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Effects of Low-cost Offsets on Energy Investment – New Perspectives on REDD –

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Effects of Low-cost Offsets on Energy Investment
- New Perspectives on REDD -

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Tropical deforestation is one of the major sources of carbon emissions, but the Kyoto Protocol presently excludes avoiding these specific emissions to fulfil stabilization targets. Since the 13th Conference of the Parties (COP) to the UNFCCC in 2007, where the need for policy incentives for the reduction of emissions from deforestation and degradation (REDD) was first officially recognized, the focus of this debate has shifted to issues of implementation and methodology. One question is how REDD would be financed, which could be solved by integrating REDD credits into existing carbon markets. However, concern has been voiced regarding the effects that the availability of cheap REDD credits might have on energy investments and the development of clean technology. On the other hand, investors and producers are also worried that emissions trading schemes like the one installed in Europe might deter investment into new technologies and harm profits of existing plants due to fluctuations in the price of emissions permits. This paper seeks to contribute to this discussion by developing a real options model, where there is an option to invest in less carbon-intensive energy technology and an option to purchase credits on REDD, which you will exercise or not depending on the future evolution of CO_2 prices. In this way, unresolved questions can still be addressed at a later stage, while producers and investors hold REDD options to maintain flexibility for later decisions. We find that investment in cleaner technology is not significantly affected if REDD options are priced as a derivative of CO_2 permits. Indeed, the availability of REDD options helps to smooth out price fluctuations that might arise from permit trading and thus decreases risk for the producer - thereby being a complement to permit trading rather than an obstacle undermining cap-and-trade.

Keywords: real options, energy investment, cap-and-trade, REDD

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1 Introduction

With up to 20% the estimates of emissions arising from deforestation each year amount to one of the major sources of anthropogenic GHG emissions. This percentage even outstrips that of emissions from transportation. The Eliasch Review (2008) estimates that by 2100 the economic cost due to deforestation could be around \$1 trillion per year; achieving stabilization at concentrations keeping warming below 2°C would be impossible if deforestation continued at the current pace. The question arises why the Kyoto Protocol was not designed to account for deforestation emissions. This had mainly to do with the fear of negotiators - at the time when the Protocol was ratified - that cheap credits granted for avoided deforestation could flood the market, thus driving down the price for carbon allowances and thereby undermining the effectiveness of cap-and-trade by e.g. destroying the incentives to develop, test and install modern, less carbon-intensive technology. Even though the need to include REDD into international agreements was identified as soon as COP9, however, it was only last year, at COP13, when this was officially recognized. In addition, many additional benefits have been emphasized: for example, compliance costs will be lower if REDD is included in the next agreement, so an even more ambitious target could be achieved at a comparatively lower cost provided REDD is included in global carbon markets (Eliasch Review, 2008).[1]

In this paper we are concerned with finding a way of implementing REDD and investigating its potential effects on energy investments. In addition, we aim to shed some light on the debate whether REDD should be integrated into carbon markets and whether it complements or undermines cap-and-trade. The latter has been opposed by stakeholders and decision-makers in many countries due to the instability of CO_2 prices that are associated with new, immature markets, which are also influenced by policy uncertainty. Such price volatility could, for instance, be observed when the European Emissions Trading Scheme (ETS) started. We find that the inclusion of REDD into existing carbon markets can help to smooth out such fluctuations, thereby reducing the risks that producers might be exposed to.

For the analysis of these problems we design a real options model. Real options are a suitable tool to assess investment decisions under uncertainty when there is irreversibility involved and the investors enjoys a certain degree of flexibility with respect to his actions (see e.g. Dixit and Pindyck, 1994). The basic idea is that it pays off to wait for the arrival of more information in the face of uncertainty if a large amount of resources has to be committed to a project. In the case of an energy investor, a less carbon-intensive power plant or equipment designed to mitigate the emissions due to combustion, require such an irreversible investment. On the other hand, deforestation also represents an irreversible decision. As will be seen in the analysis, preserving flexibility by not deforesting has an economic value, even if some methodological issues with respect to REDD remain uncertain in the near future.

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[1] Other additional benefits of REDD include that global emissions can be curbed, while excluding REDD would imply a focus on the reduction of fossil fuel combustion: under the Clean Development Mechanism (CDM), avoided deforestation does not lead to a decrease in global emissions, but simply to a “shift” of emissions from developing to developed countries (see e.g. Schwartzman et al, 2008). Furthermore, biodiversity will be preserved, rural development facilitated and poverty reduced.

The real options model used in this paper focuses on a coal-fired power plant, which can be retrofitted with a carbon capture and storage module (CCS), which will reduce a major part of the emissions generated by the combustion of coal in the power plant. The CCS module is therefore an example of a carbon-saving investment, which is suspected to be negatively affected by the availability of REDD credits. Purchasing REDD options is another way of offsetting emissions from the combustion of coal. In our framework, they will be purchased at an option price: whether the REDD option will be exercised or not depends on the realization of CO_2 prices ex post. For all emissions not offset or captured, permits must be purchased at the current ETS price in € per ton of CO_2 in each respective year. In summary, there are thus two decisions to be made on a yearly basis: (a) the number of REDD options to be purchased in the beginning of the planning period and exercised at a later point in time, and (b) the timing of the adoption of the CCS module. CO_2 permit prices follow a stochastic process, where the volatility is estimated from the spread of CO_2 price scenarios in the future. REDD options are priced as derivatives of permits, but we also compare outcomes for lower option prices as e.g. derived from carbon supply curves for global forests and other land uses (e.g. Sedjo et al, 2001). We find that the pricing of REDD is crucial in determining its impact on CCS investment and that integrating it in global carbon markets would ensure high enough a price to avoid such negative effects that are suspected to materialize by opponents of REDD.

