EFFICIENT CONTRACTS FOR CARBON CREDITS FROM REFORESTATION PROJECTS

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ABSTRACT

This paper tackles the complex issue of how buyers and sellers within a domestic carbon credit system designed to include regenerating indigenous forest would optimally design contracts for trades of the new good, "carbon sink credits". The paper begins by briefly defining the constraints that sink projects must meet. This implicitly shows the freedom we have in designing contracts. In the context of a simple numerical example I discuss the constraints that the market puts on contracts. In particular I consider the interests of the buyers and sellers, and how they can maximise and share gains through contract design. I outline the sources of risk and discuss who has advantages in dealing with these risks. The best contract designs impose the risk on those most able to address or absorb it. I illustrate the potential gains from sink contracts with a range of conditions and contracts.

1   INTRODUCTION

The Kyoto Protocol creates the potential for rewards for carbon "sinks" in both developed and developing countries. In developed (Annex B) countries that have ratified the Kyoto Protocol, sink projects could be used as part of domestic regulation to encourage carbon sequestration in new forests (Article 3.3) and changed management of existing forests (Article 3.4). International trading (Article 17) could involve removal units created from sink projects. If Annex B countries choose to use Joint Implementation to trade, sink projects are one possibility. Developing countries can develop sink projects and sell the credits through the Clean Development Mechanism. All these regulations are likely to be somewhat different in their details but in every case, there is a seller who produces sink credits by afforesting/reforesting and a buyer who wants to use those credits to comply with domestic or international commitments.

Our interest in this paper is the common problem of how to optimally design the contract between buyer and seller ("traders"). Sink contracts are more complex than many emission reduction contracts because carbon stored in forests is potentially temporary. A raging debate has argued about how international rules should deal with this. Papers that propose and discuss issues relating to the appropriate international rules include Dobes et al (1998), Fearnside et al (2000), MacLaren (2000), Marland et al (1997), Meinshausen and Hare (2000), Moura Costa and Wilson (2000), Schwarze and Niles (2000), Schlamadinger and Marland (2000), Sedjo and Toman (2001), Sedjo et al (2001) and Van Kooten et al (1997). In this paper I assume that sinks are treated as temporary stores of carbon and that either the seller or buyer is held liable for paying back any credits accrued if the sink is destroyed. This follows Chomitz (1998 and 2000), Colombia (2000), Kerr and Leining (2000), Leining and Kerr (2001) and Kerr (2001) among others. I have seen no literature on the effects of temporary storage on how traders should design contracts.

Sink contracts need to have environmental integrity and fit within the domestic or international rules for monitoring and reporting. However, this still leaves lots of freedom to choose. Understanding the limitations and flexibility available in contract design and the tradeoffs between different approaches is clearly useful for traders. It is also useful to those who are designing regulations.

They need to understand the value of contract flexibility so that they do not unnecessarily constrain the forms of contract available. Brokers and market makers could design standard contracts and make information available that helps traders understand how best to design a contract to meet their needs.

The purpose of this paper is first to design feasible carbon sequestration or "sink" contracts that meet environmental, regulatory and economic constraints. Second I characterise the performance of these contracts and show how the best choice depends on the characteristics of the parties involved.

2 ENVIRONMENTAL AND REGULATORY CONSTRAINTS

The environmental constraints on contract design will ultimately be defined in international and domestic regulations. I am considering the problem of contract design in the context of the Kyoto Protocol where land-use related credits are tradeable one-for-one with credits from reduced fossil fuel emissions. This puts constraints on land-use credit regulation at an international level. Sequestration of carbon in "sinks" that create tradeable credits needs to have the same atmospheric effect in the same time period as the emission reductions that the credits would replace. Domestic governments have more flexibility as long as they meet their overall Kyoto targets. I assume here that, at least in a broad way, any domestic regulators design a policy that links to the international rules.

2.1 Assumptions about the regulation under which the contracts operate

• I assume an annual reporting and rewarding process. This is for convenience and is not essential.

• The greenhouse gas (GHG) benefits from land use change can be lost or reversed over time, unlike the GHG benefits from emissions reductions in other sectors. I assume that all land-use carbon storage is temporary and is rewarded accordingly through tradeable credits.[2]

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[2] Thus I ignore the possibility that "ton year" accounting could be applied to some sequestration credits internationally. The literature on these ideas is discussed in the chapter by Noble et al (2000) in the IPCC report on Land Use, Land Use Change, and Forestry.

