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Investment risks under uncertain climate change policy

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Abstract

This paper describes results from a model of decision-making under uncertainty using a real options methodology, developed by the International Energy Agency (IEA). The model represents investment decisions in power generation from the perspective of a private company. The investments are subject to uncertain future climate policy, which is treated as an external risk factor over which the company has no control. The aims of this paper are to (i) quantify these regulatory risks in order to improve understanding of how policy uncertainty may affect investment behaviour by private companies and (ii) illustrate the effectiveness of the real options approach as a policy analysis tool. The study analysed firms' investment options of coal- and gas-fired power plants and carbon capture and storage (CCS) technologies. Policy uncertainty is represented as an exogenous event that creates uncertainty in the carbon price. Our findings indicate that climate policy uncertainty creates a risk premium for power generation investments. In the case of gas- and coal-fired power generation, the risk premium would lead to an increase in electricity prices of 5–10% in order to stimulate investment. In the case of CCS, the risk premium would increase the carbon price required to stimulate investment by 16–37% compared to a situation of perfect certainty. The option to retrofit CCS acts as a hedge against high future carbon prices, and could accelerate investment in coal plant. This paper concludes that to minimise investment risks in low carbon technologies, policy-makers should aim to provide some long-term regulatory certainty.

Keywords: Decision-making; Regulatory risk; Electricity

1. Introduction

Getting the right type of investment in infrastructure for energy supply and consumption is a minimum requirement to enable the transition towards a sustainable energy system. One of the key tasks of climate change policy-makers is therefore to create incentives to encourage the necessary investments to be undertaken. However, the translation of climate policies into clear investment signals is not straightforward. Energy infrastructure investments occur in a highly dynamic context, where climate policy is one of many different risk factors to take into account.

Policy uncertainty is an important example of how stated policy aims may not translate easily into investment action. Uncertainty has often been raised by business in discussion with governments and regulators as a cause for concern and a potential barrier to investment. On the other hand, business routinely deals with risk and uncertainty in decision-making and will continue to do so in the face of climate change policy uncertainty. Risk is not inherently a bad thing. It is by taking calculated risks that companies aim to make profits in excess of their cost of capital. Nevertheless, sustained additional risk raises the cost of capital, and will alter investment decisions. For example, under uncertainty, the price of carbon required to trigger investment in low-emitting technologies may be substantially higher than expected if risk is not taken into account. Uncertainty will affect different technologies to different

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extents, and so the presence of uncertainty may lead to unexpected trends in technology uptake. Policy-makers need to be aware of these potential alterations in investment incentive caused by risk if they are to understand the likely impact of proposed climate change policies.

This paper describes results of analysis carried out by the International Energy Agency (IEA) to evaluate the investment risks associated with climate change policy uncertainty. The aim of the paper is to show how this type of quantitative analysis of risk can provide useful insights for policy-makers, and to provide illustrative results based on some simple assumptions about policy risk.

2. Modelling approach

Investment decisions by private companies in power generation are subject to a wide range of risks. These include commercial risks (e.g. commodity price risk), strategic risks (e.g. considerations of first-mover advantage and market share), regulatory risks (e.g. environmental or other market regulation), environmental risks (e.g. potential impacts of global warming on operational conditions), technical risks and many other economic and financial risks.

The exposure of any individual investment opportunity will depend on the technology being considered, and the type of market in which the company operates. However, in some form or other, all these risks will affect a project's cash flow. Uncertainty in the underlying assumptions in the cash flow will lead to uncertainty and risk in the financial case for investment.

Companies will use a range of methods for appraising these risks and factoring them into the investment decision. Often a variety of scenario approaches are used, which allows the company to test the sensitivity of the financial case to various assumptions. Companies may apply various rules about the risk premiums they attach to different types of project.

Real option methodologies provide a powerful tool for quantifying investment risk (Copeland and Antikarov, 2001). It is also particularly useful in the context of this study, having three important features that support policy analysis. These are: (i) individual elements of risk can be modelled separately and in combination to look at their relative contribution to overall risk; (ii) providing an evaluation of regulatory risk in financial terms so they can be related to likely effects on investment behaviour and (iii) the approach is very flexible and allows a comparison of different policy designs in terms of their effect on investment risk.