The rest of the paper is organized as follows: the second section explains the basic ideas of real options modeling and sets it into the context of permit trading and REDD, affecting a representative coal-fired power plant owner. Section 3 provides a detailed description of the model, the data used and the pricing mechanism applied to the valuation of the REDD options. The fourth section presents the results and discusses the implications for future carbon markets. Finally, section 5 concludes and extracts recommendations for policy-makers from the analysis previously conducted.

2 Real Options, Permit Trading & REDD

While options theory has long been established in finance, real options are a relatively new concept, where the opportunity to invest into a “real”, non-financial asset is considered as an option or, in other words, as the right, but not an obligation, to commit resources to the project at a future point in time. According to Dixit and Pindyck (1994) amongst others, real options modeling is a suitable framework to analyze investments under uncertainty, which involve irreversibility with respect to the resources spent (most often large costs in terms of capital) and flexibility to postpone the project on behalf of the investor. In contrast to “standard” Net Present Value (NPV) investment rules, real options can take into account the value of waiting for more information to be revealed; the investor can thus base the optimal decision on the value of immediate profits seized from an investment and the value of investing at a later point in time, where the latter is often called the option value of the investment.

The basic idea behind real options is that it takes into account the flexibility of the investor to act later when he can make different decisions for different outcomes of the uncertain factors. It has found many applications to investment problems (see e.g. Pindyck (1993) for an early application to sequential investment).

In energy planning, real options have been used in many theoretical applications already (e.g. Reinelt and Keith, 2007), even though energy companies, in practice, have usually not been relying on real options valuations of their projects yet. Related to the topic of permit trading and the vulnerability of producers' profits to permit price fluctuations, Szolgayova et al (2008) use a real options model to investigate the impact of a price cap, which has been suggested as a form of protection against upward price spikes for power plant operators. The authors find that a too low price cap depresses investment into less carbon-intensive technologies and benefits companies with high emissions asymmetrically: similar protection is not provided for the owners of clean technology through e.g. a permit price floor.

In this paper we seek to suggest an alternative instrument to assist producers in hedging their risks: the integration of REDD options in an existing carbon market. We find that this combination of instruments (permit trading and REDD) can indeed help to smooth out fluctuations in profits and thus reduce the investor's exposure to risk. This shows that the provision of REDD options represents additional flexibility to the investor, the value of which depends on the development of CO_2 prices.

In addition, there is also a value to preserving forests, as deforestation is an irreversibility in itself and destroys the value of flexibility that REDD options imply. In other words, keeping the REDD potential open has an option value of its own account. Finally, but related to the previous point, we want to address the question of the timing of adopting REDD and the design of the underlying mechanisms. To date, there are still many unresolved issues (REDD mechanisms, climate sensitivity, REDD potential, etc) and also political difficulties (commitment of different countries) with respect to implementation. However, our suggestions point to the usefulness of going ahead with REDD already at this stage, even if many issues are not solved yet and many technicalities remain unclear at the moment. The reason for this is that the exertion of the REDD options will have to be decided upon in the future and not now, so the payment in terms of the option price has to made today, but it is low compared to the strike price and the price of CO_2 permits. So, even if some problems can only be resolved in the future, it is still possible to act optimally and with access to better information later. Furthermore, the options do not necessarily have to be exercised depending on what information becomes available.

3 Modeling REDD & CCS Options

3.1 Model Description & Methodology

The model derived in this section includes a real investment option and an option on REDD. The first option refers to investment into mitigation technology. In our specific case, we consider the option to retrofit an existing coal-fired power plant with a carbon capture and storage (CCS) module. The REDD option is an additional way of offsetting CO_2 emissions. The difficulty lies in determining the price of such an option and including it into the same framework as the real option, so that one option is valued in the presence of the other. In this way, we can determine the impact of the availability of REDD options on mitigation technology.

Let us now explain the model structure in detail and derive the mathematical formulation of the problem. The planning horizon of the model is 50 years, which is equal to the considered power plant's lifetime. The producer (or planner) owns a coal-fired power plant, which can be retrofitted to include a CCS module. Adding this module, which will capture part of the emitted CO_2, becomes more attractive as CO_2 permit prices rise. At the same time, CO_2 prices are volatile and the cost of installing the module is relatively high and will be sunk ex post. There is therefore a certain degree of investment irreversibility involved in the problem, which makes real options theory a suitable approach to finding the optimal timing of investment. Looking at the shadow prices for GHG emissions in the GGI scenarios (IIASA, 2007), there is a clear upward trend at around 5% and the spread of those paths across scenarios points to a positive value for the volatility as well.[2] We assume that the price of CO_2 will follow a geometric Brownian motion (GBM):

$$dP_t^c = \mu \cdot P_t^c dt + \sigma^c \cdot P_t^c \cdot dW_t^c \qquad (1)$$

where μ is the drift parameter, σ^c is the annualized volatility parameter and dW_t^c is the increment of a Wiener process.

Including the REDD option into the same valuation framework implies that the decision-maker can actually hedge some of the CO_2 price uncertainty by purchasing the right, but not the obligation, to offset the CO_2 emissions created by exercising the option and therefore receiving a "credit" for CO_2 savings due to avoided deforestation projects, for example. More precisely, we consider REDD credits as options, i.e. as a right but not an obligation to offset 1 ton of CO_2 at any time now or in the future for a given strike price E. This means the option can be represented as an American call option on the CO_2 price. Since the price of an American call option for an asset without dividends is the same as the price of a European call option, we can use the Black and Scholes formula (Black and Scholes, 1973) to price REDD options as derivatives of CO_2 permits, the price of which evolves according to Equation (1).

$$\begin{aligned} P_{REDD} &= P_0^c \cdot N(d_1) - E \cdot N(d_2) \cdot e^{-r(T-1)} \\ d_1 &= [\ln(P_0^c/E) + (r + (\sigma^c)^2/2) \cdot (T-1)]/\sigma^c \cdot \sqrt{T-1} \qquad (2) \\ d_2 &= d_1 - \sigma^c \cdot \sqrt{T-1} \end{aligned}$$

where P_0^c is the "stock" price, which is equal to the initial CO_2 permit price here, E is the strike price, which we set at 15$/ton. N refers to a normal distribution, σ^c denotes the volatility parameter, which we will vary according to the experimental setup later on. T is 50 years, and P_{REDD} is the option price to be determined (in $/ton).