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- Credits are given each year for sequestration and debits are applied each year for loss of carbon through harvesting or deforestation.[3] Permanent forests are simply a special case.

- I assume that the "baseline" carbon, i.e. how much would have been sequestered or stored without the policy, is known, or at least a baseline is set. Any carbon sequestration above this is "additional" and is eligible for reward.

- I assume that land-use and carbon monitoring is the same across all contract forms and in the first part of the analysis is risk free from the point of view of buyers and sellers, i.e. once the project starts, the monitoring rules are fixed and once carbon is monitored, the number of credits is set and will not change.

- Traders could be individuals, companies or countries. I assume, however, that they are both "small" enough that they cannot affect the regulatory conditions relating to trade and that they are price takers in the international market.

Thus I focus on the issue of contract form rather than other contentious and difficult issues. The contract form will be an issue for buyers and sellers regardless of the specific system.

3 THE OPERATION OF CARBON SEQUESTRATION MARKETS

The market sets limits on how much a seller can expect to receive to either sell or lease the credits they create at different points in time. The market also provides considerable flexibility in contract design and can get around some limitations of the regulation. The market can provide flexibility in when the seller sells the credits. If a buyer can be found, futures markets can be used to sell credits before they are created. These credits cannot be used for compliance until a later date. The market can provide considerable flexibility in cash flow for both buyer and seller. It also allows a range of options for risk bearing.

In this section I define a few basic contract forms and the key parameters that cause them to differ. I discuss the limitations the market places on how these contracts work—chiefly that both buyer and seller must be willing to agree to the terms. I then compare the

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[3] This is equivalent to modelling sequestration in Kyoto forests under Article 3.3 of the Kyoto Protocol.

contracts under a range of situations and with different characteristics of buyers and sellers and show what types of situations might call for different contract forms. I illustrate each of these with a concrete example of a regeneration project on 100ha of land. I initially assume that there is no risk—future credit prices and levels of actual sequestration are known with certainty.

3.1 Sell credits as you go—seller liable for credit repayment

The simplest contract is one where credits are sold as they are created and then if the forest is cleared all credits are repaid by the landowner. Each year, this contract will be worth the current credit price times the new quantity of carbon dioxide.[4] In the final year it will bear a liability equal to the current credit price times the accumulated CO_2.

Different contract designs will provide payments at different points in time. To compare contracts we need to translate payments at different points in time into a common "currency". When does the timing of payments matter? Two basic reasons apply in all economic situations. First, the buyer and seller might have different access to credit. Investors with their own money are in a different situation from people who are already in debt. This means they face different interest rates.[5]

Second, people and groups may simply have differences in time preference, or differences in when they prefer to enjoy benefits. Some people like to have their returns quickly, while others are willing to wait and may even enjoy the anticipation of future benefits. This partly depends on current versus future income as well as age and possibly culture. It can be thought of in terms of how patient the actor is. The interest rate and underlying patience are summarised in the "discount rate", which is an indicator of how much an actor would need to be paid to wait an extra year to receive payment.

If the landowner is more patient than the buyer (lower discount rate) then they will get more value from the project if they agree to receive payments later rather than earlier in exchange for higher total payments. If they are less patient (higher discount rate; for

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[4] Although forests sequester carbon, Kyoto is designated in terms of carbon dioxide (CO_2) equivalents so the international price most readers will be familiar with will be the CO_2 price. 1 tonne C = 3.65 tonnes CO_2.

[5] This is why car dealerships and others offer "interest free for 6 months" and other similar deals. The company can borrow easily whereas the buyers often cannot.

example, if they are in debt or face credit constraints) they would get more value with an up-front payment even if it is lower.

One extra issue may arise in the context of contracts on land where the sellers may be a group with multiple ownership of land (e.g. Māori land). Difficulties with governance may make it preferable to have a stream of income rather than a lump sum early on. Alternatively the group may have an investment project planned where they would really benefit from cash up front but may have difficulty raising the funds as a group or coordinating separate investments by group members. I define the discount rate for the seller as d per year.

p_t is the price of CO_2 credits on the market at time t. An active market determines this. No buyer will pay more than this because they could buy credits elsewhere for this price. No seller should accept less for risk-free credits because they could sell the credits elsewhere. q_t is the quantity of new sequestration available to be sold at time t. T is the length of the project. If it is less than infinite, then q_T, the "new sequestration" in the last period, is negative and the credits will need to be bought back. This would apply either if the land is cleared and converted to a non-forest use, or if monitoring stops so the regulator cannot assess carbon storage or sequestration.