Real options theory is an extension of standard financial appraisal methods, adding the ability to explicitly model the effect of individual sources of uncertainty, and accounting for the flexibility that managers often have over the timing of their investment when faced with uncertain future cash flows. Originally developed for valuing financial options in the 1970s (Black and Scholes, 1973; Merton, 1973), economists soon realized that option pricing also provided considerable insight into decision-making concerning capital investment. Hence the term "real" options. Early frameworks were developed by McDonald and Siegel (1986), Pindyck (1988, 1991, 1993), and Dixit and Pindyck (1994).[1]

Investment in the electricity sector has been analysed within real options frameworks before. Work was carried out by EPRI (1999) to provide a framework for managing the effects of regulatory uncertainty, and Ishii and Yan (2004) looked at the overall effects of regulatory uncertainty on investment rates in the US. In the area of short-term planning, real options were used by e.g. Tseng and Barz (2002) and Hlouskova et al. (2005). At the same time, a number of long-term planning frameworks have emerged. Recent examples include Fleten et al. (2007), who find that investment in power plants require greater returns than the traditional net-present-value (NPV) break-even point when a real options approach with stochastic prices is used.

Real options approaches have also been quite widely used to model the effects of uncertain climate change policy. Rothwell (2006) finds that returns on investment in nuclear plant need to be higher in a scenario with uncertain carbon prices than in a world with certain prices. Also Laurikka (2004), Laurikka and Koljonen (2006), Kiriyama and Suzuki (2004) deal with the influence of future uncertain emissions trading and with CO_2 penalties within a real options setup. In these models, the design of emissions trading schemes and the number of allowances that are freely distributed are main features of the overall model. Another example of the application of real options approach to the problem of uncertain climate policy is Reedman et al. (2006) who show that uptake of various electricity generation technologies varies significantly depending on investor's view of carbon price uncertainty.

In this work, we focus less on the specific design of policy, and more on the general effects of uncertain future policy decisions that could significantly and rapidly alter investor's expectations about the effective future price of carbon. Examples that could be envisaged include a significant tightening of targets from one period of an emissions trading scheme to the next, or conversely a deterioration in international negotiations that leads to a collapse in the price of carbon. We focus in particular on the timing of these uncertain events with respect to the investment decision, with a view to providing insights into how policy-makers can create greater certainty for investors.

A way to intuitively understand the approach is to realise that investors, faced with a risky irreversible decision, will value the opportunity to gain additional information about likely future conditions affecting the project, thereby reducing uncertainty. This could mean investing in

[1]For a comprehensive treatment and overview of both Financial and real options theory see Trigeorgis (1996).

additional research for example, or more relevantly for our work here, delaying investment until the uncertainty has been partially resolved. When the future cash flows of a project are uncertain, the value of waiting for additional information depends on how far in the future the uncertain event is, the likely quality of the information, and the extent to which the uncertainty will be resolved.

In order for the project to proceed immediately rather than waiting, the expected project value needs to be sufficiently high that it exceeds this value of waiting. This is described in Fig. 1. The figure illustrates a schematic cash flow, showing the expected gross margin (revenues minus costs) over time, and with capital costs also assumed to be annualised over time. The normal positive NPV rule would be equivalent to requiring that expected gross margin is greater than annualised capital costs. Fig. 1 indicates why expected project values may need to be greater than this when there is future uncertainty and when there is flexibility to wait and learn. In other words, the NPV not only needs to be positive, but needs to exceed some threshold, the value of which depends on the value of waiting.

Uncertainty is represented as an anticipated price shock or an information event (e.g. introduction of a major new climate change policy) at some time T_p. This could affect a project's cash flow either adversely or favourably. In Fig. 1A, the company facing this uncertain cash flow has to choose whether or not to invest in the project—it does not have the option to wait. The expected 'best guess' (central orange line) is that the project will continue to be profitable, so that the project satisfies the normal investment rule (i.e. gross margin is greater than capital cost) justifying immediate investment.

