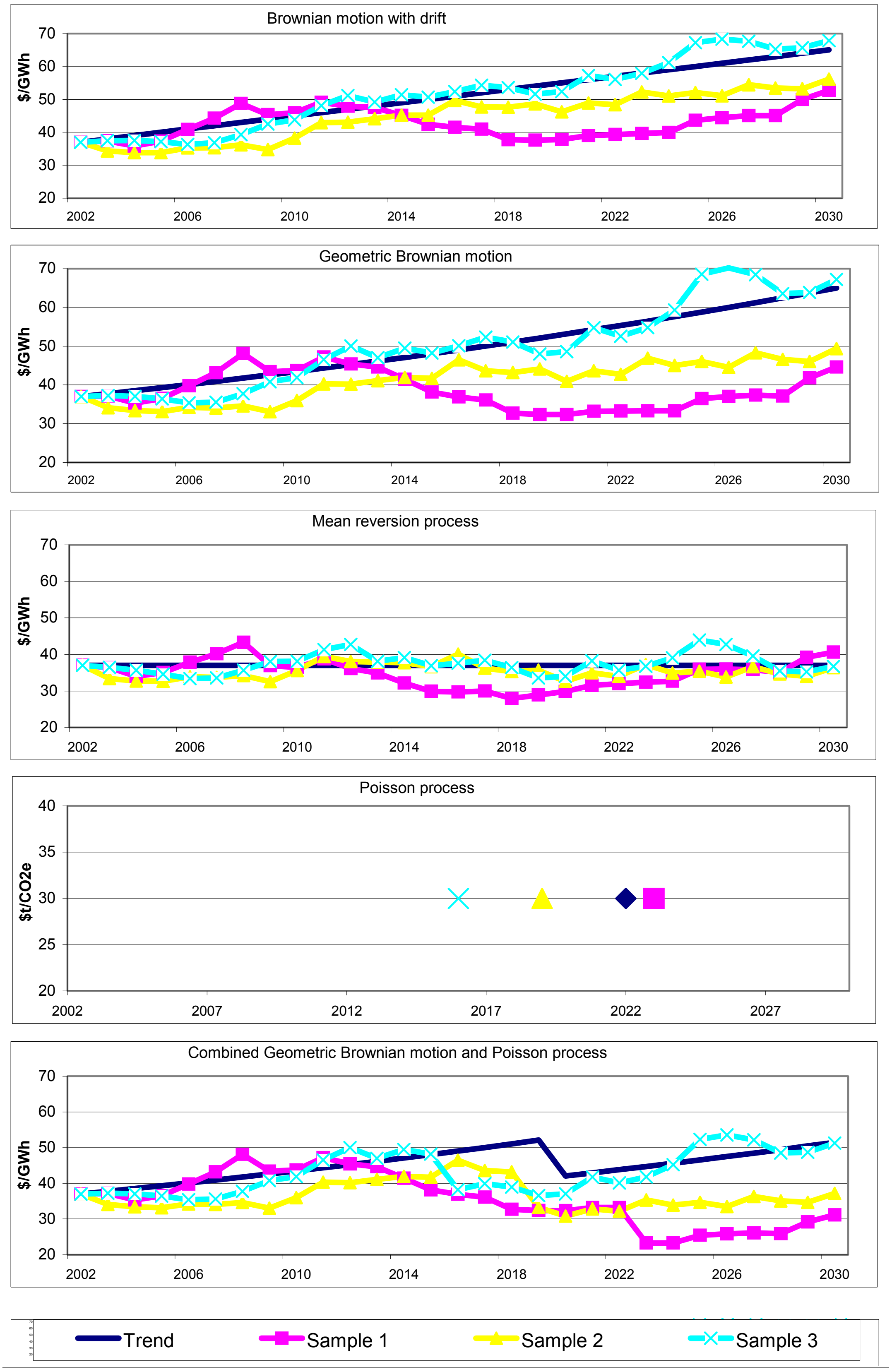
An alternative formulation is to assume Poisson processes for the effect of the carbon tax on net electricity revenue rather than the arrival of the carbon tax itself. Ultimately the level of net revenue for an individual generator depends on the change in the electricity price and their level of emission intensity and so this could be modelled as one-off change in net revenue to a higher or lower level. In this case the new formulation of the stochastic process of electricity price formation is modelled as a combined Geometric Brownian motion and jump process as follows:

$$EP_{t+1} = EP_t + EP_t\,\alpha + EP_t\,\sigma\,\varepsilon_t + CR \,.\, PD$$

PD is again the Poisson distribution but CR is the change in revenue once the impact of the carbon tax on the specific plant and electricity prices in general has been taken into account. When the carbon tax arrives EP changes by the amount CR and the normal effects of the trend and standard deviation are ignored. After that point the carbon tax impact is built into the price and the electricity price resumes its normal behavior. Note, the electricity price, EP is now interpreted as the net revenue to a specific electricity generator.