V is the present value to the seller of the revenue stream from the project. A stream of credits sold each year and repaid by the seller at T is worth V_1.

$$V_1 = \sum_{t=0}^{t=T} \frac{1}{(1+d)^t} p_t q_t \qquad (1)$$

If I define p_0 as the initial carbon price and i_t as the average rate of increase in carbon dioxide prices over the period of the contract I can rewrite this as:

$$V_1 = \sum_{t=0}^{t=T-1} \frac{(1+i)^t}{(1+d)^t} p_0 q_t - \frac{(1+i)^T}{(1+d)^T} p_0 \sum_{t=0}^{t=T-1} q_t \qquad (2)$$

This makes the final repayment of credits, the final term, explicit.

3.1.1 Basic case for project examples

- 100 hectares

- Project start date: 2003

- Project length: $T = 10$

- Accumulation of CO2 per hectare per year[6]: $(6.2)(100 \text{ ha}) = qt \ (t < T) = 620$

- Carbon dioxide price: $p_t = \$10$ per tonne CO_2

- Seller discount rate: $d = 10\%$

- Buyer/market discount rate[7]: $r = 10\%$

- Credit inflation rate: $i = 5\%$

In my base case, the project would be worth $9,949 in 2003 under this form of contract. The contract has positive value even though the net sequestration over the whole project is zero, because carbon prices rise at a lower rate than the seller's discount rate so the present value of the final liability is not too high. The lower is i and the higher is d, the more valuable the project is.

The project is worth doing if

$$V_1 > AR + \text{Cost} \qquad\qquad (3)$$

Where AR = present value of alternative return on the land over the period, and Cost = direct costs of setting up and running the project.[8] All contracts will be worth more if the credit price is higher, if the carbon is sequestered faster, and/or if the costs of setting up and running the project are a smaller proportion of the total value (e.g. because the project is larger and the costs are fixed). Projects will also be more valuable on land that has fewer alternative uses.

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[6] This number is the low end of a range (1.7–3 tonnes carbon per ha per year) provided in Trotter et al (2002). The 1.7 figure is probably a national average, while the 3 tonnes might apply in East Cape.

[7] I assume that the buyer's discount rate will be equal to the market real interest rate because all buyers will pay the same for a rental contract in a liquid market.

[8] This would include the present value of monitoring, compliance and maintenance costs.

3.1.2 Options to extend contracts

This 10-year project leaves open the option of extending the project. Once the 10 years is over, the stock of carbon on the land could be maintained. The value of maintaining it is that the credits already accumulated would not need to be paid back. In addition, the forest can continue to sequester more carbon and create more credits. The project may be more valuable after 10 years than it is at the beginning even though costs of start up have not been incorporated. If the base case simply extends, the value in 2013 of continuing for an extra 10 years rather than cutting down would be $55,562. The project creates some momentum—it is more valuable to continue than it was to start. Whether it is worth continuing depends on the current and expected future carbon prices and potential income from other uses of the land in 2013. A contract in perpetuity will be worth more than $129,000 in present value in 2003 in the base case.[9]

All temporary contracts will be more valuable if credit prices drop considerably at some point in the future (because for example we move to a hydrogen economy, discover that climate change is not a problem, or find a way to cheaply and safely permanently store carbon in the ocean).[10] The party that would have borne the liability for repayment would benefit from this fall in prices. The issues relating to extending the contract will apply in all contract forms.

3.1.3 Rental-buyer liable for credit repayment

An alternative contract form is a lease or rental contract where the buyer pays the seller a certain amount each year as long as the credits are protected. The seller maintains the right to have the credits returned at any time subject to contractual restrictions. In contrast to the sale contract, the seller maintains ownership of the credits at all times. This means they can sell them or stop the project (and not have to pay them back) when the contract ends.

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[9] I have calculated value for 100 years and assumed no repayment. After 100 years the extra value becomes extremely small because of discounting.