In Fig. 1B, the company has the opportunity to wait until after time T_p before making the investment. This allows it to avoid the potential loss that might occur if conditions turn out worse than expected (shown as a zebra dashed area). Waiting could lead to a greater return on investment—the new expected gross margin from the project would be higher than the original expected gross margin without the option of waiting—but revenues from the project would only accrue after time T_p if the project does go ahead. It would be rational to invest prior to T_p only if this value of waiting is overcome by the opportunity cost of waiting (i.e. the income forgone due to delaying the investment). In order to trigger immediate investment, the expected gross margin of the project would need to exceed some threshold level which makes the opportunity cost of waiting greater than the value of waiting. This threshold depends on the length of time before T_p, the size of the anticipated price shock and the discount rate.

These thresholds are calculated using a cash-flow model in which climate change policy is represented using carbon price as a proxy. The model allows for changes in the carbon price that arise in two distinct ways. Firstly, the stochastic nature of carbon markets, with prices fluctuating due to changes in the expectation about supply and demand, is modelled through a year-to-year random walk in carbon price. Carbon prices are also allowed to vary annually with a geometric Brownian motion with annual standard deviation of 7.75% per year leading to

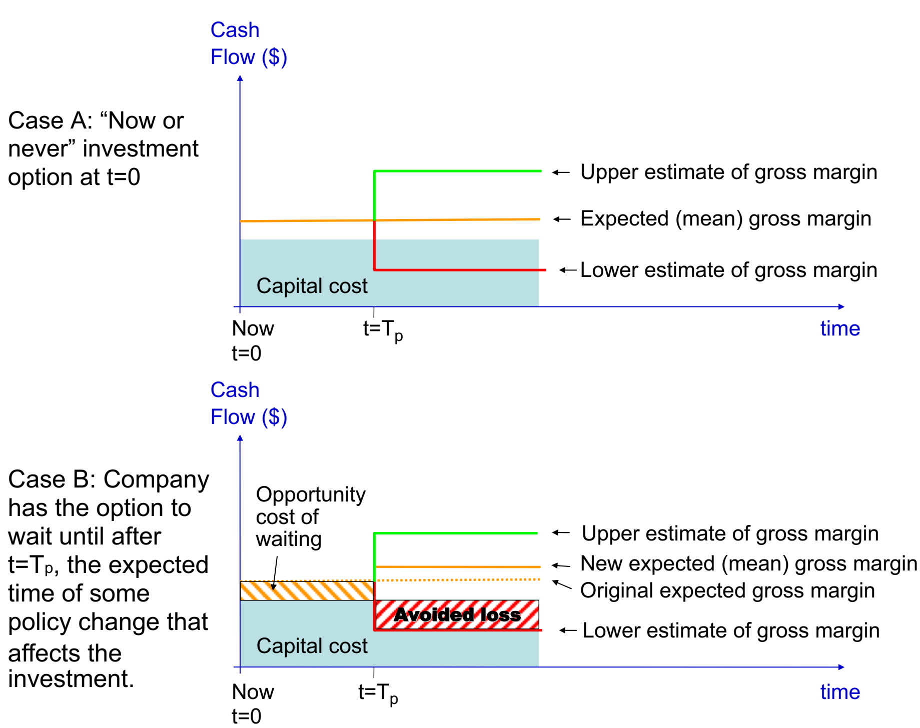

Fig. 1. A conceptual framework to show the value of waiting: (A) "Now or never" investment option at $t = 0$. (B) Company has the option to wait until after $t = T_p$, the expected time of some policy change that affects the investment.

a 1 standard deviation range after 15 years of ±30%. Secondly, discreet policy-related interventions are modelled as a stochastic jump process where some event is anticipated to occur at some fixed date in the future, which causes the carbon price to jump to a new level anywhere in the range of a zero price of carbon to double the previous year's price. In both cases, these sources of uncertainty are assumed to be exogenous, are not affected by the investment decision, and cannot be influenced by the company making decisions.

The model optimises the timing of investment in the face of this price uncertainty using a semi-commercial dynamic programming software package called the 'Real Options Calculator' from Onward Inc. (for a review of dynamic programming, see e.g. Dixit and Pindyck, 1994). Dynamic programming compares the expected outcome of investing in a project in the current year of the run with an alternative option: "continuation value" which delays investment until the timing is optimal. The calculation of the continuation value requires the investment problem to be solved from the final year of the run (i.e. the last possible date at which investment could occur), working backwards to the first year of the run in order to deduce the optimal investment rule over the whole possible investment horizon. A full description of the model is given in IEA (2007), and key assumptions used in the model are listed in Table 1.