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[2] See Section 3.2 for more information on the calibration of these parameters and the actual data.

Now that we have specified the two different ways of offsetting CO_2 (investing in CCS or exercising REDD options) and their specific costs, let us turn to some other cost items, which are deterministic in this setting, but whose level can still influence the optimal investment plan. The cost of both capital and operations and maintenance (O&M) is constant and deterministic, which abstracts from possible capital-saving technical change. We also ignore stochasticity in coal prices for now.

The investor has an installed coal-fired power plant at his disposal and needs to decide whether and when to add the CCS module, since it can be worthwhile to postpone installation and buy REDD options to offset emissions. The decision whether to install the CCS module can be taken on a yearly basis, whereas the REDD options can be bought only in the first year. The investor wants to maximize the sum of discounted expected future profits. The yearly profit π consists of the revenues from selling electricity less the cost of fuel, CO_2-related expenses,[3] annual O&M, and costs associated with the installation of the CCS module. CO_2-related expenses depend on the existence of the CCS module and on the action performed that year. The actions available each year to the investor are either to add the CCS module (if it has not been installed yet), exercise the REDD options (if there are any available) or to do nothing. The action each year will be different for different states and prices realized that year.

Let x_t denote the state that the system is currently in at time t, i.e. whether the CCS module has or has not been built so far. As already pointed out above, a_t is the control variable. Let us denote N the number of REDD options purchased in the first year and n_t the number of options currently available to the investor at time t. As x_{t+1} depends only on the current values of action and state, x_{t+1} is a function of x_t and a_t, and similarly n_{t+1} is a function of n_t and a_t. The yearly profits are thus

$$\pi_1(x_t, a_t, N, P_t^c) = q^e \cdot P^e - q^f(x_t) \cdot P^f - q^c(x_t) \cdot P_t^c - N \cdot P_{REDD} - OC(x_t) - c(a_t)$$

in the first year, and (3)

$$\pi(x_t, a_t, P_t^c) = q^e \cdot P^e - q^f(x_t) \cdot P^f - q^c(x_t) \cdot P_t^c - OC(x_t) - c(a_t)$$

in any other year, where P^f is the price of coal and OC is the operational cost per year. Note that OC also includes the costs of transporting and storing the captured CO_2. The q refer to annual quantities of electricity, fuel and CO_2 respectively. $c(a_t)$ is the cost of an action; for example the cost of installing the CCS module or the costs of exercising REDD options. P_{REDD} is the price for one REDD option. In the case where the CCS module has already been built, exercising the REDD options will offset more emissions than necessary. In that case the producer is able to retrieve what was paid in excess. Note

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[3] These include the payments for permits needed to be purchased for all emissions that are not offset by REDD or captured through the CCS-module. Not included are expenses for REDD options or the CCS-module, which are already accounted for by other cost items (investment cost, $c(a_t)$, O&M cost, $OC(x_t)$, and costs for purchasing REDD options, $N \cdot P_{REDD}$).

that exercising a REDD option will reduce q^c to zero for that year and that the only other way to decrease q^c is to install CCS.

The investor's problem is to determine the optimal number of REDD options N, and the optimal investment strategies $\{a_t\}_{t=1}^{T}$, where the optimal decision in each year depends on x_t, n_t and P_t and can be computed recursively by solving the following Bellman equation:

$$V_t(n_t, x_t, P_t^c) = \max_{a_t, n_t} \{\pi(n_t, x_t, a_t, P_t^c) + e^{-r} \cdot E[V_{t+1}(n_{t+1}, x_{t+1}, P_{t+1}^c) | P_t^c]\} \quad (3)$$

where n_t stands for the number of REDD options, x_t is the state,[4] a_t the action[5] undertaken at time t and A_t the set of feasible actions the investor/producer can choose from. r is the discount rate. This is a standard Bellman function, in which the first part of the value to be maximized is the immediate profits one would obtain upon installation of the CCS module, while the second part of the sum is the so-called continuation value, which takes into account the values when the investment option is exercised in the future (i.e. currently postponed), given today's prices. Furthermore, it includes the optimal amount of REDD options to be bought in the beginning of the planning period and actively considers into account that they can be exercised (at the strike price) to offset emissions at any later point in time.

We choose a combination of dynamic programming and Monte Carlo simulation in order to determine the optimal actions. The methodology first requires us to fix the terminal condition, in our case this is $V_T=0$, where T is the last year of the planning horizon. We then continue to compute the optimal actions, a, for all possible states, x, and prices, P^c, recursively. This endows us with a *strategy* for all possible circumstances and price realizations in terms of the optimal action, which will maximize the value function in Equation (3) accordingly. Since we are interested to learn about the frequency distributions (or the probabilities if one prefers this interpretation) with which these actions are exercised for a given price process, we simulate a large number of price paths and pick the optimal actions for each realization from the previously derived *strategy*. In this way, we can not only determine the frequency with which the CCS option is exercised and when, but also the optimal amount of REDD options to be bought and when they will be exercised.[6]

3.2 Data: Technology Costs & CO_2 Prices

Table 1 lists the data that have been used in the analysis. They have been gathered from the International Energy Agency's survey on power plants in 2005 and its technological outlook from 2006. The technology focused on is an Integrated Gasification Combined Cycle Plant (IGCC), which is more modern than many existing, standard pulverized coal-

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[4] Has the CCS module been built or not? Have the offset options been exercised?