[10] For discussion of the value of temporary carbon capture/sequestration see Herzog et al (2002).

The buyer will use the credits for compliance purposes and will buy credits (or rent credits from someone else) when they can no longer use those provided through the contract.[11] Under this contract the seller (landowner) has no deforestation liability.

The buyer faces a decision about whether to buy or rent credits. The amount the buyer is willing to pay to rent will depend on their discount rate and the rate at which they expect credit prices to rise. If the rental contract were infinite, the price rise would not matter because they would never have to pay the credits back. In a finite or potentially finite contract, however, the buyer will be concerned that at some point they will be unable to rent the credits and will have to buy them at the then-current market price.

The buyer avoids the cost of the full outlay on the credits and so saves rP_t on each credit, in each year, where p_t is the price he would have had to pay for them in the year they were created. That is, the rental price adjusts each year even on existing credits. r is the buyer's discount rate. However, each year he accumulates a larger potential obligation to repay if the value of credits rises. This obligation increases by iP_t each year where i is the expected rate of inflation in credit prices. Thus his net gain from renting rather than buying immediately is $(r-i)P_t$. This is how much he will be willing to pay each year for each credit he holds (i.e. the cumulative number, not only the additional credits that year).

If i were high or his discount rate low, he would not be willing to rent.

The value of a rental contract to the seller is the present value of all the future rental payments.[12] The seller does not have to buy back the credits at the end so there is no final term equivalent to that in Contract 1. The value is:

$$V_2 = \sum_{t=0}^{T} [(r-i) \frac{(1+i)^{t-1}}{(1+d)^t} p_0 \sum_{s=0}^{t} q_s] \qquad (4)$$

If the buyer and seller have the same discount rate (i.e. $r = d$) then $V_2 = V_1$.[13] The pattern of cashflow is different but the total value of the contract is the same.

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[11] A possibly useful analogy is that of someone deciding to rent or buy a house. The buyer needs a "house" to offset its emissions in the first year. If it rents the house that will satisfy its needs temporarily, but when the seller no longer wants to rent out the house the buyer will need to find another house.

[12] The rental payments are modelled as though they are made at the end of each year. This is simply because I am modelling in discrete time periods.

[13] See Appendix A for proof.

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Renting is most valuable when people believe that technological advances will make climate change mitigation relatively cheap in the medium term and hence make carbon prices fall. If we solve the problems of the hydrogen economy in the next, say, 50 years, carbon prices may fall close to zero even though they might be high in the interim period. Many models predict this sort of price path. Prices would also fall to zero if the international agreement collapsed or we found that climate change was not a problem and halted our efforts. Sinks are most valuable relative to emission reductions in these situations because they offer the opportunity to delay emission reductions.

In both contracts 1 and 2 (and all other contracts), if $i = r = d$ and the contract length is finite, the project has a value of zero. There is no point in buying time through temporary sinks when the credit price goes up as fast as your value of money. In contrast, a contract that lasts in perpetuity still has a positive value because the credits will never have to be paid back so the credit inflation rate does not hurt.

Because some of the payments are delayed, rental contracts are more valuable the more patient the seller is and the less patient the buyer. For example, if the seller is more patient than the buyer (seller has discount rate $r = 5\%$ rather than 10%) the value of this contract rises from \$9,949 to \$13,286. In contrast, if the seller is less patient, the contract value will shrink. A patient seller would not accept a sell-credits-as-you-go contract because it would be worth nothing to them—the liability would grow at the same rate as they gain credits—while an impatient seller would much prefer the sell-as-you-go contract to the rental (see Table 1).

3.1.4 Up-front payment

A third popular form of contract is where the seller is paid a sum up front for a project of a defined length. The buyer might be willing to pay the present value of all the credits expected to be created in the future even though they will not be able to sell them until later.[15] The seller is responsible for paying the credits back if they cut the forest. The value of an up-front contract is:

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[15] They may be able to sell on futures markets if they exist.

$$V_3 = \sum_{t=0}^{t=T-1} \frac{(1+i)^t}{(1+r)^t} p_0 q_t - \frac{(1+i)^T}{(1+d)^T} p_0 \sum_{t=0}^{t=T-1} q_t \tag{5}$$

This will be an attractive contract form if the seller is impatient and wants to be paid early—i.e. the value of d is high relative to r. If the buyer and seller are identical, the value of this contract V_3 is equal to V_1 or \$9,949.