The cash-flow model assumes that the expected value of the carbon price is at a level which under conditions of certainty would be sufficient to make the project financially viable. The actual value of carbon chosen therefore depends on the technology being analysed, and can be changed from one run to the next allowing a range of technology options to be assessed in terms of their exposure to climate policy risk (as modelled in terms of carbon price risk). The expected (mean) carbon price is indicated together with the relevant results in the following section. Under conditions of uncertainty, the results show that even though the stochastic price variations do not affect the mean carbon price, they do affect the investment decision since companies are assumed to have the option to wait for additional information. The quantitative results presented here therefore address the question of what additional level of investment incentives might be required to overcome the effects of uncertainty.

3. Results

Figs. 2 and 3 show how the financial case for various generation technologies is affected by relative prices for gas and coal and the price of CO_2. The technologies considered are coal-fired power generation plant (taken to be super-critical pulverised coal), combined cycle gas turbine (CCGT) power generation, coal-fired plant retrofitted with carbon capture and storage (CCS) and CCGT retrofitted with CCS. The light lines separate regions where each technology would be financially preferred to the other technologies under conditions of price certainty.

The modelling results are then superimposed on these regions showing the effects of CO_2 price uncertainty. The results of the modelling are based on a comparison of the following set of investment choices:

- Coal plant vs. CCGT
- Coal plant vs. retrofit coal plant with CCS
- CCGT vs. retrofit CCGT with CCS.

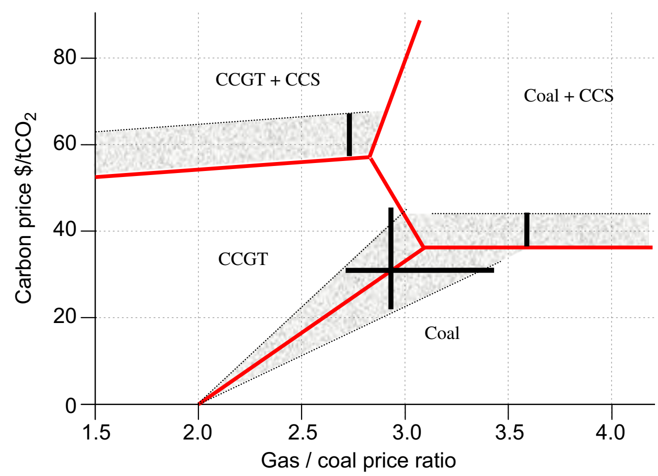

Fig. 2. Ten years prior to price shock—shaded zone indicates 'wait' rather than invest now.

Table 1
Key assumptions used in the model

Project specific assumptions	New coal	Retrofit CCS to coal	New gas	Retrofit CCS to gas
Project lifetime (years)	40	40	25	25
Capacity retrofitted (MWe)	1350	1086	1350	1208
Capital 'overnight' cost ($/kW)	1320	810	589	430
Construction period (years)	3	2	2	2
Capacity/load factor (%)	85	85	85	85
Average generation efficiency (%)	46	37	57	51
CO_2 Emissions factor for fuel (tCO_2/TJ input energy)	95	95	56	56
Fixed Op&Maint ($/kW-Yr)	42.5	65	42.5	65
Variable Op&Maint ($/MWh)	0.0	7.4	0.0	3.54
CO_2 abatement factor (CCS) (%)	–	86	–	86

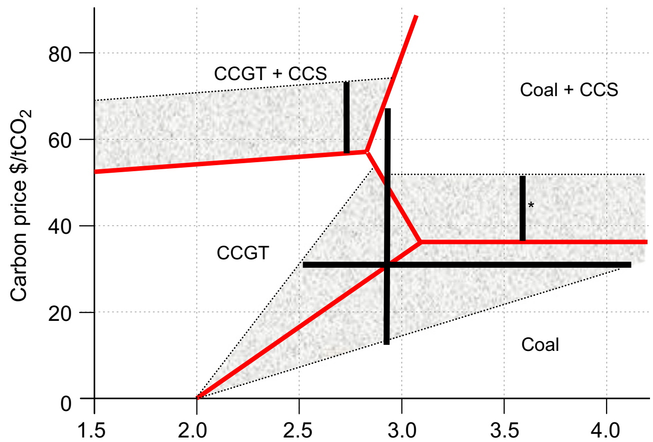

Fig. 3. Five years prior to price shock—shaded zone indicates 'wait' rather than invest now.