[5] The actions that can be undertaken are the following: a=0 ⇒ do nothing; a=1 ⇒ exercise REDD option; a=2 ⇒ exercise (real) CCS investment option.

[6] For a more detailed description of the methodology, the reader is referred to the appendix or Fuss et al (2008).

fired power plants and which will be more interesting for new installations, since it has higher conversion efficiency. This implies that this technology uses less coal and generates fewer emissions at the same time, which will be an advantage in the light of rising CO_2 prices. Retrofitting the IGCC plant with a CCS module requires an additional outlay in terms of capital costs, but also the efficiency of the plant will be lower and so the yearly output for the same amount of inputs will be lower as well. Operations and maintenance costs (O&M) will be higher for the plant including CCS, obviously. This has also to do with the fact that the CO_2 does not only need to be captured, but it also needs to be transported to a suitable site, where it can be stored. However, the savings in terms of CO_2 are large and a sufficiently high CO_2 price level can provide an incentive for CCS investment.

	IGCC	**Add-on CCS**
Capital cost (US$/kW)	1,373.00	343.00
Fuel cost (US$ per GJ_{heat} LHV)	2.06	2.06
Conversion efficiency (LHV)	0.50	0.44
CO_2 emissions (ton CO2 per yr/kW)	4.77	0.48
CO_2 storage cost (US$/ton CO2)	NA	5.45
Capacity factor	0.75	0.75
O&M (US$ per yr/kW)	92.09	124.16
Electricity generation (kWh/yr)	6,570.00	5,781.60

Table 1: Technology Data (Source: IEA, 2005, 2006)

For the CO_2 price, there are no reliable long-term data available for calibration, obviously. There is only one established carbon market so far, which is the European Trading Scheme and prices have not been stable throughout the beginning phase. However, there are multiple sources using scenario analysis to produce a range of forecasts for future emission paths and they also compute the corresponding GHG shadow prices. One example is the GGI Scenario Database (IIASA, 2007). We can use the trend implied for GHG shadow prices. For the volatility parameter, it is possible to base the estimate on the spread of the different scenarios involved. Figure 1 below shows the forecasts and trend lines for three scenarios, where A2r (yellow) is the most pessimistic one in terms of assumptions about population growth, technological progress, diffusion of efficient technology and many other factors. B1 (red) is the most optimistic scenario and B2 (blue) is in the middle of the former two. All scenarios are computed for a stabilization target of 670ppm and we choose B2 for our starting price. The trend is almost 5% for all three scenarios. A value of 5% for the escalation rate would also be supported by a Hotelling solution, where the trend would be equal to the discount rate if there is banking and perfect foresight.[7]

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[7] This result is valid as long as allocation in the future is more "tight" than in the beginning of the optimization period or if borrowing from the future emission budget is permitted without penalty.

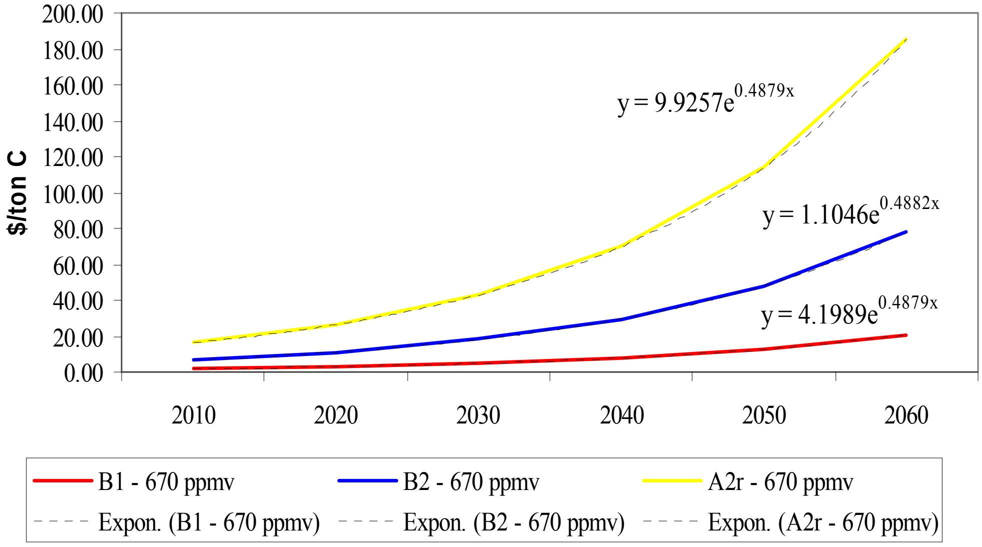

Figure 1: GHG Shadow Prices (Source: GGI Scenario Database, IIASA, 2007)

As mentioned above, there is no good "forecast" for carbon prices. There are several political factors and uncertainties like undefined future policy: what emission target the developed world commits to in the future, to what extent developing countries adopt emission targets, what rules are negotiated for offsets etc. In addition, there are several economic factors like uncertainties in BAU emissions, unknown patterns of abatement cost reductions as a result of learning processes, uncertainty about allocation mechanisms depending on policy proposals etc.