Keeping λ the same and assuming CR is equal to -\$10/MWh, Figure 13 shows how this new formulation effects the value of EP. In this case the trend or expected electricity price path is a straight line with a drop for the impact of the carbon tax in 2020. The impact on the sample paths is similar except it occurs at the different times generated from the Poisson process. Note this all assumes a constant carbon tax rate. If the carbon tax rate were to increase or decrease over time (perhaps due to a change in targets, or changes in costs of meeting the target) then that trend could also be added to the price formation process.

Figure 13: Alternative representations of stochastic processes



Appendix C

C.1 Electricity price uncertainty

From 13 December 1998 private or corporatised electricity generators in the eastern Australian States began selling wholesale electricity into a pooled bidding market - the National Electricity Market (NEM). This was a radical departure from the formerly State regulated wholesale electricity pricing which prevailed for many years before. Precisely because the NEM is a relatively new innovation it is a very uncertain market. With only three full years of data it is very difficult to make any assumptions about trends in average peak or off-peak electricity prices. Certainly there is seasonal and daily trends as one would expect, but from an annual perspective, which is the one we are most interested in, there is no clear trend. For example, in Queensland average annual prices fell in 1999, increased in 2000 and then fell again in 2001. In New South Wales and Victoria prices remained flat and then rose through 2000 only to remain flat again in 2001.

One of the theories regarding such fluctuations is that the wholesale electricity market will experience a period of fluctuating prices but will then ‘mature’ as investors eventually get the right price signals about how much new capacity needs to be commissioned. Once each State has the right capacity (either through optimal utilization of existing and new plant or interconnectors) electricity prices will stabilize at a level sufficient for all parties to cover costs plus a reasonable return on investment.

This argument is quite convincing and could lead to the conclusion that future electricity prices will not be as volatile as today. However, this is not a correct conclusion. In fact, although investors will indeed follow prices signals leading to a closer equilibrium between prices and actual costs this could only be expected to be true on average. This is because it is also expected that there will be periods where the market will be in disequilibrium. Furthermore the length of these periods should be measured in years, perhaps even decades, because supply of electricity in the NEM is characterized by very long-lived assets. When a market is characterized by long-lived assets then price signals are delayed and therefore potentially misleading and uncertain.

Taking these market characteristics into account it is assumed that the wholesale electricity price in the State in which the example power station investment projects are to be hypothetically located will always exhibit a certain level of annual volatility. Seasonal and daily volatility is also assumed but for now we disregard these by using annual averages.

When it comes to the question of a trend we must consider the underlying equilibrium which is usually defined by costs when there is a competitive market. Is there any reason to expect that the cost of generation electricity should be any more or less now than in the future? Factors which might decrease costs of generation include, favorable exchange rate movements reducing cost of imported capital, technological change, decreasing fuel prices and higher labor productivity. Factors which might increase costs are higher environmental/political compliance costs, higher fuel prices, unfavorable exchange rate movements. It would be very difficult to say which of these trends will be strongest and so no particular trend is assumed initially although this is relaxed in some scenarios to demonstrate the effect of a rising trend, for example.

C.2 GHG policy and carbon tax uncertainty

A related issue is that of the uncertainty as to whether there will be a carbon tax or some other equivalent greenhouse gas mitigating policy instrument imposed on the electricity generation industry. Despite active participation in the Kyoto Protocol negotiations, currently the Australian government has given no firm commitment to a carbon tax. On the other hand, there is a strong possibility that government policy may change during the 30 years of the electricity generating asset's life. For example a change of government policy could occur during the next election cycle which begins around 2005. To take into account this uncertainty we have allowed for an input into the model where one may assume an expectation about when a carbon tax will be imposed. From this information we are able to create a probability of this event occurring and take it into account in the valuation. To complete the picture, however, one also needs to consider what would be the likely impact of such an event.

The impact of a carbon tax on an operating electricity generation asset depends on the carbon intensity of their output and the relative cost of its competitors, in particular, alternative lower carbon intensity electricity generation. The type of system of carbon tax or permit imposed is irrelevant to new capacity since it is very unlikely to be given and special treatment such as may be afforded to existing generation capacity via grandfathering or other subsidy mechanisms. Therefore, the most important questions are, what will the level of the carbon tax or permit equivalent and what will be the carbon tax-adjusted wholesale electricity price.

For those generators who have zero carbon emissions they must compete with suppliers whose cost include the price of the carbon tax or permit multiplied by their emissions per MWh. Thus if there are many zero or low carbon emission generators who are low cost then the electricity price received by high emitters may be close to or below their costs. On the other hand, if there are very few low cost low emission alternatives then electricity prices will be higher and the carbon tax will be less of a burden. Of course, the size of the intended emission reduction will determine just how high the carbon tax or permit will need to be to get the desired level of emissions. A permit trading scheme ensures that the intended emission level is reached and the permit trading market sets the price or tax level. A carbon tax which is set by government at a particular level will lead to an unpredictable level of emissions. However, it would be expected that in such a case if it were found that the tax was leading to an undesirably small or large reduction in emissions then the government would adjust the tax level.