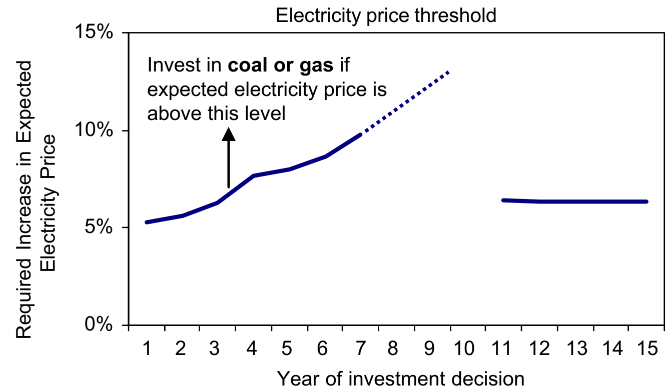

Fig. 4. Electricity price thresholds. (The dotted line is an extrapolation of the results, as in this case the model was not able to compute an investment threshold when there was less than 4 years available prior to the price shock. The extrapolation is based on experience of other results from the model which indicate that the investment threshold continues to increase up until the time of the price shock.)

In each case, it is supposed that there is flexibility over the timing of investment. This means that in addition to the choice between these pairs of technologies, the model has a third choice which is not to invest immediately, but to wait. The heavy lines are results from the model. They represent the investment thresholds calculated by the real options model, converted into the units shown in the charts. In other words, they indicate either the CO_2 price differential (vertical lines) or the gas:coal price ratio differential (horizontal lines) that would be required to overcome the investment thresholds created by the value of waiting.

The shaded areas are extrapolations based on these results to other regions in the graph. These shaded areas represent regions where the model would choose to wait rather than invest. Fig. 2 shows the results when there are 10 years of relative CO_2 price stability before the shock, whereas in Fig. 3 there are only 5 years before the price shock. It is clear from these results that the value of waiting increases strongly when there is less time available before the price shock.

For the choice between coal and CCGT plant, there is another dimension to the decision that is not shown in Figs. 2 and 3—namely the electricity price. In Figs. 2 and 3, it is assumed that the electricity price is just sufficient to make investment in coal or CCGT financially viable under conditions of certainty. Under conditions of uncertainty, the model chooses to wait when prices are within the shaded region between CCGT and coal as indicated in these charts. However, a rise in the expected future price of electricity could be sufficient to overcome the value of waiting and stimulate immediate investment. Indeed, there might well be a causal relationship between the tendency for companies to delay investment, and a resulting expectation of higher prices due to greater scarcity. In Fig. 4, we evaluate the increase in expected price of electricity that would be required to overcome the investment thresholds calculated by the model such that the shaded 'waiting' regions between coal and CCGT in Figs. 2 and 3 would be closed. In Fig. 4, the CO_2 price shock occurs in Year 11, and the chart shows the increase in expected price of electricity required to overcome the value of waiting for each year in which the investment decision is being considered. The chart shows that the nearer in time the decision-maker is to the time of the price shock, the higher the expected future price of electricity would need to be to incentivise immediate investment.

In the case of retrofiting CCS however, electricity and fuel prices are not strong drivers of the investment. So unlike the case for the choice between CCGT and coal, an increase in electricity price would not tend to close this 'waiting' region—only an increase in carbon price would be able to overcome the value of waiting. These results therefore suggest that immediate investment in CCS technology would only occur if the carbon price were higher than that required to achieve a positive NPV. The increase in carbon price shown in Figs. 2 and 3 required to drive immediate investment in the face of future price uncertainty is reproduced in Table 2.