The best we can do is to consider the variance across different scenarios, like those depicted in Figure 1 of the MIT EPPA model, which is reproduced below as Figure 2 (Paltsev et al (2007), page 10). These scenarios represent different assumptions regarding unknown factors that we take as given. Exclusion of outliers leads to conservative estimates of the spread around 30-40% of the mean. In that case annualized volatility is about 5%.[8]

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[8] Sensitivity analysis demonstrates that for σ^c from 0 to 6% the results are rather stable. Beyond these values, the number of REDD options purchased and the frequency of adding CCS decreases slightly until σ^c =10%. Beyond 10%, σ^c becomes too large and the number of REDD options purchased falls to zero, as explained before. This is related to the fact that the CCS module offers more flexibility in that case, since it can be build during the planning horizon, whereas the REDD options are bought in the beginning. Note also that the price of the REDD option is a function of volatility: the higher the volatility, the higher the price. When price is too high, the REDD option becomes less attractive. This helps to explain the result of the sensitivity analysis. At the same time, the strike price is an important determinant of the option price. Developed and developing countries can always negotiate a strike price ensuring to have the option price within the corridor they are aiming at: on one hand, to generate enough money to cover the opportunity cost of avoided deforestation and, on another hand, to be attractive for purchases as part of a hedging strategy.

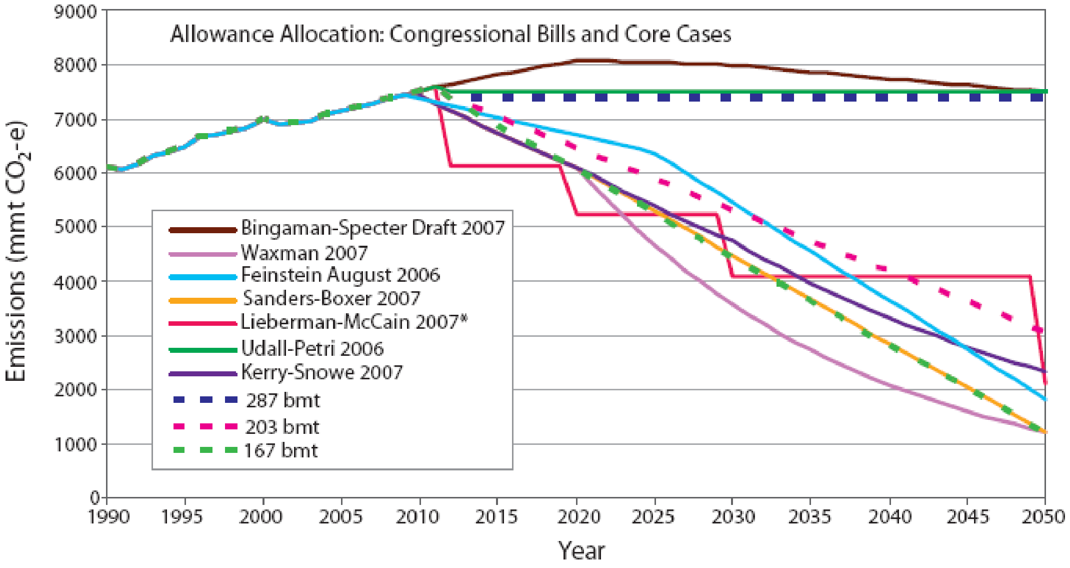

Figure 2: Scenarios of Allowance Allocation of Congressional Bills & Core Cases over Time (Source: Paltsev et al (2007), Figure 3 on page 10)

4 Results & Implications for REDD

The model developed and calibrated in the previous section was solved and we have conducted 10,000 simulations of CO_2 price paths in order to extract some statistics from the optimal solution. Figure 2 shows that in all 10,000 cases the CCS module is added to the coal-fired power plant, as long as the price of acquiring a REDD option does not fall below 2 $/ton. For 1 $/ton the investment frequency drops by about 25%, and below 1 $/ton, the CCS module is almost never adopted. The message from this result is that energy investments could indeed be negatively affected by the availability of cheap REDD options, but this depends on the pricing of the option in a framework like ours: if REDD is included in existing carbon markets and options on REDD are sold, where these options are priced as derivatives of the permits, then the resulting price is sufficiently high to still allow for investment into new technology, here CCS. On the other hand, if the price of a REDD would be equal to what the cost would be in a segmented market (according to existing carbon supply curves), then this price could be too low and reduce the investment frequency into carbon-saving technology, thus undermining the mechanism if the cap-and-trade scheme. This difference has been indicated by labeling the corresponding price levels with tags in Figure 3.[9]

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[9] Testing these results for robustness with respect to permit price volatility, we find that the results are stable for volatility parameter values below 10%.