3.1.5 Kyoto contract: Two up-front payments—seller liable for credit repayment

The regulatory form pre- and post-2008 is likely to be different. The carbon price is also likely to be quite different before and after 2008. The carbon price may change with each commitment period as global targets change and new countries join the agreement. Because credits can be banked,[16] if changes in commitments are known well in advance and the commitments become stricter, the price path will be smooth. In contrast, surprises or reductions in stringency will cause prices to jump. All these things may make it wise to write contracts that separate these periods to allow reassessment for new conditions. In the Kyoto contract, I model an up-front payment for the 5 years pre-Kyoto then another up-front payment for the first commitment period. The seller maintains the deforestation liability.

Table 1   Value of different contract forms to the landowner/seller of credits

	Sell as created	Rental/ lease	Up front payment	Payment each period	*Perpetuity (credits sold as created)*
	1	2	3	4	5
Base case: $d = r > I$	9,949	9,949	9,949	9,949	129,000
Higher future prices: $d = r = i$ [17]	0	0	0	0	372,000
Impatient seller: $d = 15\%$	15,251	7,625	23,398	18,927	71,000
Patient seller: $d = 5\%$	0	13,286	-11,260	-5,386	434,000

Table 1 shows that in the contracts where the seller receives funds earlier and has to pay back credits, 1, 3, and 4, the more impatient the seller is, the higher the value is. A

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[16] Credits from land use, land use change and forestry are called RMUs or removal units. They are not strictly bankable but are fungible with other types of international credit such as AAUs so can in effect be banked. The only situation where they could not would be if there was no active market internationally, so RMUs could not be sold internationally, and one country had so many RMUs they could not use them all for compliance. Then they would be left with RMUs that would have no value.

more impatient seller is less concerned about future liabilities so finds these contracts more attractive other things being equal. In contrast, if the seller is more patient, the rental contract becomes more favourable.[18]

If credit prices rise fast, the "in perpetuity" contract becomes the only favourable contract. There is little or no value from temporary sequestration. The "in perpetuity" option would not have to be chosen in advance. Extension of any of the other contracts or translation into an "in perpetuity" contract would become more attractive over time if actors see that credit prices are continuing to rise. The "in perpetuity" contract will be more attractive to patient than impatient sellers because patient sellers value the payments in the distant future and are concerned about future liability.

3.1.6   Summary of contracts without risk

- All contracts are more valuable if the price of carbon is higher.

- All contracts are more valuable if the carbon yield per year is higher or the project covers a greater land area.

- All contracts of the same length have the same value if the buyer and seller are identical.

- All finite contracts have zero value if the rate of credit inflation i is greater than or equal to the buyer's and seller's discount rates r and d.

- If the seller is more impatient than the buyer, then contracts with the payments up front are more valuable than payments with the cash flow spread over time.

- Impatient sellers are less concerned about bearing liability.

- If the buyer is more impatient than the seller, the opposite is true.

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[17] Inflation assumed to be 10% for 50 years, then zero. This is probably a high estimate of future carbon prices.

[18] I have not modelled a contract with rental payments all made up front but with the buyer still bearing the liability. The impatient buyer would prefer higher payments in exchange for the liability, while the patient seller would prefer the stream of somewhat higher rental payments and buyer liability. Thus it is dominated by other contracts. I have also not modelled a contract where the seller is paid at the end of the contract. This will have the opposite effects and attractiveness to an up-front contract.

4   CONCLUSION

The appropriate form of contracting in this complex and uncertain environment is not obvious and deserves careful thought. The contracts are constrained by environmental, regulatory and market consideration but considerable flexibility still remains. The value of the contract to both parties can be maximised by careful design.

Without considering risk, the key factor in choosing a contract form is the "patience" of the buyer relative to the seller. If the buyer has greater access to cheap credit and greater ability to wait for income it is better for the contract to be biased toward payments up front. If the seller is more "patient" the contract should spread the payments out further. Curiously, the less patient actor also should take responsibility to repay the credits when the contract ends because they heavily discount the future liability.