Given the difficulty of predicting the carbon tax level for the electricity generation industry it is was decided that the best course of action would be to pick a mid-point from estimates which have been calculated in the literature. Australian Greenhouse Office (1999) summarizes the literature and finds that most Kyoto Protocol consistent emission limits are in the $10-$50 range. Thus $30 a tonne would seem to be an appropriate guess. At this level the emission compliance costs of CPF, IGCC and NGCC are $32, $26, and $14 per MWh respectively. Given there are likely to be a reasonable amount of low cost low emission substitutes for these fossil fuel generators it is expected that the electricity price will rise by less than these emission costs, thus having a detrimental effect on the returns of carbon emission intensive assets.

Appendix D

D.1 Software requirements

As discussed in the introduction real options analysis is derived from stock option analysis. The software to support stock options modelling and analysis is fully developed, has been widely adopted by stock market firms and is available from many suppliers. In contrast, real options software is in its infancy, has been adopted by a small number of innovative firms and is only available from a few suppliers. The reason why real options software is in a relatively poor state is because valuing real assets is typically more complicated than valuing paper assets. Real assets are affected by asset-specific sets of variables which means that the data set cannot be readily applied to a simple formula. Real assets also have a much broader set of flexibilities than paper assets. Real assets need to be managed strategically to achieve optimal financial outcomes. Also, real assets often involve a series of strategically linked investments.

The few real options software that is available falls into two categories. Generic and asset market specific. Generic real options software is simply a calculator for standard real options formulas. If the real options valuation that one is trying to carry out is of a relatively standard variety and the user is confident of calculating the necessary data separately, then generic software packages are sufficient and inexpensive. However, as discussed above, real assets often tend to have some non-standard flexibilities which the software will not be able to handle. Non-standard assumptions about stochastic behavior are also a problem for generic software.

Asset specific real options software is designed to be applied in a specific asset market. It therefore takes into account most of the likely asset flexibilities or options that will be available and specific to an investor in that asset. It also takes into account the specific types of functional forms a user will require to value the asset appropriately. For example there is software on the market which is designed specifically for valuing oil reserves and exploration effort.

An example more relevant to the CCSD is EPRI’s Generation Asset Evaluator and Project Evaluator and Risk Manager software which are sub-modules of its Energy Book System software. Although the authors of this report were unable to view the software directly (presumably due to EPRI’s copyright concerns) EPRI’s electricity generation assets valuation software appears to have a broad range of capabilities. It has been in development since the mid-1990s and is no doubt a very professional package. The cost of the software was quoted at US$65,000. Additional fees apply for commercial use. US$65,000 is a non-member price. EPRI typically offers membership to its various research ‘targets’ for US$25,000 for a period of 3 years. However, information from via their website and various personal communications indicates that other types of affiliation are also possible. Therefore depending on how the relationship between EPRI and CCSD develops it may be able to obtain the software for less.

Setting aside issues of cost effectiveness, the CCSD must first determine what it requires. If the CCSD intends to carry out a broad range of real options analysis in the future including not just power stations, but valuing investments in research and other stages of pre-investment and valuing alternative policies and societal choices, then the EPRI software will not be sufficient.

That is, valuing a diverse range of assets, policies and options requires specific models and software to be built, modified or outsourced. It is not possible to build one model that can value a diverse range of investment proposals from a variety of perspectives. The only approach the CCSD can take in such a situation is to determine, on a project basis, which set of software and modelling expertise providers, internal and external, have the most cost effective service.

If, on the other hand, the main focus of CCSD efforts in regard to real options and portfolios risk assessment is valuing individual power station projects then EPRI's Energy Book system may be the most appropriate.

D.2 Transparency of real options models

One of the less desirable features of real options models, including those in this report is that, although possible, they are generally not presented as easy to follow model solution processes using simple spreadsheet formulas. Instead the user presses a 'button' which sends a computer command to run another program such as Visual Basic which runs the model and then sends the results back to the spreadsheet. This approach is liken to a 'black box' since the mechanics of the process are all hidden in Visual Basic code. Such approaches rely on the faith of the user that the model is doing what it should and generally does not inspire much confidence in the whole process.

Given the potential drawbacks the purpose of this brief note is to explain why the authors of this report chose to follow this approach. No doubt the reasons here apply equally to other software developers.

By far the most important consideration was screen space. In order to use the binomial lattice solution technique that was chosen to solve the real options models the technique requires the modeller to create a 'decision tree' with thousands of branches. While one can reduce the number of branches (or options), this reduces the accuracy of results since binomial approximations of the normally distributed time events improve the greater the number of discretization of time events.

An alternative was use partial differential equations. However, this would arguably have been even less transparent given one only has a set of mathematical equations as a guide.

To improve transparency of the modelling process each example is accompanied by a diagrammatic representation of the decision tree. This shows the decisions that are generally made at each decision node. Although the whole tree is not shown this gives a good sense of what the model is trying to determine. We also show a random sample of the price path or other relevant random variable together with the confidence interval so that the user has a better understanding of exactly what behavior is being assumed by values such as the standard deviation.