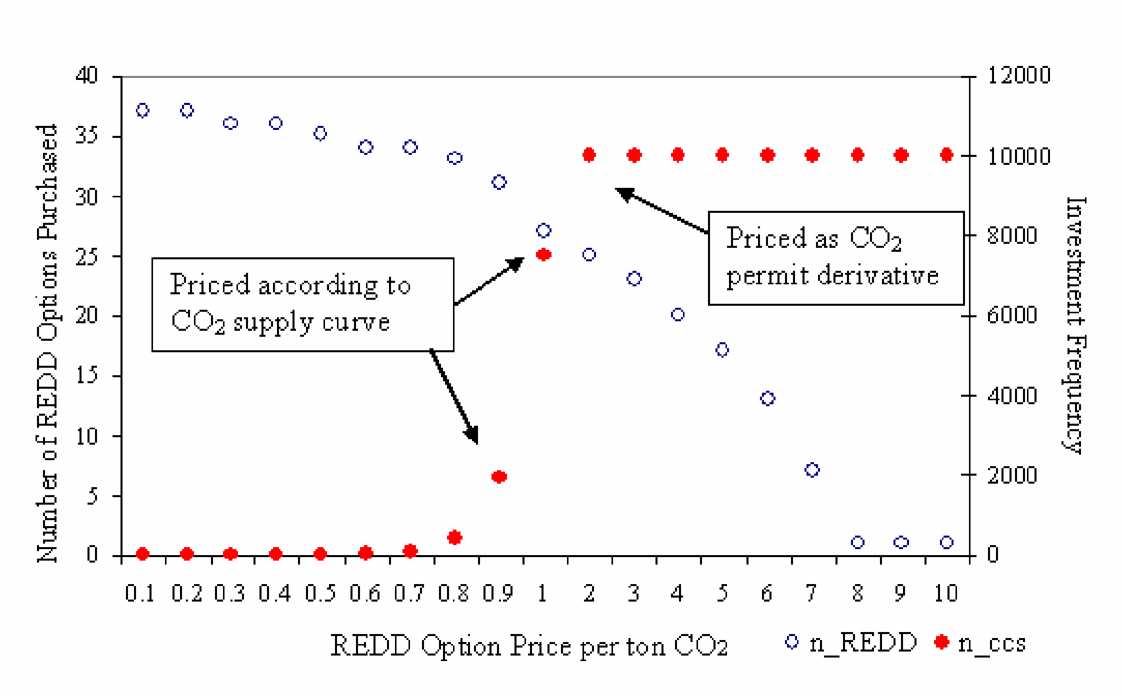

Figure 3: Number of REDD Options Bought & CCS Investment Frequency

The left y-axis of Figure 3 measures the amount of REDD options, which are bought in the beginning of the planning period and which can be exercised at a given strike price of 15$/ton of CO_2 at a later point in time when there is demand for offsetting emissions. It can be seen that there is a negative relationship between the number of REDD options purchased and their option price. Obviously, a very low option price will make the way of offsetting via REDD more attractive compared to CCS investment, where larger sums have to be committed to achieve a reduction in CO_2. This attractiveness diminishes, however, as the option price increases. For a price of 8$ or higher, the CCS module becomes the less expensive solution and zero offset options are bought in the beginning. An option price around \$2/t CO_2 will not harm CCS investment and will instead be likely to generate part of the upfront investment funds needed to start prevention of deforestation.

Now that we have investigated the general impact on the investment decision and the decision on the amount of REDD options bought, we are also interested in a more detailed analysis of the situation of the producer. Therefore, profit distributions have been computed for the case where the REDD options can be bought and for the case where they are not available. Figure 4 shows that the inclusion of REDD in the carbon market where permits are traded indeed has a positive effect on profits: even though the average level of profits remains unchanged, the associated *risk* decreases. This result can be confirmed for three risk measures: the variance, the Value-at-Risk (VaR) and the Conditional Value-at-Risk (CVaR).[10]

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[10] The β-VaR of a portfolio is the lowest amount α such that, with probability β, the portfolio loss will not exceed α, whereas the β-CVaR is the conditional expectation of losses above that amount α, where β is a

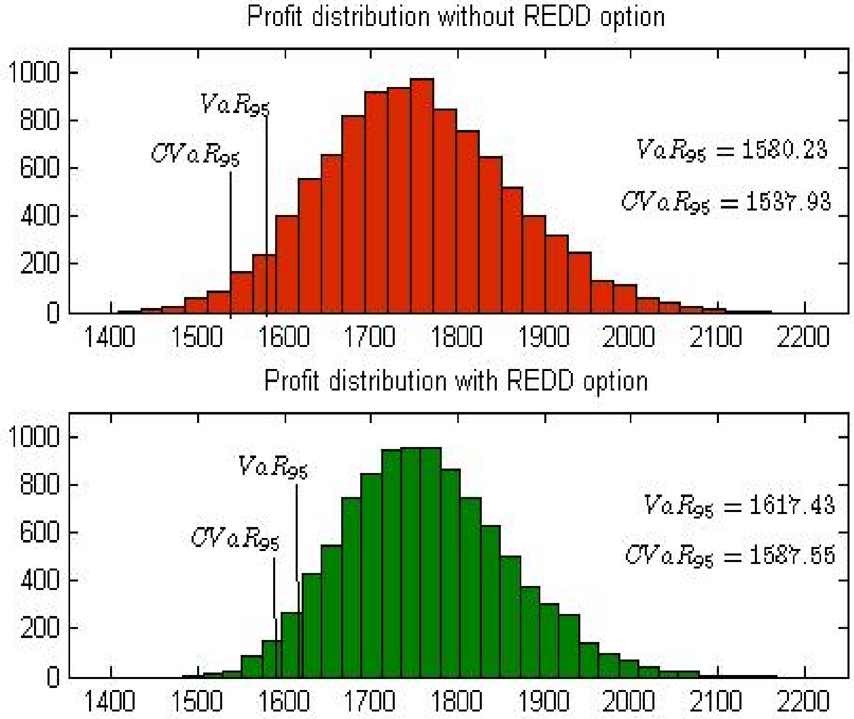

Figure 4: Profit Distributions with (green) and without (red) REDD

The numbers in Figure 4 can be interpreted as follows: with a probability of 95%, the producer can be sure that the profits will exceed the VaR value, i.e. the higher the VaR, the lower the risk. A similar argument holds for CVaR, which is not about the *amount* at risk at the 95% threshold, but the conditional expectation of that amount. This makes CVaR a suitable risk measure when distributions have fat tails, which can be the case with loss distributions when there can be catastrophic events, for example. In the case at hand, the distributions have a relatively normal shape, so the variance is also an informative risk measure. It is obvious that the variance is larger in the optimization without REDD options, so all three risk measures indeed confirm that including REDD helps producers hedge price spikes in permit prices and thus reduce their exposure to risk.[11] REDD is thus complementary to permit trading rather than undermining it, as long as the options are priced in the same framework, i.e. not sold at too low a price.

5 Conclusion & Policy Recommendation

This paper has presented a real options model where there are two ways to reduce emissions from ongoing operations of a coal-fired power plant in the face of a rising carbon price based on permit trading. On the one hand, the producer can decide to retrofit the plant and add a carbon capture module, which will dampen the amount of CO_2

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specified probability level. For a more precise definition and an introduction to optimization problems using CVaR see Rockafellar and Uryasev (2000, 2002).