4.1   What does this mean for Māori?

Māori land creates opportunities and challenges that are not present on non-Māori land and that require special thought. Māori have a strong desire to maintain control and ownership of their land and assets for cultural and social reasons as well as for the economic reasons that affect all others. This makes them suspicious of contracts to protect land in perpetuity. They are also concerned that if they protect the land it could become part of the DOC estate or locked up by local councils as Protected Natural Areas. This requires care in contract design. Many Māori landowners are already protecting land under "Ngā Whenua Rahui" (similar to QEII Trust) in which land is covenanted for 25 years, and then there is a renewed kawenata (agreement) with landowners. They have found ways to provide effective protection using a mechanism that Māori trust. Any carbon contracts should build on these already successful mechanisms.

Māori land creates issues also in terms of the complexity of governance structures on multiply-owned land and limited ability to borrow, as well as low capacity to negotiate and administer contracts. To the extent that sequestering carbon is technically a relatively non-challenging activity that requires little capital investment, it has an advantage relative to other land uses. The special issues on Māori land also mean that setting up effective contracts will be slow and the use of this mechanism is likely not to achieve its full potential.

In terms of contracts, Māori need to consider their characteristics in terms of "patience" and ability to absorb risk, and any governance or cultural issues that would make them prefer one form of contract over another.

5 REFERENCES

Chomitz, K. M. (1998). "Baselines for Greenhouse Gas Reductions: Problems, Precedents, Solutions" Development Research Group, World Bank, Washington, DC, USA, 62pp.

Chomitz, K. M. (2000). "Evaluating Carbon Offsets from Forestry and Energy Projects: How do They Compare?" World Bank Policy Research Working Paper 2357, New York, 25 pp., wbln0018.worldbank.org/Research/workpapers.nsf.

Colombia, Ministry of the Environment (2000). "Expiring CERs, A Proposal to Address the Permanence Issue" pp. 23–26 in United Nations Framework Convention on Climate Change, UNFCCC/SBSTA/2000/MISC.8, submitted 13 Sept., 2000, www.unfccc.de.

Dobes, L., I. Enting, and C. Mitchell (1998). "Accounting for Carbon Sinks: The Problem of Time" pp. 1–15 in L. Dobes (ed.) *Trading Greenhouse Gas Emissions: Some Australian Perspectives*, Occasional Papers no. 115, Bureau of Transport Economics, Canberra, Australia.

Fearnside, P. M., D. A. Lashof, and P. Moura-Costa (2000). "Accounting for Time in Mitigating Global Warming Through Land-Use Change and Forestry" *Mitigation and Adaptation Strategies for Global Change* No. 5, pp. 239–270.

Herzog, H., K. Caldeira, and J. Reilly (2002). "An Issue of Permanence: Assessing the Effectiveness of Temporary Carbon Storage" MIT Joint Program on the Science and Policy of Global Change, Report No. 92.

Kerr, S., and C. R. Leining (2000). "Permanence of LULUCF CERs in the Clean Development Mechanism" Paper prepared for Conference of the Parties 6, The Hague, November, www.motu.org.nz.

Kerr, S. (2001). "Seeing the Forest and Saving the Trees: Tropical Land-use Change and Global Climate Policy" in *Can Carbon Sinks Be Operational?* RFF Workshop Proceedings, R. A. Sedjo, and M. Toman, July, Resources for the Future Discussion Paper 01-26, www.rff.org.

Leining, C., and S. Kerr (2001). "Deciding the Eligibility of Land Use, Land-Use Change and Forestry Projects under the CDM: Negotiation Issues Post COP6" in R. Saner, S. Jauregui, and L. Yiu eds. *Bolivian Environmental Conflict Management Cases and CC + CDM Sectoral Preparations for Kyoto Protocol Negotiations*, www.motu.org.nz/climate.htm.

MacLaren, J. P. (2000). "Trees in the Greenhouse: The Role of Forestry in Mitigating the Enhanced Greenhouse Effect" *Forest Research Bulletin* No. 219, Forest Research, Rotorua, New Zealand, 72 pp.

Marland, G., B. Schlamadinger, and P. Leiby (1997). "Forest/Biomass Mitigation Strategies: Does the Timing of Carbon Reductions Matter?" *Critical Reviews in Environmental Science and Technology* No. 27, pp. S213–S226.