The existence of an option to retrofit CCS technology to coal plant has an interesting effect on the investment case for the coal plant itself. One of the key risks facing investment in coal is the possibility of carbon prices being higher than expected. The possibility of retrofitting CCS at a later date acts as a good hedge against this risk, and reduces the investment risk for coal.

This can be illustrated by considering an investment option for coal when the expected carbon price is up at \$47/t CO_2 placing the investment opportunity at around the position of the asterisk within the shaded 'wait' region of Fig. 3. Two cases can be envisaged, the first when there is an opportunity to invest in coal without the option of subsequent retrofit of CCS, and the second when there is the option of subsequent retrofit of CCS. The first case is shown in Fig. 5A. The heavy line indicates the threshold carbon price, below which expected future carbon prices must fall if immediate investment in coal plant can proceed. The vertical bars show the probability that investment proceeds in any given year. The results indicate that at these expected prices, investment never occurs before the price shock, and will take place after the price shock if the carbon price falls sufficiently (which occurs in around 45% of cases).

Table 2
CO_2 price required to exceed threshold and trigger CCS investment

	Expected CO_2 price required under certainty (DCF calculation) $/t$CO_2$	Expected long-run price required with 10 years before price jump $/t$CO_2$	Expected long-run price required with 5 years before price jump $/t$CO_2$
CCS retrofit to coal	38	44	52
CCS retrofit to CCGT	57	67	77

Fig. 5B shows the case where retrofit of CCS is available. Expected carbon prices remain the same as before, but in this case the threshold carbon price is significantly closer to actual prices, meaning that there is a significant level of coal build (around 80%) prior to the price shock. Total coal build over all years is close to 100%, since the coal plant can operate either on its own if CO_2 prices turn out to be low, or with retrofitted CCS if CO_2 prices turn out to be high. Investment in the CCS plant itself tends to be delayed until after the price shock, and is only built in about 50% of cases. However, but the option to retrofit CCS acts as a hedge against the risks of higher-than-expected future carbon prices, and effectively accelerates investment in coal