[11] These results also point to the potential usefulness of a portfolio approach to these issues, but such considerations are beyond the scope of this paper and will thus be postponed for future research.

generated by the combustion of coal considerably (see Table 1). On the other hand, CO_2 credits can be purchased in the beginning of the planning period, which can serve as offsets for emissions at a later point in time. We suggest that such REDD credits should be regarded as options, where the buyer acquires the right, but not the obligation to offset emissions at a given strike price in the future. In this framework we have investigated some questions central to the current debate on REDD, its mechanisms and implementation - the most important one obviously being the potentially negative impact that the availability of cheap REDD credits could have on investment in new and less carbon-intensive (or even carbon-saving in the case of CCS) technology.

The analysis has shown that there are no negative consequences of including REDD for energy investments. This result hinges on the pricing of the REDD options, however. Some estimates for carbon supply curves find prices as low as 5$ per ton of carbon from marginal cost calculations, which would reduce the frequency of retrofitting the coal-fired power plant with CCS by about 25% in our framework. However, if the REDD options are priced as CO_2 permit derivatives, the price will be sufficiently high, so as not to distort incentives to add CCS. This implies that the inclusion of REDD into existing carbon markets does not undermine the goals of cap-and-trade, as the necessary investments in new technology will still be triggered 100% of the time (see Figure 3). Only for very low option prices, REDD will be the more attractive alternative to reduce emissions and thus affect energy investments negatively.

In addition, we have investigated the effects on the producer's ongoing operations in more detail. This has led to the finding that the average level of profits remains unchanged, but at the same time the risk associated with profit volatility is substantially lower if REDD is made available. Three risk measures have been used (variance, VaR, CVaR) and all three suggest that REDD options help the producer in smoothing out fluctuations arising from permit trading (see Figure 4). Therefore, REDD represents a source of flexibility to the producer or the investor, which is comparable to other forms of flexibility allowing for a costly decision to be postponed until better information becomes available. Bosetti and Lubowski, for example, investigate the effects of linking REDD with existing carbon markets in an integrated assessment model, where they compare scenarios where banking of permits is allowed to scenarios without banking. They show that banking provides a sort of flexibility that removes any negative effects of REDD on innovation and even enhances investments in that area (cross reference to Bosetti and Lubowski, 2009). Cap-and-trade and REDD are thus complementary and should be considered in one and the same market to ensure stability and avoid distortion of incentives.

Interpreting these results in a policy-context, it is important to note that there is not only investment irreversibility in terms of sunk costs for new technology involved in this optimization problem, but that there is also environmental irreversibility concerning deforestation: deforestation is an irreversible process in the short run and it kills the option to make a better-informed decision in the future. By committing relatively little resources now to keeping the option to offset emissions through avoided deforestation open for later, much can be gained in terms of flexibility and risks can be reduced – not only at the individual but also on the aggregate level if the analysis is extended to regions or countries or the world. Current computations about costs and benefits of including REDD should explicitly assign a value to this flexibility or account for the cost of eliminating the flexibility by not slowing down deforestation rates. And finally, the uncertainty about unresolved issues with respect to the mechanisms, pricing schemes and political framework of REDD should not forestall its implementation in the near future and – more precisely, its integration into the next agreement following the end of the Kyoto period after 2012. The analysis in this paper has shown that treating REDD as an option and keeping that option open is valuable and that the final decision about its exertion can still be made at a later point in time in the light of more complete information. If resolving issues that are currently unclear in the future reveals that REDD is not needed, then the option does not need to be exercised and the strike price does not need to be incurred. If it turns out that REDD is necessary to meet the stabilization target, the option to do so will still be available and the target can be still be reached (and with much certainty at a lower cost than without).

With respect to implementation issues, numerical simulations demonstrate the feasibility of a mutually beneficial agreement on REDD. There are several "moving" parts in the climate negotiations puzzle, which may be more easily solved step by step. According to an EDF-WHRC study (Nepstad et al, 2007), the opportunity cost of avoided deforestation is around $2 per ton of carbon to prevent up to 95% of all deforestation. This is negligibly small compared to all available estimates of allowance prices at a carbon market. However, due to scale effects, the required capital inflow is of sizable (see Golub and Greenberg, 2009). These investments are vitally important to save tropical forests. The option approach allows raising those funds first and solving other issues later.

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Appendix: Solving the Real Options Model

The problem underlying our real options model is essentially an optimum control problem, where the actions (do nothing, install the CCS module, buy a certain number of REDD options and exercise them) are the controls and the target to be maximized is the power plant operator's (or the investor's) profit. Let us first remember the Bellman equation that we have sketched out in the main text:

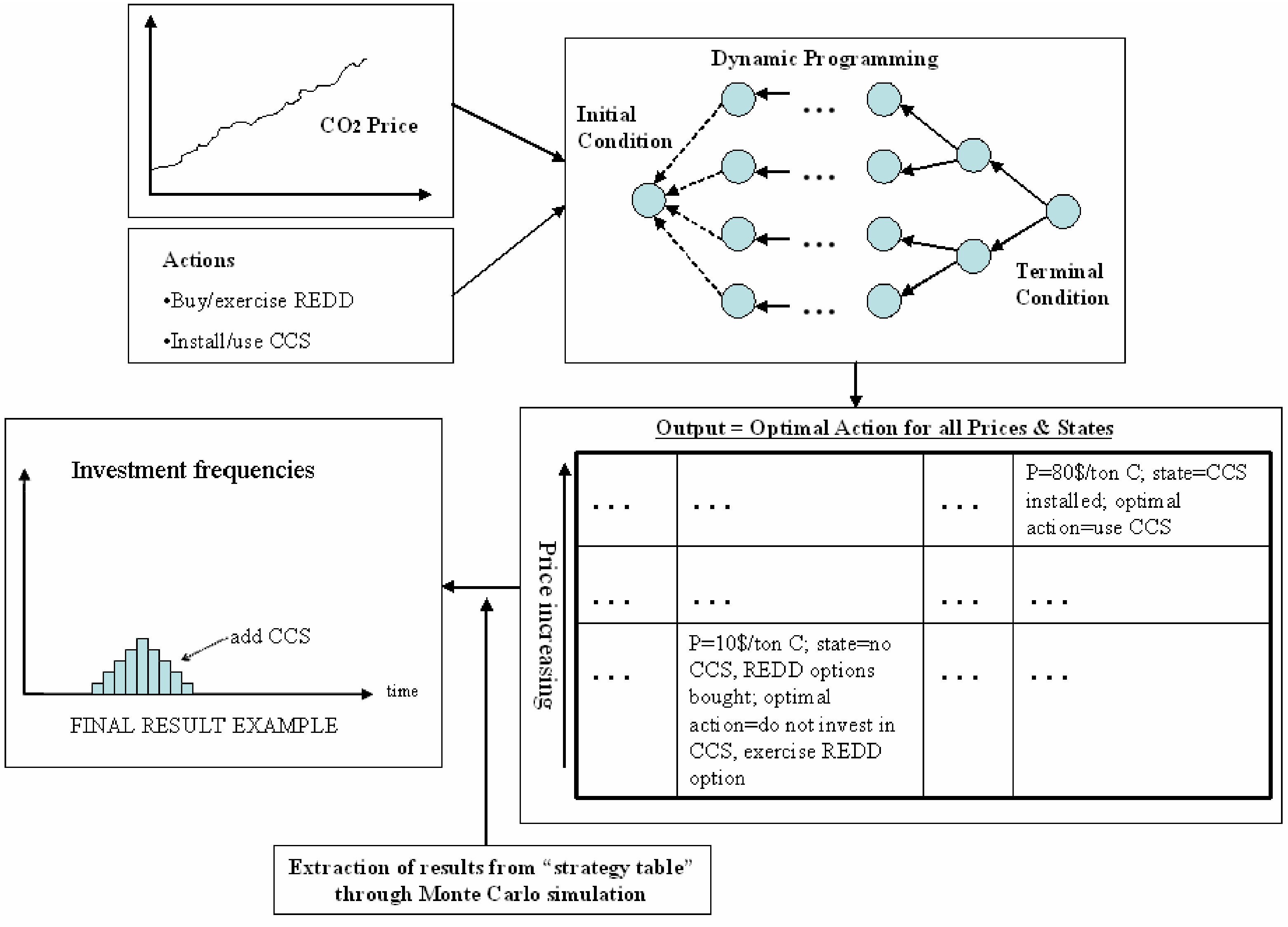
$$V_t(n_t, x_t, P_t^c) = \max_{a_t, n_t}\{\pi(n_t, x_t, a_t, P_t^c) + e^{-r} \cdot E[V_{t+1}(n_{t+1}, x_{t+1}, P_{t+1}^c) \big| P_t^c]\}$$

As has been explained before, the Bellman equation consists of the immediate profits, but also of the discounted, expected continuation value, which takes into account all value of the function that materialize at a later point in time for all different realizations of the carbon price and all possible states, if the power plant owner would not have committed his resources to the installation of the carbon capture and storage module. While it is clear how the first part (the immediate profits, $\pi(n_t, x_t, a_t, P_t^c)$) should be valued, the question remains how the continuation value ($e^{-r} \cdot E[V_{t+1}(n_{t+1}, x_{t+1}, P_{t+1}^c) \big| P_t^c]$) can be computed. In fact, we do not compute the continuation value, but we *estimate* it – a procedure, which gives us the same results as other methods, but which is much less time-consuming and more flexible for experiments and marginal changes to the model.

In particular, we first discretize the carbon price, i.e. we have a grid for all possible realizations of the price between a predefined minimum and maximum, so that 95% of the possible price paths lie within the grid. Then we use dynamic programming, fixing a terminal condition and finding the optimal action in each of the price nodes in the grid. So we end up with a sort of investment "recipe" for all values the price could have and for all the states the producer can be in. In the main text we have been referring to his "recipe" as a strategy.

Then we use Monte Carlo simulation to simulate 10,000 price paths and "look up" in our "recipe" the optimal action. In this way we can derive the investment frequency distribution, the average timing of investment etc. The following diagram is adapted from Fuss et al (2008) and is supposed to visualize the method more clearly.

The "ingredients" into the optimization are the stochastic process of the CO_2 permit price, which is at the same time used to price the REDD options, and the actions available to the power plant owner, namely whether to invest into the CCS module or not and whether to buy and exercise REDD options and how many (see first panel in the figure below). With the help of dynamic programming, the optimal action for each possible price realization and each potential state is found (upper right panel in the figure below). The arrows pointing at the initial node are dotted because the optimal actions found will hold also if the initial conditions are changed. The only fixed point needed to solve the problem is the terminal condition. For each price realization on the grid and each possible state, the optimal action is then stored in a matrix, from which the desired output can be extracted trough Monte Carlo simulation (lower right panel in the figure below. The last panel shows one output example, where the CCS investment frequency distribution for a simulation of 10,000 price paths is displayed.



. . .	. . .	. . .	P=80$/ton C; state=CCS installed; optimal action=use CCS
. . .	. . .	. . .	. . .
. . .	P=10$/ton C; state=no CCS, REDD options bought; optimal action=do not invest in CCS, exercise REDD option	. . .	. . .