Meinshausen, M., and B. Hare (2000). "Temporary Sinks Do Not Cause Permanent Climatic Benefits" Manuscript distributed at the 6th meeting of the Congress of Parties to the UN Framework Convention on Climate Change, The Hague, The Netherlands, September, www.carbonsinks.de.

Moura Costa, P., and C. Wilson (2000). "An Equivalence Factor Between CO_2 Avoided Emissions and Sequestration—Description and Applications in Forestry" *Mitigation and Adaptation Strategies for Global Change* No. 5, pp. 51–60.

Noble, I., M. Apps, R. Houghton, D. Lashof, W. Makundi, D. Murdiyarso, B. Murray, W. Sombroek, and R. Valentini, et al.: (2000). "Implication of Different Definitions and Generic Issues", in R.T. Watson, I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verado, and D.J. Dokkens, (eds.) *Land use, Land use Change, and Forestry*, Cambridge University Press, Cambridge UK, pp. 53–156, http://www.grida.no/climate/ipcc/land_use/index.htm.

Schlamadinger, B., and G. Marland (2000). "Land Use & Global Climate Change: Forests, Land Management, and the Kyoto Protocol. Pew Center on Global Climate Change" Arlington, Virginia, USA, 54 pp., www.pewclimate.org.

Schwarze, R., and J-O. Niles (2000). "The Long-Term Requirement for CDM Forestry and Economic Liability" *Journal of Environment and Development* 9 (4), pp. 384–404.

Sedjo, R. A., and M. Toman (2001). *Can Carbon Sinks be Operational?* RFF Workshop Proceedings. RFF Discussion Paper 01-26, July. www.rff.org.

Sedjo, R. A., G. Marland, and K. Fruit (2001). "Renting Carbon Offsets: the Question of Permanence" Resources for the Future Manuscript, August 20, 2001, www.rff.org.

Trotter, C.M., K.R. Tate, L.J. Brown, N.A. Scott, R.H. Wilde, J.A. Townsend, W.T. Baisden, D.J. Giltrap, G.M.J. Hall, J. Hunt, P.F. Newsome, E.J. Pinkney, N.J. Rodda, S. Saggar, and N.A. Trustrum (2002). "A Multi-Scale Analysis of a National Terrestrial Carbon Budget: Uncertainty Reduction and the Effects of Land-Use Change" *Proceedings of the International Symposium on Evaluation of Terrestrial Carbon Storage and Dynamics by In-situ and Remote Sensing Measurements*, Gifu University, Gifu, Japan, pp. 1–21.

Van Kooten, G. C., A. Grainger, E. Ley, G. Marland, and B. Solberg (1997). "Conceptual Issues Related to Carbon Sequestration: Uncertainty and Time" *Critical Reviews in Environmental Science and Technology* No. 27, pp. S65–S82.

APPENDIX A

Proof: That rental contract has equal value to contract where credits are sold as they are created when the seller and buyer have equal discount rates.

The left hand side is the present value of the sum of rental payments, over the length of the project, for 1 tonne of carbon sequestered in year 1. The right hand side is the initial money received for the sale of 1 tonne of carbon in year 1 minus the present value of the deforestation liability for 1 tonne of carbon when the project ends.

$$
\sum_{t=1}^{T}(d-i)\frac{(1+i)^{t-1}}{(1+d)^{t}}\,p_0 \quad = p_0\left(\frac{d-i}{1+d}\right)\sum_{t=1}^{T}\left(\frac{1+i}{1+d}\right)^{t-1}
$$

$$
= p_0\left(\frac{d-i}{1+d}\right)\sum_{t=1}^{T}\left(\frac{1+i}{1+d}\right)^{t-1}
$$

$$
= p_0\left(\frac{d-i}{1+d}\right)\left\{\frac{1-\left(\frac{1+i}{1+d}\right)^{T}}{1-\left(\frac{1+i}{1+d}\right)}\right\}\times\frac{(1+d)}{(1+d)}
$$

$$
= p_0\left(\frac{d-i}{1+d}\right)(1+d)\left\{\frac{1-\left(\frac{1+i}{1+d}\right)^{T}}{d-i}\right\}
$$

$$
= p_0\left\{1-\left(\frac{1+i}{1+d}\right)^{T}\right\}
$$

$$
= p_0 - \frac{(1+i)^{T}}{(1+d)^{T}}\,p_0
$$