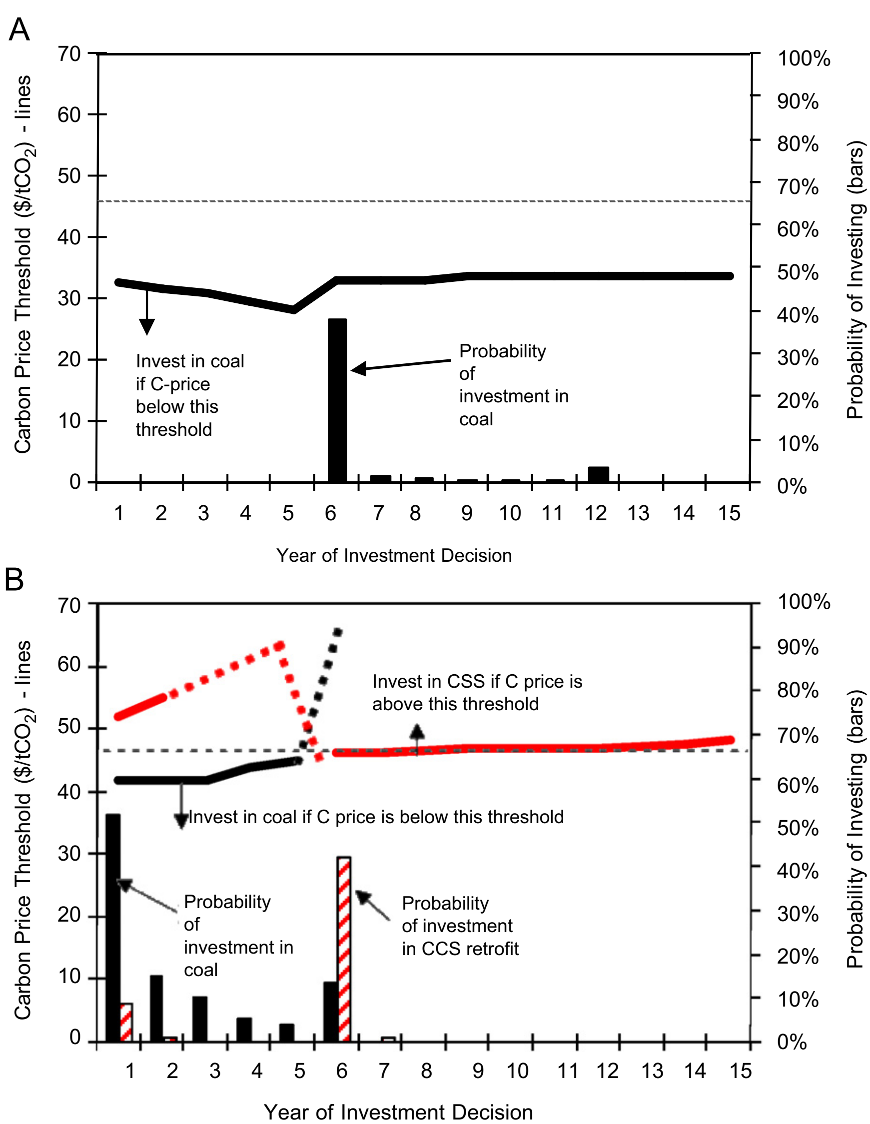

Fig. 5. CCS acts as a hedge against uncertain CO_2 price, accelerating investment in coal-fired power generation plant. (A) Investment rates for coal-fired generation without CCS retrofit option under CO_2 price uncertainty, with a price shock in Year 6. (B) Investment rates in coal-fired generation with the option of future retrofit of CCS under CO_2 price uncertainty, price shock in Year 6.

plant relative to the case where the CCS option is not available.

4. Conclusions

This paper models the effect of policy uncertainty as an exogenous risk factor facing investment decision-makers in private companies. Climate policy is assumed to be implemented through imposition of a carbon price, which is then factored into the cash-flow analysis of the technology being considered for investment. Uncertainty is modelled through stochastic variations in the carbon price.

The results show that policy uncertainty creates a risk premium, and the paper demonstrates how the use of risk quantification techniques can lead to valuable insights into the potential effects of policy uncertainty on investment behaviour. The paper describes the modelling approach, representing climate change policy uncertainty as a potential step-change shock (positive or negative) to carbon prices at some fixed point in time. The value to private investors of waiting for information on the sign and magnitude of this change in prices is calculated using real options modelling techniques. Illustrative results are presented for investment choices involving coal, gas and CCS plant. The key conclusions from the modelling are as follows:

1. The closer in time a company is to a change in policy, the greater the policy risk will be, and the greater the impact on investment decisions. If there are only a few years left before a change, policy uncertainty could become a dominant risk factor.
2. Policy risk increases the payoffs required from the project in order to justify proceeding with the project immediately rather than waiting. The greater and closer in time the policy risk, the higher the necessary investment threshold will be.
3. In the case of the investment choice between coal and gas generation, this additional payoff would likely be supplied by an increase in the expected electricity price. Expected future electricity prices would need to rise by around 5–10% or more depending on how much time was available prior to the uncertain policy event.
4. In the case of retrofitting CCS to coal plant, the additional project returns would have to come from an increase in the price of carbon. Compared to the breakeven price of carbon required to stimulate the project under conditions of certainty, policy uncertainty would increase the required price of carbon by 16–37% or more depending on how much time was available prior to the uncertain policy event.
5. The option to retrofit CCS to coal plant acts as a hedge against the risks of higher-than-expected future carbon prices, and effectively accelerates investment in coal plant relative to the case where the CCS option is not available.

A key policy recommendation arising from this research is that policy-makers need to be aware that policy uncertainty creates risk for private companies which can affect their investment behaviour. Policy-makers should therefore aim where appropriate to find ways to reduce these risks by increasing policy certainty. The modelling approach described here can be adapted to look at a range of sources of risk, and to incorporate different assumptions about the nature of climate change policy risks. The intention of this paper is to illustrate the effectiveness of the approach for providing policy-relevant insights into the nature of the investment incentives created by climate change policies.

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More detailed information on the topic of this article is available in a book published by the IEA in April 2007. See: http://www.iea.org/w/bookshop/add.aspx?id = 305.

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